25 years gef

UNDP 50 YEARS

Empowered lives. Resilient nations.

A NEW VISION
for Weather and Climate Services in Africa

Empowered lives.
Resilient nations.

UNDP partners with people at all levels of society to help build nations that can withstand crisis, and drive and sustain the kind of growth that improves the quality of life for everyone. On the ground in more than 170 countries and territories, we offer global perspective and local insight to help empower lives and build resilient nations.

The Global Environment Facility (GEF) was established on the eve of the 1992 Rio Earth Summit to help tackle our planet's most pressing environmental problems. Since then, the GEF has provided US$14.5 billion in grants and mobilized US$75.4 billion in additional financing for almost 4,000 projects. The GEF has become an international partnership of 183 countries, international institutions, civil society organizations and the private sector to address global environmental issues. For more information, visit www.thegef.org.

Publication Design: Camilo J. Salomón, www.cjsalomon.com

Copy-editing: Meghan Lynn, Annalisa Viray and Montserrat Xilotl

Manufactured in USA

ABOUT THIS REPORT

This report is a learning product from the UNDP's Programme on Climate Information for Resilient Development in Africa (CIRDA), a four-year programme supporting work in 11 African least developed countries with US$50 million from the Global Environment Facility's Least Developed Countries Fund (LDCF). As such, it builds on the expertise of the CIRDA technical team, the products of several workshops, and initial consultations between CIRDA experts and public and private representatives of CIRDA-supported countries. The vision described here is closely related to the work plan and activities of the CIRDA programme. Learn more about the CIRDA programme at www.adaptation-undp.org/projects/cirda, or see p28.

The United Nations Development Programme provides support to countries to adapt to climate change in the context of the 2030 Agenda for Sustainable Development, seeking to promote pro-poor and pro-growth adaptation that encourages climate-resilient economic development and sustainable livelihoods in the face of climate change.

UNDP-supported projects and programmes at the country level are organized around six Signature Programmes: Supporting Integrated Climate Change Strategies; Advancing Cross-sectoral Climate Resilient Livelihoods; Ecosystem-based Adaptation (EbA); Fostering Resilience for Food Security; Climate Resilient Integrated Water Resource and Coastal Management; and Promoting Climate Resilient Infrastructure and Energy.

The CIRDA Programme works within the Advanced Cross-sectoral Climate Resilient Livelihoods Signature Programme. By supporting the development of early warning systems across Africa, Asia and the Pacific, it assists countries to respond to both short-term/rapid-onset climatic hazards (e.g., cyclones, floods and storms), as well as long-term/slow-onset hazards (e.g., drought and long-term climate change).

AN ALL-IN-ONE AUTOMATIC WEATHER STATION (AWS) BEING INSTALLED ON A CELL-PHONE TOWER NEAR KOTIDO, UGANDA. FIVE SUCH AWS HAVE BEEN INSTALLED ON CELL TOWERS ACROSS UGANDA THROUGH THE COUNTRY'S STRENGTHENING CLIMATE INFORMATION AND EARLY WARNING SYSTEMS PROJECT. CONNECTED DIRECTLY INTO THE TELEPHONE BACKBONE NETWORK, THE DATA ARE SENT TO UGANDA NATIONAL METEOROLOGICAL AUTHORITY (UNMA) FOR PROCESSING AND ANALYSIS. THE FIVE STATIONS, EACH OF WHICH ALSO INCLUDE A LIGHTNING LOCATING SENSOR, WILL PROVIDE DATA TO AN END-TO-END MONITORING AND FORECASTING SYSTEM, WHICH ALLOWS UNMA TO ISSUE EARLY WARNINGS FOR IMPENDING HAZARDOUS THUNDERSTORMS, CONNECT WITH REGIONAL MONITORING SYSTEMS AND IMPROVE THE COUNTRY'S OVERALL SUSTAINABILITY OF INVESTMENTS IN CLIMATE INFORMATION SERVICES. PHOTO BY SOLOMON MANGENI.

UNDP supports developing countries to access financing for climate change adaptation through several sources of global environmental finance, including those managed by the Global Environment Facility, namely, the Least Developed Country Fund (LDCF), Special Climate Change Fund (SCCF) and the Adaptation Fund (AF); the Green Climate Fund; and bilateral and multilateral donors. These projects cover a wide range of sectors and involve governments, Community-Based Organizations (CBOs) and Non-Governmental Organizations (NGOs) working together to deliver information and solutions for adaptation to climate variability and change. A key component of many of these projects is delivering accessible, credible, appropriate and actionable weather

PHOTO BY UNDP.

and climate information, at time and space scales that can be used for decision-making in project-relevant sectors and areas.

To achieve this, investments are made in all aspects of the information value chain, from building and strengthening observation networks, developing risk-related and tailored products, improving communications and information sharing, to building services for communities, decision makers and businesses to use and understand weather and climate-related information. In least developed countries (LDCs) where human, technical and financial capacities may be limited, this involves focusing resources to address critical gaps, for example in operating and maintaining observing IT infrastructure, developing hazard modelling and forecasting capabilities, promoting institutional cooperation, introducing mobile-phone-based technologies and involving communities in both data collection and contributing to the development of warnings and advisories. To do this in sustainable ways is often difficult, but can be achieved by least developed countries through carefully building on existing capacities, developing links between projects and institutions, and introducing new low-cost technologies and promoting revenue streams through both public and private sectors.

CONTRIBUTORS

Editorial Director

Bonizella Biagini

Dr. Bonizella (Boni) Biagini currently manages the UNDP CIRDA Programme. She was the editorial director of this publication, providing overall direction for the content, scope and extent of the work.

Prior to joining UNDP in 2014, Dr. Biagini worked at the Global Environment Facility (GEF) for 12 years, leading the creation and development of the GEF Adaptation programme and project portfolio. She was the senior official responsible for mobilizing resources for the first two dedicated adaptation funds: the Least Developed Country Fund (LDCF) and the Special Climate Change Fund (SCCF), which together have received donor support of US$1.5 billion. Before joining GEF, Dr. Biagini worked at several NGOs including the Climate, Energy and Pollution Program at the World Resources Institute and the international office of Legambiente, a leading Italian environmental research organization.

A physicist by training, Dr. Biagini has worked on climate change and other global environmental issues for 25 years in Europe, the United States, Africa, Asia, and several small island states. In addition to her technical skills, her background encompasses an unusual combination of operational experience on the ground and high-level participation in international environmental meetings including the Earth Summit and the United Nations Framework Convention on Climate Change.

Authors (ALPHABETICAL ORDER)

Greg Benchwick

A long-time communications consultant for international agencies, Mr. Benchwick works as a Senior Communications Specialist for the CIRDA programme. He has worked as a communications officer for the International Fund For Agricultural Development and is the Founder and Executive Director of Communications For Development Global Partnerships (www.c4d-global.com). Mr. Benchwick is a reformed travel writer and journalist. He has contributed to dozens of guidebooks for Lonely Planet and Fodor's Travel, interviewed presidents, senators and grammy-award winners, and worked in the field to highlight the voices of smallholder farmers and rural enterprisers the world over.

Ulrich Diasso

Dr. Diasso is a Country Support Specialist in Meteorology and Climate Monitoring for the CIRDA programme. He holds a PhD in Meteorology and Climate Sciences. Besides his role in the CIRDA programme, Dr. Diasso supports climate change assessment at the African Centre of Meteorological Application for Development (ACMAD). He is also a member of the Coordinated Regional Climate Downscaling Experiment (CORDEX) group for model evaluation in Africa.

Georgie George

Georgie George is a Country Support Specialist in Alternative Technologies for the CIRDA Programme. Mr. George has a background in electrical and radar engineering and has 12 years of experience in aviation and meteorological technology. Mr. George has a passion for environmental and social issues and is a strong proponent of sustainable design, skills transfer and the use of technology for the improvement of collaborative decision-making in forward planning across all commercial sectors affected by climate variability.

Joost Hoedjes

Joost Hoedjes is a Country Support Specialist in Hydrology for the CIRDA Programme. Mr. Hoedjes holds a PhD in Meteorology, Hydrology and Remote Sensing. His scientific interest lies in the development of innovative hydrometeorological observation systems. Besides his work for the CIRDA programme, he holds a part-time position as assistant professor in hydrometeorology at the Faculty of Geo-Information Science and Earth Observation (ITC) of the University of Twente, The Netherlands, and is ITC representative for East Africa.

Alan Miller

Alan Miller is an internationally recognized authority on climate finance and policy. His clients include UNDP, USAID and ADB. In January 2014 he retired after 16 years of working on climate change issues for the World Bank Group (WBG), including 10 years for the International Finance Corporation (IFC), the private sector lending arm of the Bank, and six years at the Global Environment Facility (GEF), a multilateral fund supporting climate change projects. His responsibilities included representing the IFC/WBG in international forums focused on climate change and green growth, including meetings of the UN Climate Convention and the G20, as well as climate change policy development, training and publications. At the GEF he was Climate Change Team Leader responsible for managing policies and the approval of over US$1 billion in donor funding for clean energy projects in more than 70 developing countries.

He previously created and directed the Center for Global Change at the University of Maryland (1989–1996) and served on the staffs of the World Resources Institute and Natural Resources Defense Council. He is a lawyer and widely published author and contributor of chapters in multiple books, including a leading environmental law textbook. He has taught courses at numerous universities including the University of Michigan, Maryland, and Iowa, the Vermont Law School, the American University, George Washington and Duke. His degrees are from Cornell University (A.B. Government, 1971) and the University of Michigan (J.D. and M.P.P., 1974). He was a Fulbright Scholar in Australia (1977) and Japan (1987).

Jean Ngamini

Jean Blaise Ngamini is a country support specialist in Meteorology, Climatology and Alternative Technology with the CIRDA Programme. He possesses an MS in Meteorology as well as an MS in Management Science from the University of Miami, Florida, USA. He is a retired Senior Meteorologist of the Head Office of ASECNA (Agency for Air Traffic Navigation and Meteorology in Africa and Madagascar) based in Dakar, Senegal.

John Snow

Dr. John Snow is Regents' Professor Emeritus of Meteorology and Dean Emeritus for the College of Atmospheric and Geographic Sciences at the University of Oklahoma. He holds a B.S. in Electrical Engineering and M.S. in Electrical Engineering from the Rose-Hulman Institute of Technology, and a PhD in Atmospheric Sciences from Purdue University. He was a faculty member at Purdue University from 1977 to 1993, Professor of Meteorology and Dean of the College of Atmospheric and Geographic Sciences at the University of Oklahoma from 1994 to 2010, and a Regents' Professor of Meteorology from 2010 to 2013.

Dr. Snow's research has included many aspects of meteorological measurements, such as the design and evaluation of meteorological instruments, optimal deployment of surface networks, and application of weather radars to various types of meteorological observations. He has chaired national and international groups setting standards in these areas, and currently chairs the Technical Advisory Committee for the National Weather Service's Radar Operations Center. As an emeritus faculty member, Dr. Snow directs the University of Oklahoma's Office of Weather Programs and Projects, which has provided training and technical assistance to national hydrometeorological services in Korea, Shanghai, Taiwan, Croatia, Nigeria, the Philippines and Indonesia. He is also Founder and Principal of Snow & Associates, L.L.C., a meteorological consulting firm that provides public and private sector clients with forensic meteorological services; observing network and forecasting services design, engineering, and implementation; and expert advice and testimony for legal and industrial/commercial purposes.

Dr. Snow is a Fellow of the American Meteorological Society and a member of the Royal Meteorological Society of the United Kingdom. He is a Certified Consulting Meteorologist (certification by the American Meteorological Society).

Jeremy Usher

Jeremy Usher has over 20 years of experience working in the international environmental, climate and weather monitoring sectors. He has an undergraduate degree in Electrical Engineering from Auburn University and an MBA from Duke University. His professional roles have included a wide range of responsibilities, with substantial work in technology, business management and public policy.

These include his role as a key architect and team lead for the development of Yahoo's original weather website—Yahoo! Weather. This innovative project was the first to successfully create 10-day weather forecasts for any location in the world and distribute them on the Internet, thus changing the way the public receives weather information today. Mr. Usher also formed part of the international firm Weathernews Inc., where he worked as Chief Information Officer and Chief Executive Officer. During this time, he was responsible for building and managing weather services for commercial clients in the agriculture, aviation, energy, marine transportation and mobile telecommunication industries.

Invited Contributors

Market Study and Country Profiles

Dr. Anthony Mills is the CEO of C4 EcoSolutions—a company of 15 climate change consultants that develop innovative, evidence-based solutions for adapting to climate change. C4 operates in more than 40 countries across Asia and Africa. The company's clients include the International Finance Corporation (IFC), UNEP, IFAD, FAO, CarbonPlus Capital and UNDP. C4's work includes designing and implementing adaptation projects and investments in both the public and private sectors. Dr. Mills is also Extraordinary Professor in the Department of Soil Science, University of Stellenbosch.

Olga van den Pol studied Tropical Land Use at Wageningen University in the Netherlands, graduating with an MSc in 2006. She has worked with the WWF in Cambodia, the Charles Darwin Research Station (CDRS) in the Galapagos Islands, and, more recently, the IUCN in the Netherlands. Her work with IUCN involved developing strategies for the sustainable financing of international projects. In 2014, she joined C4 EcoSolutions as a climate change and environmental consultant. Her work at C4 focuses on designing and implementing ecosystem-based adaptation projects in developing countries across Africa, Asia, and Central and South America.

Onno Huyser studied Conservation Science and Zoology at the University of Cape Town, graduating with a MSc in 2000. He has worked in the private sector, and as the Fund Manager for the Table Mountain Fund. He ran the Fynbos and Succulent Karoo Biome Programmes for WWF South Africa for over two years until late 2014, when he started Oh! Consulting, which focuses on adaptation and green finance.

African Centres for Lightning and Electromagnetics (ACLE)

Mary Ann Cooper, MD, Professor Emerita of Emergency Medicine, University of Illinois at Chicago, is the recognized international authority on lightning injuries and injury prevention.

Richard Tushemereirwe is the Senior Presidential Advisor on Science and Technology, the Disaster and Climate Resilience research fellow at Makerere University School of Public Health, and the Relationships Advisor for ACLE. Learn more at www.aclenet.org.

Addressing Risk to Infrastructure with Improved Climate Forecasts

Raffaello Cervigni is a lead environmental economist with the Africa Region of the World Bank. He holds an MA and a PhD in Economics from Oxford University and the University College London, and has some 18 years of professional experience on programmes, projects and research in a variety of sectors.

Linking Smallholder Farmers to Insurance

Diana Rodriguez. Acre Africa evolved from the Kilimo Salama project, established in 2009 and funded by the Syngenta Foundation for Sustainable Agriculture and the IFC Global Index Insurance Facility (GIIF). To learn more, visit www.acreafrica.com.

Leapfrogging Technology: Trans-African HydroMeteorological Observatory Aims to Install 20,000 Weather Stations in Africa (TAHMO)

John Selker is a Professor of Hydrology at Oregon State University and the Co-Director of TAHMO. His research and development work on sensing applies to irrigation, hydrology and water systems. To learn more about TAHMO, visit www.tahmo.org.

3-2-1 Innovation: Human Network International (HNI) Program Goes 'The Last Mile' to Bring Public Alerts to Cell Phones

David McAfee is the President, CEO, and Co-Founder of HNI. He has over 20 years of development experience and a proven record of social entrepreneurship. He was a Peace Corps volunteer in Gabon from 1991 to 1994. In 1996 he joined Population Services International (PSI), the world's largest social marketing organization, and held various positions including Country Representative in Rwanda and Madagascar and Regional Director for Southern Africa. In 2008, he left PSI to promote the use of technology in development as the leader of HNI. He has a BA in Economics from the University of Chicago. Learn more about HNI at www.hni.org.

IMPROVED HYDROMET SERVICES CAN HELP REDUCE RISK FROM FLOODS (SUCH AS THIS ONE IN MALAWI IN 2015) AND OTHER NATURAL DISASTERS. PHOTO BY UNDP.

CELL-TOWER SITES CAN BE USED TO POSITION METEOROLOGICAL EQUIPMENT, EITHER ON THE TOWER, SUCH AS AN AUTOMATIC WEATHER STATION AND/OR A LIGHTNING LOCATING SENSOR, OR ADJACENT TO IT, SUCH AS THE RAIN GAUGE SHOWN HERE. THE CELL NETWORK CAN ALSO BE LEVERAGED TO DISTRIBUTE EARLY WARNINGS AND CLIMATE INFORMATION. PHOTO BY JOOST HOEDJES.

Monitoring and Evaluation

Roxana Manea collaborates with CIRDA as a Project Analyst. She has previously worked on issues linked to climate change adaptation and common-pool resources. Roxana graduated in 2014 with a master's degree in international economics that focused on environmental and development issues. In addition, she holds an MSc in audit and a BSc in finance.

The Economics of Adaptation

Dr. Pradeep Kurukulasuriya leads the climate change adaptation team within the Bureau of Policy and Programme Support's Global Environmental Finance Unit in UNDP. He provides strategic and technical leadership to UNDP staff in supporting more than 100 developing countries to design, access finance for and implement adaptation programmes and projects. He holds a PhD in Environmental Economics from Yale University.

Peer Reviewers

GEF

Fareeha Y. Iqbal is Climate Change Specialist at the Global Environment Facility and is currently Adaptation Programme Manager for the Asia Region. She has 14 years of experience working on resilience with various environmental and development agencies. She holds a master's degree in Environmental Policy from the Massachusetts Institute of Technology.

Dustin Schinn is Climate Change Analyst at the Global Environment Facility. Previously, he provided management support at the Green Climate Fund. He holds a Bachelor of Science from University of Potsdam and a Master of Environmental Management from Yale University.

International Center for Climate Change and Development (ICCCAD)

Dr. Nazneen I. Khan is a social scientist. She is currently involved with the International Center for Climate Change and Development (ICCCAD) as a researcher. She obtained her PhD from the University of Dhaka, Bangladesh, and her research has focused on social, political and climate change issues.

Acclimatise

Dr. Richenda Connell is CTO and Co-Founder of Acclimatise, a specialist adaptation advisory firm. She is an expert in adaptation and climate resilience with more than 20 years' experience. She is co-author of a World Bank report on climate resilience and infrastructure PPPs. She sits on the Steering Committee of the Urban Climate Change Research Network (UCCRN). She holds a doctorate in atmospheric chemistry from the University of Oxford.

WMO

The authors gratefully acknowledge the detailed comments received from WMO staff, including the discussion at a meeting with more than a dozen WMO staff on 2–3 July 2016. This text reflects many changes and editions made in response to these comments but the authors remain responsible for any errors or unintended differences with WMO policies or views.

EMBRACING INNOVATION IN THE CLIMATE INFORMATION AND SERVICES SECTOR

As we move further into the 21st century and the average global temperature increases, we are likely to witness more frequent and severe weather, droughts, floods, and sea-level rise around the globe. If not addressed, as committed to by world leaders in Paris, climate change will be a major challenge to efforts to achieve the Sustainable Development Goals. Providing accurate, reliable, and timely weather and climate information is central to building resilience to climate change, empowering nations, saving lives and strengthening livelihoods across Africa's most vulnerable communities.

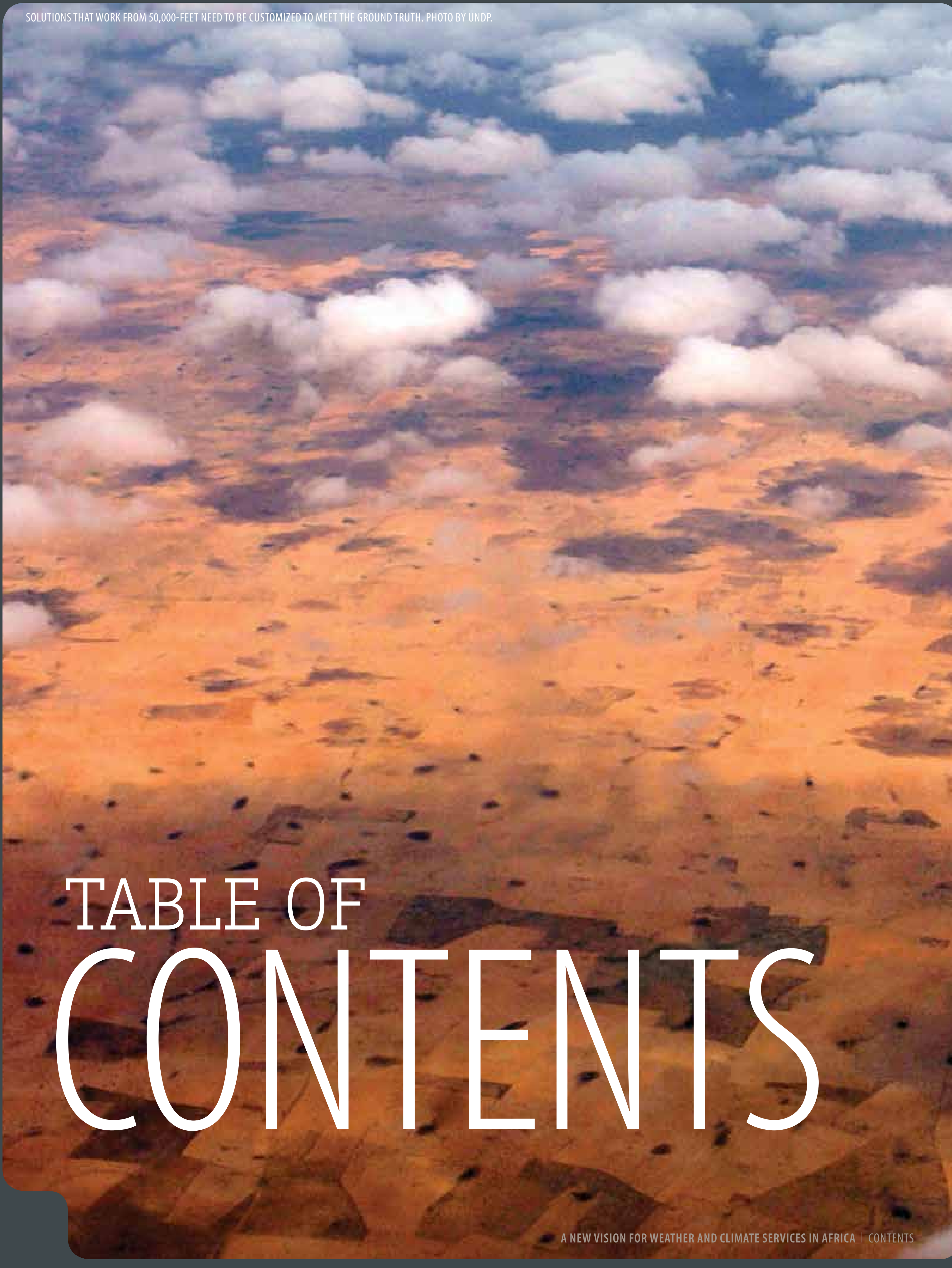
While people in Africa have contributed the least to human-induced climate change, they are among the most vulnerable to its effects. Every year, thousands of lives and countless millions of dollars of livelihoods, crops, and infrastructure investments are lost due to severe weather, contributing to a poverty trap. Timely and effective early warnings and improved climate information can help minimize these losses by improving decision making in government and communities. Businesses, from the large to the micro, benefit from access to quality and localized weather information.

With the right information, the latest technology, and increased capacity, Africa can scale up efforts to achieve the Sustainable Development Goals, support regional cooperation, and fight climate change.

In doing so, countries will need to rethink the status quo and be innovative. Cost-effective and sustainable technologies need to be deployed. The private sector also has a role to play in the emerging field of global climate information and related services, and should be considered partners in bringing about innovative solutions. An example of innovation is the leveraging of cell-phone networks, which have spread rapidly across Africa, to collect near-real-time data from integrated, all-in-one, automatic weather stations, and to disseminate information, alerts and warnings. Proactively engaging with international weather and climate information companies, including a growing number based in Africa, to provide weather forecasts and customized industry products and services across the continent will also be important. Such a transformation would also benefit from and contribute to the emergence of widespread entrepreneurial activity in Africa. Small businesses, many of which are internet based and linked to cellular communications, are becoming a new force for economic growth which can be connected to the new world of weather services.

It is time for a new vision in the weather and climate services sector. As African leaders look at these challenges and make decisions on how to invest new funds, it will be important to take into account the new technology offerings, models for sharing climate and weather information, and ways of doing business presented in this publication. These innovative approaches will need to be tested, reviewed and evaluated, but an important first step is to put aside preconceived notions, and be open to innovation and to partnerships with the private sector.

Helen Clark
Administrator of the United Nations Development Programme



SOLUTIONS THAT WORK FROM 50,000-FEET NEED TO BE CUSTOMIZED TO MEET THE GROUND TRUTH. PHOTO BY UNDP.

TABLE OF CONTENTS

SECTION 5 – A NEW VISION FOR PUBLIC-PRIVATE PARTNERSHIPS 64

This section reveals the specific needs of both public and private stakeholders, identifying enabling actions needed to initiate public-private partnerships in Africa's least developed countries. New opportunities from the telecommunications, farming, aviation and other sectors are examined.

SECTION 6 – STRUCTURING EFFECTIVE PUBLIC-PRIVATE PARTNERSHIPS 82

This section looks at effective methods to structure public-private partnerships. Creating these strategic partnerships requires a conducive regulatory framework and business environment, sustained financial and political support, transparent and effective procurement processes, clear allocation of risks, and continual monitoring and evaluation.

SECTION 7 – CONCRETE EXAMPLES 92

SMALLHOLDER FARMERS CAN PROTECT PRODUCTIVE ASSETS WITH IMPROVED CLIMATE INFORMATION.

SECTION 1

INTRODUCTION

CELL PHONES HAVE BECOME UBIQUITOUS ACROSS SUB-SAHARAN AFRICA, OFFERING AN EASY PLATFORM FOR THE DISTRIBUTION OF EARLY WARNINGS OF IMPENDING HAZARDOUS WEATHER CONDITIONS AND CLIMATE INFORMATION TO BOTH RURAL AND URBAN AREAS. PHOTO BY ©IFAD/MWANZO MILLINGA.

The collection, analysis and distribution of reliable weather, water and climate information—collectively referred to as hydromet services—has the potential to greatly benefit efforts by African nations to reduce poverty, build resilience and adapt to a changing climate. For over 30 years, the international development community has made substantial investments in the procurement of weather, water and climate technologies for Africa. Nevertheless, today, according to the World Bank, "most hydromet services in sub-Saharan Africa are unable to meet current needs for weather and climate information, and offer only limited areas of transboundary cooperation."[1] In this report a new vision to address sub-Saharan Africa's weather, water and climate monitoring and forecasting needs is explored. The basis for this new vision begins with a review of problems with traditional approaches and how this has affected the ability to achieve development goals, reduce risks and empower Africa's least-developed countries in supporting their citizens with hydromet services and early warning systems that can save lives, boost productivity and protect the environment in a changing climate.

This new vision includes the implementation of advanced hydrometeorological technologies and services, capacity-building and enabling policies that fortify the position of Africa's National HydroMeteorological Services (NHMS), as well as the formulation of new partnerships between the public and private sectors. Creating a sustainable model for the delivery of effective hydromet services in sub-Saharan Africa will require policymakers to critically examine the status quo and establish a new vision for the implementation of this essential public service. This new vision goes beyond the simple procurement and installation of new technologies, to an end-to-end systems approach. There is no silver bullet, but with effectively structured public-private partnerships, new technology and services, strengthened institutions, increased regional cooperation and continued capacity-building, sustainable hydromet solutions are a realistic and attainable goal. Reaching this target will have a significant impact on the achievement of the Sustainable Development Goals, protecting lives and building powerful resilience for Africa and beyond.[2]

> "A RECENT WORLD METEOROLOGICAL ORGANIZATION (WMO) MONITORING SURVEY SHOWED THAT 54% OF THE SURFACE AND 71% OF THE UPPER AIR WEATHER STATIONS IN THE REGION DID NOT REPORT DATA."
> –WORLD BANK[1]

BUILDING RESILIENCE TO CLIMATE CHANGE

Sub-Saharan Africa is already facing a combination of challenges perhaps greater than any other region—rapid population growth, urbanization leading to megacities, challenges in providing basic services, the lowest rates of electricity and energy access in the world, low rates of agricultural productivity, and outbreaks of disease (HIV, Ebola).[3] Despite continued economic growth and advances in food security, the lack of political stability, regional cooperation, strong government institutions, and access to new technologies, information and training remains persistent and creates tough-to-break poverty traps that hinder progress in resilient development and poverty reduction. Today in Africa, an estimated 400 million people live in extreme poverty, with projections from the World Bank's Global Monitoring Report indicating only small gains in poverty reduction in sub-Saharan Africa over the next 15 years.

Virtually all of these problems will be exacerbated by the higher temperatures, droughts, floods and changing weather patterns expected from climate change, as summarized in a 2013 study for the World Bank, *Turn Down the Heat*:

- With 4°C in global warming by the end of the century, sea level is projected to rise up to 100 cm, droughts are expected to become increasingly likely in central and southern Africa, and never-before-experienced heat extremes are projected to affect increasing proportions of the region.
- Projections also show a growing probability of increased annual precipitation in the Horn of Africa and parts of East Africa, which is likely to be concentrated in heavy downpours, and, thereby, increase the risk of flooding.
- Sub-Saharan Africa is particularly vulnerable to impacts on agriculture. Most of the region´s agricultural crop production is rainfed and therefore highly susceptible

[1] World Bank, 'Creating an Atmosphere of Cooperation in Sub-Saharan Africa by Strengthening Weather, Climate and Hydrological Services', Geneva, 2 June 2015.

[2] For more information on the Sustainable Development Goals, refer to www.un.org/sustainabledevelopment/development-agenda/.

[3] In its annual Climate Change Vulnerability Index, the U.K.–based risk analysis firm Maplecroft lists the top 32 countries at 'extreme risk' from climate change. "The top 10 are all tropical countries: Bangladesh, Sierra Leone, South Sudan, Nigeria, Chad, Haiti, Ethiopia, the Philippines, the Central African Republic, and Eritrea. Of these, all but Nigeria and the Philippines are on the UN's list of the world's 48 poorest countries. The reasons that the poor living at low latitudes will bear the heaviest burdens of climate change are meteorologically, economically, and geopolitically complex, but they all arise from an inescapable statistical fact: normal temperature ranges in the tropics fall within a narrower range than those in more northern climes, and so any deviation is likely to have more significant effects." Richard Martin, 'Climate Change: Why the Tropical Poor Will Suffer Most', *MIT Technology Review*, 17 June 2015, https://www.technologyreview.com/s/538586/climate-change-why-the-tropical-poor-will-suffer-most/.

to shifts in precipitation and temperature. A net expansion of the overall area classified as arid or hyper-arid is projected for the region as a whole, with likely adverse consequences for crop and livestock production.

- Savannah grasslands may be reduced in area, with potential impacts on livelihoods and pastoral systems. By the time 3°C in global warming is reached, savannahs are projected to decrease from about a quarter at present to approximately one-seventh of total land area, reducing the availability of food for grazing animals.[4]

The same report provides a graphic overview of the range and timing of climate impacts already occurring and expected in the future in the region (see Table 1.1).

Taken as a whole, climate and weather services (or hydromet services, to include the essential monitoring of water)[5] encompass the effective collection, analysis, packaging and distribution of weather, water and

Table 1.1 Summary of climate impacts and risks in sub-Saharan Africa.

Risk/Impact		Observed Vulnerability or Change	Around 1.5°C[A,B] (≈2030s[D])	Around 2°C (≈2040s)	Around 3°C (≈2060s)	Around 4°C (≈2080s)
Heat extreme[D] (in the Southern Hemisphere summer) Drought	Unusual heat extremes	Virtually absent	20–25 percent of land	45 percent of land	70 percent of land	>85 percent of land
	Unprecedented heat extremes	Absent	<5 percent of land	15 percent of land	35 percent of land	>55 percent of land
		Increasing drought risk in Southern, Central, and West Africa, decrease in East Africa, but West and East African projections are uncertain	Likely risk of severe drought in Southern and Central Africa, increased risk in West Africa, decrease in East Africa but West and East African projections are uncertain	Likely risk of severe drought in southern and Central Africa, increased risk in West Africa, decrease in East Africa but West and East African projections are uncertain	Likely risk of extreme drought in Southern Africa and severe drought in Central Africa, increased risk in West Africa, decrease in East Africa, but West and East African projections are uncertain	Likely risk of extreme drought in Southern Africa and severe drought in Central Africa, increased risk in West Africa, decrease in East Africa, but West and East African projections are uncertain
Aridity		Increased drying	Little change expected	Area of hyper-arid and arid regions grows by 3 percent		Area of hyper-arid and arid regions grows by 10 percent. Total arid and semi-arid area increases by 5 percent
Sea-level rise above present (1985–2005)		About 21 cm to 2009[E]	30cm[F]-2040s 50cm-2070 70cm by 2080–2100	30cm-2040s 50cm-2070 70cm by 2080–2100	30cm-2040s 50cm-2060 90cm by 2080–2100	30cm-2040s 50cm-2060 105cm by 2080–2100

[A] Refers to the global mean increase above pre-industrial temperatures.
[B] Years indicate the decade during which warming levels are exceeded in a business-as-usual scenario exceeding 4°C by the 2080s.
[C] Years indicate the decade during which warming levels are exceeded with a 50 percent or greater change (generally at the start of the decade) in a business-as-usual scenario (RCP8.5 scenario). Exceedance with a likely chance (>66 percent) generally occurs in the second half of the decade cited.
[D] Mean heat extremes across climate model projections are given. Illustrative uncertainty range across the models (minimum to maximum) for 4°C warming are 70–100 percent for unusual extremes, and 30–100 percent for unprecedented extremes. The maximum frequency of heat extreme occurrence in both cases is close to 100 percent, as indicator values saturate at this level.
[E] Above 1880 estimated global mean sea level.
[F] Add 20 cm to get an approximate estimate above the pre-industrial sea level.

[4] Sophie Adams et al., *Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience* (Washington, D.C.: World Bank, 2013). The recent Paris Agreement may prove effective in reducing this level of warming. However, other impacts of climate change may not be thoroughly covered by the Agreement.

[5] In general terms, weather refers to short-term events, water refers to hydrology (the scientific study of the waters of the earth, especially in relation to the effects of precipitation and evaporation upon the occurrence and character of water on or below the land surface), while climate refers to events over a longer period of time (usually several decades). The glossary and acronyms index on p132 provides definitions of commonly used meteorology and hydrology terms.

climate information. These basic public services include the issuance of early warnings of fast-acting storms, fires and extreme weather events. The concept of services goes well beyond a simple procurement-based approach and takes a systematic end-to-end approach where, according to the WMO Strategy for Service Delivery, the "product or activity meets the needs of a user or can be applied by a user". According to the WMO, "service delivery should be available and timely, dependable and reliable, usable, useful, credible, authentic, responsive and flexible, sustainable (affordable and consistent over time), and expandable (to be applicable to different kinds of services)".[6]

Providing vulnerable farmers and communities with improved hydromet services has the potential to increase farm production and lower risk. With better information on extreme weather events, improved crop forecasts and more actionable information on what to do when bad weather hits, farmers can protect property and human lives, access risk-management mechanisms like index-based insurance, and create long-term plans for a future that will be highly dependent on rainfall patterns, droughts, floods and other natural disasters.

Investment in hydromet services is also smart business. It is said to have a return of fivefold or greater in economic development for every dollar spent.[7] This is often mentioned as a metric to justify government expenditure on hydromet infrastructure. Decision makers can use this valuable information to inform National Adaptation Plans, strengthen production and local economies, lower migration caused by climate change, and build climate-smart infrastructure designed to withstand the potential dangers presented by a changing climate. Private sector enterprises can also use the information to inform their own climate adaptation strategies, while on the community level, village leaders can develop climate-resilient strategies to improve local enterprises and protect productive assets.

While much of the international focus on climate change has centred on mitigation—efforts to slow and gradually reduce the rising level of global greenhouse gas emissions—the African continent, with a few limited exceptions, has a very limited ability to affect global mitigation by reducing their own emissions. All of the emissions from sub-Saharan Africa amounts to only a few percent of total global greenhouse gas emissions. At the same time, African nations are very vulnerable to the impacts of climate change. Consequently, the climate change focus for African countries has mainly to do with adaptation—increasing resilience and reducing as much as possible the adverse impacts of climate change. But how? And with what resources?

The climate convention process holds forth the promise of greater donor support for adaptation, particularly for the poorest and most vulnerable countries, but how can such funds be used most effectively without reliable data on weather and climate?[8]

To date, most donor funds for adaptation to climate change have been used for capacity-building measures, such as studies to make projections of climate impacts and identify vulnerabilities, training to enhance knowledge and human resources, and policy reviews to identify incentives for potential reforms (e.g., land-use planning to discourage construction in coastal areas) and counter maladaptation (e.g., subsidies for water use in drought-prone areas, and to locate flood-prone lands).[9] While useful, such measures can in general be termed as precursors or preparations for adaptation, and not significant adaptation actions. In addition, almost all adaptation financing has been in the form

6 'The WMO Strategy for Service Delivery', https://www.wmo.int/pages/prog/amp/pwsp/documents/SDS.pdf.

7 WMO, 'Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services', 2015, WMO-No. 1153, "NHMS improvements to reduce disaster losses in developing countries—benefit-cost ratios (BCRs) range from 4-1 to 36-1. Drought early warning system in Ethiopia to reduce livelihood losses and dependence on assistance—BCRs range from 3-1 to 6-1." The economic returns of investments in weather services are explored later in this publication.

8 On 12 December 2015, the 195 nations signatory to the UN Framework Agreement on Climate Change reached a historic agreement to combat climate change and redirect investment towards a more climate-friendly future. Learn more about the implications of the Paris Agreement on Climate Information and Early Warning Systems projects at undp-cirda.blogspot.com/2015/12/implications-of-paris-cop21-agreement.html. The primary source of donor funding for adaptation is now the Green Climate Fund; see www.greenclimate.fund.

9 For a recent review of experience with adaptation projects, see the Global Environment Facility (GEF), 'Time to Adapt: Insights from the GEF's Experience in Adaptation to Climate Change', June 2016, www.thegef.org/gef/taxonomy/term/1700.

of grants to government entities with little or no effort to engage the private sector, despite the likelihood—as studies have shown—that most adaptation investment will ultimately be made by businesses and individuals.[10]

A NEW VISION FOR CLIMATE AND WEATHER INFORMATION

This report focuses on a promising new vision to build enabling actions that present immediate opportunities to enhance the capacity of African countries to prepare for climate change, and to achieve other economic, environmental and social goals simultaneously.

Innovative technologies and business models have come together to offer new ways of collecting, analyzing and communicating weather, water and climate information. For most African countries this is a dramatic, almost revolutionary prospect. As will be discussed in some detail, national efforts to modernize the current status of hydromet services in sub-Saharan Africa are inadequate at best, or, in many areas, non-existent.[11] Consequently, despite many qualified staff making their best efforts, national weather services are not a significant source of weather, water and climate information for most businesses and individuals (with limited exceptions, such as in aviation, due to legal requirements). The approach described in this report emerged from UNDP's response to requests from 11 African nations to help respond to this need.

Since the mid-1980s, donor support for modernizing weather and climate services in developing countries has conservatively totalled almost US$1 billion, with the majority of commitments since 2000.[13] Nevertheless, a recent WMO monitoring survey showed that "54% of the surface and 71% of the upper air weather stations in the region did not report data", leading the World Bank to call for an additional 5,000 weather monitoring systems to be deployed across Africa.[13] So what hasn't worked? And why do National HydroMeteorological Services in sub-Saharan Africa remain caught in a non-virtuous cycle where systems break down and are not maintained; resources are constrained; and vulnerable communities still need to look to the sky to understand local weather systems, or, even worse, where local planting and crop management traditions are turned on their head by changing weather patterns, droughts, severe storms and floods?

The specific challenges are complex and nuanced and explored in Section 2 of this publication. The problems vary by country but typically include some combination of poor planning for the ongoing expenses and skills required for the maintenance, service and management of weather and climate monitoring systems. They also include a preference for technological solutions that work well in the developed world but are not well suited for the unique rigours of deployment in sub-Saharan Africa, as well as poor integration between disparate donor-supported investments in the hydromet services space. This has led to new concerns in response to increased competition from new private sector players. There have also been any number of regional and local challenges that have the tendency to derail non-customized solutions for Africa's persistent development challenges and perpetuate the aforementioned non-virtuous cycle. A benefit of the innovative technologies and business models described in this report is that they advance climate adaptation goals, including reducing the impact of storms, lightning and other extreme weather events

[10] Bonizella Biagini and Alan Miller, 'Engaging the Private Sector in Adaptation to Climate Change in Developing Countries', *Climate and Development* 5, no. 3 (2013), www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/cb_home/news/feature_publication_adaptation_nov2013.

[11] "Low investment [in hydromet services] is especially evident in Africa. The network of hydromet stations is sparse and deteriorating, and hydromet data are often spotty and inaccurate. Existing stations are often not functioning or fail to communicate with the global meteorological network. These shortcomings are especially serious given the large proportion of Africans engaged in agriculture and the very high variability of African precipitation relative to the mean." Independent Evaluation Group (IEG), World Bank, 'Adapting to Climate Change: Assessing World Bank Group Experience', ieg.worldbankgroup.org/Data/reports/cc3_full_eval_0.pdf.

[12] "Over 1985–2011, the World Bank has financed 132 projects that supported hydromet improvements. Twelve projects provided comprehensive support for national-level hydromet systems at a cost of $380 million. About nine-tenths of project funding went to 8 IBRD countries (Albania, Brazil, Dominican Republic, Mexico, Peru, Poland, Russia, and Turkey), while the remainder went to 4 IDA countries/regions (Afghanistan, Central Asia, Moldova, and Sri Lanka). An additional 120 projects (including 18 in Sub-Saharan Africa and 5 in the Middle East and North Africa) supported partial systems or specific needs, at a cost of at least $917 million." IEG, World Bank, 'Adapting to Climate Change: Assessing World Bank Group Experience'.

[13] World Bank, 'Creating an Atmosphere of Cooperation in Sub-Saharan Africa by Strengthening Weather, Climate and Hydrological Services'.

through the timely communication of warnings as well as the collection of real-time weather data, which is valuable for short-term-weather and long-term-climate forecasts. Consequently, they can receive, and already have received, support from climate funds, which are expected to become increasingly available as a product of the UN Framework Convention on Climate Change.[14]

Engagement with the private sector will be a key component to addressing some of these persistent challenges. In 2015, the Seventeenth World Meteorological Congress highlighted "the different, and at times, complementary roles and responsibilities of NHMSs, academic institutions, research and technological agencies, and the private sector." During the Congress it was agreed that "closer interactions between the public and private sectors could stimulate innovation and facilitate cross-fertilization, ultimately benefitting the achievement of the WMO Strategic Plan and Expected Results. It was noted that "WMO has a unique opportunity to initiate this interaction and emphasized that inaction may limit the benefits to be derived for the users." On the other hand, "such activities could also lead to proliferation of non-authoritative weather and climate information which could challenge the NHMSs mandate to disseminate authoritative weather information and warnings to the public, media and disaster management authorities. With these challenges in mind, the Congress "encouraged the development of specifications and service-level agreements by NHMSs in order to ensure accuracy, traceability and delivery of quality services to their end users."[15]

The challenges to this new vision are thus in part technical—introducing new technologies and vendors and demonstrating the effectiveness of their products and services—but even more so they involve the need to change established ways of doing things, create bespoke solutions, ensure the long-term sustainability of investments, overcome an existing lack of trust between the public and private sectors, and create different ways of operating that focus on going beyond the procurement of technologies to an end-to-end systematic approach. This is not an easy task, but the potential rewards are so great that a significant effort to make it happen is justified.

INVESTMENTS IN WEATHER, WATER AND CLIMATE MONITORING AND FORECASTING HAVE A GOOD RETURN ON INVESTMENT, PROTECTING LIVES AND LIVELIHOODS, PROPERTY AND INFRASTRUCTURE. PHOTO BY UNDP.

In the end, addressing the challenges of climate change—and building smart adaptation mechanisms across sub-Saharan Africa—will require engagement with a broad grouping of actors from both the public and private sectors. In order to make it work, African nations will need to take the lead, creating a series of enabling actions that engage the numerous actors that are coming together to provide weather services. By engaging with these potential partners—and working to establish win-win relationships—African nations have the opportunity to ensure the long-term sustainability of investments in hydromet systems, build resilience to a changing climate, and create working models that provide valuable weather, water and climate information and early warning systems to the vulnerable farmers and communities that need them the most. As with any initiative, these innovative approaches will need to be carefully monitored and evaluated, allowing practitioners and NHMS leaders to test and pilot innovation, measure its impact and adjust approaches to foster long-term sustainability.

[14] Parties have already agreed to the creation of a Green Climate Fund with the aim of mobilizing US$100 billion per year by 2020, with funding evenly balanced between mitigation and adaptation, and with priority in adaptation funding for least developed countries and small island states; Cancun Agreements, Dec. 1/CP.16 (2010), para. 95, 98 and 102. As set forth in the Paris Agreements, Part III, para. 54 under 'Finance', "developed countries intend to continue their existing collective mobilization goal through 2025 in the context of meaningful mitigation actions and transparency on implementation; prior to 2025 the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall set a new collective quantified goal from a floor of USD 100 billion per year, taking into account the needs and priorities of developing countries". In November 2015, a project managed by UNDP was approved for $11 million to support hydromet services in Malawi.

[15] 'Seventeenth World Meteorological Congress', Geneva, 25 May–12 June 2015, WMO-No. 1157, 2015.

A BRIEF HISTORY OF FINANCING FOR ADAPTATION TO CLIMATE CHANGE

In Article 4, para. 4, the 1992 UN Framework Convention on Climate Change recognizes the need for developed countries to provide financing to assist the most vulnerable developing countries to pay the costs of adapting to climate change. However, donors were slow to honour this commitment. The Global Environment Facility (GEF), a financial mechanism of the Convention established in the early 1990s, issued numerous operational programmes for the support of mitigation but for almost a decade financed only vulnerability assessments and capacity-building related to adaptation. In 2001 the GEF initiated a US$50 million pilot programme to support adaptation and shortly thereafter was given a mandate to manage two additional funds with adaptation objectives, the Least Developed Countries Fund (LDCF) and the Special Climate Change Fund (SCCF). Together, these funds achieved cumulative commitments of over US$1 billion. From the LDCF, of the 50 countries that had completed their National Adaptation Programmes of Action (NAPAs), 49 had accessed a total of US$905 million for 161 projects as of 22 September 2015. On the same reporting date, 79 countries had accessed a total of US$345 million for 76 projects under the SCCF.[16]

The Pilot Programme for Climate Resilience (PPCR), a component of the Climate Investment Funds managed by the World Bank and established in 2008, has attracted a little more than US$1 billion for adaptation projects. In contrast with the wider range of countries supported by the LDCF, funds from the PPCR have gone to only nine countries and two regions reflecting a strategy concentrating larger amounts of resources in a smaller number of countries with the aim of greater impact.

The Adaptation Fund (AF) was created by the Kyoto Protocol, which took effect in 2007 and was to be financed by a share of the proceeds from transactions under the Clean Development Mechanism (CDM), a provision allowing for developed countries to achieve emission reduction targets in part through projects in developing countries. Originally expected to be a large source of funds, the AF has to date received only about $331 million, as the expected scale of CDM transactions never materialized due to the absence of the United States from the market and reduced demand in the European Union following the economic downturn of 2008–2009.

Prospects for future adaptation funding largely focus on the Green Climate Fund (GCF), a new financing mechanism under the UNFCCC formally agreed by the Parties at meetings in Cancun and Durban in 2010 and 2011. The goal is to 'mobilize' US$100 billion per year in additional financing for climate mitigation and adaptation by 2020. Among the initial policy decisions made by the GCF Board was a commitment that, over time, funding for mitigation and adaptation should be roughly balanced, and that roughly half of adaptation funds should go to particularly vulnerable countries, including least developed countries, small island states and African states. As of mid-2015, pledges from donors for contributions to the GCF for the next few years total roughly US$10 billion. In 2015, the UNDP, alongside 19 other entities, received GCF certification to implement projects with GCF funds. The first eight awards were announced in November 2015, with total support of US$168 million.

CELL PHONES ARE NOW UBIQUITOUS IN SUB-SAHARAN AFRICA. PHOTO BY IFAD/MWANZO MILLINGA.

[16] Global Environment Facility (GEF), 'Progress Report on the Least Developed Countries Fund and the Special Climate Change Fund', 25 September 2015.

Table 1.2 Multilateral funding for adaptation in low-income countries in sub-Saharan Africa (source: www.climatefundsupdate.org).

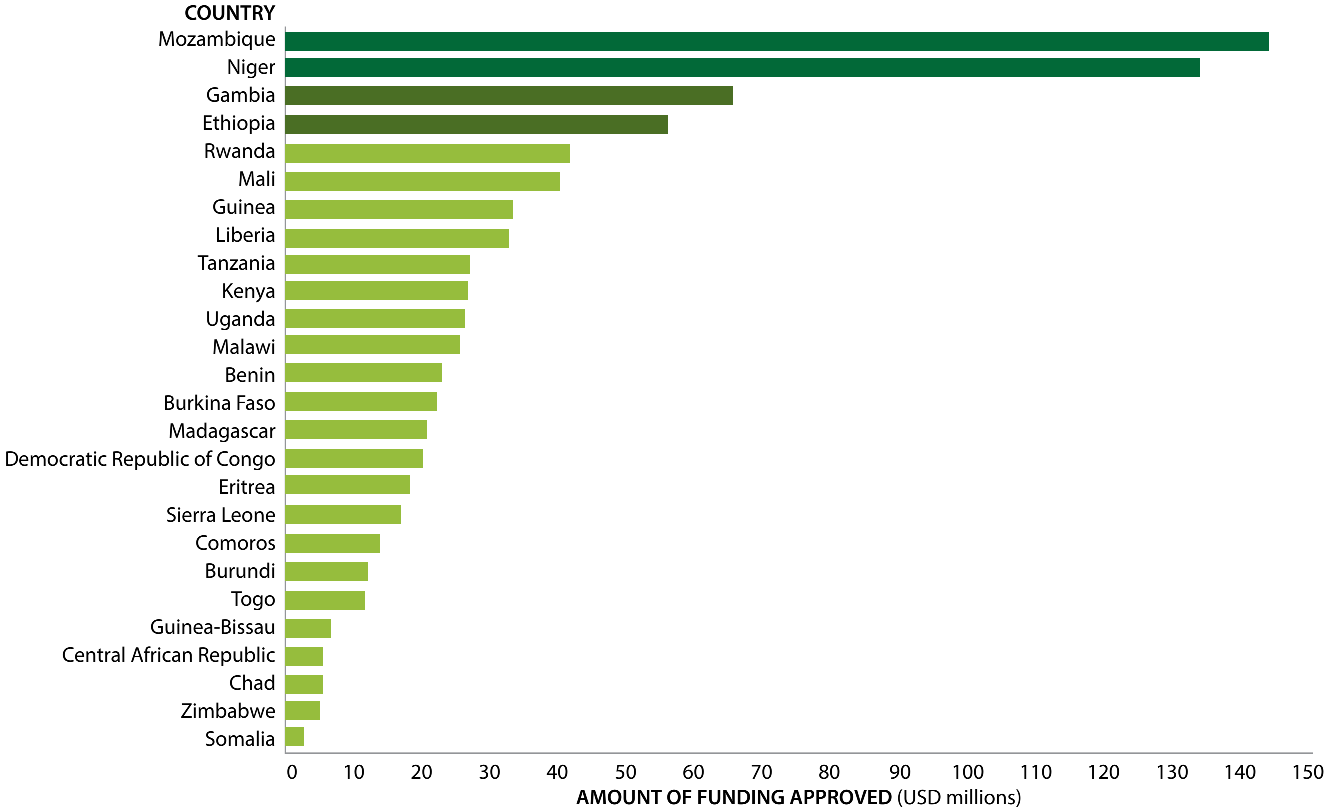
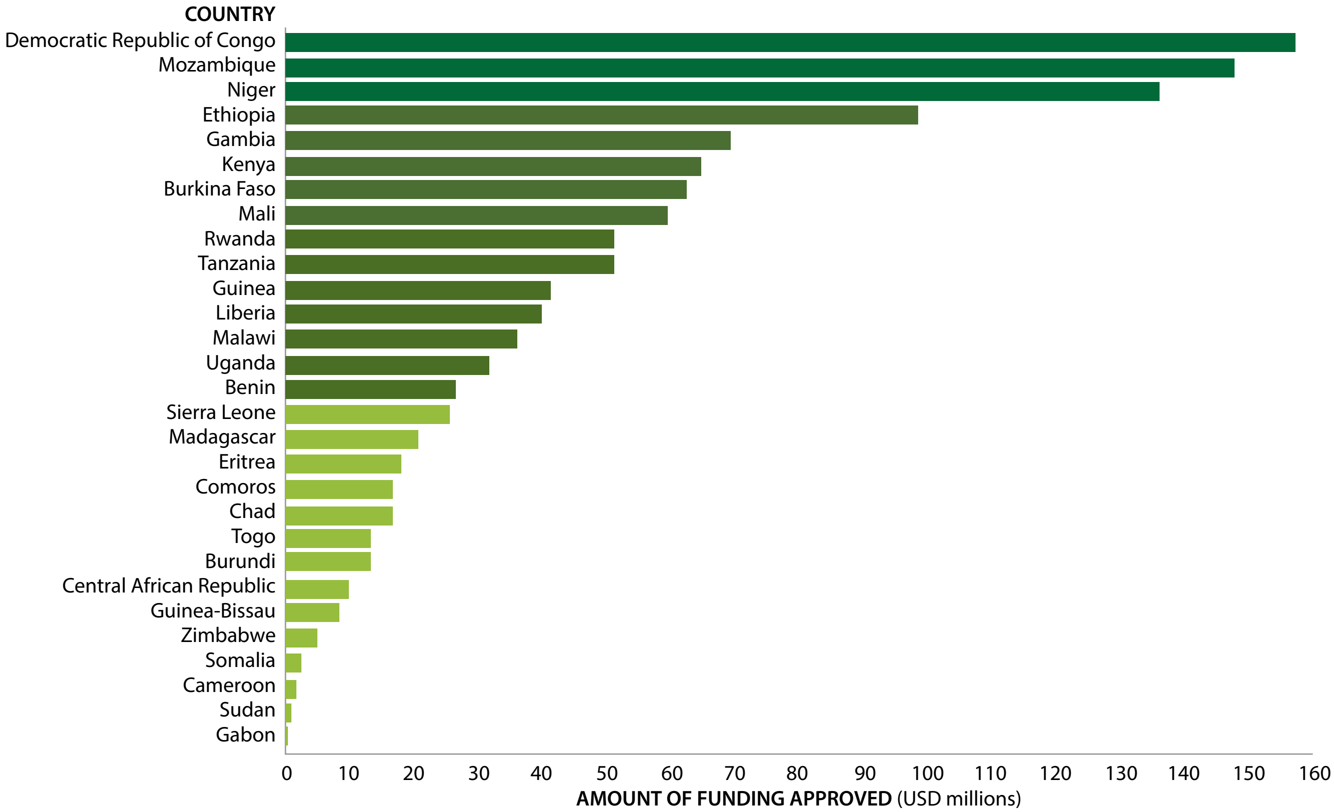
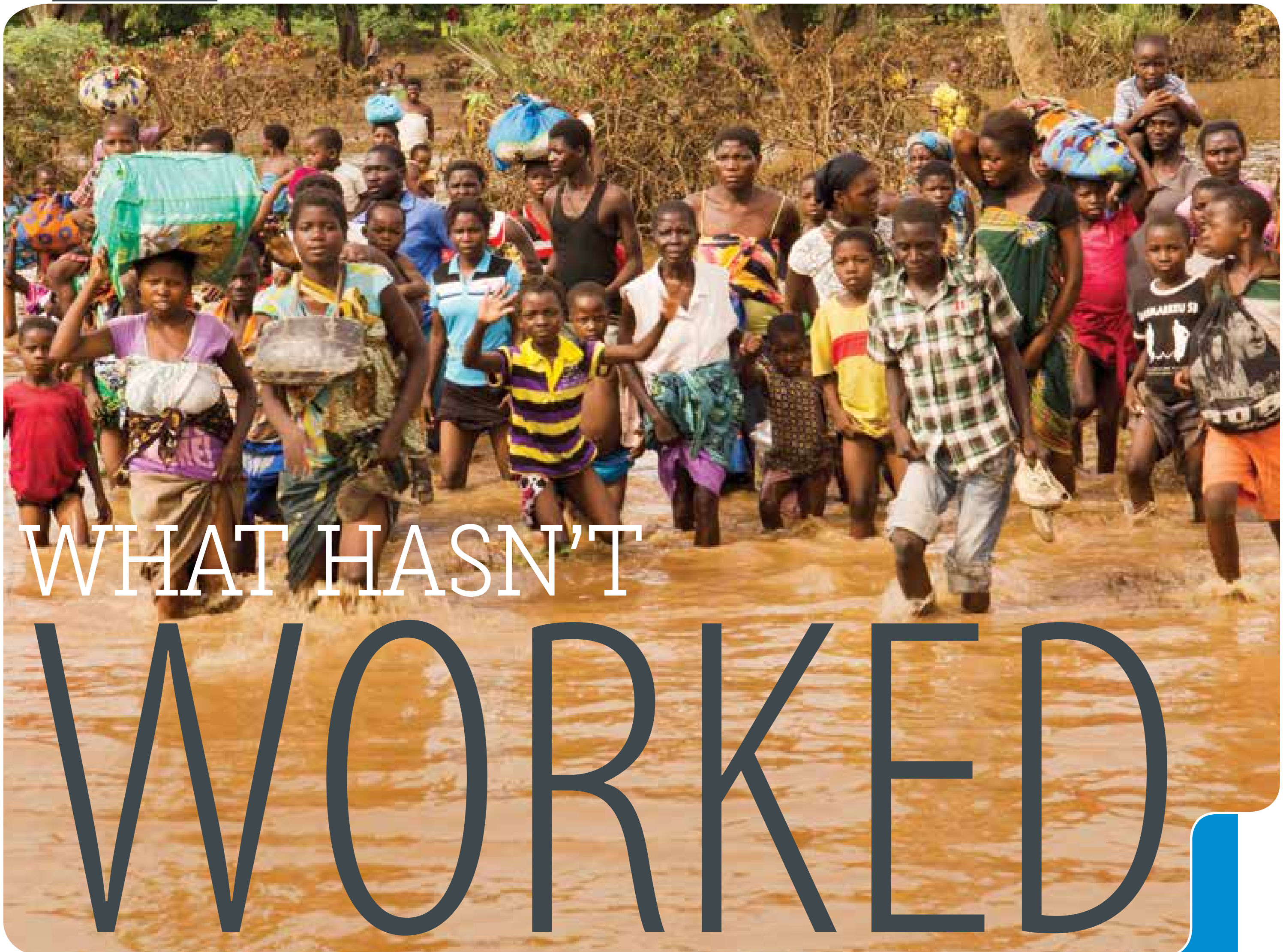


Table 1.3 Total multilateral climate funding (mitigation and adaptation) in low-income countries in sub-Saharan Africa (source: www.climatefundsupdate.org).





WHAT HASN'T WORKED

MALAWI FLOODS IN 2015. PHOTO BY UNDP.

Learning from the past is essential to appreciating the challenges that have prevented many National HydroMeteorological Services in sub-Saharan Africa from implementing sustainable solutions for local hydromet monitoring and forecasting.[16] An appreciation of these challenges and of past efforts to address them allows decision makers and key stakeholders to then articulate and execute a plan of action to ensure the continued sustainability of investments in weather and climate services. Sustainable solutions for local hydromet monitoring and forecasting are critical, as many of the countries in question are highly vulnerable to climate change. These countries require the capability to produce timely, reliable local hydromet information for government entities, the private sector, and the public. At a minimum, early warnings are needed to protect lives and livelihoods from hazardous weather and water events in the short term. From a broader perspective, climate information is critical to supporting the adaptive measures necessary to ensure these countries' survival in the longer term. In this section, an example from Uganda provides a view into the reality facing many developing countries, while snapshots from other countries give perspectives on the true-life consequences that result from poor hydromet monitoring and the associated failure to provide early warnings of high-impact weather, water and climate events—lost lives, livelihoods put at risk, decreased productivity, and failure to attain long-term economic development goals.

OVERVIEW

Across sub-Saharan African, millions of people—mostly near-subsistence farmers and pastoralists, but also many urban dwellers—remain caught in poverty traps in which access to timely local weather, water and climate (collectively known as 'hydrometeorological', or, more simply, 'hydromet') information can mean the difference between life and death. These life-and-death decisions may become progressively more difficult as a changing climate continually modifies the seasons, extending the warm summers and shortening the cool winter periods; changing rainfall patterns to bring more droughts and floods; and warming daily temperatures, resulting in more extreme temperatures and life-threatening heatwaves. More subtle effects will also become progressively important, such as warmer winter seasons, decreasing the 'winter kill' of disease-bearing insects, and warmer temperatures at higher elevations, allowing those same insects to spread more widely. Outbreaks of unfamiliar diseases in humans, livestock and crops will be the result.

"THE NETWORK OF HYDROMET STATIONS [ACROSS SUB-SAHARAN AFRICA] IS SPARSE AND DETERIORATING, AND HYDROMET DATA ARE OFTEN SPOTTY AND INACCURATE. EXISTING STATIONS ARE OFTEN NOT FUNCTIONING OR FAIL TO COMMUNICATE WITH THE GLOBAL METEOROLOGICAL NETWORK." –WORLD BANK

Recognizing the importance of hydromet information, since the mid-1980s international donor support for modernizing hydromet services in developing countries has conservatively totalled almost $1 billion, with the majority of commitments occurring since 2000.[17]

While there have been a few success stories,[18] in too many developing countries the outcomes have been poor. The results obtained over the last three decades from substantial investments—particularly when viewed from the lens of long-term sustainability and adaptation to climate change—have been discouraging.[19] In many cases, government agencies, private sector businesses, and the general public are still unable to access critical local hydromet information to make better informed decisions. This localized hydromet information is essential for protecting lives, sustaining and improving livelihoods, and building local and national resilience. Given these decades of mixed outcomes at best, there is a need to investigate on-the-ground situations and determine the root causes of why the desired outcomes have not happened, to appreciate the short- and long-term impacts of restrictions in local capacity, and to update approaches to ensure that future efforts yield better results. This is especially true in Least Developed Countries (LDCs), where one often finds the poorest and most vulnerable populations.

[16] The focus in this report is mostly on lessons learned from experiences with the 11 countries that are participating as partners with the United Nations Development Programme in the 'Programme on Climate Information for Resilient Development in Africa' (CIRDA). Despite their varying national realities and differences in their hydromet regimes, common problems and potential solutions have been identified that are broadly applicable not only to these 11 CIRDA partners but also to other countries in sub-Saharan Africa.

[17] David Rogers and Vladimir Tsirkunov, 'Weather and Climate Resilience: Effective Preparedness through National Meteorological and Hydrological Services' (Washington, D.C.: World Bank, 2013); Lucy Hancock and Vladimir Tsirkunov, 'The World Bank Portfolio Review (1996 to 2012)', March 2013. Historical review identified more than 150 World Bank projects with hydromet elements.

[18] Projects in middle-income countries such as Mexico and Russia appear to have had the best results.

[19] "Over 1985–2011, the World Bank has financed 132 projects that supported hydromet improvements. Twelve projects provided comprehensive support for national-level hydromet systems at a cost of $380 million. About nine tenths of project funding went to eight IBRD countries (Albania, Brazil, Dominican Republic, Mexico, Peru, Poland, Russia and Turkey), while the remainder went to four IDA countries/regions (Afghanistan, Central Asia, Moldova and Sri Lanka). An additional 120 projects (including 18 in sub-Saharan Africa and five in the Middle East and North Africa) supported partial systems or specific needs, at a cost of at least $917 million. . . . As noted, sub-Saharan Africa deserves special attention because of the poor state of its hydromet systems and its high level of climate variability. Over 1990–2010, 24 World Bank projects involving partial hydromet systems were approved; 12 are closed and evaluated. . . . Only four of the 12 closed African projects reported attention to maintenance and only in the Senegal River Basin did the self-evaluation report consider sustainability to be likely." Independent Evaluation Group (IEG), World Bank, 'Adapting to Climate Change: Assessing the World Bank Group Experience' (2011), ieg.worldbankgroup.org/Data/reports/cc3_full_eval_0.pdf.

The people and governments of LDCs in sub-Saharan Africa understand that a changing climate poses serious challenges to their countries' economies and threats to their nations' political and social security, both in the short term through changes in the intensity, frequency and location of high-impact/severe/hazardous weather and water events, and in the long term through changes to annual rainfall patterns and wildfire seasons and the appearance of or longer-term persistence of tropical diseases, etc. Despite the urgency, the conventional modus operandi has yet to deliver critical climate information and early warning services to key stakeholders—including farmers, vulnerable communities and policymakers—to enable them to understand and manage their hydromet risks. This section will attempt to explore the causes of this lack of progress and identify areas where a new approach to climate and weather services has the possibility of achieving more robust and sustainable results.

Since most international aid programmes to date have focused heavily on the deployment of observation systems, herein the focus will be on those experiences and the lessons to be learned from them. A first measure of the health of a National HydroMeteorological Service (NHMS) is the number of its ***synoptic***[20] **and local hydromet observing systems that are fully operational** and reporting data in real time. Synoptic stations provide meteorological data at the scales of space and time needed to resolve continental-, regional- and national-scale weather patterns for periods ranging from one to approximately ten days. The usually much more numerous local stations provide the data at space and time scales needed to better resolve mesoscale and microscale weather systems, complimenting and extending the data from the synoptic observations. In essence, synoptic observations provide the big picture while local observations provide the details. The data from synoptic and local observing systems are essential ***inputs*** for all weather and water monitoring and forecasting, and they serve as the foundation for climate services across the region. Local observations are particularly important in regions with complex terrain and/or large urban complexes, and are essential for early warnings of the approach of hazardous weather events. The data from observations taken at synoptic stations and perhaps those from some of the local stations are shared around the world via the Global Telecommunications System operated by the World Meteorological Organization.

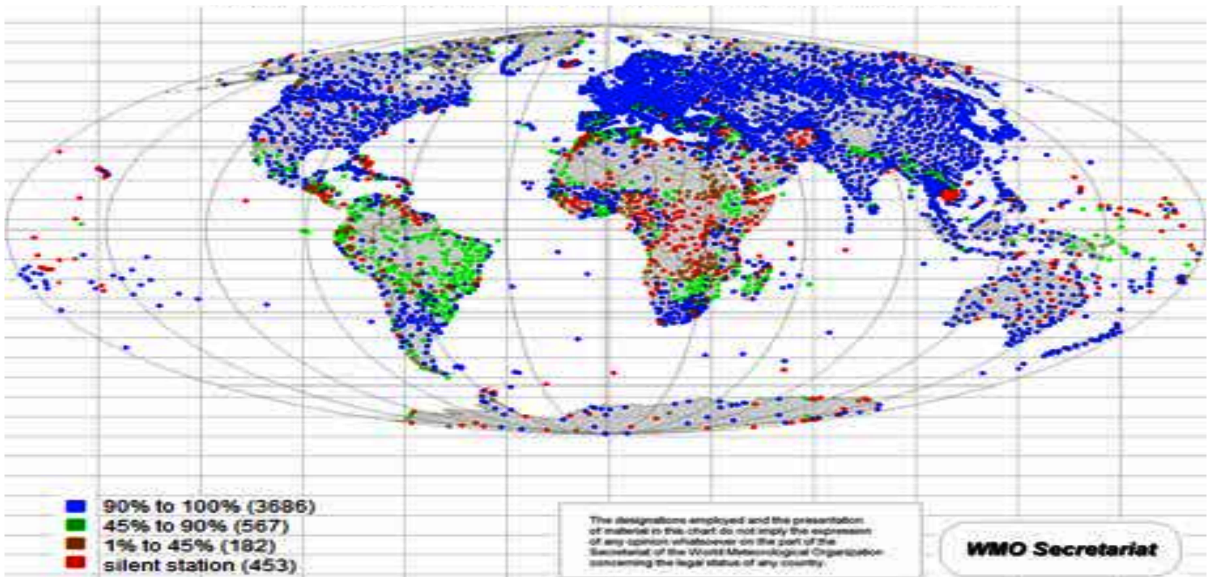
A second measure of the health of an NHMS is its ***outputs***, that is, **the quantity and skill of its local hydromet products and services**—ones that directly impact critical decision-making in the government, in the local business community, and by individuals in the general population. Success here requires that the NHMS understands and reaches out to its users, and provides the products and services that those users need. This is a challenge because the users are normally very diverse and have very different needs. (The next section explores how timely, accurate and localized hydromet information can promote sustainable economic development.) Many of the hydromet products and services provided by an NHMS are routine and straightforward, e.g., the daily weather report/forecast covering yesterday, today and tomorrow, and so should not be a challenge to produce with high skill and effective delivery.

A third measure of the health of an NHMS is its **ability to anticipate the onset of severe weather** later in the day, then monitor it in real time and deliver effective warnings for the imminent arrival of hazardous events such as severe thunderstorms and flash flooding. Accomplishing this task requires a well-synchronized forecast centre able to blend real-time observations with radar or lightning-locating data, hydrologic data, and satellite imagery to identify the onset of hazardous weather, monitor the developments and movements that are indicative of severe weather, carry out continuous nowcasting of the future path of the hazard, and communicate warnings to the regions in the path of the storms. This is not a simple task and continuous specialized training is required for it to be done well.

[20] Synoptic stations are constructed and operated in accordance with detailed guidelines provided by the World Meteorological Organization in order to assure the consistency essential for integrating data from multiple, diverse sources.

FIGURE 2.1

AVAILABILITY OF SYNOP REPORTS FROM TBSN STATIONS ACCORDING TO THE WMO.



FOR UP TO DATE DATA, REFER TO WWW.WMO.INT/PAGES/PROG/WWW/OIS/MONITOR/INDEX_EN.HTML.

Similarly, a fourth measure is **the skill of climate information products** produced and delivered effectively to various user communities—products such as seasonal information on local planting and harvesting dates, anticipated wet/dry periods, and anticipated soil conditions (the temperature and moisture from surface to depth). Many such climate products require the ability to interpret climate model output; take into consideration global discussions from centres in the United States and Europe; and integrate forecasts of such planetary scale phenomena as the El Niño-Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), the Artic Oscillation (AO), and other factors; and then downscale the information into a local context.

HYDROMET OBSERVING SYSTEMS

Understanding the causes of the failures of observing systems to report data is a key step in unravelling the challenges that have contributed to the substandard cycle noted in this publication's introduction. A 2011 review by the World Bank Independent Evaluation Group described the situation as follows: "Low investment [in hydromet services] is especially evident in Africa. The network of hydromet stations is sparse and deteriorating, and hydromet data are often spotty and inaccurate. Existing stations are often not functioning or fail to communicate with the global meteorological network."[21]

Figure 2.1 from WMO shows the geographic distribution of top-level (synoptic) surface observing stations around the world as of October 2014. Much of the African continent is shown as lacking such stations, or as having those that are silent. Examining historical weather records shows that the number of synoptic observing stations across Africa has slowly but steadily decreased over the last 50 years. For example, hydrological stations in Angola dropped from over 150 working stations before Independence and the Civil War (1975–2002), to zero in 2000.

[21] Evaluating World Bank efforts to improve these systems, the report found: "Over 1990–2010, 24 World Bank projects involving partial hydromet systems were approved; 12 are closed and evaluated. . . . Maintenance continues to be a problem. Only four of the 12 closed African projects reported attention to maintenance and only in the Senegal River Basin did the self-evaluation report consider sustainability to be likely." (World Bank IEG, 2011).

Reasons for this situation have been well documented. Many involve political and socio-economic issues that are well beyond the direct influence of NHMS, including civil strife and war, vandalism, and, most recently, regional-scale epidemics. These issues have been discussed *ad infinitum* within the development community and will not be further addressed here. However, these high-level challenges provide the background against which small cadres of dedicated NHMS meteorologists, climatologists, hydrologists and supporting technical staff carry out their work and advocate for modern solutions to sub-Saharan Africa's hydromet monitoring and reporting challenges.[22]

The challenges to both NHMS and international aid agencies invariably also include lack of capacity, including out-of-date institutional structures, inadequate local financial support, lack of technical infrastructure (either in the NHMS or in the surrounding society), and a lack of trained, experienced staff.[23] The particular challenges to NHMS resulting from these problems are most evident in LDCs, which maintain their observing networks and associated services by relying on support from international agencies. Their NHMS lack the local political backing, financial resources and internal capacity necessary to maintain their observing systems or effectively utilize the data from these systems.

Enhanced coordination among international agencies is also desirable. Often working simultaneously with several agencies in parallel on programmes with differing objectives, NHMS staff, already stretched thin, struggle to comply with the different rules, policies and strategies for implementation. In many cases, further complexity comes from the support for hydromet services being managed not by the NHMS, but by other national agencies, including the ministries for disaster relief, water, transportation, communications, agriculture or finance.

With overlapping projects and initiatives, NHMS are left with disparate systems they are hard-pressed to operate or maintain, let alone integrate into a coherent whole that actually produces improved local hydromet information. As the systems fall into disrepair, a new cycle begins, with the main focus of the next projects again limited to inputs, emphasizing observing systems and data collection.

According to the WMO, fragmented implementation and a lack of coordination is costing hydromet services projects both in terms of efficiency and effectiveness.

> "Currently, implementation of development projects tends to be fragmented, with loose internal coordination across Technical/Scientific Programmes and Regional Offices and a lack of an organization-wide project implementation oversight. Thus, lack of an internal, institutionalized project management framework leads to a variety of project formulation styles, monitoring, reporting and evaluation procedures. To overcome the above shortcomings, it is clear that greater internal coordination is needed for more effective and efficient project implementation. Improved internal coordination should lead to increased value-adding by the joining of complimentary activities at regional levels."[24]

Significant and concrete improvements in hydromet services will require integrating disparate systems into end-to-end monitoring and forecasting systems.

Long-term financial support for the operation and maintenance of the systems that produce and deliver hydromet products and services is also needed. The most recent World Meteorological Congress stressed the importance of providing adequate financing in order to assure the sustainability of the observing systems/networks, especially in developing and least developed countries. In particular,

[22] Vladimir Tsirkunov and Makoto Suwa, undated, 'WB/GFDRR Hydromet Program Towards effective partnerships in support of global hydromet services,' Hydromet Program Global Facility For Disaster Reduction and Recovery , World Bank (PowerPoint presentation, www.wmo.int/gfcs/sites/default/files/Makoto_Suwa_World%20Bank.pdf), and 'GFDRR on Hydromet' (brochure, undated).

[23] John Snow, 'Non-Traditional Approaches to Weather Observations in Developing Countries', International Finance Corporation (IFC), 2013; Rogers and Tsirkunov, 'Weather and Climate Resilience' (2013). Note that as used here, "technical infrastructure" is an all-inclusive term that includes such items as common tools, parts and hardware, instruction manuals, mechanical and electronic services, etc., and includes electrical and telecommunications services.

[24] World Meteorological Organization (WMO), 'Project Management Framework,' Informal Planning Meeting, Voluntary Cooperation Programme, Mexico City, 6–7 March 2012.

“Congress strongly recommended to donors and/or funding bodies taking an end-to-end approach to include in the projects, besides the initial investments in acquisition, installation, maintenance and training, adequate operational funds to ensure the sustained operation of observing systems and supporting activities for the period of at least 10 years.“[25]

UNDERSTANDING THE CHALLENGES

As illustrated in more detail in the Uganda case study presented later in this section, the challenges facing NHMS often fall under the rubrics of technology, capacity and politics. An overarching trend observed in case studies, the UNDP-supported market study, and initial user-needs assessments is the growing willingness from both the development community and African governments to address these challenges and build real capacity and fulfil long-term goals of reducing poverty, increasing productivity and building resilience to a changing climate.

In the past, various traditional hydromet technologies—proven to work in developed nations in the mid-latitudes—have been viewed as 'drop-in' solutions to a complex set of interrelated challenges.[26] All too often, this approach has proven to be inadequate in sub-Saharan Africa due to the nature of its tropical environment (ranging from hot, dry and dusty, to hot, wet and very humid), the lack of supporting infrastructure, and/or the associated costs of expendable supplies, maintenance and telecommunications, to name only a few of the more common issues.

However, in the last decade innovative technologies have become available that, when deployed in a comprehensive modernization effort, can reduce investment costs, simplify operations and maintenance, and allow for improvements in the reliability, timeliness and rapid communication of hydromet data to assimilation systems in NHMS offices. These innovative technologies are creating opportunities for the deployment of end-to-end monitoring, forecasting, warning and delivery solutions that were not possible even a few years ago. However, the situation is not amenable to a purely technical solution—new partnerships and institutional relationships will be essential, as will be discussed in Sections 5 and 6.

WHILE APPROPRIATE AND COST-EFFECTIVE TECHNOLOGICAL SOLUTIONS EXIST FOR MAKING BOTH SYNOPTIC AND LOCAL HYDROMET OBSERVATIONS, DEPLOYING AND INTEGRATING ALL THE COMPONENTS INTO END-TO-END MONITORING AND FORECASTING SYSTEMS CAN BE A CHALLENGE.

Technology Challenges

Many NHMS challenges arise from attempts to utilize hydromet monitoring equipment originally designed for use in developed countries. As discussed in detail in Section 4, the design and materials in such equipment are often inappropriate for the arid and tropical environments found throughout much of sub-Saharan Africa.[27] Such equipment is difficult (and, all too often, impossible) to maintain in these environments.

Unfortunately, NHMS often have little professional engineering support to assist them in preparing specifications for procurement actions or with evaluating proposals for potential suppliers. All too often, NHMS staff have to utilize material from company

[25] Seventeenth World Meteorological Congress, Geneva, 25 May–12 June 2015, WMO-No 1157.

[26] “Automated systems would seem to be one solution—but experience so far has not been encouraging”; World Bank IEG, 2011, p. 60. Notably, this conclusion references a WMO report from 2009. As will be discussed, technology and relevant experience has evolved considerably since then.

[27] Snow, 'Non-Traditional Approaches to Weather Observations in Developing Countries.'

representatives to prepare specifications and evaluate proposals. Typically, equipment is specified without sufficient consideration for how it will be integrated into NHMS operational systems or of the importance of training the NHMS to properly utilize the data generated.

Further, equipment is often procured without due consideration of the costs of operation and maintenance, or of the costs associated with the inevitable technological changes that require regular updates and continuous staff retraining. The local supporting infrastructure is usually limited, so almost all expendable supplies and repair parts have to be shipped in from developed countries. A good example in this regard is provided by weather radars, which are very attractive to meteorologists because they provide area coverage as opposed to the point measurements made by synoptic or local surface stations. Weather radars are very complicated electromechanical systems that require dedicated maintenance staff, and a steady stream of expendable supplies, specialized tools and repair parts. Experience shows that it has been difficult to maintain operational weather radars across most of sub-Saharan Africa. Lightning systems, however, offer in some cases a viable and more manageable alternative for monitoring certain types of hazardous weather, as will be discussed in Section 4.

Aggravating these situations is the fact that too often equipment is purchased without sufficient consideration of how it will be integrated into NHMS operations. Integrating diverse observation platforms, telecommunications, data processing computers, analysis and assimilation systems, numerical models, and forecaster work stations into an end-to-end system is a persistent engineering challenge for NHMS. Addressing this challenge requires dedicated technical staff capable of developing bespoke technological solutions that are platform agnostic and can work fluidly to integrate new systems into the varied patchwork of information technologies and monitoring systems currently in place. This need for careful systems integration is seldom recognized.

"Consider Mozambique, which received considerable donor support from the European Union, Finland, Spain and other economies after massive floods in 2000. That support included the installation of modern equipment (such as several dozen automatic weather stations, a

AS EVIDENCED BY THIS BROKEN ANEMOMETER, EVEN WHEN WEATHER AND CLIMATE MONITORING SYSTEMS HAVE BEEN PROPERLY DEPLOYED, SECURITY AND MAINTENANCE ARE ONGOING CHALLENGES. PHOTO BY JOOST HOEDJES.

hydrological telemetric system, and two Doppler radars) and training. But a few years after their installation, these expensive instruments and systems became inoperable, mostly owing to a lack of basic maintenance (unattended automatic instruments), resources (such as the lack of diesel fuel for uninterrupted power supply for Doppler radar), inadequate design, and vandalism." (Rogers and Tsirkunov, p. 124.)

Capacity Challenges

Keeping NHMS staff skills up to date is an ongoing challenge. Staff training and professional development are seldom available locally, making them expensive both in terms of time and money. Sending an individual for training not only incurs the cost of the training and travel, but also often results in complaints by others in an office already thinly staffed. Further, as the skill sets required for meteorologists, climatologists and supporting technical staff are often readily transferable to higher-paying positions in the local private sector, or in the NHMS or private sector of another country, the retention of skilled staff is an issue. These factors have become disincentives for the leadership of an NHMS in a least developed country to significantly invest in staff training and development.

There is also a very understandable human element at play here. New automated systems, internal politics, protectionist stances (both for the ownership of data and the assignment of responsibilities), and a lack of incentives to change create roadblocks, limiting the willingness of many staff and even senior managers to depart from the status quo. Experience from middle-income countries such as Brazil and the Philippines (as illustrated in Section 7) shows that the introduction of highly automated, end-to-end monitoring and forecast systems, focusing on the 'last mile', and undertaking outreach and sustainability efforts involving private sector partners are seldom successful unless there is careful management of the inevitable cultural shifts within the NHMS.

Political Challenges

When an NHMS fails to adequately address the preceding challenges, the result is poor service and the perpetuation of a non-virtuous cycle. This leads to a loss of credibility, which, in turn, often produces a cycle of ever-weakening political (and consequently, internal financial) support for the NHMS. In this cycle, limited budgets further erode the ability of the NHMS to retain talented staff or maintain its technology, resulting in the dissemination of even lower quality information; and the sharing of poor information results in tarnished personal and institutional reputations. Some NHMS retreat into providing a very small suite of products, with most going to government agencies, with the risk of becoming practically invisible to the majority of the government and largely irrelevant to the general public.

There are also internal power struggles and trust issues to consider. Aside from the lack of budgetary support and inadequate skilled human resources, there are often issues related to fear of change. This is particularly true when the private sector offers delivery or support for services traditionally provided by public authorities, who may understandably fear they will become obsolete.

EVEN WHEN HYDROMET MONITORING SYSTEMS ARE DEPLOYED, SECURITY AND MAINTENANCE ARE ONGOING CHALLENGES. PHOTO BY JOOST HOEDJES.

ADDRESSING CLIMATE RISK TO INFRASTRUCTURE WITH IMPROVED PROJECT PLANNING AND DESIGN

By Raffaello Cervigni

Climate change presents a major threat to African Infrastructure—hydropower efficiency levels are compromised, transportation systems are washed away, and the long-term viability of major investments are put at risk.

A new report from the World Bank, 'Enhancing the Climate Resilience of Africa's Infrastructure', examines climate change impacts on hydropower, irrigation and electricity expansion in Africa and finds that the continent's economic growth prospects can be improved by fully integrating climate change models into infrastructure planning.

Improving infrastructure is critical for development. Over the past 10 years, much of Africa has seen consistent economic growth of over 5 percent. In order to sustain this growth, and build resilient systems, Africa needs to invest in infrastructure. These long-term investments can improve productive systems both on farms and in cities, increase renewable energy generation, and aid in the achievement of overall development objectives.

It's estimated that Africa has exploited less than 10 percent of its hydropower potential, the lowest proportion of anywhere in the world. The 2010 Africa Infrastructure Country Diagnostic recommends $93 billion per year in infrastructure investments over the next decade in order to fill the continent's infrastructure gap. Much of this investment will support the construction of long-lived infrastructure—such as dams, power stations and irrigation canals—that are vulnerable to changes in climatic patterns.

Africa can reduce its risk by building, planning and protecting climate-smart infrastructure designed to support long-term growth and adapt to changing climate patterns.

Varying climate change scenarios will greatly affect the long-term productivity, maintenance costs and survivability of major infrastructure investments, especially in the hydropower sector. Climate change forecasts for the sub-Saharan Africa region suggest increases in temperature in the range of 1 to 2 degrees Celsius by 2050, but precipitation forecasts vary widely by location and time period, and suggest that both drier and wetter futures are possible.

In the driest weather scenario, failure to integrate climate change in the planning and design of hydropower infrastructure could result in revenue losses of between 5 and 60 percent. Consumer cost for energy could increase threefold. The potential foregone revenue in the wettest climate scenario is estimated to be in the range of 15 to 130 percent of the baseline.

This means that African decision makers face a tough climate-based dilemma. If Africa's future is wet, expanded hydropower capacity makes sense. In a dry scenario, portfolio diversification becomes more attractive.

So how do we anticipate and plan for climate change to protect large investments in infrastructure? It's about balancing risk and making informed decisions based on better data. Four proposed key steps could aid in making better-informed decisions.

- Develop technical guidelines on the integration of climate change in the planning and design of infrastructure within climate-sensitive sectors like energy and water.
- Promote open-data knowledge repositories for climate-resilient infrastructure development. To bring down the cost of the analysis needed to integrate climate considerations into infrastructure development, there is a need to establish common data sources (on climate scenarios, standard construction costs, etc.) hosted by African institutions, which could be made available to industrial/commercial entities and the general public on open-data platforms.
- Launch training programmes for climate-resilient infrastructure professionals. To ensure adequate strengthening of the technical skills that are required to enhance the climate resilience of infrastructure, one or more training programmes could be established for professionals involved in the planning, design and operation of climate-sensitive infrastructures.

Reliable, localized and consistent hydromet data and analysis tools show that potential impacts are essential components in empowering decision makers to balance this infrastructure dilemma and make wise investments. An improved ability to include current climate variability and future change in project planning has the potential to greatly improve infrastructure sustainability and efficiency by reducing risk, informing climate-smart decisions and ensuring targeted approaches that fit within local contexts.

RAFFAELLO CERVIGNI is a lead environmental economist with the Africa Region of the World Bank. He holds an MA and PhD in Economics from Oxford University and University College London, and has some 20 years of professional experience on programmes, projects and research in a variety of sectors. The content of this section was adapted from Cervigni, Raffaello, Rikard Liden, James E. Neumann, and Kenneth M. Strzepek, 'Enhancing the Climate Resilience of Africa's Infrastructure: The Power and Water Sectors' (Washington, D.C.: World Bank, 2015), hdl.handle.net/10986/21875.

Agencies without a history of serving the public may also see this change as downgrading their role as providers of specialized information.

The challenges of building sustainable funding, political support and institutional structures that will facilitate better information—and better information exchange—are discussed in greater detail in the next sections, while the example of Uganda provides good lessons on how these challenges are being addressed on the national level.

THE UGANDA EXAMPLE

An in-depth review[28] of Uganda's meteorological services was carried out in 2013, with recommendations from the United States Trade and Development Agency (USTDA) documented in 'A Modernization Plan for Uganda's Meteorological Services'.

The Government of Uganda is taking steps to address the challenges laid out in the report (see an updated country profile on p124). The review's findings underscore the limited assets and lack of political buy-in that impede the Uganda National Meteorological Authority[29] (UNMA) in achieving its goals, while at the same time highlighting opportunities and existing assets that could propel the challenging work of modernizing Uganda's hydrometeorological services forward over both the short and long term. Simply making the first step to take stock of existing assets, identify obstacles and look critically at the past is an important move by the Government of Uganda in rehabilitating its hydromet monitoring and forecasting infrastructure, and creating sustainable solutions that leverage better hydromet information to improve the livelihoods of Uganda's poorest, most vulnerable communities.

The road map laid out in the report's recommendations will enable UNMA to produce more skilful weather and water discussions, forecasts, and warnings, and improved climatological seasonal and inter-annual outlooks. This will allow UNMA to provide valuable services to at-risk farmers, businesses, banks, insurers and the general population while fulfilling obligations to international bodies like the World Meteorological Organization and the International Civil Aviation Organization.

"UGANDA'S METEOROLOGICAL SYSTEM DOES NOT ADEQUATELY MEET THE NEEDS OF ITS CITIZENS FOR SIMPLE ACCESS TO PAST WEATHER AND CLIMATE DATA, PRESENT CONDITIONS AND HAZARDS, OR DETAILED AND ACCURATE FORECASTS OF FUTURE WEATHER."

–A MODERNIZATION PLAN FOR UGANDA'S METEOROLOGICAL SERVICES (MDA, 2013)

While countries throughout sub-Saharan Africa are taking steps to create tailored hydromet monitoring and distribution solutions (as evidenced in the Country Profiles section at the end of this publication), the Uganda example provides some overarching lessons that can be leveraged to replicate best practices (and avoid persistent challenges) across the continent.

The Challenges from 2012

As presented in the Modernization Plan, operational challenges as of 2012 included the following. Many of these challenges have already been addressed by the Government of Uganda with support from the CIRDA programme. That said, this unique example from an external auditor provides a good perspective on the persistent challenges facing NHMS:

- **"Uganda's meteorological system does not adequately meet the needs of its citizens** for simple access to past weather and climate data, present conditions and hazards, or detailed and accurate forecasts of future weather.

[28] This review was funded by the United States Trade and Development Agency (USDTA) and produced by MDA Information Systems in 2013.
[29] UNMA is a semiautonomous government institution formed in 2012 from the former Department of Meteorology.

IMPROVED HYDROMET FORECASTING CAN HELP SMALLHOLDER FARMERS REDUCE RISK AND IMPROVE CROP PRODUCTIVITY, WHILE EARLY WARNING SYSTEMS ARE ESSENTIAL IN PROTECTING HUMAN LIVES.

- **Many Ugandans have grown accustomed to this state of affairs and are sceptical of the possibility of accurate weather forecasts.** The coarse spatial resolution of forecasts (issued only for particular cities and not for distinct regions on a map), the daily-only issuance of forecasts in a climate dominated by fast-evolving convective systems, and the limited (thrice yearly) issuance of long-range (seasonal) forecasts has given the public little opportunity to gain confidence in the Department's forecast skills. Public forecasts are issued once a day to four cities.

- **There is no operational lightning detection network or weather radar**, which are essential means of identifying and predicting thunderstorm activity.

- **Essential and preventive maintenance of weather sensors and other equipment is lacking.** Spare parts and supplies are often unavailable. The result is that many observing systems do not function, and those that do suffer compromised accuracy and reduced measurement frequency.

- **Field and headquarters staffs have the required basic technical skills and demonstrate a desire to carry out their responsibilities** but are frustrated with the inadequacy of the equipment and facilities provided, and the lack of advanced and recurrent training.

- **By failing to meet its responsibilities to the International Civil Aviation Organization**, Uganda is risking the safety, reliability and efficiency of international and domestic flight operations.

- **Continual underfunding of operating budgets** has contributed to too many of the deficiencies above."

A Road Map to Modernization

One key factor in modernizing Uganda's hydrometeorological services has already been achieved with the formation of the Uganda National Meteorological Authority in 2012. With a strengthened institutional framework, this authority is taking positive steps towards upgrading and transforming the country's hydromet systems.[30]

The Government of Uganda National Adaptation Programme includes plans to protect development goals from the effects of climate change by means of adaptation and risk management. Further, in response to an invitation from the Government of Uganda, Kampala was the host site for the 2015 UNDP Programme on Climate Information for Resilient Development in Africa (CIRDA) workshop, which examined the opportunity to modernize weather and climate services and identify opportunities for engagement with the private sector.[31]

The road map to modernization, as captured by the Modernization Plan report, underscores numerous opportunities, which fall under the basic rubrics of leadership, technology and capacity-building. One of the country's greatest assets remains its people, and

[30] From the MDA report: "It is incumbent on the [Uganda] Department of Meteorology (DoM) to modernize its meteorological observing, forecasting and warning technology and expand its services in order to more effectively achieve its mission. The reorganization of the DoM into the Uganda National Meteorological Authority (UNMA) will serve to enhance the ability to meet this challenge, including access to higher levels of funding for capital investment, maintenance and staff training."

[31] The agenda and documents from this workshop are available online at www.undp-alm.org/projects/cirda/meetings-and-workshops.

the report goes out of its way to underscore that staff have the technical skills required, but are frustrated with inadequate equipment, outdated facilities and lack of ongoing training and professional development. Another pitfall comes in the form of limited advancement opportunities for personnel within the National Meteorological Centre (NMC). Some highlights from the report's recommendations over the first five years include the following:

Leadership

- "Although radio stations do broadcast the forecasts generated by the NMC, the mindset of the print and television industry is that communications of weather products for public consumption is not a service demanded by the public, but rather a service performed for the Department of Meteorology (DoM), from which they expect to derive revenue. This has restricted the flow of such information, since DoM lacks the funds to pay for newspaper space and television time.

- Field offices should be improved to allow for secure 24-hour operations, and provide a stable environment for personnel and equipment."

Technology

- "The establishment of robust, high-bandwidth Internet connections at all UNMA facilities will allow for the rapid transmission of weather data and imagery to all UNMA staff.

- A total lightning detection system covering at least the region within a 200 km radius of Entebbe should be acquired as soon as possible. By 2014 this should be expanded to the entire country. (See p53 for more details on this programme.)[32]

- The installation of nine new automatic weather systems and additional scientific sensors for synoptic observations, together with the upgrade of the 23 existing automatic weather systems, will form a mesonet that will ultimately expand to include 50 sites."

PLANTING AND HARVESTING SCHEDULES ARE EXTREMELY VULNERABLE TO THE BEGINNING AND ENDING OF THE RAINY AND DRY SEASONS. TO GENERATE THE MOST PRODUCTIVE OUTPUT, THE SECTOR REQUIRES BETTER INDICATORS FOR THE TIMING TO PLANT AND HARVEST. THIS INFORMATION IS BEST UTILIZED WHEN FORECASTS OF THE START AND DURATION OF THE RAINY SEASON CAN BE OPTIMALLY DETERMINED. EQUALLY IMPORTANT ARE PREDICTIONS OF DRY SPELLS THAT CAN HINDER CROP YIELDS AND MANAGEMENT.
HEAT WAVES AND INADEQUATE GRASS GROWTH FOR CATTLE GRAZERS IN THE DRY SEASON ARE ANOTHER MAJOR CONCERN, ESPECIALLY IN THE MIDDLE SECTION OF UGANDA (MDA REPORT). AFRICA924/SHUTTERSTOCK.COM

Capacity

- "A continuous training programme for UNMA staff must be developed by the National Meteorological Training School, which should be incorporated into the UNMA. The programme should include the use of the Internet for distance learning, periodic training sessions run by the school with guest lecturers drawn from fully modernized national weather services, and formal education leading to advanced degrees for qualified staff.[33]

- The accounting and inventory management programme must be improved so that an up-to-date record of the condition of all UNMA equipment is maintained."

[32] To learn more about the demonstration lightning detection system being installed in Uganda, visit www.earthnetworks.com/all-africa-early-warning-system-update/.
[33] Efforts to develop and implement a training programme along the lines proposed were under discussion in 2015.

ACCORDING TO THE WORLD BANK, THERE HAVE BEEN VERY LIMITED RETURNS ON INVESTMENTS MADE OVER THE LAST THREE DECADES IN HYDROMET MONITORING AND FORECASTING ACROSS SUB-SAHARAN AFRICA. WHILE ADVANCED HYDROMET SOLUTIONS HAVE THE POTENTIAL TO IMPACT LIVES, REDUCE RISKS AND BUILD RESILIENCE, PERSISTENT CHALLENGES HAVE IMPEDED THE ADOPTION AND IMPLEMENTATION OF THESE SOLUTIONS, LIMITING THE REACH AND EFFECTIVENESS OF INVESTMENTS IN COUNTRY-LED EFFORTS TO DEVELOP SYSTEMS PROVIDING EARLY WARNINGS AND CLIMATE INFORMATION.

Cost-Benefit Analysis

As will be shown in upcoming sections, there are numerous benefits to investments in modernizing national hydrometeorological services. According to the Uganda Modernization Plan, the road map to modernization would cost about US$32 million, with most early investment coming from multilaterals and international financial institutions.

The projected economic return is outstanding, showing a cost-benefit ratio of between five- and ten-fold.

> "Even at the 5:1 level, this is an impressive benefit/cost ratio to demonstrate that funds spent on weather, climate and water-preparedness can prevent much larger sums from being spent on disaster-related economic costs. . . . An investment in the meteorological services provided by the UNMA through implementation of the modernization program translates into more added value to the various sectors of the Ugandan economy and the social framework of the country, particularly because of its susceptibility to weather and climate impacts." (For more information on the potential economic benefits, see Section 3) –MDA report

Future revenue streams could limit the dependence on international funding, but only if sufficient internal political and social capital is leveraged to underscore the importance of good meteorological systems and modern forecasting. To be able to carry out this leverage, UNMA must increase its credibility and status as a producer of skilful forecasts and warnings, and useful climatological outlooks. For an expanded discussion on valuing meteorological information, see p86.

Conclusion

While the challenges are great, there is a growing recognition and acknowledgement within the sub-Saharan region that short- and long-term climate risks are real and that it is the responsibility of African governments to provide leadership and resilient socio-economic solutions that adapt to this changing reality. Essential to building such resiliency are working meteorological and climatological observing systems supporting modern weather and climate information systems. Unfortunately, for much of Africa, such systems are antiquated and, all too often, non-functioning, leaving policymakers, economic developers and the population as a whole under-informed as to what is happening around them. There is a growing consensus,* however, that better weather and climate information can protect human lives and livelihoods, and build national productivity in the face of a changing world.

[34] According to the MDA report, "Any government investment needs to demonstrate that it can, aside from meeting essential requirements for public health, safety and welfare, provide an economic return. This begs the question whether the necessary expenditure of capital and operating costs for the modernization programme are justified. The World Meteorological Organization has addressed this matter through the conduct of benefit/cost studies and found the ratio to be between five- and ten-fold."

[35] The Uganda Agricultural Sector employs 80 percent of the population, accounting for 20 percent of GDP. Lighting, hail, sporadic rains, drought and floods all affect agricultural productivity and impact the livelihoods of Uganda's most vulnerable communities. About 50 people are killed each year by lightning strikes, while high winds on Lake Victoria take thousands of lives each year, according to reports by the BBC (see p26).

* Refer to Section 4 for discussions on lost productivity and other dangers associated with bad weather.

AFRICAN CENTRES FOR LIGHTNING AND ELECTROMAGNETICS NETWORK

By Mary Ann Cooper and Richard Tushemereirwe

THE AFRICAN CENTRES FOR LIGHTNING AND ELECTROMAGNETICS NETWORK (ACLENET) IS A PAN-AFRICAN NETWORK DEDICATED TO DECREASING DEATHS, INJURIES AND PROPERTY DAMAGE DUE TO LIGHTNING.

THE CHALLENGE

Global lightning-occurrence maps based on satellite data show that many parts of the African continent have the highest lightning strike densities in the world. The first major lightning accident reported in Africa, in 1998, was an incident where 11 players of a single football team were killed by lightning in the Eastern Province of Kasai in the Democratic Republic of Congo.[36] Witchcraft was suspected. The actual details of the incident were never investigated as the region of incident was inaccessible due to civil unrest.

There are other recent reminders that lightning continues to pose a threat to people in Africa: One tragic example involved the deaths of 18 schoolchildren from a single strike in 2011, with at least 38 others hospitalized. (See p35 for more examples on the Cost of Bad Weather).

ACLENet was formed to address these challenges. The scope of its work is divided into four major categories to address the different facets of lightning hazard: detection, protection, response, and research and education. The organization has initiated activities in each of these categories and plans more.

ACTIVITIES

1. **Organization**—The National Centres work with national meteorological offices and other agencies to provide Severe Weather Early Warning Systems (SWEWS) for those most at risk, relying on lightning detection data as a proxy for other severe weather. In collaboration with four other organizations (Earth Networks, Trans-African Hydro-Meteorological Observatory, Human Network International, and Climate Change Adaptation Innovation), ACLENet was awarded one of the first eight Global Resilience Partnership (GRP) grants to create an SWEWS for vulnerable communities in Uganda on a sustainable basis.

2. **Response**—The National Centres work with national meteorological offices and other agencies to provide Severe Weather Early Warning Systems (SWEWS) for those most at risk, relying on lightning detection data as a proxy for other severe weather. In collaboration with four other organizations (Earth Networks, Trans-African Hydro-Meteorological Observatory, Human Network International, and Climate Change Adaptation Innovation), ACLENet was awarded one of the first eight Global Resilience Partnership (GRP) grants to create an SWEWS for vulnerable communities in Uganda on a sustainable basis.

3. **Detection**—ACLENet facilitates and enables technology transfer by working with international lightning detection companies and national governments to bring new technologies to Africa. ACLENet facilitated Earth Network's deployment of lightning sensors in all of the East African Community states of Burundi, Kenya, Rwanda, Tanzania and Uganda surrounding Lake Victoria, where an estimated 5,000 people die each year due to erratic weather (p26).

4. **Research and Education**—The organization works to understand cultural aspects that will help change local customs and behaviours to mitigate the effects of lightning. In February 2015, the organization won a grant from Resilience African Network (RAN), a programme funded by USAID, to survey fishing communities on Lake Victoria, where prior SWEWS have failed.[37] The survey served to generate baseline data for the Global Resilience Partnerships grant application.

5. **Protection**—ACLE strives to decrease deaths by protecting schools. More than half of lightning injuries and deaths reported by the media in Africa happen to children in school. The 'Lightning Kills—Save a Life in Africa' project was initiated in October 2014 to focus on the installation of Lightning Protection Systems (LPS) for the most vulnerable schools across Africa. Engaging with schools and building a sense of awareness, safety and control are the first steps to reducing damage from lightning. These efforts will spread from students to their families and gradually decrease deaths and injuries.

MARY ANN COOPER, MD, Professor Emerita of Emergency Medicine, University of Illinois at Chicago, is the recognized international authority on lightning injuries and injury prevention.

RICHARD TUSHEMEREIRWE is the Senior Presidential Advisor on Science and Technology, Disaster and Climate Resilience research fellow at Makerere University School of Public Health, and the Relationships Advisor for ACLE. Learn more at www.ACLENet.org.

[36] World: Africa, 'Lightning kills football team,' *BBC News*, 28 October 1998.

[37] Work to build a transcontinental all-Africa hydromet monitoring system first began around 2008, when Kofi Annan and the Global Humanitarian Forum launched the Weather Info For All (WIFA) initiative, which was to work through public-private partnerships with telecommunications companies to install 5,000 AWS across the continent.

BAD WEATHER TAKING ITS TOLL IN AFRICA

Weather can be dangerous and destructive. This is especially so in much of sub-Saharan Africa, where there are few monitoring and forecasting systems producing credible alerts and warnings. This lack of warnings, together with limited knowledge of how to respond, all too often results in the loss of lives and destruction of livelihoods. On the village level, it's largely local weather—high winds, lightning and flash floods—that causes death and destruction. On the national or regional levels, the major causes of population displacement, death, famine and political instability are sustained flooding, lasting for days, weeks, and even months; droughts, lasting for a season to a decade or even longer; and the spread of mosquito-borne diseases.

"With proper local weather alerts many of these disasters could have been averted, but with only coarse satellite data to go on in most cases, and limited distribution channels to share alerts, much of Africa's rural population must simply look to the skies to see what weather is coming their way", notes John Snow, CIRDA Technical Advisor and former Dean of the College of Atmospheric and Geographic Sciences at the University of Oklahoma.

LIGHTNING

Lightning is probably the number one weather-related danger for villagers living in rural tropical Africa. The region, because it sits under the globe-encircling band of thunderstorms known as the Inter-Tropical Convergence Zone, receives more lightning strikes than anywhere else in the world. Poorly designed buildings and a general lack of awareness of what to do when a lightning storm rolls in only add to the risk.

For example, in Tanzania, lightning is common during the rainy seasons, especially in the northwestern region of the country. There, in April 2015, a lightning strike killed a teacher and six students, injuring 15 others. That same year, a bolt killed five people at a church in the Geita region and killed a teacher and six children at another school in the Kigoma region. In Kenya, one student was killed and 51 injured while seeking shelter from a storm in a schoolhouse during a 2015 lightning storm. Today, South Africa alone reports around 260 annual lightning-related deaths.

Overall, the annual numbers of fatalities from lightning strikes in Africa are similar to those in the developed world over a hundred years ago, when, for example, the United States experienced around 400 deaths a year. The communications revolution that began in the mid-1800s with the cross-regional spread of the telegraph and then telephone systems facilitated the formation and growth of national weather services and their ability to emit effective warnings in the United States. In parallel, populations began to concentrate in urban areas where they were more easily warned and advised on how to protect themselves, and able to access more protective buildings. The combination of improved communications and increased urbanization has resulted in the drop of the U.S. lightning-strike death toll to around 30 per year.

And as if the present situation was not difficult enough, the global numbers of lightning-related casualties could increase as populations grow and climate change affects weather patterns. Some scientists indicate a 10 percent increase in lightning activity for every one degree in increased temperature.[37] One might reasonably expect a similar increase in lightning fatalities barring early warnings, the provision of shelters and other protective measures.

Programmes like the African Centre for Lightning and Electromagnetics (ACLE) are working to install lightning rods on schools and build awareness with campaigns like the one entitled 'Lightning Kills: Save a Life in Africa,' which is working to install lightning shelters in schools at a cost of approximately $4,000/shelter.[38]

FISHERMEN AT RISK

Lack of reliable storm information has taken a substantial toll on the vulnerable communities living around Lake Victoria, where an estimated 5,000 people die each year due to erratic weather and a lack of communications and resources, according to CNN.[39] The numbers are so high that some people now consider the lake to be the most dangerous in the world.[40]

Sam Kabonge is a fisherman from Bugala Island in Lake Victoria. "There are times when you may leave the landing site when the lake is still," Kabonge told CNN in 2013. "As you are in the middle of it, it starts getting rough—rain, winds, clouds, and you know what happens next because... our boats cannot resist the strength of the waves. Sometimes they break; others capsize."[41]

Numerous projects have been launched on the lake to reduce weather-related deaths, including a pilot programme where locals receive customized mobile alerts with daily forecasts, warnings and recommended safety precautions. Efforts have been hindered, however, by a lack of consistent follow-up; accurate and functional end-to-end monitoring, forecasting and warning systems; and sustained support for these projects.

[37] Colin Price, as cited in Navin Khadka, 'Are lightning Deaths Increasing,' *BBC*, 14 March 2014, www.bbc.com/news/science-environment-26554974.

[38] For more information, visit aclenet.org/lightning-kills-save-a-life-in-africa/; and Jack Williams, 'Project launched to reduce lightning deaths in Africa, targets schools', *Washington Post*, 26 March 2015.

[39] Similar hazards exist and corresponding yearly loss of lives occurs on the other big lakes found in East Africa.

[40] Errol Barnett, 'Lethal weather on "world's most dangerous lake"', *CNN*, 17 January 2013.

[41] Ibid.

THE BIG PICTURE

The effects of anthropogenic climate change can impact peoples' lives and livelihoods in both positive and negative ways, depending on where they reside. But the difficulties in predicting when and where the good and the bad consequences will occur make it hard to create long-term plans for economic development and adaptation.

Climate change is having some positive effects on some parts of Africa, such as by bringing rains to some previously drought-stricken areas, while in others floods are displacing tens of thousands. According to recent UN assessments, overall, Africa is at risk from the increased frequency and intensity, and increased spatial and temporal extent of heatwaves, flooding and drought, leading to more crop failures, greater water shortages, and the wider spread of certain diseases.

As a specific example, consider the Sahel, where more than 100,000 people died of starvation in the 1970s and 1980s due to more than a decade of failed annual rains, consequent prolonged drought and persistent famine. Since the mid-1980s, average rainfall has partially recovered in the region. The cause of this "greening" of the Sahel is a point of debate among climatologists. Some point out that the now-observed less frequent, but more intense downpours are less predictable and have led to recurrent flooding in recent years; they cite changes in sea-surface temperatures as inciting factors in the "greening" of the Sahel.[42] Others look at the steady warming of the global atmosphere, an effect of the increasing concentration of atmospheric greenhouse gases, as the main culprit, pointing to the fact that such warming first became noticeable in the late 1970s and early 1980s. According to scientists at the National Centre for Atmospheric Science at the University of Reading,[43] about three quarters of this additional rain can be attributed to the warming due to increased greenhouse gases. In the end, it is the overall unpredictability of local situations that puts farmers at risk. At the end of 2015, a strong El Niño—a warming of sea-surface temperatures in the Pacific Ocean that can cause unusually heavy rains in parts of the world and drought in others—brought severe drought back to the Ethiopia, leaving 8.2 million in need of emergency food aid, according to the United Nations.

On a macroeconomic and global policy level, shifts in continental to regional weather patterns on timescales of a season to one or two years not only take lives, but also negatively affect regional production levels. Such shifts can thus greatly delay the achievement of national Sustainable Development Goals. In a joint study, the World Meteorological Organization and the Centre for Research on the Epidemiology of Disasters found that "from 1970 to 2012, there were 1,319 reported weather-related disasters in Africa that caused the loss of 698,380 lives and economic damages of US$26.6 billion". Although floods were the most prevalent type of disaster (61 percent), droughts led to the highest number of deaths. The severe droughts in Ethiopia in 1975 and in Mozambique and Sudan from 1983–1984 caused the majority of deaths. Storms and floods, however, caused the highest economic losses (79 percent).[44]

APART FROM LIGHTNING, UNPREDICTED HIGH WINDS PRODUCED BY THUNDERSTORMS ARE ALSO A FREQUENT HAZARD. SOME ESTIMATES SHOW THAT AROUND 5,000 FISHERS PERISH EACH YEAR ON LAKE VICTORIA DUE TO THE TALL WAVES PRODUCED BY SUCH STRONG WINDS.

Floods are indeed threatening food security and lowering production. On a more human level, floods in 2015 killed hundreds and displaced thousands of people in Madagascar, Malawi and Mozambique. January 2015 floods in Malawi killed some 276 people, displacing another 230,000. The floods also raised the spectres of disease and malnutrition, even famine, and taxed donor and national resources.

According to UNICEF, about 47 percent of Malawi's children are already stunted. With half the country declared a disaster zone, corn crops destroyed, livestock killed and villages literally swept away, ensuring that children have enough to eat—or schools to go to—becomes a massive challenge.

Neighbouring Mozambique was hit by flooding from the same storm, affecting around 160,000 people, and destroying houses and schools. In Madagascar, some 74 people were killed and 20,000 displaced.

Smaller microclimatic issues like strong "Mere Winds" on Lake Malawi often affect productivity, and in one event in June 2014, a dozen fishermen died on the lake when high winds capsized their canoes.

[42] Allessandra Giannini,'Hydrology: Climate change comes to the Sahel,' *Nature Climate Change* 5 (July 2015), and the discussion found at iri.columbia.edu/news/climate-change-is-greening-the-sahel-not-so-fast/.

[43] As cited by Jennifer Newton, 'Climate change is HELPING Africa because greenhouse gases are bringing rain to areas that have suffered drought for decades,' *Daily Mail*, 1 June 2015, www.dailymail.co.uk/news/article-3105940/Climate-change-bringing-rain-Africa-30-years-Live-Aid-tried-help-end-famine.html#ixzz3eC9vmq2l.

[44] WMO, 'Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970-2012)', 11 July 2014, library.wmo.int/opac/index.php?lvl=notice_display&id=16279#.VZ05fLdrVBh.

CIRDA PROGRAMME AT A GLANCE

CONNECTING IDEAS, PEOPLE AND TECHNOLOGY

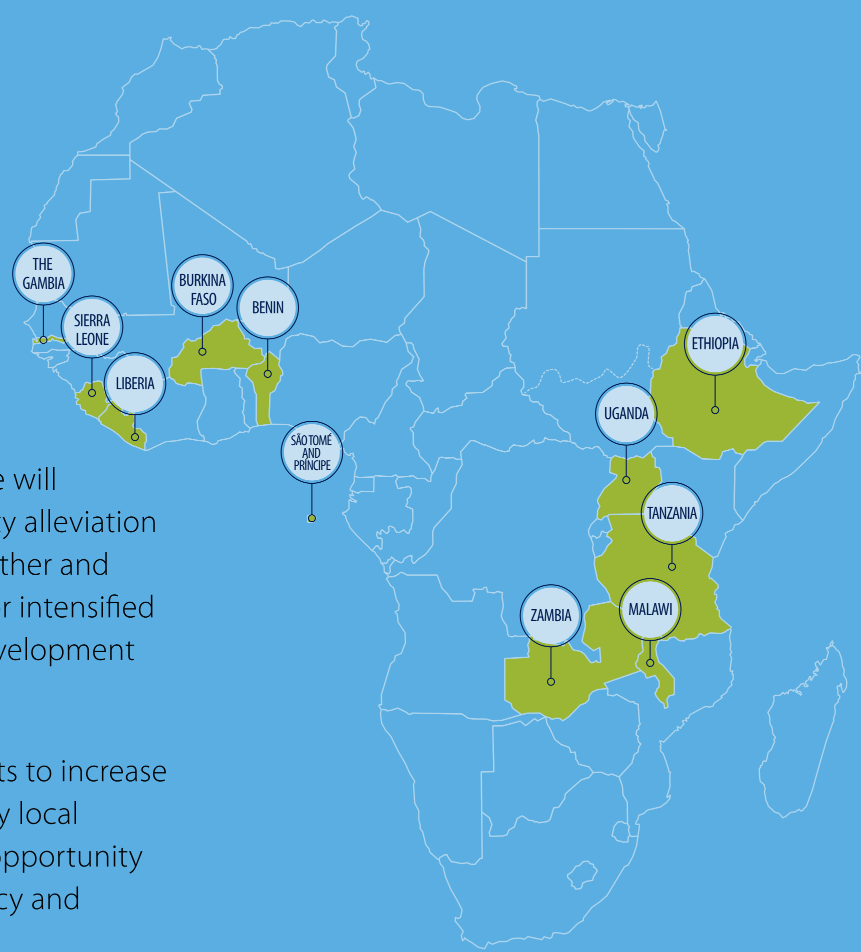
The Programme on Climate Information for Resilient Development in Africa (CIRDA) connects ideas, people and technology to build resilience to climate change in 11 of Africa's Least Developed Countries.

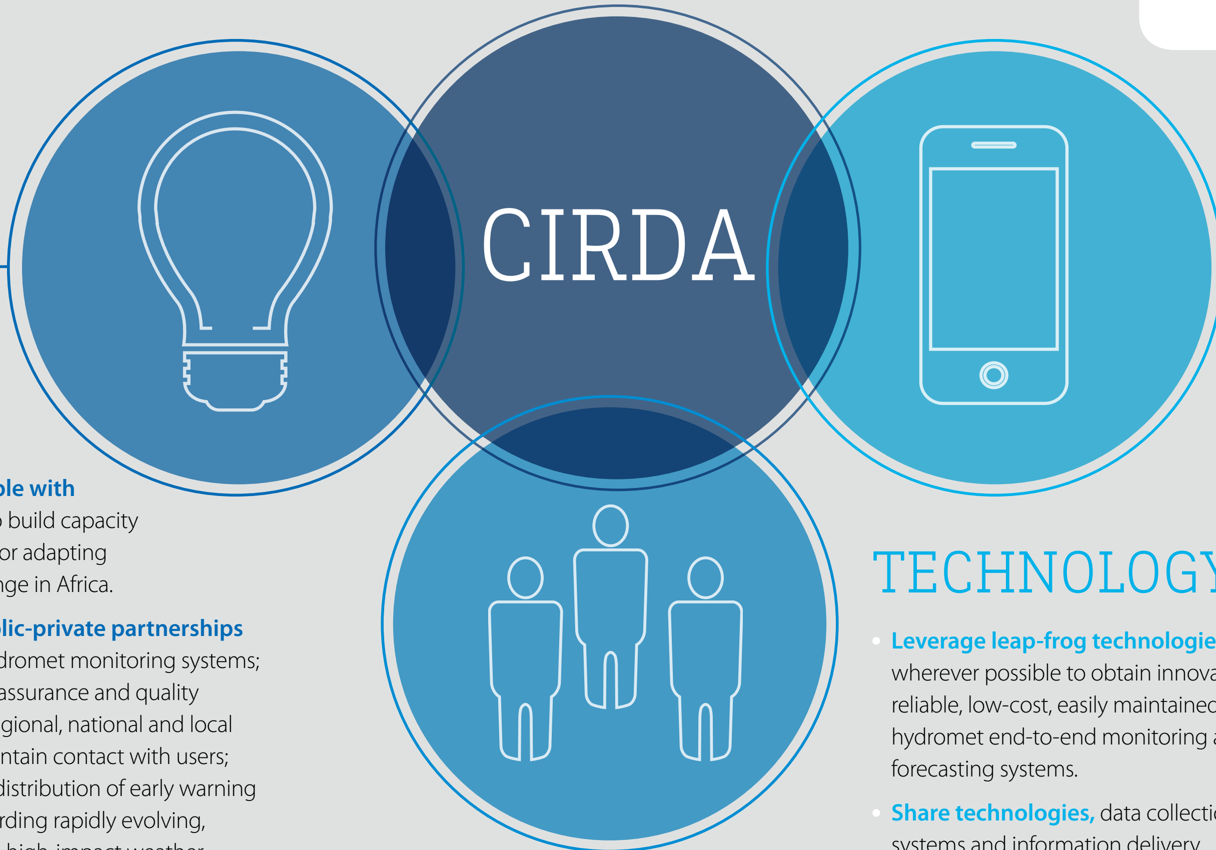
THE BOUNDARIES AND NAMES SHOWN ON THIS MAP DO NOT IMPLY OFFICIAL ENDORSEMENT OR ACCEPTANCE BY THE UNITED NATIONS.

Accurate, timely hydromet information, delivered as a routine 24/7 service and as early warnings when dangerous conditions threaten, is essential for building a resilient Africa. Weather- and climate-related shocks to vulnerable communities, the economy, ecosystems and infrastructure will threaten development goals and poverty alleviation strategies—bad weather, changing weather and unpredictable weather brought about or intensified by a changing climate can eliminate development gains overnight.

By partnering with national governments to increase the capacity to produce, share and apply local hydromet information, CIRDA sees the opportunity to protect human lives, increase resiliency and jump-start productivity.

WHERE CIRDA WORKS





IDEAS

- **Connect people with technology** to build capacity and resiliency for adapting to climate change in Africa.
- **Leverage public-private partnerships** to maintain hydromet monitoring systems; ensure quality assurance and quality control; help regional, national and local forecasters maintain contact with users; and aid in the distribution of early warning messages regarding rapidly evolving, rapidly moving high-impact weather.
- **Build in sustainability** from the ground up.
- **Listen, reflect, and ask questions.**
- **Impact human lives and livelihoods,** increase productivity and build resiliency.
- **Spread knowledge** across the global South to advance the dialogue on climate information, early warning systems, resiliency and adaptation.

PEOPLE

- **Enable vulnerable communities,** poor rural people (especially those farmers and pastoralists living at near-subsistence levels), **and national and regional policymakers** to access and use timely and reliable hydromet information to make informed decisions to respond to high-impact weather events (short-term) and to a changing climate (long-term).
- **Engage with decision makers and experts** to create integrated hydromet (weather-water-climate) management systems.
- **Inform sustainable policies** that support adaptation to a changing climate.
- **Build resilience and capacity** at all levels through training, education, and the professional development of staff; and provide incentives to retrain and retain staff.

TECHNOLOGY

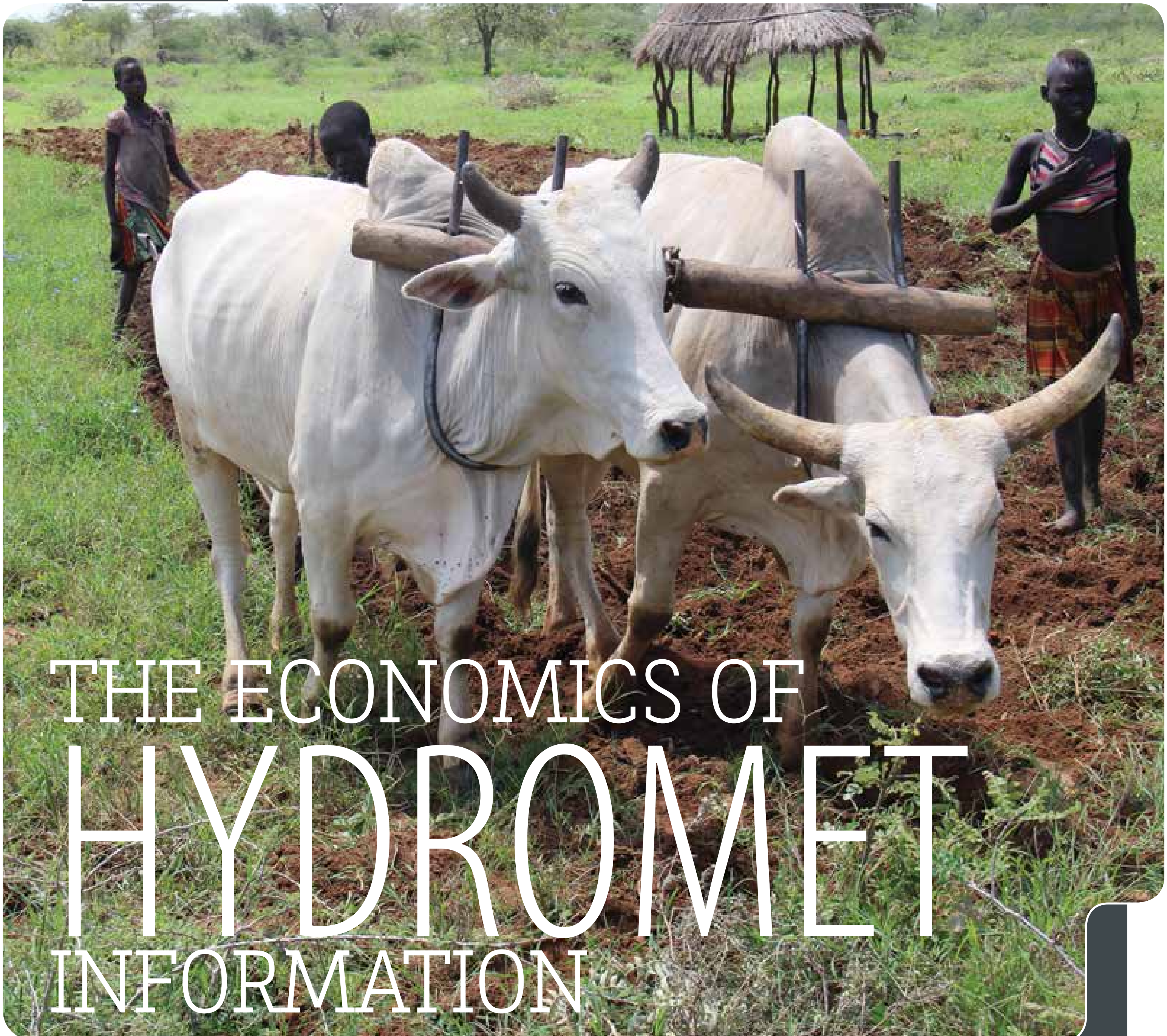
- **Leverage leap-frog technologies** wherever possible to obtain innovative, reliable, low-cost, easily maintained hydromet end-to-end monitoring and forecasting systems.
- **Share technologies,** data collection systems and information delivery mechanisms across 11 African nations.
- **Identify and deploy next-generation solutions,** including all-in-one automatic weather stations, cloud-based archiving and computing, advanced lightning detection, data-based solutions and cell-tower integration.

FUNDING

$50 MILLION (GLOBAL ENVIRONMENT FACILITY'S LEAST DEVELOPED COUNTRIES FUND)

$4 MILLION MULTI-COUNTRY SUPPORT (UNDP)

www.adaptation-undp.org/projects/cirda



THE ECONOMICS OF HYDROMET INFORMATION

PHOTO BY SOLOMON MANGENI.

This section explores the economics of hydromet information and services. Such information comes with significant costs—establishing and sustaining end-to-end hydromet systems and training and retaining staff to maintain and operate them requires continuing investments. But there is a large return on these investments in the form of better decisions. Timely, accurate hydromet information supports informed decision making regarding adaptation to a changing climate. The provision of hydromet information is an important component towards achieving the Sustainable Development Goals and empowering sub-Saharan Africa's least developed countries to continue their work towards poverty alleviation, food security and continued economic and social development. Hydromet information can improve productivity, protect human lives and build resilience, helping to stabilize volatile markets and socio-political conditions.

TIMELY, ACCURATE, LOCALIZED HYDROMET INFORMATION PROMOTES AND SUSTAINS ECONOMIC DEVELOPMENT

The innovative technologies and end-to-end approaches described in the next section have the potential to provide a wide range of hydromet information that, if properly applied, can be of great benefit to the people, economies and governments of developing countries. Realizing these benefits requires collecting, processing and analyzing weather, water and climate data to create and deliver specific, consistent and credible hydromet information immediately applicable to users' decision-making processes. The broad range of potential users points to the many opportunities for positive impacts created by the availability of quality hydromet information.

Many developing countries are prone to disruptive events—severe storms, droughts, floods—so one driver for improving hydromet services has been the provision for early warnings so that government agencies, the private sector and individuals can respond proactively. Further, in many developing countries a high percentage of the population works the land in smallholder agriculture. Daily, seasonal and annual hydromet information tailored to the needs of these farmers reduces risks and increases production. Modern national hydromet systems, with end-to-end systems for monitoring, analyzing, and skilfully predicting weather, water and climate events, can support these needs (and many others), saving lives and reducing the costs of disaster relief and reconstruction on the one hand, while improving the daily lives of a large portion of the population and a nation's economic vitality on the other.

Many examples from developing as well as developed countries document the return on the investments necessary to establish and sustain an effective hydromet information system.

> "UPGRADING ALL HYDROMETEOROLOGICAL INFORMATION PRODUCTION AND EARLY-WARNING CAPACITY IN DEVELOPING COUNTRIES WOULD SAVE AN AVERAGE OF 23,000 LIVES ANNUALLY AND WOULD PROVIDE BETWEEN US$3 BILLION AND US$30 BILLION PER YEAR IN ADDITIONAL ECONOMIC BENEFITS RELATED TO DISASTER REDUCTION." –ROGERS AND TSIRKUNOV (MDA, 2013)[45]

Cuba and Bangladesh, both countries frequently impacted by tropical cyclones, have significantly reduced weather-related deaths through a combination of early warning systems and shelters.[46] In recent years India and the Philippines have been hit by typhoons of similar force, but thanks in part to preventive efforts only about 50 people died in India compared with thousands in the Philippines.[47] (See p93 for more information on the Philippines system of 1,000 Automatic Weather Stations.) An example from Mozambique dramatically illustrates the much lower costs of prevention relative to disaster relief. In 2000, the country requested $2.7 million from donors to help prepare for impending floods but received only about half that amount. After the floods

[45] David Rogers and Vladimir Tsirkunov, 'Weather and Climate Resilience: Effective Preparedness through National Meteorological and Hydrological Services' (Washington, D.C.: World Bank, 2013), p. 3.

[46] 'Natural Hazards, Unnatural Disasters' (Washington, D.C.: World Bank, 2010), p. 118.

[47] "Supertyphoon Haiyan may have killed as many as 10,000 people in the central Philippines. A storm of near strength, Cyclone Phailin, hit India's east coast last month and was expected to cause massive death and destruction. It didn't. About 50 people died, and while nearly a quarter-million houses and over 860,000 hectares of cropland were destroyed, the damage amounted to about $150 million. Yet, in 1999, a cyclone that struck the same region resulted in more than 10,000 deaths and almost $4.5 billion in damage." Nilanjana Bhowmick, 'How India Prevented Catastrophe When It Was Hit by a Massive Storm Last Month,' *TIME*, 12 November 2013, world.time.com/2013/11/12/how-india-prevented-catastrophe-when-it-was-hit-by-a-massive-storm-last-month/.

FLOODS NOT ONLY PUT LIVES AT RISK, THEY ALSO DESTROY PRODUCTIVE INFRASTRUCTURE LIKE ROADS. PHOTO BY UNDP.

struck, donors provided more than $100 million in relief alone, and pledged more than $450 million for recovery and reconstruction. According the UNDP,

"In the last decade, almost one million people have been killed by disasters and more than $1 trillion have been lost. Yet only 1 percent of international aid is spent to minimize the impact of these disasters. . . . Every dollar invested into disaster preparedness saves seven dollars in disaster aftermath."

Reducing the impacts of natural disasters is a powerful argument for early warnings of extreme hydromet events. The broader economic benefits of public investment in good hydromet services have not been as well documented but are also sizable, and offer the potential for different sources of political support. In countries with good hydromet services, this value is almost self-evident. For example, a U.S. Department of Commerce report on the value of government data notes that a public survey found an overwhelming majority of the public make multiple references to weather forecasts each day and that the aggregate value is in excess of $31 billion per year, or more than six times the total public and private expenditure to generate the information. In developing countries without good hydromet services, this value is estimated as a combination of lost opportunities and economic inefficiency representing a drag on development. As a recent WMO report notes,

"Almost every meteorological and hydrological variable is of importance to some section of society, and hence part of a meteorological or hydrological service, whether in the form of long-term statistics or analyses (for example, for dam, bridge or building design), information on current conditions (for example, for air traffic management, runway selection and ground crew stoppages) or forecast conditions on timescales from minutes to months, years or decades (for example, for crop harvesting, electricity load planning or drought preparedness)."

Economic studies of the costs and benefits of weather services can be complex and costly, and to date relatively few such studies have been done in developing countries.[48] A recent example for Uganda is presented in Section 2.

The sector that has been studied the most is probably agriculture and, more specifically, smallholder farming, which represents a significant share of employment and economic activity in many African countries. As noted in a study by the World Economic Forum,

"With insurance, farmers can invest in higher yield agricultural inputs without fear of financial ruin in the event of a drought. Some estimates suggest this can increase their income by 200 to 300 percent per acre. For most developing country farmers, this is the difference between living above or below the poverty line."

The provision of insurance, such as agricultural area-yield index insurance, usually comes with risk-based premiums. In this case, a farmer's choice of highly vulnerable crops would entail higher premiums that would have to be paid towards insurance. This variable premium could help farmers to better determine the suitability of certain crops for certain climate conditions, and may trigger behavioural change. (For an expanded conversation on agricultural insurance, see p78). The safety and productivity of many other sectors also depend on good hydromet information.

An important feature of some of these sectors is the potential for revenue generation if fees are paid for services. This is most obvious if information tailored

[48] The WMO maintains a website that provides guidance and precedents for studies of the economic and social costs and benefits of weather services: www.wmo.int/pages/prog/amp/pwsp/SocioEconomicMainPage.htm.

Figure 3.1 The main qualitative benefits of services provided by NHMSs.

ECONOMIC

AGRICULTURE: Avoidance of crop losses from frost, hail, drought, flood or extreme temperatures; timing of crop protection, planting and harvesting; increased farm production and sales; more efficient scheduling of the use of agricultural machinery; minimization of drought relief costs.

AIR TRANSPORT: Reduced fuel consumption through route planning; improved scheduling of flight arrivals and departures; minimization of airline costs from aircraft diversions; minimization of search and rescue costs; reduction of accidents and emissions; savings in passenger times, materials and working times (airport maintenance).

MARITIME TRANSPORT: Reduction of accidents and environmental damages, fuel savings, more efficient rescue operations.

OIL PROSPECTING: Avoidance of unnecessary shutdown of offshore oil and gas operations; more efficient planning of energy production and delivery.

ENERGY: Prediction of power demands, power failure reduction, savings in material and working times (maintenance), energy savings.

CONSTRUCTION: Potential to eliminate serious construction problems a priori (risk control system).

FLOOD PROTECTION: Savings in human lives and property, more efficient rescue operations.

SOCIAL

PROTECTION OF LIFE AND PROPERTY: Avoidance of loss of life and property from natural disasters.

RESEARCH: Improved information and data to the scientific community.

LEISURE: Contribution to the day-to-day safety, comfort, enjoyment, and general convenience of citizens, including recreation, travel/commuting and other direct and indirect forms of societal benefits.

HEALTH: With improved information NHMS are able to provide advisories on malaria and other vector-borne outbreaks.

ENVIRONMENTAL

AIR QUALITY MONITORING AND WARNINGS: Reducing adverse health impacts; saving human lives in possible environmental accidents (evacuations); minimization of release of toxic substances and other pollutants; management of local environmental quality.

Source: MDA Information Systems, A Modernization Plan for Uganda's Meteorological Services (Report funded by USTDA, 2013).[49]

to address specific needs is provided to major commercial businesses such as aviation, mining, shipping and banking. The value of such information can be significant. A WMO report gives several examples:

- The incremental value of hurricane forecast information to oil and gas producers in the Gulf of Mexico amounted to **US$8.1 million** annually in terms of avoided costs and foregone drilling time—much lower than the value that could be achieved with investments to improve forecast accuracy, but even so, the value is substantially greater than the budget of the National Hurricane Center;[50]
- The use of meteorological (weather) services by the transportation sector in Switzerland would result in **US$56.1 million** to **US$60.1 million** in avoided governmental spending; and,
- Avoided fuel costs associated with the use of terminal aerodrome forecasts (TAFs), which allowed Qantas Airways to carry alternate fuel only when justified by weather forecasts, saved between **US$19 million** and **US$30 million** per year.[51]

[49] This list will vary, reflecting differences in national economies, but it may also include banking and insurance (particularly for lending to small farmers), tourism, and transportation modes in addition to aviation.

[50] Timothy Considine et al., 'The Value of Hurricane Forecasts to Oil and Gas Producers in the Gulf of Mexico,' *Journal of Applied Meteorology* 43, no. 9 (2004), www.researchgate.net/publication/241384359_The_Value_of_Hurricane_Forecasts_to_Oil_and_Gas_Producers_in_the_Gulf_of_Mexico.

[51] World Bank et al., 'Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services', WMO-No. 1153, p. 71. For continued discussion on the value to aviation, see p81.

THE ECONOMICS OF ADAPTATION

By Pradeep Kurukulasuriya

The economics of adaptation is a key consideration for smart investments in the hydromet information space. In a world with competing demands for limited resources, critical questions need to be asked to form the most efficient policy response. Questions such as what is the magnitude of climate change impact on a sector like agriculture? To what extent will households that rely on agriculture be affected? Where are these changes expected? What kinds of interventions will have the highest return in terms of social welfare improvements? It is also key to address concerns over where and when adaptation investments should be made (recognizing that if one adapts too soon, resources may be wasted, and conversely that adapting too late will at the very least increase vulnerability for at-risk populations and perpetuate poverty traps, and may mean much greater costs).

In recent times, the need to demonstrate the costs and benefits of adaptation options has elevated in importance. In part, financiers of adaptation projects, such as the newly established Green Climate Fund (GCF), require countries to demonstrate that the rate of return on investments by the fund is sound. This is not the case with other climate funds, such as the Least Developed Country Fund and Special Climate Change Fund, which throughout their history have focused on highlighting the cost-effectiveness of preferred courses of action while not demanding a positive financial return. Policymakers themselves, faced with adaptation choices, are increasingly interested in finding the optimal mix of responses that maximize net benefits. A more rigorous understanding of the benefits and costs of adaptation to a changing climate has therefore become necessary, not only to justify donor funding but to strengthen national capacity to identify, assess and adapt to climate changes.

There are techniques to estimate the value of the early warnings and the climate information produced by hydromet systems as they relate to both security and economic livelihood. These valuation systems are not uniformly applied, nor do they use consistent metrics in all cases, making it hard at times to track the true impact of these investments. An example in UNDP's portfolio comes from a recently approved GCF-funded project in Malawi. Estimates suggested that an investment of approximately US$16 million—for the expansion of the hydromet observation networks and capacity strengthening within the National HydroMeteorological Service (NHMS) to gather, analyze and package relevant information for local districts, villages and communities—would result in a net benefit of about 1.5 times the cost of the project. Assuming a 10-year useful life of the early warning system and a 10 percent discount rate, the internal rate of return was estimated to be 31 percent, which exceeds 10 percent, the economic opportunity cost of capital.

Arriving at these estimates is by no means without its challenges. Questions need to be asked about both the market and non-market benefits of investments in climate information systems as the latter can be particularly important in poor countries but difficult to quantify. In the case of the cost-benefit analysis of the Malawi project, benefits incorporated into the analysis include (a) expansion of the networks that generate climate-related data to save lives and safeguard livelihoods from extreme climate events; (b) development and dissemination of products and platforms for climate-related information/services to communities engaged in agriculture-based livelihoods; and (c) strengthened community capacities for use of early warning and climate information in preparedness for response to climate-related disasters. Projected damages included damages to ecosystem services; physical and economic impacts such as housing damages and possessions lost, loss of agriculture, etc.; and human impacts such as injury or loss of human life.

Conducting a rigorous cost-benefit analysis using secondary data drawing on relevant experience is possible, and does not necessarily involve months and months of research time. In the case of Malawi, the benefits of the early warning system included loss and damage savings estimations based on the impact of the 2015 floods, which resulted in 280 deaths and an estimated cost of US$451 million.[52]

The potential benefits of tailored hydromet information for farmers were based on a study of smallholder farmers in four villages in neighbouring Zimbabwe. The study observed that farmers that participated in training on the uncertainty of climate forecasting—and reported changing management practices based on forecast information—experienced a 19 percent yield benefit in 2003–2004, and a 9 percent benefit averaged across years, relative to farmers who did not respond to forecast information.

The probability of extreme events was also taken into account. Analysis showed that catastrophic hydromet events like the 2015 floods occurred three times in the past 30 years. This indicated that the probability of this event is about 1 in 10 years. Using such estimates, it was assumed that less-severe annual hazards will only have about 5 percent of the economic and social impact of major events similar to the 2015 floods.

Finally, when conducting a cost-benefit analysis for such investment decisions, a prudent step is to aim at conservative estimates of benefits. If the investment is economically justifiable under the most constrained of assumptions, then it stands to reason that the project will be even more investment-friendly if all benefits were taken into account. Given the implicit challenges and time-consuming nature of estimating non-market benefits, focusing initially on working exclusively with market benefits (which are easier to estimate) is pragmatic. If necessary, subsequent efforts can include non-market benefits. For example, one of the ways benefits were underestimated in the Malawi project was by restricting the market benefits of early warnings to only the directly targeted districts where the network was to be strengthened. In reality, the benefits should of course reflect a larger geographical area given that the benefits of warning systems can be national in nature, with the information from the rehabilitated monitoring network contributing to a higher precision of national forecasts. The analysis also excluded the statistical value of lives, another significant but difficult to quantify impact.[53]

The robustness of the results can be tested, as they were in the Malawi example, via sensitivity analysis. One way to do this is to test if the attractiveness of the investment relative to the opportunity cost of capital holds even in the worst case (whereby either the investment cost increases by 20 percent and/or total benefits reduce by 20 percent). If the investment holds its attractiveness relative to a minimum threshold of 10 percent economic internal rate of return, then this suggests a safe investment. The Malawi project satisfied this test.

UNDP is currently supporting a number of countries to better understand the economics of adaptation. Technical assistance is provided to strengthen the capacity of technical officers in ministries such as planning, finance, environment, agriculture, water, public works and lands to understand the economics of adaptation in relation to medium- and long-term national, subnational and sectorial development planning, and in evaluating different adaptation investment projects. In coordination with other ongoing and planned UNDP initiatives, and working together with USAID, the Global Water Partnership and other partners, the objective of the technical assistance is to strengthen governmental capacity to more fully integrate climate change adaptation into planning and budgeting at the national, subnational and sector levels. For more information, visit www.adaptation-undp.org/projects/ecca.

[52] A Post-Disaster Needs Assessment by the World Bank and UNDP provided the estimates. Avoided losses and damages to agriculture, education, the health sector, businesses, housing and transport were calculated using available official Government estimates.

[53] Loss of human life was excluded from the analysis for a number of reasons, including a requirement by the Green Climate Fund based on political reasons. Conservative estimates on the project effectiveness suggested that about 28 lives are likely to be saved by the investment in the targeted districts based on probability calculated from past flooding events alone.

THE COST OF BAD WEATHER

Driven by large-scale changes in global and regional climate over the last four decades, floods, droughts, changing weather patterns, sporadic or increased rains, and other hydromet-related disasters are affecting African agricultural productivity at an astonishing rate. If the rate of climate change does not alter its current course, serious issues of public health and food security will come to the forefront of both regional and global agendas.

Inequality, poor value-chain linkages and lack of productive infrastructure already mean the continent loses an estimated $4 billion worth of grain annually due to post-harvest losses. "About 25 to 40 percent of the food produced on the continent is lost because of inadequate harvest, storage and transport practices. Market access has remained weak and very little food makes it up the value chain."[54]

WEATHER IMPACT — THE BIG PICTURE WORLDWIDE

1.94
MILLION DEATHS
(1970–2012)

$2.4
TRILLION IN ECONOMIC LOSSES
(1970–2012)[55]

BY THE NUMBERS

650
MILLION PEOPLE
Live in arid or semi-arid areas where floods and droughts impact lives and productivity (WFP)

50%
The possible increase in the cost of corn if climate change continues (Mary Robinson Climate Justice Foundation)

2
BILLION
Extra mouths to feed by 2050 (Mary Robinson Climate Justice Foundation)

15%
The percentage of wheat crops Egypt expects to lose if temperatures rise 2°C (IFPRI)

1 IN 4
Sub-Saharan Africans remain undernourished (IFPRI)

5%-22%
Possible crop decline in sub-Saharan Africa if global warming continues by 2050 (IFPRI)

1-2
DEGREES CELSIUS
Anticipated temperature jump by 2050

50%
Nearly half of all emergency multilateral food assistance to Africa is in response to natural disasters (ARC)

[54] According to World Bank and FAO figures as cited in Voice of America, 'Africa Still Suffers High Food Crop Losses', "December 13, 2013", www.voanews.com/content/africa-still-suffers-high-food-crop-losses/1809746.html.
[55] WMO, 'The Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes 1970-2012', 11 July 2014, library.wmo.int/opac/index.php?lvl=notice_display&id=16279#.VZ05fLdrVBh.

Potential Lost Productivity in Africa

If temperatures increase by 2 degrees Celsius, the costs to African agriculture production could be substantial, and include the following impacts:

- Negative effects on major cereal crops across Africa, with regional variability.
- Sub-Saharan Africa sees decreases of 19% for maize yields, and 68% for bean yields.
- Decreased crop yields of 18% for southern Africa to 22% across sub-Saharan Africa.
- Increasingly high vulnerability of wheat production in North Africa.
- Decreased dairy yields of 10%–25% are projected in South Africa by 2050.
- Range expansion of crop pests into the highland Arabica coffee-producing areas of eastern Africa.
- Annual landed value of fish estimated to decline by 21%.
- Fifty percent decline in fisheries-related employment, total annual loss of US$311 million to the regional economy.
- Severe child stunting (leading to higher mortality risk) could increase by 31%–55% across sub-Saharan Africa by 2050 due to climate change.
- Cholera outbreaks likely to increase in frequency and duration in coastal West African countries such as Ghana and Senegal.
- Malaria is greatly impacted by temperature and precipitation and its geographic range and incidence will be affected by climate change.[56]

More severe temperatures are projected with warming greater than 2 degrees Celsius, a result considered inevitable unless significant reductions are made in global greenhouse gas emissions.[57]

The Picture from Insurance

Insurance payouts give a 50,000-foot perspective on current crop losses. African Risk Capacity (ARC) is providing disaster relief for extreme weather events for several countries in Africa, using both global satellite data and human development indices to assess risk and provide payouts. Insurance payouts from ARC in 2014–2015 can be used as an indicator of crop losses in Africa today. To give more perspective from a global lens, weather-related crop losses reported in the United States in 2012, a banner year for crop losses due to droughts across the western United States, added up to US$17.3 billion. (For more discussion on insurance, see p78.)

ARC PAYOUTS

2014–2015
US$43 million in payouts

US$9 MILLION Kenya

US$1.4 MILLION Mauritania

US$3.6 MILLION Senegal

US$16.5 MILLION Senegal (payouts triggered-in late due to drought)

US$6.3 MILLION Niger (payouts triggered-in late due to drought)

US$3 MILLION Niger

2014–2016

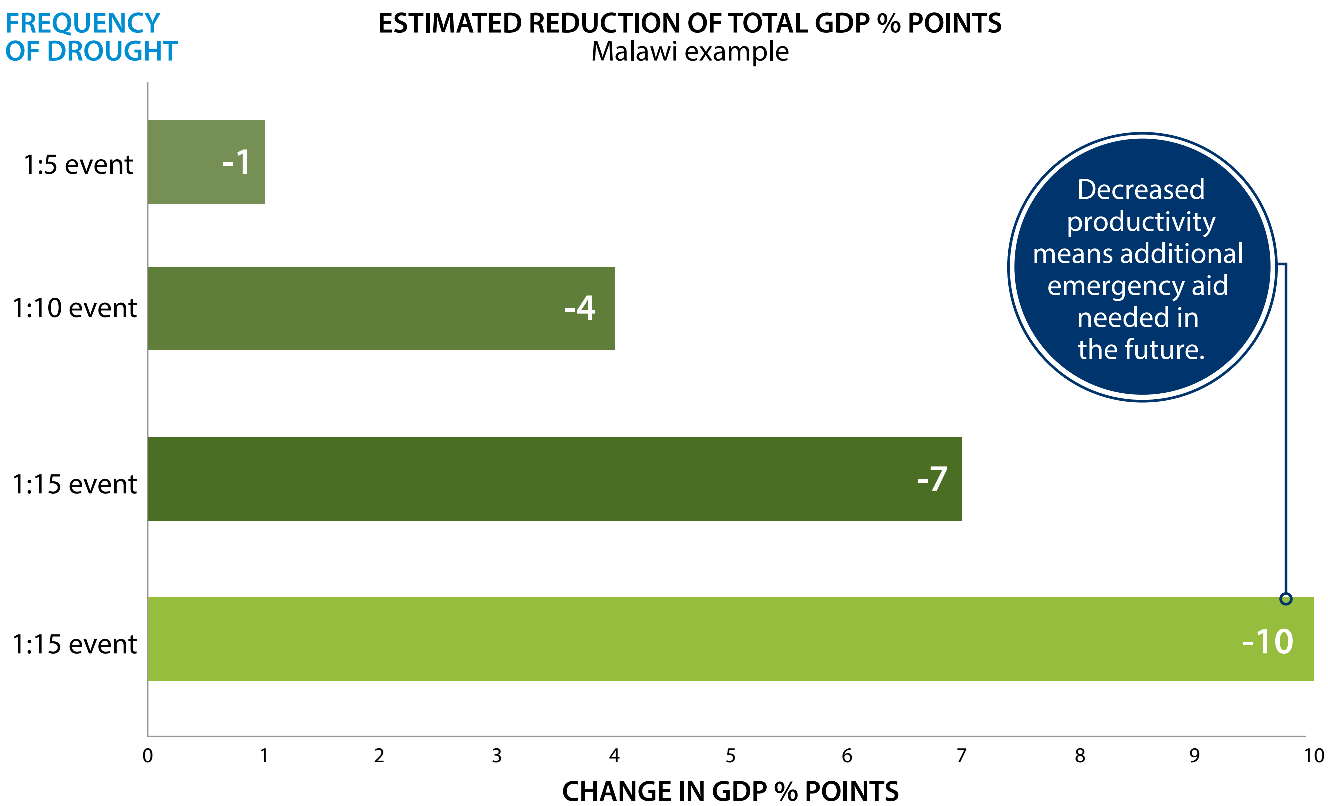
US$25 MILLION FOR THE EIGHT COUNTRIES

Kenya, Mauritania, Niger, Senegal, Burkina Faso, The Gambia, Malawi, Mali

[56] Responding to Climate Change, 'Climate Change Could Devastate Africa Crop Yields', 25 March 2014, http://www.rtcc.org/2014/03/25/climate-change-could-devastate-africa-crop-yields/#sthash.LcNjfX6h.dpuf.

[57] For a detailed description of potential consequences of 2 and 4 degrees warming in sub-Saharan Africa, see S. Adams et al., *Turn down the heat: climate extremes, regional impacts, and the case for resilience* (Washington, D.C.: World Bank, 2013), documents.worldbank.org/curated/en/2013/06/17862361/turn-down-heat-climate-extremes-regional-impacts-case-resilience-full-report.

Figure 3.2 The impact of drought events on Malawi's GDP2.



A HABOOB, PRODUCED BY THE FAST-MOVING SURFACE OUTFLOW FROM A DISTANT THUNDERSTORM, SWEEPS ACROSS A PART OF BURKINA FASO. PHOTO BY ULRICH DIASSO.

A NEW VISION FOR TECHNOLOGY

INSTALLATION OF A LIGHTNING LOCATION SENSOR AND AN ASSOCIATED ALL-IN-ONE AWS ON A CELL TOWER IN UGANDA. PHOTO BY SOLOMON MANGENI.

In this section, a new vision to produce and distribute local weather, water and climate (hydromet) information across Africa is articulated. This vision first looks briefly at existing observation techniques and technologies, and then focuses on new approaches to making local observations that can be applied to meet Africa's unique needs. The long-term sustainability of this vision relies on building the reliability and credibility of the products and services produced using these observations and delivered by the National HydroMeteorological Services so that synergies become possible between the public and private sectors–especially mobile telecom operators. Better local hydromet monitoring and forecasting in Africa have huge potential benefits for the agriculture, banking, insurance and communications industries–and even larger upsides for increasing productivity, reducing poverty and building resilience.

HYDROMET OBSERVATIONS IN SUB-SAHARAN AFRICA – THE FOUNDATION FOR WEATHER, WATER AND CLIMATE SERVICES

The data collected by hydromet observing networks and made available in near-real time are essential to the work of every National HydroMeteorological Service (NHMS). Routine, periodic observations of standard meteorological variables allow NHMS analysts and forecasters to properly describe atmospheric events on both short-term (weather) and long-term (climate) timescales.

Just a few of the major environmental variables that are routinely observed or measured include the following: temperature, atmospheric moisture, wind and precipitation; solar radiation received at surface and infra-radiation from surface to atmosphere; radar reflectivity, Doppler velocity, and polarization data[57] on precipitation and other particles in the atmosphere; observations from space of the flows of moisture and heat through the atmosphere; the occurrence and location of lightning discharges between clouds and from clouds to the ground; soil temperature and moisture down to one or two metres below the surface; the transport of dust and sand by winds; the water levels of dams and rivers, and the streamflow of rivers; and groundwater levels. Which quantities are measured, and with what frequency and to what accuracy, depends on the requirements of the intended purpose(s).

Most meteorologists, in discussing the requirements that observing systems and networks must meet, take a tiered approach, where the tiers are determined by the necessary quality of the resulting data. A four-tiered approach is common:

"WHILE EACH SUB-SAHARAN NHMS FACES CHALLENGES UNIQUE TO ITS PARTICULAR SITUATION IN ESTABLISHING AND SUSTAINING OBSERVING NETWORKS, THERE ARE COMMON FACTORS. THE MOST FREQUENTLY CITED ARE THE COUPLED CHALLENGES OF LIMITED BUDGETS; POOR NETWORK, STATION AND EQUIPMENT DESIGN; AND LACK OF TECHNICAL EXPERTISE AND SUPPORTING INFRASTRUCTURE. SUCCESS IN DEPLOYING AND MAINTAINING WEATHER OBSERVING NETWORKS IN DEVELOPING COUNTRIES REQUIRES THAT THESE CHALLENGES BE ADDRESSED."

1. **Aviation and synoptic observations.** These are the high-quality observations made in accordance with the technical and procedural guidelines developed by the World Meteorological Organization (WMO) and, in the case of aviation observations, the requirements of the International Civil Aviation Organization (ICAO). These observations are taken at standard times, and when there are changes in atmospheric conditions, and then shared globally via the Global Telecommunications System (GTS) operated by the WMO. Aviation and synoptic observations are also used for many climate studies.

2. **Climate observations.** These are the highest quality observations that are made routinely, often with instruments that are regularly calibrated and at locations carefully selected to be representative

[57] 'Radar reflectivity is a quantity determined by the drop-size distribution of precipitation, which is proportional to the radar reflectivity if the precipitation particles are spheres small compared with the radar wavelength. Doppler velocity is the radial component of the velocity vector of a scattering object as observed by remote sensors. Polarization refers to the correlation between two orthogonal components of a propagating electromagnetic wave.' From the American Meteorological Society Glossary (glossary.ametsoc.org/wiki/Main_Page).

of a large region. The goal is to detect with a high level of precision the small changes that occur in global and regional climates over a period of years.

3. **Routine public weather; air quality observations; highway, railway, and marine observations.** These do not require the high quality of aviation and synoptic observations, but are often required more frequently (5-, 10-, and 15-minute observing intervals are common). These observations support early warnings/alerts of severe or hazardous weather to the public, the operation of wind generation systems, as well as a wide variety of surface transportation/industrial/commercial applications.

4. **Agricultural observations.** These are observations made at or near fields and pastures to support very local agricultural weather and climate services to farmers and pastoralists, and may include measurements in the soil as well as in the atmosphere.

   These meteorological observing systems can be combined with hydrological monitoring to create a complete hydrometeorological observation, with hydrological measurements including the following:

5. **Hydrological observations.** Water levels in dams, lakes and rivers are monitored routinely. River-level data are converted into river discharge. These measurements are taken at regular intervals, at carefully selected rivers, lakes and dams. The goal is to monitor flood risk, but also to establish high-quality time series of hydrological data that are needed in fields such as urban planning, but also for civil engineering projects such as dams. For flood risk assessment and early warnings, the integration of meteorological data (such as rainfall) with these hydrological observations is crucial, and leads to improved lead times and accuracy of the early warnings.

Herein, the report authors are focused on 3, 4 and 5. Due to the nature of these observations and their emphasis on smaller spaces and timescales, these are often characterized as mesoscale and microscale observations, but the authors will refer to them simply as ***'local observations'***; these are discussed in more detail throughout this section. Local observations should always be looked upon as complementing and extending the synoptic observations.

These various observations and measurements provide the foundation for modern hydromet information services. In a typical NHMS, the data streams from the various observing networks are merged with other spatial data such as terrain/elevation, soil type and vegetative cover, as well as the output of Numerical Weather Prediction (NWP) models, to produce weather, water and climate information. This information is then used by the NHMS and others to produce a host of products and services with a wide range of applications. These services can be as diverse as a warning based on a short-term forecast, or 'nowcast' of the projected path of an evolving, moving thunderstorm, an estimate of the amount of water likely to be entering a reservoir in the next 24 to 36 hours, the updating of the seasonal precipitation climatology for a region, or the prediction of temperatures and precipitation likely to be experienced in a coming growing season.

Unfortunately, as discussed in the previous section, it has proven to be very difficult for the NHMS of the developing countries of sub-Saharan Africa to establish and sustain hydromet observing networks. All too quickly, networks installed with the best of intentions—and at significant cost—have failed to provide the desired data due to a variety of adverse factors, leading to discouragement on the part of NHMS staff, and a lack of credibility with other government agencies, the nation's business community and citizens.

Each sub-Saharan NHMS faces challenges unique to its particular situation in establishing and sustaining its suite of hydromet observing networks. Properly addressing these challenges requires solutions tailored to each nation. However, there are some factors that are common to most of the NHMS in sub-Saharan Africa. The most frequently cited are the coupled challenges of limited budgets; poor initial design, improper implementation, lack of tailored end-to-end systems that run from sensors in the field to products

and services delivered (or not) to users; and lack of technical expertise and supporting infrastructure. As a consequence, the NHMS is unable to deliver in a timely, reliable fashion the many hydromet monitoring, alerting and forecasting services needed by the people it is supposed to serve. The NHMS thus loses credibility with the citizens and the government of which it is a part, receives even less support, and has the potential to enter into a non-virtuous cycle as a government agency.

The situation can be exacerbated rather than improved when new technology or techniques arrive if there is a failure to do a valid gap analysis that considers the requirements for integration within existing NHMS systems; if long-term sustainability is given short shrift during the process of planning and design; and if too much reliance is placed on 'one size fits all' solutions. Uncoordinated and piecemeal approaches result in multiple observing networks using different equipment and various observing/communication protocols.[58] Equipment is deployed that works properly in the northern high and mid-latitudes, but does not function for long in the more challenging tropical environments of sub-Saharan Africa. The use of proprietary or unsupported software reduces local flexibility and updating, and often leads to large service costs. Rather than address them, the resulting complexities and management issues increase the already difficult financial, operational and maintenance challenges faced by NHMS.

For hydrological services, one of the main challenges is the lack of end-to-end solutions. Traditionally, hydrological services have mainly focused on the collection of accurate time series of surface and groundwater levels, and less on integrated water resources management. The advent of new observation technologies and innovative connectivity solutions have made it possible to replace manual observation systems with automatic systems to gain real-time information on water levels and river discharge.

[58] See, for example, the following discussion and recommendations made in WMO, 'Project Management Framework', Informal Planning Meeting, Voluntary Cooperation Programme, Mexico City, 6–7 March 2012, IPM//2011/Doc.6: "Currently, implementation of development projects tends to be fragmented, with loose internal coordination across Technical/Scientific Programmes and Regional Offices and a lack of an organization-wide project implementation oversight. Thus, lack of an internal, institutionalized project management framework leads to a variety of project formulation styles, monitoring, reporting and evaluation procedures. To overcome the above shortcomings, it is clear that greater internal coordination is needed for more effective and efficient project implementation. Improved internal coordination should lead to increased value-adding by the joining of complimentary activities at regional levels."

These systems have, at least theoretically, also given the hydrological services the possibility to expand their services to the provision of real-time flood warnings, drought monitoring, water resources planning and abstraction licenses, to name a few. Furthermore, the maintenance of dams and waterways can be carried out in a much more timely and efficient manner. However, without adequate integrated water resources management software solutions, which integrate hydrological and meteorological data, the possibilities offered by the new automatic observation infrastructure (combined with the ease of digital data exchange) cannot be fully exploited. Despite the new systems, the focus of the hydrological services remains on data, rather than information products.

Given the essential nature of observations, many NHMS have become tightly focused on deploying observing systems. However, while observations are necessary, they are only one input to the end-to-end system that is necessary to providing hydromet monitoring, forecasting and alerting services. NHMS often lack the in-house programme management, engineering and technical staff required to independently procure[59] integrated, innovative early warning and climate information systems that are sustainable, increase NHMS capabilities and build organizational capacity. For similar reasons, many of the NHMS often are unable to properly evaluate, critique and offer viable alternatives to proposed system solutions.[60]

Building hydromet observing and sustaining hydromet observing networks in developing countries requires that these factors be addressed holistically. Proactive approaches to addressing these challenges can provide NHMS with opportunities to procure, deploy and sustain observing networks as the first element in the end-to-end systems they need to properly serve their countries. The proactive approaches include tailoring solutions and providing supporting technical capacity, country by country; taking advantage of a convergence of new technologies in the meteorology, hydrology, climatology and cell-phone industries; designing model end-to-end systems that provide monitoring, forecasting and alerting services; and appropriately constructing public-private partnerships so as to contribute to long-term sustainability.

Surface Observing Networks — Point Hydromet Measurements to Describe Events over a Nation

On land, surface observing networks are one of the primary ways that hydromet data are collected. A surface network consists of 'stations', each station having a set of sensors tied to on-site processing, recording and telecommunications packages, usually in two-way communication with a central data collection and processing facility.[61] The suite of sensors at each station and the spacing between stations is set by the intended applications. Each station's location is selected to ensure that the data from that station (essentially data from a point) are, to the extent possible, representative of the immediate surrounding area. Or, in the case of hydrological stations, representative of the upstream catchment area. Thus, a network provides a set of point observations, each of which describes the hydromet situation over its associated area; the resulting picture of the weather or water situation over the nation looks a bit like

[59] To support procurement actions in its CIRDA Programme, the UNDP has established a long-term agreement (LTA) to accelerate the procurement of the critical hardware, software and services that are required to cost effectively and sustainably update NHMS technical infrastructure and support CI-EWS project goals and outcomes. The LTAs include the provision of recent, yet proven, innovations in ICT and meteorological monitoring and forecasting technology, lightning-detection-based early warning systems, ensemble and MOS-based forecasting solutions, and data visualization. The LTA was established through a competitive process, with two providers being selected based on their ability to design, deploy and assist in the provision of services to help NHMS keep the acquired systems operational.

[60] "While warranty services help with initial maintenance, they generally do not prepare NHMS staff to properly maintain a system once the warranty ends. Extended maintenance contracts are often not available or, if available, can be too expensive for the NHMS. The costs of spare parts (which usually have to come from the original manufacturer) and expendables can also become very expensive." John Snow, 'Non-Traditional Approaches to Weather Observations in Developing Countries', International Finance Corporation (IFC), 2013.

[61] Ideally, the modernization of an NHMS would begin with establishing flexible and resilient Information and Communication Technology (ITC) infrastructure as the basis for the deployment of renovated and new observing systems. Such modern ICT infrastructure should be part of the vision for every NHMS in the developing world. However, in the Least Developed Countries with very limited capacity, this could involve a significant delay (WMO, 2015a, as follows). In these countries, the WMO and other authorities have recognized the value of utilizing the growing cell-phone network and, in regions that the cell network has yet to reach, radio communications as the basis for providing "a practical link between experts in climate and farmers, shepherds and fishermen" that should be expanded across Africa and other regions (WMO, 2015b, as follows). WMO, 2015a, 17th Annual Congress, para. 5.3.2:"Congress further recalled that the Least Developed Countries are characterized by extreme poverty, inadequate institutional and productive capacity, and other vulnerabilities and constraints. The LDCs constitute the weakest segment of the international community and their economic and social development represents a major challenge for themselves as well as for the international community." WMO, 2015b, 17th Annual Congress, para. 8.1.18: "Congress noted that the METAGRI and METAGRI OPS projects, funded mainly by Spain and Norway, have trained more than 12,000 farmers in 17 Western Africa countries in the use of climate and weather information for decision-making at final-user level. The project METAGRI has been implemented in Mauritania, Senegal, Cabo Verde, Gambia, Mali, Niger, Burkina Faso, Guinea-Bissau, Guinea, Ghana, Côte d'Ivoire, Benin, Togo and Nigeria."

a patchwork quilt. Meteorologists and hydrologists analyze such data, producing a smoothed picture.

As implied in the opening discussion of the various tiers of observations, a nation will have a number of surface observing networks, often overlapping, each tailored to collect data for particular purposes. Examples are synoptic and local or mesoscale networks, the former covering large areas required for the prediction of large-scale events, with stations relatively widely spaced, and the latter for smaller-scale ones, with stations relatively closely spaced. Microscale networks, such as air quality monitoring stations in urban areas, provide observations from sites even more closely spaced. Synoptic networks support national general forecasting while mesoscale/microscale networks support localized services, such as storm warnings and poor air quality alerts. In addition, there may be special networks that provide support to aviation operations; hydrologic monitoring of the flow of water through watersheds and drainage basins; specialized agrometeorological services to farmers and herdsmen; and tailored services to rail and road operations. All these networks are complementary to one another, providing a degree of resilience to the overall national observing capability.

Surface Observing Networks — Technical Issues

All too frequently, attempts to meet the hydromet observing needs of developing countries in Africa by deploying observing equipment and by following procedures commonly used in developed mid-latitude countries have resulted in networks that perform poorly and quickly prove to be unsustainable. This unfortunate outcome is often due to poor design—of the network, the stations, and/or the selected equipment—and to the lack of supporting technical expertise and infrastructure.

Equipment deployed in tropical, arid/desert or near-ocean environments experience especially harsh environmental conditions. Unfortunately, such environments are characteristic of many of the least developed countries in sub-Saharan Africa. Experience has shown that designers of meteorological equipment intended for long-term use in this region must take into consideration factors that are often minor when it comes to equipment designed for mid-latitude environments.


AUTOMATIC WEATHER STATIONS PROVIDE A NUMBER OF UNIQUE ADVANTAGES FOR THE HARSH CLIMATIC CONDITIONS OF SUB-SAHARAN AFRICA.

For example, in the warm, moist tropics, moisture and mould can destroy wiring and electrical assemblies. In arid areas, sand and dust will invariably find their way into bearings, switches and electromechanical devices. Blowing sand can strip away protective coatings and accumulate inside enclosures. Small rodents, snakes, insects and birds can damage wiring and jam mechanical devices. The intense shine from the sun passing almost directly overhead can cause plastics to become brittle and drive temperatures inside sealed electronics enclosures to very high levels, causing electronic components to fail rapidly. Sea-salt-enhanced corrosion and high winds with tropical cyclones are issues for stations near oceans. In all settings, lightning can pose special challenges for hydromet observing equipment. Rain gauges and wind-measuring devices are particularly difficult to design for long-term, low-maintenance operation in such environments.

Solutions for Africa — All-in-One Automatic Weather Stations Comprising Local Observing Networks

One approach to addressing some of these technical issues is to utilize automatic weather stations (AWS). This notion is not new—since the end of the Second World War, meteorological observing and measuring equipment has evolved in parallel with the growth of modern technology. Mechanical chart recorders gave way to computer-based data loggers; mechanical wind instruments have been replaced by ultrasonic anemometers; one-use batteries have given way to solar panels and rechargeable batteries. Today, 'smart' stations can be tailored with a wide variety of sensors to provide data to meet a broad range of operational requirements.

The capabilities of modern AWS are sufficiently sophisticated that these stations can now play the central role in an observing network. An approach being promoted in the UNDP's Programme on Climate Information for Resilient Development in Africa (CIRDA) is to exploit the capabilities of the latest generation of smart, integrated, all-in-one (AIO) AWS, supplemented where necessary by even more powerful stand-alone data loggers, to provide sustainable observing networks for the 11 sub-Saharan African countries partnered with the support programme. In these all-in-one systems, the majority of the sensors and the related electronics are housed in one package. This significantly reduces the workload during deployment and subsequent field maintenance. As described in the section below, exploiting the cell-phone network to link the AWS to a central data collection facility and, subsequently, as a means to deliver hydromet services and information is another key component of this new vision.

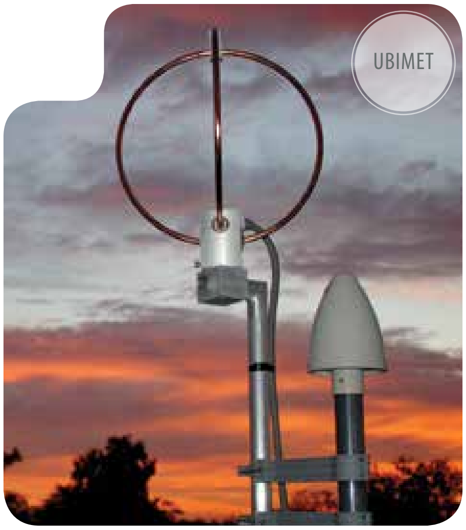
In most modern AWS, a specialized on-board computer or 'data logger' handles the collecting and initial processing of sensor readings. This has eliminated the need for human observers, handwritten observing forms, and calling or mailing in the recorded observations to a central office. Within a few seconds of being made, observations from AWS spread across a wide region can be collected at a central location, quality-checked using a consistent set of rules, archived, and made available for use by forecasters, climatologists and other users.

Many such AWS are now 'smart', incorporating an on-board computer that autonomously provides for the generation and transmission of formatted meteorological reports, changing sampling rates and/or special observations when preset environmental thresholds are crossed, and providing alert messages when preset thresholds in key variables are exceeded.

Following guidance from the central data-collection facility, the distributed network of individual station computers may manage all the necessary communications protocols. Individual stations will usually have some storage capability, so that when communications to the central collection point are interrupted, data continues to be collected. They are then forwarded to the central collection point when communications are restored. This not only means that one is comparing apples to apples for long-term climate monitoring, in an ideal world, this could also mean automated storm, lightning and flood alerts for local communities.

Up until the last decade or so, most AWS consisted of discrete components: individual sensors, computers/data loggers, and interconnecting cabling. These features offered numerous opportunities for things to go wrong, for example, water getting into one of the several connectors or fine dust working its way into a wind-speed sensor's bearing.

Fortunately, the last decade has seen rapid advances in both sensor design and packaging technologies. As noted above, this has led to the recent emergence of a generation of 'integrated, all-in-one' automatic weather stations (AIO AWS). The details of the specifications of these stations vary by manufacturer, but most are quite flexible, allowing for the tailoring of the station to meet specific applications. Typical AIO AWS contain sensors for measuring air temperature, relative humidity, precipitation intensity, precipitation type, precipitation quantity, air pressure, and/or wind direction and speed, all contained in a single package. Most moving parts have been eliminated, with wind speed and



THERE ARE NUMEROUS LIGHTNING SENSING TECHNOLOGIES AND ALL-IN-ONE AWS ON THE MARKET TODAY. HERE ARE THREE EXAMPLES.

direction sensed by ultrasonic anemometers. Overall, AIO AWS prices are quite reasonable, particularly when long-term maintenance savings are considered. Most importantly, accumulating experience suggests that properly designed AIO AWS do quite well in difficult environments.

One measure that continues to require a moving part is precipitation. The tipping bucket gauge, which as its name indicates incorporates a moving element, remains the leading choice for rainfall measurements.

Numerous new technologies have been offered by manufacturers as replacements for the tipping bucket gauge, holding out the possibility of an all-in-one automatic weather station with no moving parts. These include a very small, vertically pointing Doppler radar, which measures the size and speed of individual rain/snow or ice particles. Precipitation quantity and intensity are calculated from the correlation between drop size and speed. The difference in drop speed determines the type of precipitation (rain/snow). Another new technology is the laser distrometer. Using an optical laser, the system measures the particle size and velocity of falling precipitation, and then computes the precipitation rate and accumulation over time. Other outputs can be meteorological visibility and an estimate of radar reflectivity. Both of these technologies have been known and applied for some time, however, they can now be provided in small, much more affordable configurations than in the past. It remains to be seen if one of these, or another technology all together, will finally replace the tipping bucket rain gauge in future AIO AWS.

At present, the best option for precipitation measurement, particularly in Africa where almost all precipitation is liquid, remains the tipping bucket gauge, augmented with an Alter shield to reduce wind effects and some device to discourage birds from sitting on the rim of the collecting funnel. In recent years, tipping bucket gauges have been greatly improved in both design and choice of materials, minimizing maintenance and calibration requirements. WMO provides detailed guidance for the exposure of the gauge, the height of the rim of the collecting funnel above surface being a key point.

Solar panel technology (supplemented in some cases with small wind turbines) has developed to the point where it can now provide power to even large stations. However, careful design is necessary to provide sufficient back-up power for night-time operation as well as for operations during extended cloudy periods. The vandalism and theft of solar panels has become a problem that also needs to be taken into account in the overall design of an integrated automatic weather station system. Fortunately, the power requirements for AWS can be minimal and the efficiency of solar panels is now sufficiently high that panels can be small and less attractive for theft. Secure location on cell-phone towers can also address the problem, an option discussed on page 46.

THE PROS AND CONS OF AUTOMATIC WEATHER STATIONS

A NETWORK OF AUTOMATIC SYSTEMS HAS ADVANTAGES AND DISADVANTAGES OVER TRADITIONAL MANUAL SYSTEMS:

PROS

- **Autonomous, automatic operation** on a 24/7 basis, eliminating the need for human observers; especially important in remote, harsh or dangerous climates;
- **Greater reliability**—increased consistency through standardization of observations, improving their overall quality;
- **Improved accuracy** (eliminates reading and recording errors, and the differences due to how different observers read charts and instruments differently);
- **Collection of data** in a greater volume, e.g., data are collected every 1 to 15 minutes, as desired, as opposed to on an hourly basis or once or twice per day; such data, when analyzed and merged with satellite, radar, and/or lightning data, allow the meteorologist to watch the weather evolve in near-real time;
- **Automatic or remote** adjustment of sampling intervals of different parameters in response to changing weather events;
- **Automatic Quality Assurance and Quality Control** during collection and reporting stages, including automatic alerts to users and maintenance personnel when errors are detected;
- **Automatic meteorological message** generation and transmission, including alerts when critical thresholds are crossed;
- **Automatic data archiving**;
- **Access to data**, both real-time and archived, locally or remotely.

CONS

- **Initial cost** of instrumentation and associated equipment, and then ongoing costs of operation, such as for maintenance, communications, security, etc. AIO AWS are designed for minimum maintenance, but in many cases, systems must be returned to the manufacturer for all but minor repairs. This increases with the requirement for spare systems—10 to 20 percent of installed base—and associated costs;
- **Without human observers present**, a more elaborate (and hence costlier) security system may be required;
- **It is not possible to observe all meteorological** parameters automatically; at key locations, such as airfields and central synoptic observatories, it will be necessary to augment automatic observations with a human observer to obtain supplementary information such as cloud coverage and cloud types;
- **Final quality control/assurance** is best carried out by a staff of well-trained operators working on a 24/7 basis, supported by an automatic system that does an initial screening—the cost of these individuals partially offsets the savings from eliminating the need for observers in the field;
- **The high volume** of data generated by a network of AWS requires the development of a sophisticated data archival system that can be costly in its own right and which requires periodic forward migration as software changes;
- **If solar panels are used to power a station**, this may limit the amount and type of instrumentation, local computing and telecommunication equipment that can be used; it may also lead to theft and vandalism;
- **Routine preventative** and as-required corrective maintenance, together with periodic sensor calibrations, still requires a staff of trained maintenance technicians, spare sensors, repair parts and expendables, and the availability of appropriate facilities;
- **Staff may be displaced**, and in order for them to be retained they may be required to develop and demonstrate greater skill levels in computing abilities or maintenance techniques.

Hydrological Observing Systems

A lot of progress has been made in hydrological sensor design. Manual networks, relying on observers reading out staff gauges or simple, analog-level gauges, are being replaced with telemetric automatic water-level gauges. Surface-water-level monitoring systems based on pressure transducers, bubblers, or ultrasonic or radar sensors have reached maturity and can be deployed in remote, unmonitored areas provided the security, connectivity and power requirements mentioned above are met. Automatic groundwater-level monitoring, using pressure transducers or bubbler-type sensors, provides crucial data for drought monitoring.

In terms of connectivity, automatic hydrological stations are often at a disadvantage compared to automatic weather stations, since they are often being installed in low-lying terrain, such as at the bottom of valleys. However, technological developments in recent years mean that a number of options are available to connect hydrological stations in some of the remotest of locations. Low-power, wide-area networks can connect stations to places with decent GSM or GPRS signals, radio links can be used, and in case no ground-based option is available, satellite uplinks (such as the EUMETSAT Data Collection and Distribution System) can be used to transmit data from these stations.

Recent advances in active remote-sensing methods, such as satellite altimetry, have made the monitoring of water levels in major rivers, dams and lakes from space a useable option. By combining networks of automatic hydrological stations with satellite altimetry data, information from the point measurements provided by the automatic stations can be upscaled to be representative of larger areas.

Likewise, passive remote-sensing techniques (notably from microwave and visible/infra-red satellite platforms) are very well suited for evapotranspiration and soil-moisture monitoring. Combined with in-situ groundwater-level and meteorological observations, these data can be used to provide advance information on agricultural and hydrological droughts.

PHOTO BY SARINE ARSLANIAN/SHUTTERSTOCK.COM.

A crucial part of the hydrologic monitoring infrastructure is the integrated water resources management system. Without this system, the different observing systems would merely send data to a server or cloud-based data management system, resulting in a (number of) large database(s), and not much more. Although hydrological time series are extremely important for a number of applications and users, much more information can be generated from the available hydrometeorological datastreams. Automatic systems provide the basis on which integrated water resources management can be built. Flood early warnings can gain in lead time when meteorological data and hydrological data are combined, river flow can be modelled, and a better understanding of the interactions between rainfall, surface-water resources and groundwater can be had. Agricultural and hydrologic droughts can be observed and forecasted, giving policymakers more time to respond, adapt and mitigate. Water resources planning and allocation strategies can be developed, to work towards fair and sustainably managed water resources management systems.

PASSIVE REMOTE SENSING – AREA OBSERVATIONS TO DESCRIBE EVENTS OVER A NATION

The observing networks discussed above provide surface-based, point-location measurements. While such measurements are adequate for many purposes, they do not provide a complete picture of what is happening, weather-wise, over a nation. This is especially true with regard to rainfall, which has high variability in both space and time. While satellite observations can be helpful in estimating rainfall over an area, the tool of choice for for this task has been weather radar, an active sensing technology.[62] However, weather radars are expensive to procure, install, operate and maintain. Consequently, they have proved impractical for deployment in least developed countries in Africa.[63]

A significant proportion of the total annual precipitation in sub-Saharan Africa is produced by the massive thunderstorms that together form the Inter-Tropical Convergence Zone (ITCZ). When mature, these rapidly developing clouds stretch from near surface level to the top of the troposphere (10km to 20km above the surface of the Earth). In addition to heavy rain, tropical thunderstorms produce a lot of lightning, both cloud-to-cloud and cloud-to-ground (together called total lightning). Sub-Saharan Africa in general, and Equatorial Africa in particular, contain many of the most lightning-prone regions on Earth.

It is thus very fortunate that, in recent years, NHMS in North America and Europe, research organizations, and several commercial vendors have made significant advances in lightning-location technologies[64] and in processing the data they produce. Such passive systems complement observations of the lightning-producing storms by radar and satellite sensors, and can now effectively serve as easily maintained substitutes for weather radars where the eminence of such complex systems has proved to be impractical.[65] Given that these lightning-location technologies are also much less expensive to install and maintain[66] than weather radars, they provide an attractive alternative for many countries in Africa.

While a single lightning sensor can provide useful information regarding the occurrence of lightning strikes within its detection range (a few hundred kilometres), operating a network of such sensors spaced a few hundred kilometres apart allows for the geolocation and monitoring of the evolution of thunderstorms over a country or region. Ideally, countries within a region would cooperate in the location of sensors and receipt of information to improve the efficiency and reduce the cost of networks.

[62] Radar is an 'active sensing technology' in that electromagnetic pulses are generated by the radar and emitted into the atmosphere to produce electromagnetic echoes. These echoes are then processed by the radar system to determine the location, movement and other properties of particles in the air.

[63] RG du Preez, S. Piketh Sr., R. Burger Sr. and J. Holm Sr., 'Operational weather radar networks in Africa: A South African case study', 18 September 2015, 37th AMS Conference on Radar Meteorology, ams.confex.com/ams/37RADAR/webprogram/Paper275516.html.

[64] Lightning-locating systems are a 'passive sensing technology' in that they do not emit electromagnetic radiation, but rely on detecting electromagnetic signals produced by nature in the lightning discharge.

[65] The justification for this assertion is the extensive body of applied research that has been done across North America and, to a lesser extent, across Europe since the 1970s by both public- and private-sector entities, together with the experience gathered through both experimental and operational deployments of lightning-location systems in regions where it has proved impossible to sustain weather radars. Three decades of research have resulted in the development of much-improved geolocation technologies and the development of correlations between the occurrence of lightning and the producing storm structure. See, for example, Chonglin (Charlie) Liu, Elena Novakovskaia and Stan Heckman, 'Creating Proxy Radar Reflectivity Maps from Total Lightning Data', Earth Networks, 2012, www.wmo.int/pages/prog/www/IMOP/publications/IOM-109_TECO-2012/Session1/P1_17_Liu_Proxy_Radar_Reflectivity_from_Lightning_Data.pdf. These studies compare/correlate geolocated lightning strikes, both cloud-to-ground and in-cloud, to radar observations of the clouds producing the lightning. For example, there has been a major effort in the United States that utilizes the national network of S-band Doppler/dual-polarized weather radars (operated by the NOAA National Weather Service) in comparison/correlation studies with the lighting-location data produced by three or four different commercial companies. The resulting correlation algorithms provide future paths and speed of the storms, an estimate of what a radar reflectivity field might show (e.g., a pseudo-reflectivity), and likely rain rates. These algorithms have been successfully applied at several other locations around the world, for example in a nationwide demonstration network in Guinea, now in its third year at the time of writing. Some examples are shown in the figures in the section below entitled 'Value of Regional Cooperation'.

[66] To compare costs of radar and lightning detection, consider that on the factory floor, the system cost for X-band radar is ~US$500K; for a C-band radar, ~US$1M; for an S-band radar, ~US$2.5M. Transportation and installation costs vary widely depending on the distance to and the environment at the point of installation; 10 to 50 percent of system cost likely brackets most installations, but they can be much higher for elaborate installations or at difficult-to-access locations. Routine annual operating expenses can be taken to be about 10 percent of the system cost per year, though depending on the situation, telecom and fuel costs (for generators) can quickly drive these costs up. Given issues with beam blockage due to rough terrain, some flash-flood-prone regions may require a large number of radars to properly monitor regions where significant numbers of people live. A lightning-locating sensor can run ~US$100K, delivered by the manufacturer and installed on a commercial cell tower. The number of sensors required depends on the size of the nation or region to be covered, but between 5 and 10 would cover most nations in Africa (helped by the fact that the technology is largely terrain insensitive). So a national lightning-location network would run from ~US$500K to ~US$1M, the cost of either an X-band (low-end) or C-band (high-end) radar. The difference is that the lightning network would cover the whole country (and indeed a good portion of the region around the country) while the radar would only cover a circular region of a radius of 40–50 km (X-band), or 100–125 km (C-band). Operating costs for the lightning network would be low for maintenance (since this is a passive system) but communications costs could be comparable to those for radars, ~US$50K to US$500K or more a year for a national network. However, there are innovative business models that involve partnering with a cell-phone company that could reduce this cost significantly—see the discussion of public-private partnerships later in this report.

Recent developments in the detection of total lightning timing and location, coupled with parallel developments in telecommunications technologies, have greatly enhanced the capability to acquire and quickly process signals from a network of lightning sensors deployed across a region, resulting in useful data sets of time and location of discharge occurrence, intensity/polarity, and other characteristics. Such networks now also allow for the near-real-time monitoring of lightning flashes in a particular thunderstorm, from which much can be inferred regarding the evolution of that storm. Compositing the data from a lightning-location network with contemporaneous satellite observations, visible and infra-red, and, where available, radar reflectivity fields can produce mosaics that provide severe weather forecasters with valuable insights as to where life-threatening events may be occurring.

FAST-MOVING STORMS CREATE SEVERE WEATHER THAT DAMAGES CROPS, KILLS LIVESTOCK AND AFFECTS LIVELIHOODS. SOUTH AFRICA ALONE REPORTS AROUND 260 LIGHTNING-RELATED DEATHS EVERY YEAR.

Further, using known correlations between spatial and temporal densities of flashes on the one hand and storm evolution and rainfall rates as observed by radar on the other, maps of lightning-flash rates can be presented in formats very similar to what is done for radar reflectivity. These pseudo-reflectivity values can be used to monitor thunderstorm evolution and movement. By applying formulae similar to those used with radar reflectively fields, the lightning-based values can be used to produce precipitation estimates. When accumulated through time, just as is done with radar-based precipitation estimates, one can display an estimated accumulated rainfall over periods ranging from one hour to several days, weeks or months. These capabilities well illustrate what can be done with modern passive detection techniques and advanced signal processing systems.

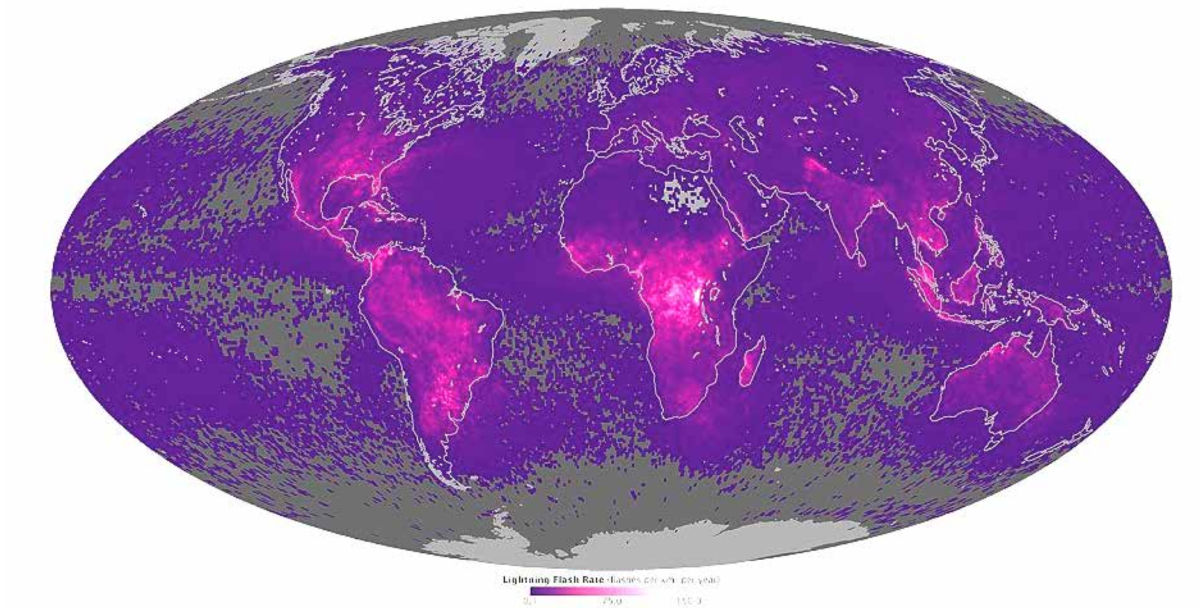
Cloud-to-ground strikes are major life-threatening events across sub-Saharan Africa, with many people killed each year by lightning strikes. This is due in large part to a lack of warning of the approach of a lightning-producing storm (see 'Bad Weather Taking Its Toll,' (p26), coupled with limited places to take shelter or understanding of how to shelter from lightning. Even in developed countries, it is a challenge to provide effective warnings for such dangerous electrical storms (which can also bring strong gusty winds and cause flash floods through heavy local precipitation), particularly when they move quickly across the landscape. However, it has been demonstrated in several areas (including Guinea in Africa) that it is possible to track such storms by following their lightning discharges. This type of tracking, if it can be done in near-real time, can become the basis for an early warning/nowcasting service. (One also has to consider how to disseminate the warning information in a timely manner. This is an example of a 'last mile' issue. Messages disseminated by cell phone may be one viable means of reaching the technically savvy part of the population. Collaborations with local radio stations may be another possibility.)

Total lightning and other lightning-detection systems have one shortcoming. They require that at least one lightning discharge occur before they can be used to infer the presence of deep convection, precipitation and other weather elements. With deep convection, this means the initial stages of the formation of a cloud cannot be detected. Further, some rainfall comes from stratiform (layered) clouds that seldom produce lightning. Lightning-detection networks need to be complemented with other observation systems to detect precipitation associated with

FIGURE 4.1

THIS MAP FROM NASA REVEALS AVERAGE YEARLY COUNTS OF LIGHTNING FLASHES PER SQUARE KILOMETRE FROM 1995 TO 2013.

The density of strikes in Africa led the *Daily Mail* to label Africa 'The Lightning Capital of the World'.



forming thunderstorms and stratiform clouds. Satellite observations and emerging rain-fade technologies offer possibilities in this regard.

Along with local contributions to the Global Observing system, several developed nations maintain constellations of geostationary and polar-orbiting meteorological spacecraft that add satellite data to enhance our understanding of sub-synoptic to global-level weather, water and climate.[67] While satellite observations can help with some short-term forecasts and long-term climatic predictions, most operational satellite systems do not usually produce well-calibrated data with a sufficient level of granularity to be useful by themselves for creating local hydromet information products that can be used by farmers, extractive industries, banks and small-businesses to manage risks and optimize productivity. (Refer to the discussion on insurance on p78 for more information on how weather data is used to assess risk.) However, as noted above, if high-resolution satellite observations can be made available to forecasters in a timely manner, they can be used in a complementary fashion with surface hydromet and lightning data to produce nowcasts, localized hydromet forecasts and specialized warnings or alerts.

LEVERAGING THE CELLULAR TELEPHONE NETWORK TO SITE AWS

Reference has been made several times to the relevance of the telecommunications sector as a partner for the collection of data and the communication of critical hydromet information to users, particularly in rural areas. In the past, this meant hard-wire phone lines or finicky radio systems. Fortunately, in parallel with the development of the meteorological technologies described above, cell-phone networks are rapidly spreading across sub-Saharan Africa. This technology allows for remarkable new opportunities to collect data and then distribute hydromet information—opportunities that were inconceivable just a decade ago.

The spread of cellular telephone networks across sub-Saharan Africa is one of the most amazing techno-sociological phenomena of the early 21st century. In the developing nations of this region, the cellular phone has become a 'leap frog' technology. Such nations will almost certainly never have national-scale hardwired telephone or data networks. Everywhere there are people, cell towers are becoming ubiquitous—it was projected that in 2015, the number of cell-phone contracts would exceed the population of sub-Saharan Africa for the first time.[67]

From the perspective of the NHMS, the spread of this network offers several opportunities. One is to leverage the local cellular telephone networks to develop robust national synoptic and local observing networks.[68] As for-profit ventures, the telephone companies (or their supporting cell-tower service companies) have strong incentives for maintaining the functionality of the equipment supporting the services they provide. They have the cash flow to provide security, reliable electrical service, automatic rerouting during outages of links, and wide bandwidth connectivity at each cell tower. The companies also have trained electronics and mechanical staff to install and maintain the equipment at each cell-tower site (frequently trained in-country and paid wages that allow for retention). The communication system would also serve to inform the NHMS if the AWS is not working, and the telecom or tower company staff servicing the tower could also check/replace the AWS as necessary.

A national- or regional-scale local meteorological observing system could consist of a network of stations located at or on cell towers. Given the characteristics of the cell-tower environment, with its security and stable telecommunications, stations at these locations should be highly reliable. Unfortunately, since cell towers are positioned to serve communications needs, they are not likely to be at sites representative of a large region, or at locations that permit good observations of all desired elements, or to be found at all sites where specific observations and measurements are needed. However,

RELIABLE, ACCURATE AND TIMELY FORECASTS PROVIDE SMALLHOLDER FARMERS WITH NEW OPPORTUNITIES TO IMPROVE PRODUCTIVITY. PHOTO BY ©IFAD/MWANZO MILLINGA.

as the name 'cell tower' implies, each tower serves as the fixed base station for phones (and other transceivers) in a geographic area around the tower—its 'service area' or 'cell'. Thus, it is better to have the local observing station at or on the tower serve a similar function. That is, while the local station takes observations at its location, it could also act as a central collection node for other surface hydromet observing stations located throughout the cell. In this sense, the local observing stations at or on cell towers comprise a high-reliability backbone network, judiciously engineered so that each tower station receives, stores (temporarily) and forwards data from other sites, such as temperature and rain-gauge measurements supporting local agricultural meteorology services, within its cell. This would provide the overall network with a high degree of resiliency.

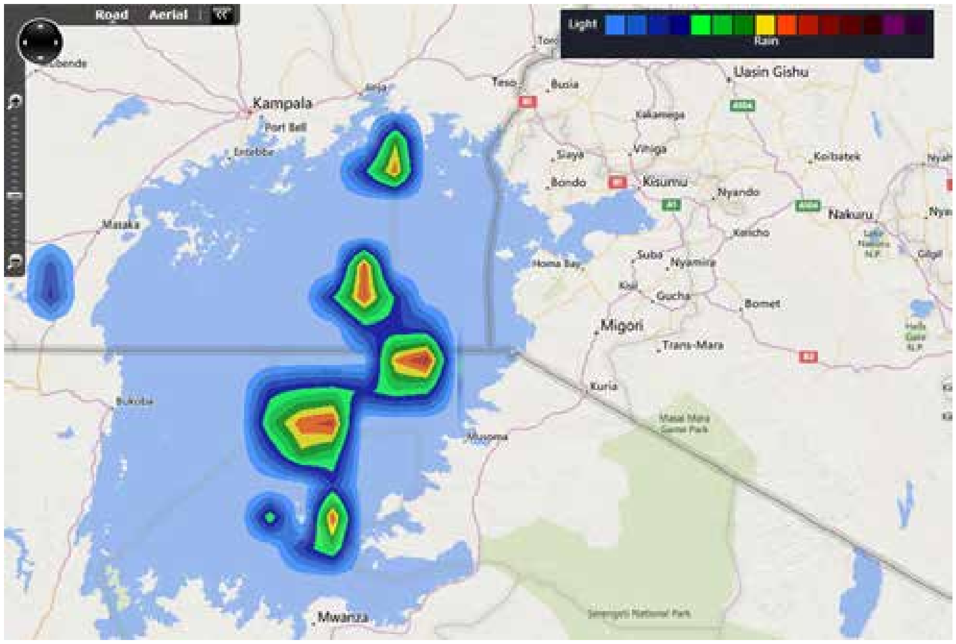
As previously noted, under the WMO Integrated Global Observing System (WIGOS) programme, the details of the siting of each local observing station, at or on a cell tower and elsewhere in the cell, need to be carefully

[67] Learn more about this rise of mobile telephones in the GSMA report entitled, 'Mobile Economy 2014: Sub-Saharan Africa', at www.gsma.com/newsroom/press-release/gsma-report-forecasts-half-a-billion-mobile-subscribers-ssa-2020/.

[68] In addition to providing external communications services, telephone companies can also be used internally by an NHMS as a contracted Information Technology and Communication (ITC) provider. Often this is a less expensive and more productive way of obtaining internal secure, flexible and resilient ITC services than for the NHMS to develop, sustain and retain its own ITC staff.

FIGURE 4.2

Real-time thunderstorm rainfall intensity estimates as visualized through the computing infrastructure of the Pilot Project on Severe Weather Nowcasting Based on Total Lightning Detection in Lake Victoria Region.



documented. The application of WMO guidelines in cell-tower siting of AWS is discussed in greater detail on p60.

Further, sensors for the detection/location of lightning are well suited for installation on or in proximity to cell towers, as illustrated by the pilot project on Lake Victoria discussed in more detail below. A network of such detectors is very attractive since the sensors are passive with low power requirements while the telephone network supporting local cell service provides the reliable, wide-bandwidth communications necessary to transmit the lightning data back to a central server for processing.

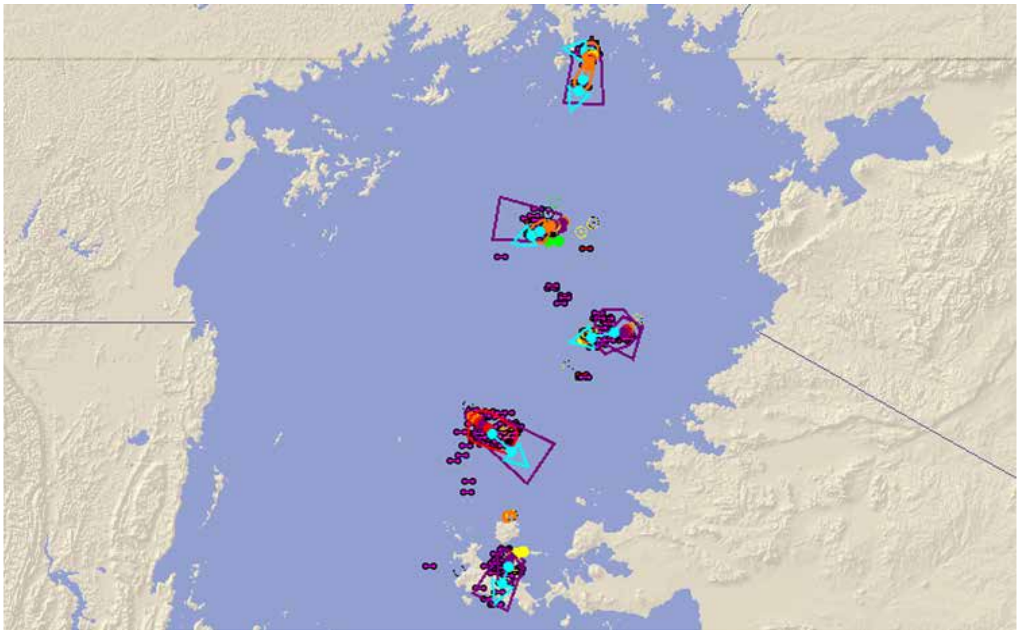
The use of cell networks to distribute and monetize hydromet information will be discussed in greater detail in Section 5.

VALUE OF REGIONAL COOPERATION

Hydrometeorological events do not respect borders. Rains in one country may produce flash floods in another. Drought in one country will result in river levels that are insufficient for, e.g., irrigation in the downstream countries. Increased cooperation, data-sharing and system compatibility are needed to improve early warning systems and the overall climatological record of the African continent. With improved synoptic and local monitoring, country-specific hydromet data and information can be shared both with the WIGOS and Global Telecommunication System. Reciprocal data shared both ways across border regions can improve the analyses in each participating country and thereby enhance the accuracy of forecasts along the border and provide early warnings for storms that originate in Country X, but don't have significant strength until they reach Country Y. And in some regions—Lake Victoria

FIGURE 4.3

Lightning-detection technology and data analysis generate polygons where dangerous thunderstorms are active. These polygons can be used by NHMS to issue early warnings to fisherman and lakeside communities likely to be affected by these storms.



for instance—purposeful regional monitoring systems should be considered with the goal of providing data and forecasts not just for national use, but for the entire region.

Work to build a transcontinental all-Africa hydromet monitoring system first began around 2008, when Kofi Annan and the Global Humanitarian Forum launched the Weather Info For All (WIFA) initiative, which was to work through public-private partnerships with telecommunications companies to install 5,000 AWS across the continent.[69] The first step was a demonstration project around Lake Victoria. The project never really took off—limited political support, failure to build strong local ownership and the eventual demise of the Global Humanitarian Forum all contributed to its failure to deliver on its promises.

In spite of this initial failure, interest in providing better weather support in the Lake Victoria region remained high in the surrounding nations of Burundi, Kenya, Rwanda, Tanzania and Uganda. A new pilot project was launched in 2014 to try to tackle the unique challenges of creating a smart weather network for the region. The 'Pilot Project on Severe Weather Nowcasting Based on Total Lightning Detection in Lake Victoria Region' brought together a diverse group of actors from both public and private sectors, with the East African Community (EAC) playing a vital role in initiating the project, building political will across the countries, and, finally, ensuring that the project design included both technical and knowledge transfer.[70] The main actors include technicians and trainers from the private company Earth Networks; community outreach and technical experts from a regional non-profit, the African Centres for Lightning and Electromagnetics (ACLE); and public-sector leaders from the NHMS.

To date, the pilot has successfully deployed all planned stations to provide coverage to the region. This early warning system is based on networks of real-time AWS installed on existing mobile telecommunication towers and equipped with total lightning sensors.

[69] Of the three planned phases of the WIFA initiative, only the first was completed before the Global Humanitarian Forum (GHF) ceased all activities in 2010 due to lack of funds (WMO, 2013).

[70] Meeting of Heads of Meteorological Services and Joint EAC/WCRP/WWRP Workshop for the Proposed Lake Victoria Field Program and Nowcasting Project, Arusha, Tanzania, 5–7 May 2014, EAC Secretariat, Ref: EAC/SR/2014.

In-situ observation data from the proposed system is integrated into cloud-based data repositories as well as nowcasting and numerical weather prediction (NWP) systems. This solution provides easy access for the four NHMS to surface observation and forecast data for historical analysis as well as for real-time, current weather conditions.

If all the stations are operating with uninterrupted electrical power and Internet communications, the pilot network provides a cloud-to-ground lightning detection efficiency of over 95 percent for the high resolution area. It also provides intracloud detection efficiency of over 60 to 70 percent in the region, which enables key information on storm development and behaviour. When working at maximum capacity, the system provides detailed total lightning data for storm cell identification and tracking in the region and serves as a tool for the monitoring of storm intensity, positioning and movement. Lightning location accuracy is 200 to 300 metres within the region.

This information is then processed through the cloud computing infrastructure to create an integrated early warning solution. All the data points and layers are visually presented in a specialized display environment, which is utilized by the NHMS to aid in the issuance of early warnings. Select NHMS staff have received several rounds of training on applying the new technology, and the project aims to continue training to ensure both meteorologists and field technicians are functionally prepared to use the information generated by the system. This modality has introduced and aims to sustain total situational awareness across this broad region with real-time tracking and automatic alerting of impending hazards. It means that timely, localized decisions on the issuance of early warnings can be made now, without the need to install expensive, hard-to-maintain weather radar systems across the region.

Political cooperation on issues of technical implementation and data sharing is certainly key, as is the transfer of knowledge and skills to NHMS with limited in-house capacity. Furthermore, the use of an innovative, common base technology for real-time weather monitoring and operations provides consistency in data, alerting protocols and modelling, making this a good case study in transboundary cooperation.

Numerous climate information, climate services and early warning projects are at work in sub-Saharan Africa. With multiple funders and institutional agendas, this patchwork support provides NHMS decision makers with a wide assortment of technical options, policy suggestions and support vehicles. To ensure that the technologies procured through these programmes work in synergy within nations and across borders will require the support of regional cooperation entities, as well as careful planning and coordination between NHMS. While this is not an exhaustive list, some of the main players in the climate information and services space in sub-Saharan Africa include:

- **UNDP Climate Information and Early Warning Systems Projects and the UNDP CIRDA Programme** (p28).
- **WMO Severe Weather Forecasting Demonstration Project (SWFDP).** "The project has improved the lead-time and reliability for alerts about high-impact events such as heavy precipitation, severe winds and high waves. It has strengthened interaction with disaster management and civil protection agencies, local communities and media. SWFDP is making a major contribution to disaster risk reduction and is supporting the Millennium Development Goals on sustainable development, as well as climate change adaptation. It is benefiting socio-economic sectors, including agriculture, fisheries, aviation, and marine transportation."
- **ClimDev Special Fund.** "The objective of ClimDev Special Fund (CDSF) is to strengthen the institutional capacities of African national and subregional bodies to formulate and implement effective climate-sensitive policies by providing up-to-date information to support-related activities." The ClimDev- Africa Special Fund forms one of the three elements of the ClimDev Africa Programme, the others being the African Climate Policy Centre at the United Nations Economic Commission for Africa (UNECA), and the Climate Change and Desertification Control Unit at the African Union Commission (AUC).

- **Climate Services for Action Africa Project.** "The Climate Services for Action Africa Project in Tanzania and Malawi is part of the Global Framework for Climate Service (GFCS). It is a multi-partner pilot to provide improved weather and climate information to help better manage the climate risks to health and food security. It is jointly implemented by the World Food Programme (WFP), the World Meteorological Organization (WMO), the World Health Organization (WHO), the International Federation of Red Cross and Red Crescent Societies (IFRC), and several research institutions that include the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), the Centre for International Climate and Environmental Research (CICERO) and the Chr. Michelsen Institute (CMI). Through the use of radio, cell phones and extension workers, among other means, the project is providing tailored weather and climate information to smallholder farmers and pastoralists to help them enhance their agricultural or livestock production. The pilots in Malawi and Tanzania will serve as models for how different organizations can work together to design and implement comprehensive climate services in the humanitarian and development sectors."

- **Strengthening Climate and Disaster Resilience in Sub-Saharan Africa.** "The World Meteorological Organization, African Development Bank and World Bank Group launched this new initiative in June 2015 to support the modernization and strengthening of sub-Saharan African meteorological and hydrological services, which are key to strengthening resilience to extreme weather events and enabling economic development."

- **Climate Services for Resilient Development.** "This partnership aims to develop new tools, services and approaches that bridge technology and organizational gaps in order to strengthen climate resilience to populations around the world. USAID has committed $10 million towards the partnership, with the total financial and in-kind contributions at $34 million by the founding-partner institutions: USAID (leveraging NOAA, NASA, and other U.S. agencies), U.K. Government (Department for International Development, and the U.K. Met Office), Inter-American Development Bank, Asian Development Bank, Esri, Google, American Red Cross, and Skoll Global Threats Fund. Through the end of 2016, the partnership will deliver tailored and targeted services to three subregions in the Andean region of South America, Eastern Africa, and South Asia—with Colombia, Ethiopia and Bangladesh serving as pilot countries. Thereafter, the partnership aims to expand to a second phase of activity in three more subregions (the Sahel region of Africa, Southeast Asia, and the Caribbean) and build on lessons learned and replicable tools and services."

AWS BEING PREPPED FOR DEPLOYMENT ON A CELL TOWER IN UGANDA. A LIGHTING SENSOR WILL ALSO BE DEPLOYED ON THIS TOWER. TO INCREASE THE LIKELIHOOD THAT EACH LIGHTNING STRIKE IS PROPERLY LOCATED, THE LIGHTING LOCATING SYSTEM WILL ALSO INTEGRATE LIGHTNING DATA FROM NEIGHBOURING NETWORKS IN BURUNDI, KENYA AND TANZANIA, MAKING FOR IMPROVED REGIONAL COOPERATION IN EARLY WARNING SYSTEMS. PHOTO BY SOLOMON MANGENI.

THE IMPORTANCE OF RELIABILITY AND CREDIBILITY

Much of what is recommended here hinges on the NHMS routinely and reliably monitoring hydromet events, making skilful local hydromet forecasts and using this information to create credible products and services that can be used to make informed decisions by the target audiences: the general public, industry and commerce, and government agencies. This will require many of the sub-Saharan NHMS to improve both the quality and extent of their suite of products and services.

LIGHTNING DETECTION SYSTEM INSTALLATION IN UGANDA.

Only if an NHMS is reliable and credible will the phone companies, national banks, insurance providers and other key stakeholders be interested in developing partnership arrangements.

Few NHMS in developing countries run their own NWP systems.[71] Their forecasting systems typically are built using NWP products generated in Europe, the United States, Japan, or elsewhere in the mid-latitudes. These NWP products are provided at little or no cost to the NHMS of the least developed countries through the WMO via the Global Telecommunication System (GTS). At present, little original forecast guidance information is generated at the local level and thus the forecasts are developed from these numerical outputs largely through extrapolation. Looking at market forces and demands, NHMS would need to begin routinely adding significant additional value to the forecasts and products they produce to gain the necessary credibility with their audiences.

To move away from simple extrapolation and develop a skilful Module Output Statistics (MOS)[72]-based near- and medium-range forecast system, high-quality local hydromet observations are required in the selection, verification and fine-tuning of the statistics for the location where those observations are taken. The 'integrated, all-in-one' automatic weather stations will generate detailed local data that can be used to develop skilful MOS for specific localities.

FINAL POINTS ON TECHNOLOGY

The installation of local hydromet observing networks such as those described here are only the beginning. In addition to local networks for surface hydromet observations, a lightning-locating system, and access to satellite imagery and NWP products, as well as other complementary or emerging technologies need to be considered for implementation. These include:

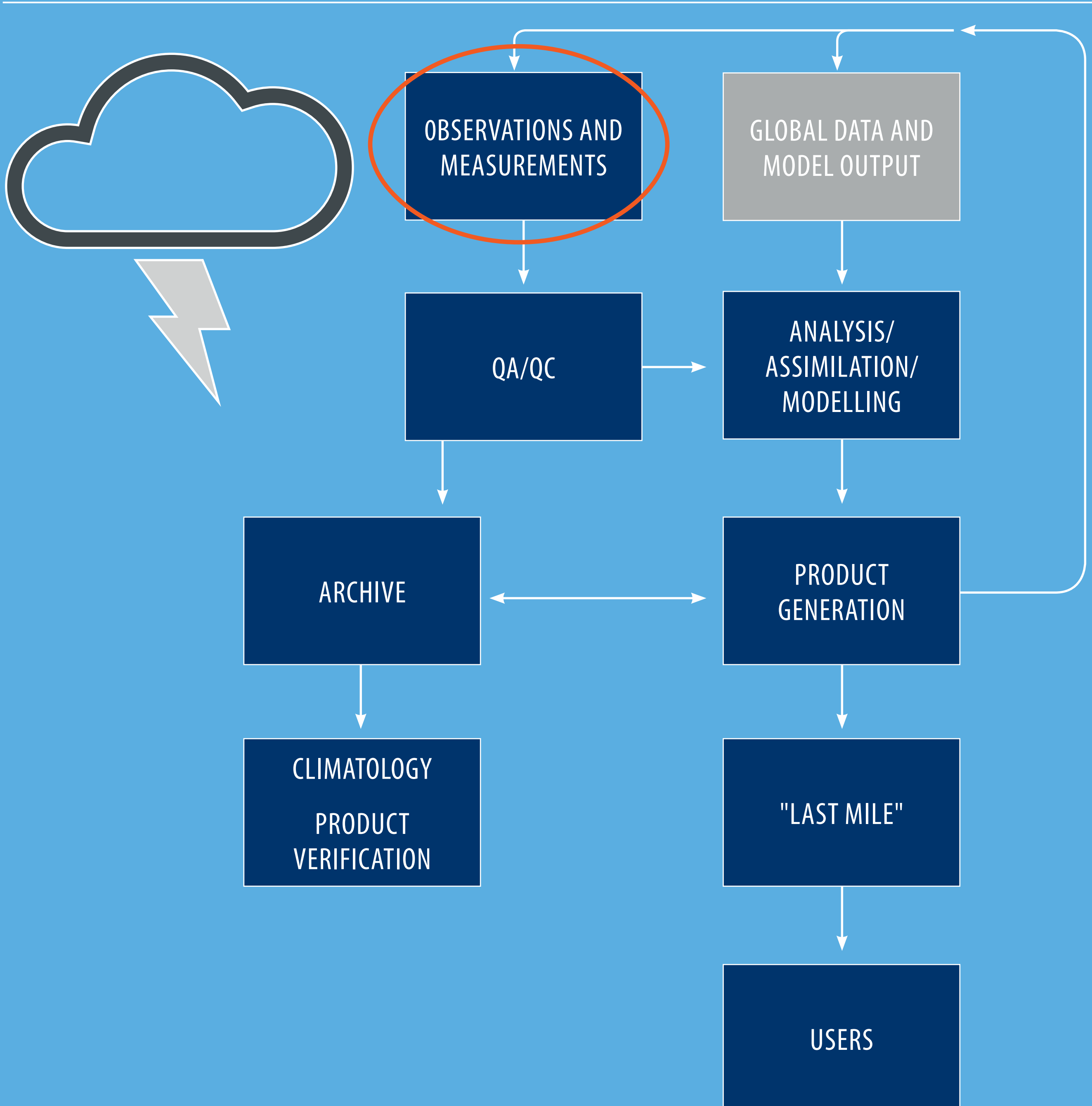
- Obtaining vertical soundings of temperature and moisture from instrumentation on commercial aircraft, particularly those flying regional routes.
- Utilizing the emerging 'pilot-sonde' technology to obtain lower tropospheric winds aloft information, e.g., see Ansari et al., 'Pilot-sonde Method of Upper Air Observations' (https://www.wmo.int/pages/prog/www/IMOP/publications/IOM-109_TECO-2012/Session5/P5_02_Ansari_Pilot-Wind_GPS.pdf), and commercial literature.
- Deploying integrated, semi-autonomous networks of small X-band radars where active sensing is fully justified. An example might be support for the management of a hydroelectric power system, where more quantitative rainfall data are required.
- Using enhanced feature phones and smart phones as hydromet observing systems and for dissemination of hydromet information, products and services.

Finally, a local network of AIO AWS does not, in and of itself, constitute an early warning system or a climate monitoring system. AWS networks are good for the monitoring of current hydromet conditions but they do not directly support prediction. They are but the first step in a lengthy series of steps in which the data from the networks is processed to produce meteorological information. This is illustrated in the following figure:

[71] "Modern weather forecasting is based on the application of computer models that describe the way the atmosphere changes using mathematical equations. This approach requires fast communications, to gather the observations, and very fast computers to carry out the large number of calculations required." Brian Golding, 'Numerical Weather Prediction (NWP)', Royal Meteorological Society website.

[72] MOS is an objective, site-specific weather forecasting technique that consists of determining a statistical relationship between a quantity (such as temperature) to be predicted and variables forecast by a numerical model at specified forecast time(s).

FIGURE 4.4
A schematic illustrating the flow of information in the production of a meteorological product, such as a weather forecast. Large white arrows represent the forward flow, in which data (from Observations and Measurements and Global Data and Model Output) are converted to information in the form of decision-support products and services, which are then delivered to users. Light grey areas represent information feedbacks in the system, which work to adjust procedures and so continuously improve performance.



WORLD METEOROLOGICAL ORGANIZATION GUIDELINES

The World Meteorological Organization (WMO) is an agency of the United Nations (www.wmo.int). Its mission is to provide world leadership in expertise and foster international cooperation in the areas of hydrometeorology (weather, water and climate) and related geophysical sciences. Among other activities, it encourages the standardization of hydromet observing procedures and issues consensus guidelines on the characteristics of observing equipment. In short, it strives to make the world's meteorological measurements consistent and comparable.

One of the most important functions of the WMO is the operation of the Global Telecommunication System (GTS). The GTS connects the central offices of all NHMS to one another. Through the GTS, NHMS share standard synoptic observations and a wide variety of other meteorological information. Standard synoptic observations are those observations that are made in strict compliance with the guidelines contained in the WMO Guide to Meteorological Instruments and Methods of Observation (WMO-No. 8).[73] Many standard synoptic observations are made at airfields or at central meteorological observatories operated by NHMS.

However, WMO has come to recognize that there is a need for NHMS to make large numbers of additional measurements on smaller time and space scales, for very local, very applied purposes, such as specialized weather forecasts and detailed climate analyses. While the WMO Guide referenced above contains a lot of useful information applicable to local observations, these non-synoptic, often mesoscale observations may demand procedures and measurement systems that depart from the Guide. To identify best practices for these observations designed to meet more localized needs, and as the basis for policies for other than traditional synoptic observations, WMO started the WMO Integrated Global Observing System (WIGOS) initiative (www.wmo.int/wigos).

The following are examples of the types of local (non-synoptic) networks of interest to the WIGOS initiative and to present purposes:

- Agro-meteorology
- Hydromet monitoring (water management, including for irrigation and hydroelectricity, along with flash-flood monitoring)
- Road/rail/airport/seaport local hazard monitoring
- Support to renewable energy generation (solar, wind)
- Wind-wave monitoring
- Monitoring of air/water quality
- Support to fire danger monitoring, controlled burns, and wildfire response

An important requirement of the WIGOS programme is that if the data are to be shared with others, then the details of the local observing system have to be documented so that other potential users understand where and how the data are being collected.

While each of the above could lead to a different observing network, NHMS try to make the national weather observing networks as multipurpose as possible. This may require collaborations and even partnerships with other government ministries and the private sector.

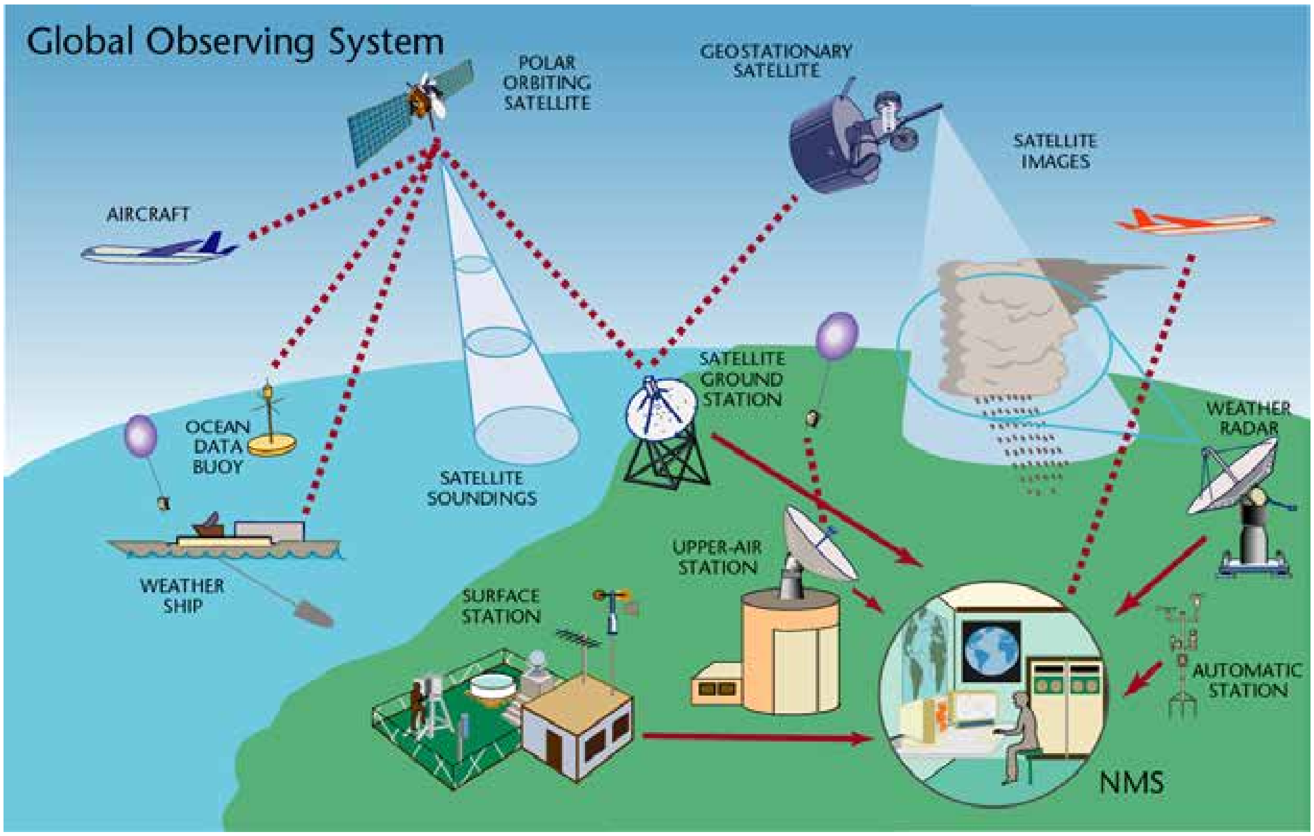
The following are examples of the meteorological uses of local observations, illustrating their importance to the NHMS:

- Monitoring onset, then following evolution of high-impact weather (HIW) → forecasting, then monitoring, nowcasting
- 'Ground truth' → using point measurement to calibrate area measurements (radar/satellite and lightning) and verify forecasts

[73] WMO, 'Guide to Meteorological Instruments and Methods of Observation', WMO-No. 8 (2008 edition; updated in 2010). The 2014 Provisional Edition is available at www.wmo.int/pages/prog/www/IMOP/publications/CIMO-Guide/Provisional2014Edition.html.

FIGURE 4.5

The WMO Global Observing System (GOS) uses information from the automatic weather stations, radar, satellite and other monitoring systems to create a 50,000-foot overview of weather and climate. The information produced by this global network is effective in predicting large storms and monitoring macro-level climate issues, but it falls short in providing the granular data needed by smallholder farmers in Africa to avoid localized storms and optimize profits using better weather data. (Illustration courtesy WMO).



- Assimilation into initialization for numerical models
- Development of local model output statistics (MOS) to improve forecast operations
- Local (mesoscale and microscale) climatologies → the foundation for monitoring the evolving microclimates where people live and work

These and other meteorological uses produce the decision-support information needed by end-users (e.g., banks making agricultural loans; index-based crop insurance).

Understanding WMO Guidelines and Their Application in Climate Information and Early Warning System Projects

Hydromet observations should be made on at least two levels (see discussion on p38 for a four-tier approach). Synoptic stations provide the hydrometeorological data needed to resolve continental- to regional- to national-scale weather patterns, and to issue forecasts of the movement and evolution of such large-scale weather systems for periods ranging from one day to about ten days out. Synoptic data also support global efforts to describe the climate, and they aid in mapping the impacts of climate change on the same large time and space scales over relatively long periods of time—seasons, decades or even longer.

At the same time, a national network of synoptic stations should work in concert with mesoscale and microscale observing networks, commonly called local networks. These local networks provide the fine-grain, local-level data needed to track and predict the future evolution and movement of hazardous weather events, such as thunderstorms, flash floods and wildfires, to name but a few examples, and to protect lives and infrastructure. Such data also aid in environmental and business decisions where smaller space scales and shorter timescales are important, such as in the operation of seaports and airports, the management of hydroelectric systems, and in surface mining operations. Given the relatively low initial cost, the lack of need for staffing, and other considerations, local networks are best achieved using AIO AWS. Taken together with synoptic observations, these local monitoring systems provide data that can also be used to provide local detail within the global climate record, particularly in areas with complex terrain. The growing importance of local observations to meet local needs has led to the establishment of the WMO Integrated Global Observing System (WIGOS) programme described above.

Siting AWS on Cell-Phone Towers

The suggestion to site observing stations on cell-phone towers is about ensuring the overall sustainability of national investments in local climate and weather observing systems.

Both synoptic and mesoscale/microscale/local hydromet observing sites must be developed to meet regional and local needs. A relative few synoptic stations are required to characterize regional-scale weather and climate. These are often staffed 24/7, well secured, and supplied with power and telecoms. They should be developed and maintained in strict accordance with WMO guidelines. Their small number makes their establishment, operation and maintenance affordable. This is not the case for local networks, for which large numbers of stations are required. Such stations still need security, power and communications, and their installation, operation and maintenance need to be affordable. Where they are available, cell-phone towers meet all of these needs and have been shown to provide adequate sites for local observations.[74]

Further, it can be strongly argued that observations at a local cell tower—specifically placed by a mobile telephone company to serve people where they live, work and play—is actually positioned to bring higher quality local hydromet information and (through improved model output statistics) better forecasts to the public when and where it is most needed.

A lightning-locating system requires a very reliable wide bandwidth communication system to quickly move the signals detected by several sensors to a central location for processing. Cell-phone towers thus provide ideal sites at which to locate the sensors of a lightning-locating system.

The development and operation of local networks is about creating practical, pragmatic applications of the recommendations contained in several WMO guidelines, such as those for emergency warnings, and for agricultural and urban meteorology. This was another reason that WMO created the WIGOS programme.

Site Density Requirements

When building an integrated synoptic and local hydromet monitoring system, the following considerations should be taken into account:

- A country only needs a relatively few synoptic observing sites to comply with WMO guidelines and meet the needs for global- to synoptic-scale monitoring and forecasting.
- This synoptic network can be complemented with local observing sites to make the observations necessary to support mesoscale and microscale forecasting, particularly where people live in complex terrain (which includes urban environments),

[74] See Roman Bakhtin et al., 'Cell-phone tower mounted meteostation and standard meteostation data four seasons inter-comparisons', 2012, www.wmo.int/pages/prog/www/IMOP/publications/IOM-109_TECO-2012/Session1/P1_14_Koldaev_Cell_phone_tower_meteostation.pdf.

and fine-grain data are needed to track localized, fast-evolving phenomena such as thunderstorms and flash flooding.

- One could easily end up with 20 or 30 local observing sites, serving diverse purposes, for every synoptic site.
- Synoptic sites are selected to be broadly representative of a region, so their data produce a broad-brush view of the meteorology and climatology of that region, one which gives the big picture but at very low resolution. What is lost is the fine detail of the small watersheds and meso- and micro-climatic zones—the space scales where people live and work—that comprise the region. By only looking at synoptic data, meteorologists may recognize that it is raining at a moderate rate, on average, over a broad region, but they will not have sufficient data to know that there is heavy rain in a flood-prone valley and that an early warning alert should be issued to help farmers get out of harm's way.
- According to WMO, "In particular, applications have their own preferred timescales and space scales for averaging, station density and resolution of phenomena—small for agricultural meteorology, large for global long-range forecasting. Forecasting scales are closely related to the timescales of the phenomena; thus, shorter-range weather forecasts require more frequent observations from a denser network over a limited area in order to detect any small-scale phenomena and their quick development."
- Using various sources (WMO, 2003a; 2001; Orlanski, 1975), the weather systems of horizontal meteorological scales may be classified as follows, with a factor of two uncertainty: (a) microscale (less than 100m) for agricultural meteorology and the urban environment, for example evaporation and industrial fires; (b) topo- or local scale (100m–3 km), for example air pollution plumes and gust fronts; and (c) mesoscale (3 km–100 km), for example monitoring thunderstorms, sea and mountain breezes.

A TRADITIONAL RIVER-LEVEL GAUGE IN LIBERIA. PHOTO BY JOOST HOEDJES.

- There is also the practical consideration of cost: establishing, maintaining and operating a synoptic site is relatively expensive compared to the costs necessary to establish, operate and maintain a local observing site.

Understanding the Recommendations of the CIMO Guide

The WMO Guide to Meteorological Instruments and Methods of Observation (better known as the CIMO Guide) were drafted between 1998 and 2003. The goal during that time was to improve the spatial representation of synoptic stations to develop the global climate record. Priorities have changed since then.

Addressing these changes, WMO created a new guide that is slated for distribution in 2016, having been approved by the CIMO-16 group. In 2014, a provisional edition of the guide (CIMO 14) was issued. With regard to the siting of AWS, it states,

> "The siting of an AWS is a very difficult matter and much research remains to be done in this area. The general principle is that a station should provide measurements that are, and remain, representative of the surrounding area, the size of which depends on the meteorological application. Existing guidelines for conventional stations are also valid for AWSs . . . . Some AWSs have to operate unattended for long periods at sites with difficult access both on land and at sea. Construction costs can be high and extra costs can be necessary for servicing. They may have to operate from highly unreliable power supplies or from sites at which no permanent power supply is available. The availability of telecommunication facilities should be considered. Security measures (against lightning, flooding, theft, vandalism, and so forth) are to be taken into account and the stations must, of course, be able to withstand severe meteorological conditions. The cost of providing systems capable of operating under all foreseen circumstances at an automatic station is prohibitive; it is essential that, before specifying or designing an AWS, a thorough understanding of the working environment anticipated for the AWS be obtained. At an early stage of planning, there should be a detailed analysis of the relative importance of the meteorological and technical requirements so that sites can be chosen and approved as suitable before significant installation investment is made."
>
> 'Automatic Weather Station Siting Considerations', in Part 2, chapter 1 of CIMO 14, Provisional Edition ('Measurements at Automatic Weather Stations').

Furthermore, the preface of the CIMO Guide states that it "is not intended to be a detailed instruction manual for use by observers and technicians, but rather, it is intended to provide the basis for the preparation of manuals by National Meteorological and Hydrological Services (NHMS) or other interested users operating observing systems, to meet their specific needs."

From this discussion it should be clear that it is very important to archive comprehensive metadata for each observing site—images of the surroundings of each site, commentary on the characteristics of the soil and vegetation at each site, changes in and the maintenance history of the instrumentation, etc. All should be updated at least on an annual basis, or whenever site maintenance or sensor replacement occurs. Ready access to this metadata will help users, including forecasters, to properly interpret the data reported from a site.

PUTTING THE PIECES TOGETHER

The vision introduced in this section is an enticing one: the lower cost, easily maintained, reliable collection of local hydromet data; automatic, real-time data processing for transmittal to NHMS; automatic early warnings of extreme hydromet events through the most locally effective communications systems; and credible, tailored hydromet information services that support economic development in a wide range of weather-, water- and climate-sensitive sectors. This can and should result in new revenue from both the government and commercial entities. The fact that it has not been happening despite the many benefits reflects a complex set of barriers explored in the sections that follow.

As will become clear, the basic challenge is less about technology, economics or even legal frameworks, and more about changing long-established assumptions and accepting new ways of doing business. New relationships have to be created between public

PHOTO BY VADIM PETRAKOV/SHUTTERSTOCK.COM.

and private parties that do not have a history of working together, building what has been termed 'a climate of trust' as the basis for public-private partnerships (PPPs).[75] As explained in a report of the World Bank, "the responsible actors require a new culture—one of trust, mutual understanding, and learning from each other—that is aimed at a common public welfare-oriented goal, not simply an economic one. . . . A PPP must be based on a win-win situation with the advantages and risks to all of the parties carefully weighed."[76]

Some elements of this proposed new vision are likely to be widely shared, including the use of particular technologies (e.g., AIO AWS; lightning networks) and collaboration with mobile-phone providers for some combination of hosting automatic weather stations on towers and the communication of regular hydromet information as well as early warnings of extreme events. However, many specifics, including the combination of technologies, the allocation of roles between public and private parties, financial arrangements, and legal frameworks, will need to be country specific.

One set of issues will relate to partnerships with commercial vendors to collect and analyze selected hydromet data, while a very different set of issues exists with respect to the delivery of tailored information services to meet business needs. Public agencies will likely consider incorporating a new set of skills, perhaps beginning with the help of outside consultants, to manage very different procurements and risk sharing.

Governments may understandably prefer to try out these new arrangements in pilot programmes for particular regions or particular sectors before revamping national programmes. Fortunately, in recent years, international financial institutions have developed technical assistance programmes, sometimes including donor support, to help governments interested in pursuing PPP concepts.[77] Many PPPs have been implemented in Africa, most often for infrastructure projects such as those in energy and water, but in recent years also for a wider range of public services including health and education. However, to date no such structures have been used in Africa for hydromet services. How this might be accomplished, and what some of the challenges appear to be, will be explored in the next section.

[75] The term 'climate of trust' is particularly appropriate in this context, having been first introduced in the climate negotiations as a collaborative project of 16 NGOs from developing countries and one from the United States. See Bonizella Biagini, ed., *Confronting Climate Change: Economic Priorities and Climate Protection in Developing Nations* (Washington, D.C.: National Environmental Trust, 2000).

[76] David Rogers and Vladimir Tsirkunov, 'Weather and Climate Resilience: Effective Preparedness through National Meteorological and Hydrological Services' (Washington, D.C.: World Bank, 2013), p.110.

[77] See, e.g., www.ifc.org/wps/wcm/connect/AS_EXT_CONTENT/What+We+do/IFC+and+PPPs (describing support for PPP development and implementation provided by the International Finance Corporation across a range of sectors including agribusiness, energy, water, transportation, ICT, health and education).

A NEW VISION FOR PUBLIC-PRIVATE PARTNERSHIPS

AN EXAMPLE FLASH FLOOD WARNING PROVIDED VIA CELL PHONE. PHOTO BY JOOST HOEDJES.

The challenges facing countries in adapting to climate change are enormous, while the human and financial capacity to address them within least developed countries is limited. As in most sectors, these constraints are also acute within the narrow context of the hydromet services sector, a key cross-cutting element that underpins most adaptation efforts. Given the size and scale of the problem, and the limited resources that governments and donors can apply to resolving it,[78] engaging the private sector becomes more than just an interesting idea—it is a necessity. However, creating partnerships that benefit both parties—'win-wins'—is an essential component of these engagements and an important factor in sustainable development. This section will highlight the opportunities and address the issues that exist in bringing about public-private partnerships for weather and climate information services in order to reduce risk, build resilience, improve productivity, and ensure long-term sustainability.

By engaging with a variety of new actors in the hydromet services space—including telecommunications firms, private weather companies and potential clients for hydromet services such as the aviation and insurance sectors—African governments can gain access to new technologies, build in-house capacity and expand revenue streams. Contrary to some fears, this transformation can enhance, not threaten, the traditional role of the National HydroMeteorological Services (NHMS) as the entities responsible for the issuance of early warnings and the delivery of basic weather information essential for farmers and daily life.

IGNITING ENABLING ACTIONS

The hydromet services sector is changing rapidly worldwide. As discussed in the previous section, technology advances are providing new low-cost, easy-to-maintain climate information solutions for Africa's persistent monitoring system challenges. The deployment of local observing networks by siting automatic weather stations (AWS) on cell towers, which are increasingly ubiquitous across sub-Saharan Africa, provides an opportunity to protect hardware investments by ensuring their security, power and communications.

However, the availability of technology and siting solutions is only part of the equation. In order to effectively deploy integrated monitoring systems—and eventually reach vulnerable end users—enabling actions will need to be initiated by African governments to ensure the long-term sustainability of these networks. Special consideration should be given to the software—namely, through enabling policies that will support the long-term sustainability of these systems and partnerships with private-sector weather service providers that can bridge the technology and capacity gaps to bring 21st century solutions to Africa. These enabling actions include steps to define roles and responsibilities, protect national interests, and support National HydroMeteorological Services (NHMS) that are too often trapped in non-virtuous cycles (with poor information, limited support and limited staffing levels and capacities).

> "THE PUBLIC SECTOR RETAINS THE DOMINANT RESPONSIBILITY FOR THE DELIVERY OF WEATHER AND CLIMATE INFORMATION SERVICES TO ALL SECTORS OF THE ECONOMY AND SHOULD BE CENTRAL TO THE DELIVERY OF PUBLIC GOODS, INCLUDING OFFICIAL WARNINGS OF EXTREME WEATHER EVENTS TO THE PUBLIC AND NATIONAL GOVERNMENT AGENCIES."

As has been the case in most developed nations, the private sector will be a key actor—both as a provider of technologies and information, and as a consumer. As noted by the Africa Development Bank,

> "The future of African economic growth—and the futures of millions of Africans and thousands of African communities—is closely tied to the private sector. . . . It is African businesses that will create African jobs, by training and using African talent, and by developing the potential of services and industries, through the sustainable management and prudent use of Africa's considerable natural resources. This will plough the dividends of enterprise back into the lives of Africans and African societies. The private sector can also deliver services to society's most vulnerable people and—if it is properly regulated and responsible—it can help to make society at large well regulated and responsible. . . . The private sector already generates two-thirds of Africa's investment, three-quarters of its economic output, and

[78] According to the Landscape of Climate Finance 2015, the most comprehensive inventory of public and private climate finance available, in 2014 about US$25 billion was invested in defined 'adaptation' measures, out of a total of US$391 billion in all climate change–related activities. As the authors note, this is a "partial and uncertain estimate" due to the limitations of the data available, but nevertheless indicative of the range of total resources available for *all* developing countries for *all* adaptation purposes. Climate Policy Initiative, 'Landscape of Climate Finance 2015', www.climatefinancelandscape.org/.

nine-tenths of its formal and informal employment." At the same time, "The public sector still needs to create an environment in which the private sector can thrive and the two must work together to deliver services and opportunities."[79]

Enabling actions could include policy frameworks and legal authority from national governments that would allow NHMS to establish mutually beneficial relationships with individual private-sector partners in multiple sectors of the economy to ensure the widespread distribution of weather and climate warnings of national public interest. Partnerships could also be authorized between the NHMS and the private sector that would allow for tailored weather information products and services. As in other parts of the world, such products can enhance agricultural productivity, support index-based insurance that lowers risk for smallholder farmers, and provide valuable information to large enterprises (such as those within the resource extraction, energy, aviation and banking sectors) that can use this information to build profits and support strong, climate change–resilient local economies.

Change can be good. But change is often unwelcome and hard. On the supply side of the equation, it will be a challenge for the NHMS to create new relationships with private weather vendors that are well versed in new technology and the commercialization of weather products as well as the new ways of doing things that would result from such relationships. Private weather providers may be perceived as a threat to job security, data ownership, government obligations to supply public goods such as early warnings, and myriad other roles and responsibilities traditionally owned by the public sector. On the consumer side—where NHMS have unique opportunities to build new revenue streams by partnering with private sector actors—deficiencies in business-development skills or a lack of enabling regulatory environments could create roadblocks and diminish the value proposition being created by NHMS. These deficiencies pose risks to public-sector leaders who may receive mandates to build revenue streams or may face increased competition from private-sector suppliers entering the space.[80]

Other problems include the difficulty in recouping costs, economic losses and lost productive potential that result from making this information expensive or unavailable.[81] Taking all of these problems into account, it is clear that some level of public support will most likely always be needed. The level of support will vary depending on the ability within the NHMS to create a value proposition, establish trust, and overcome institutional obstacles to monetize weather information and build virtuous cycles that balance business-driven development with public interests.

So what can African leaders do to ensure they are leading the conversation on public-private partnerships in hydromet services? Lead. By taking the lead on engagement with the private sector—a trend already advanced in many other sectors in Africa, including energy and communications—African governments uniquely position themselves to define win-wins; take advantage of new technology offerings; define roles, responsibilities and ownership on their own terms; and build effective partnerships that will break the non-virtuous cycle perpetuated by the status quo. This will allow the governments, and specifically government leaders from within the weather and climate sector, to embrace new modalities that support the overall mission to provide valuable public goods like early warnings, weather reports and long-term climate forecasts. These solutions can and must respond to the unique needs, cultures and institutions of the NHMS in Africa.[82] Ideally, such relationships should include both the supply side, or the provision of hydromet services, and the demand side, or the delivery of information products to a wide range of users, including some that are willing and able to pay for them. The best and most lasting partnerships are those which are clearly win-wins, where both sides give and receive benefits.

[79] Africa Development Bank, 'Supporting the Transformation of the Private Sector in Africa: Private Sector Development Strategy, 2013–2017', www.afdb.org/fileadmin/uploads/afdb/Documents/Policy-Documents/2013-2017_-_Private_Sector_Development_Strategy.pdf.

[80] For instance, in 2015 the United Kingdom Met Office lost its long-term multimillion dollar contract with the BBC. Nicola Harley, "Met Office loses multi-million pound BBC weather contract", *Telegraph*, 23 August 2015, www.telegraph.co.uk/news/bbc/11818872/Met-Office-loses-multi-million-pound-BBC-weather-contract.html.

[81] David Rogers and Vladimir Tsirkunov, 'Weather and Climate Resilience: Effective Preparedness through National Meteorological and Hydrological Services' (Washington, D.C.: World Bank, 2013), p. 5.

[82] Several international organizations including the IFC, WMO, and UNDP offer advisory services that can help support agencies in their efforts to negotiate with private parties and develop fair and sustainable arrangements.

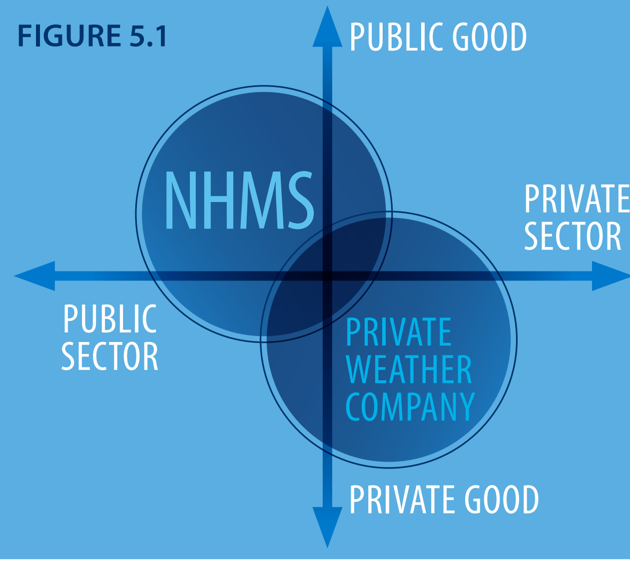
WHAT ARE HYDROMET PUBLIC-PRIVATE PARTNERSHIPS?

Public-private partnerships (PPPs) within the hydromet services space work on three basic levels, and service the needs of both the public and private sectors. As discussed in the previous section, the first is PPPs with telecommunications providers, which can be leveraged to site automatic weather stations. These telecommunications partnerships have a natural extension to the distribution of early warnings and the packaging of weather information products (p50). The second facet of these nuanced arrangements is the involvement of private weather vendors providing technology, training, information services and integrated software packages for use by NHMS and distribution to end users in partnership with the private company. The final aspect of these partnerships for the delivery of hydromet services comes with the monetization (or demand-side consumer-based applications) of this data as a collaborative process of co-development between information suppliers and at-risk entities within the private sector.

Within the climate and weather sector the boundaries between public and private activity are constantly evolving, but recent experience shows the public-private collaboration to be broadly connected to sustainable economic development and prosperity on regional and national levels.

Investment in the weather sector is smart business. It is said to have a fivefold or greater return in economic development for every dollar spent (as discussed in more detail in Sections 1 and 2).[83] This is often mentioned as a metric to justify government expenditure on weather and climate infrastructure. However, the benefits from properly structured engagements with the private sector—on both the supply side and the demand side—can provide more immediate and direct returns. This type of engagement not only responds to public-sector requirements to support early warning systems and provide more accurate climate and weather information, it also unleashes the development of innovative products and services that advance hydromet service–based economic development across a wide range of sectors.

FIGURE 5.1



THE MODELS PRESENTED HERE CAN BE VISUALLY UNDERSTOOD ON AN X-Y GRAPH WHERE THE VERTICAL AXIS INDICATES THE RANGE FROM PUBLIC GOOD TO PRIVATE GOOD, AND THE HORIZONTAL AXIS INDICATES THE RANGE OF INTERESTS, INVOLVEMENT, ASSUMED RISK, AND RESPONSIBILITY FROM PUBLIC TO PRIVATE.

These types of relationships are nothing new for the hydromet services space, but understanding their application across the world gives a good perspective on possible models and their application within the unique cultural, economic, technological and political space of Africa's least developed countries.

Understanding Public Goods

Taking case studies from across the globe and in-depth analysis provided by practitioners working in the climate information and services space, there are a number of potential models for the commercialization of hydromet services and the integration of private-sector weather service providers. These models embody a range of possibilities but are not intended to be definitive; they will need to be adapted and tailored to fit the unique challenges and opportunities within the African context.

The models presented below could be plotted onto an X-Y graph where the vertical axis indicates the range from public good to private good, and the horizontal

[83] WMO, 'Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services', 2015, WMO-No. 1153, "NHMS improvements to reduce disaster losses in developing countries—benefit-cost ratios (BCRs) range from 4-1 to 36-1. Drought early warning system in Ethiopia to reduce livelihood losses and dependence on assistance—BCRs range from 3-1 to 6-1." The economic returns of investments in weather services are explored later in this section.

axis indicates the range of interests, involvement, assumed risk, and responsibility from public to private. Public goods—including services like education, health, security, and yes, the issuance of early warnings—are generally not easily monetizable by the private sector and thus experience limited engagement. They do, however, provide a great benefit to the overall health of a society, economy and the nation, with well-known push-on effects that benefit private industry.

In the climate services space, the public sector retains the dominant responsibility for the delivery of weather and climate information services to all sectors of the economy and should be central to the delivery of public goods, including official warnings of extreme weather events to the public and national government agencies. This responsibility can become manageable and effective only with substantial political (and regulatory) support, sufficient economic and human resources, and valid data that can be readily analyzed, packaged and shared with both private industry partners and the public in general. It is a very large endeavour for cash-poor, minimally staffed NHMS, making the possibility of engagement with private-sector providers with access to advanced technologies to fill that capacity gap an interesting proposition.

Understanding Private Goods

In contrast to public goods, private goods often provide some value to society, but most of that value is required by and/or captured by private interests. On the southern sphere of the north-south axis presented in Figure 5.1—where private goods are the dominant interest—high-quality information, consumer goods and value-added services generate income for suppliers while also providing benefits to the overall public good. In the intersection between public and private interest, a sweet spot can be found where public interest (in providing early warnings to protect lives) and private interest (in building business, tapping new markets and creating value-added products for consumers) converge.

While outreach to enterprise users of climate information in sub-Saharan Africa is limited, lessons from middle-income countries such as South Africa and Brazil (p97) suggest that economic returns can be achieved by using such information to reduce losses, decrease risks and improve productivity. By monetizing weather and climate information, NHMS have the potential to create sustainable revenue streams while supporting overall economic development. Given the upward mobility of Africa's overall economy, which has seen sustained economic growth of 5 percent over the past ten years, the opportunity to leverage these partnerships both in Africa and across the Global South has the potential to shield these growing economies from some of the risks associated with climate change and work to propel business forward. It also has the potential to protect investments in monitoring infrastructure with long-term servicing agreements.[84]

In this scenario, the private sector retains its responsibility to its shareholders and to market forces, but it is able to capture deeper market penetration and new users, and leverage highly relevant weather and climate information to engage customers. For instance, in Zimbabwe, private-sector telecommunications leader EcoNet has pioneered the creation of localized weather monitoring stations to provide low-cost information and insurance to farmers (p100).

This sweet spot is also where many private companies with substantial public support reside. For example, private telecommunications firms require government-managed radio frequency bands and conducive regulatory frameworks. Aviation enterprises require public goods like air-traffic control, weather reports and runways, and are highly valuable to both

[84] One of the pitfalls of past investments in hydrometeorological monitoring infrastructure has been a lack of long-term viability of surface observation networks. In traditional arrangements, equipment is installed and the vendor is paid and leaves the scene. Once acquisition funds are expended, however, the NHMS struggles to operate and maintain the equipment. One example where the high cost of operating a surface observation network has been made more sustainable through a partnership is in Brazil, where INPE, an organization more narrowly focused on space- and energy-related research, partnered with Earth Networks, a private-sector company with a broader range of cross-sectoral private good interests, to establish a lightning-detection network. This partnership allowed for joint ownership and responsibility in the construction and maintenance of the network, which would be paid for through a commercial partnership providing economic benefit to both parties from the sale of follow-on, value-added data services to additional sectors of the economy. See p97 for an expanded exploration of the Brazil project.

society and private business. Resource extraction often requires the use of government land but provides economic energy for society—and profits for private industry. This sweet spot is where NHMS and private-sector actors within the climate information space will find natural win-wins and synergies.[85]

Models for Public and Private Partnerships

Around the world, public and private partnerships in the weather and climate sector have evolved over time and tend to follow a cycle that is synchronized with a country's state of economic development. These partnership paradigms are loosely defined in the four models below and named in order of their most likely occurrence on a country's economic development path.

Model 1 – Complete Government Ownership

In this model, which we call the traditional paradigm, the government supplies all hydromet products and services. Commercially valuable products and services are provided to all sectors (public and private) either free of cost or virtually so—a policy typical of sub-Saharan Africa today. Often the government itself is the biggest consumer of these products and services.

LACK OF AVAILABILITY OF AFFORDABLE CROP INSURANCE MEANS SMALLHOLDER FARMERS AND THE BANKS THAT LOAN THEM MONEY ARE LESS WILLING TO TAKE RISKS. PHOTO BY JOOST HOEDJES.

In essence, this model places all hydromet products and services as a public good, and in principle it eliminates the need for or existence of additional services from a private commercial sector. Often this is where a country begins when the overall state of economic activity is low.

As a nation's economy grows and diversifies, this model begins to become unsustainable as the government becomes unable or unwilling to provide the wherewithal to meet demands from non-government users for enhanced or specialized services; a commercial market—perhaps drawing on international sources of hydromet information—begins to develop spontaneously. This model is representative of the status quo in many developing countries in sub-Saharan Africa (see the example of Ethiopia on p110).

As is illustrated in the country profiles at the end of this publication, some countries have begun to recognize the need to change how hydromet information is produced and distributed, and have put into place legal and regulatory frameworks that allow for an effective departure from the traditional paradigm. Other countries still need to take the initial steps to change the way they do business to embrace models that depart from this traditional paradigm.

It should be noted that even in the traditional paradigm there are always opportunities for limited partnerships on the fringes, including by leveraging national networks (like Ethiopia's nationalized telecommunications provider) to site AWS or provide the dissemination of early warnings.

[85] High-risk weather-sensitive ventures such as offshore oil and gas exploration and production have special needs (e.g., high insurance costs) that may be inconsistent with small private weather companies. If a good public forecast is available, resource companies may wish to deal with a government-backed organization, or they may require two or more forecasts.

PROVIDING SECURITY FOR METEOROLOGICAL EQUIPMENT IS A CHALLENGE. PHOTO BY JOOST HOEDJES.

Model 2 – Government Funds Public Goods and Partners with Private-Sector Weather Service Providers

This model, which can be identified as a post-traditional-but-transitional paradigm, keeps government funding and the control of public goods and services while establishing direct engagements with the private sector to jointly develop the commercial market. Examples of this model come from the Philippines, Brazil and Canada where this partnership model focused primarily on the establishment of new monitoring infrastructure, as examined in Section 7. In South Africa, the South African Weather Service (SAWS) facilitated its Model 2 commercialization efforts by directly engaging the private sector to address its capacity gaps in marketing and business development.

Another example comes from New Zealand: "During the 1980s there was increasing pressure on government funding for meteorology in New Zealand, together with a government-wide move to 'user-pays' for specialized services, and to more autonomy and accountability for government departments. A combination of commercial competition in the deregulated market for meteorological services, and reform of publicly funded science, led to the establishment of the Meteorological Service of New Zealand Ltd (MetService) as a State-Owned Enterprise in July 1992."[86]

Model 2 may be of most interest to LDCs seeking to fill quickly significant capacity gaps in both technology and marketing as a way to address the critical challenges these societies are facing today with limited government resources.

Model 3 – Government Funding for Public Goods with Commercial Services Paid for by Private Sector

Historically, countries have traditionally transitioned from the Model 1/traditional paradigm to Model 3/modern paradigm when demand for services outstrips the government's capacity or willingness to supply services of economic value to the private sector for free.

In several countries, including the United Kingdom, Japan, the Netherlands and South Africa, the NHMS reorganized a portion of its basic weather services into a new commercially oriented function providing specialized or tailored weather services as a partial source of revenue.[87] In the Netherlands, this NHMS commercialization existed for many years while the commercial market developed in parallel with government-driven activity. This situation was maintained until the Government of the Netherlands elected to exit the provisioning of these private goods and allowed free enterprise to operate on its own, thus moving from Model 2 to Model 3, as described in the next section.

[86] MetraWeather, 'History', www.metraweather.com/about-MetraWeather/history.

[87] These models were discussed in presentations at a CIRDA workshop on 3 March 2015 in Kampala, Uganda. The agenda and presentations from all the CIRDA workshops are available under 'Programme Meetings and Workshops' at www.undp-alm.org/projects/cirda/meetings-and-workshops.

In South Africa, the Government initiated activity under this model by adopting a statute in 2001 that allows the South African Weather Service (SAWS) to earn income for services beyond the public obligation to provide basic weather information. However, today—as was the case in the Netherlands midway through its Model 2 experience—SAWS does not have a monopoly and must compete with private weather companies. Almost half the SAWS budget is now from commercial services—38 percent from aviation (required of international airlines by regulation) and 10 percent from other commercial sources. Revenue has increased more than fivefold since 2010 and it continues to grow by about 32 percent year on year. Aside from having the budgets, institutions and relative political stability of a middle-income country, South Africa also has a long tradition of embracing PPPs. In 2000, the Government of South Africa established a PPP Unit, also incorporating legal definitions of PPPs into South African law.[88]

The decision to create a commercial business development function should not be taken lightly, as success requires staff with appropriate skills and a commitment to provide a level of service consistent with business needs. As the South African and Dutch examples illustrate, there is no simple distinction between commercial and non-commercial services, and boundaries will need to be determined by each country.

Model 4 – Government Funds All Public Goods and Supplies Data to An Open Commercial Market

In this scenario, which can be labelled the postmodern paradigm, the government funds all public goods and supplies raw data (at a simple recovery cost) to enable a free and open market for commercial hydromet services. There is no direct participation in revenue streams or economic development with the private vendors; rather, private enterprises are able to compete in a free market to create applicable uses of publicly available data, and add weather monitoring services that fill in specific gaps within this data approach. This model is used primarily in countries with highly developed NHMS, large budgets and supportive legal frameworks, such as the United States and Germany. As mentioned above, the Netherlands has now largely adopted this postmodern paradigm as well. This model also includes more advanced versions that enable the acquisition of data, not just hardware and software, from the private sector as a function of the government's public service.

For example, in the United States, where the National Weather Service is not permitted to compete with private companies, independent weather-service enterprises are filling market gaps and providing more tailored hydromet information services to supplement publicly available information.[89] These independent services offer a combination of television and mobile-phone advertising along with tailored information for businesses, with 350 companies generating estimated annual revenues of US$3 billion a year in 2012.[90] While initially these large revenue streams were generated in the television market, broader services are now supplied across a wide range of sectors. Especially rapid growth is currently taking place in the mobile telecommunications sector. Developments within this mobile sector are likely transferable to Africa in much the same way as infrastructure investments have caught on within mobile telecommunications and could easily be added to the establishment of infrastructure partnerships as previously addressed. Application developers are fast adapting their products for featureless phones, and the rise of affordable smart phones and increased bandwidth across Africa point to expanding market possibilities.[91]

[88] South Africa law defines a PPP as follows: 'A contract between [a] government institution and private party. [The] private party performs an institutional function and/or uses state property in terms of output specifications. Substantial project risk (financial, technical, operational) [is] transferred to the private party. [The] private party benefits through: unitary payments from government budget and/or user fees.' Sikhumbuzo Gqoli, National Treasury, PPP Unit, 'Public Private Partnerships in South Africa', PowerPoint presentation, www.oecd.org/investment/investmentfordevelopment/35624345.pdf.

[89] The U.S. National Weather Service is fully funded by the U.S. Government and has an open-data policy. "It is charged with responsibility for observing and reporting the weather and with issuing forecasts and warnings of weather in the interest of national safety and economy." 'National Weather Service Mission', www.nws.noaa.gov/wsom/manual/archives/NA027045.HTML.

[90] 'Today's Forecast for the Weather Business: Increased Revenues and a Focus on Innovation', University of Pennsylvania, Wharton, 10 April 2013, knowledge.wharton.upenn.edu/article/todays-forecast-for-the-weather-business-increased-revenues-and-a-focus-on-innovation/. The acceptance of a competitive weather business in the United States is at least partly cultural, as reflected in a statement by an official from the national University Corporation for Atmospheric Research: "Given advances in meteorology, modeling and computing, private companies can do a lot of value-added work for specific clients that the National Weather Service can't—and shouldn't." One drawback of the U.S. system has arguably been a lag in matching the most sophisticated modelling capability being used in Europe, an investment difficult for any private company (ibid.). Another recent development in this regard was the acquisition of a major weather forecasting company by IBM in October 2015. The deal is expected to provide much greater resources for the increasing technological sophistication required for weather forecasting. Angela Fritz, 'IBM to Buy Digital Branch of Weather Company, Leaves Weather Channel Behind,' *Washington Post*, 28 October 2015, www.washingtonpost.com/news/capital-weather-gang/wp/2015/10/28/ibm-buys-digital-branch-of-weather-company-leaves-weather-channel-in-the-dust/.

[91] 'Today's Forecast for the Weather Business', University of Pennsylvania.

MARKET ASSESSMENT ESTABLISHES BASELINE TO UNDERSTAND EXISTING ASSETS AND POTENTIAL OPPORTUNITIES FOR ENGAGEMENT WITH THE PRIVATE SECTOR

By Anthony Mills, Olga van den Pol and Onno Huyser

Understanding market forces, players, dynamics, threats, opportunities and weaknesses in the climate and weather services sector will be a driving factor in building demand-driven private-sector strategies in Africa.

With the goal of better understanding market forces, the UNDP CIRDA Programme conducted a continental-scale market assessment[92] that examined the unique opportunities for developing tailored weather and climate products in the 11 least developed countries supported by the CIRDA programme. Country profiles informed by that survey—and reviewed by the individual NHMS—are presented in the annex of this publication (p104). The market assessment was produced by the South Africa–based climate change consultancy firm C4 EcoSolutions.

The research indicates that there is considerable variability in readiness across the NHMS, with some in a position to start negotiations with private-sector companies now, and others requiring further institutional strengthening before proceeding. The market study suggests that markets do exist, but that many NHMS may not possess the business acumen, culture or packaging skills to effectively tap these markets. Prime 'low-hanging fruit' include mobile-phone operators, the aviation sector and agriculture. Reaching these sectors will require cultural shifts and in all likelihood intense engagement with companies specializing in the packaging and reselling of specialized weather data.

"The market for tailored weather and climate products will expand with continuing increases in the quality and affordability of satellite data, outputs from high-quality global and regional forecasting models, and availability of advanced telecommunications," according to the assessment. "It therefore follows, and our research confirms, that weather and climate information products sourced from private weather companies—for consumption by both the public and private sector across Africa—will become increasingly sophisticated and affordable. African NHMSs consequently need to move quickly to establish well-defined roles for themselves within this new private-sector market for weather and climate services, or face the risk of becoming increasingly marginalized."

The results of the market assessment show that it is unlikely that meaningful revenue streams will be generated for the NHMS by the sale of raw data per se, but rather that the private-sector opportunities for NHMS lie in the taking of shares in future revenue generated through the sale of tailored weather information products developed in partnership with selected private weather company partners.

According to the assessment, the competitive advantages of the NHMS should be used to define their roles in the private sector. These advantages include their physical infrastructure on the ground (which can greatly increase the accuracy and granularity of hydromet information), their central role in forming national weather markets, their access to policymakers and legislators, and their inherent neutrality as mandated public institutions responsible for the national climate record. According to the assessment, "if NHMSs capitalize on these advantages and help shape the emerging markets for weather and climate information in their respective countries, then private weather companies can become allies that share their revenue streams as opposed to competitors or antagonists that do not."

The assessment also noted, "Our research also revealed that participating directly in the private weather market will require the NHMSs to undergo cultural change. Public institutions, such as NHMSs, experience 'cultural inertia', which acts to protect stable (existing) relationships and practices. Here, this inertia includes funding models, traditional (and limited) client bases, and a relationship with the WMO that focuses mainly on conducting synoptic observations."

The assessment goes on to observe that while participating in a national weather market is important, equally as important is to maintain clear boundaries between public and private service providers. This is necessary to avoid unfair competition, and to ensure that early warning alerts are authoritative, and delivered to the public "with one voice".

[92] Read the full market study at www.adaptation-undp.org/resources/knowledge-products/climate-and-weather-services-market-assessment-revenue-generating.

"A good model can be found in the Netherlands. Here, national law outlines clear roles and responsibilities for both the national weather service and the private weather sector, with a strict separation between government and market. The Netherlands' NHMS, KNMI, for example, works for the national government on the monitoring of weather at the national level, and maintenance of the national climate record, whilst private weather companies complement these roles and responsibilities by developing tailored weather products and services for local governments, the private sector and individuals."

SPECIFIC MARKETS

The list of potential private sector partners below is not exhaustive, but it captures some of the major potential markets for tailored weather and climate information. Individual country profiles indicate specialized markets (such as tourism in the case of São Tomé and Príncipe) that may be attractive for individual NHMS.

Mobile Phone. Mobile-phone companies are willing to work with NHMS because providing even basic weather information products to customers, as part of a wider suite of desirable content, pays back over time. For the operator the addition of reliable weather information—currently mostly derived from satellite data and other free services—catalyzes the value-added uses of other mobile services that are profitable, such as mobile banking. It also serves to reduce customer churn and attract new customers. However, the mobile-phone companies ultimately require—but are not necessarily prepared to pay for—a carefully tailored and expertly packaged weather information product (not the raw weather data).

Specialized Weather Information Packaging Companies. NHMS are experts in producing raw data. But with limited budgets, and limited experience, few possess the capacity to package and tailor raw data for consumers, according to the study. That's where packaging companies such as Speedwell Weather may come in. These companies aggregate weather data and produce a value-added product to resell it to end consumers (like financial services firms, mobile-phone operators or mining companies). Engaging with packaging agencies like Speedwell Weather poses both opportunities and challenges for NHMS. They may be able to tap new markets and share in the profits, but they may be limiting their potential long-term value—and overall value propositions—by focusing mainly on raw data collection.

Aviation. The best example of where NHMS are packaging and gaining some revenues comes from aviation. Many NHMS have existing relations with the aviation sector, and in some cases already receive some nominal funding for the information and services they provide. Creating better tailored products for this sector—and placing well-thought-out monetary valuation on the services provided—is a strong opportunity for NHMS, according to the report, and "can forestall the risk of disintermediation from private weather companies".

Resource Extraction. Mines and other resource extraction enterprises often use customized weather reports for localized early warnings. Lightning forecasts and local weather monitoring are used to manage the use of roads and other infrastructure. In some cases, mines already have local monitoring systems set up, or turn to private weather monitoring companies to provide local monitoring.

Agriculture. Agriculture accounts for a dominant share of GDP in many African LDCs. In some areas, large agricultural interests (such as tea and sugar plantations) are already monitoring variables like soil moisture, humidity, the number of sunny days and night-time temperatures to improve production. With support from seed companies and other businesses that sell to farmers, mobile-phone companies in some African countries are already providing free seasonal weather information as a dial-up service. Local monitoring systems could be integrated into the monitoring systems of NHMS, and information received could potentially be shared with the WMO Integrated Global Observing System (WIGOS) to improve overall climatological monitoring. NHMS can also work with both large producers and national agricultural authorities to create customized crop reports. In many cases these reports already exist, but lack the granular level necessary to create significant impacts, especially for smallholder farmers.

Banking and Insurance. Packaged weather and climate information can be used to mitigate risk, create pay-out thresholds and foster climate-smart investments. Banks can use tailored data to predict market cycles, offer consulting services, protect data centres affected by severe weather, and produce better analytics. An in-depth discussion on insurance can be found on p78.

Energy and Infrastructure. Not only can one predict overall consumption, having a better understanding of local weather can also aid in making better-informed decisions for long-term investments. For a more in-depth discussion of energy and infrastructure, see p20.

Health. Weather and climate information can be key in predicting the spread of mosquito-borne diseases. The health industry can benefit in other unexpected ways. For instance, early weather warnings and consistent forecasts can prevent damage to costly equipment, minimize false alarms, or help predict fluctuations in patient admissions to hospitals.

IDENTIFYING MUTUAL BENEFITS

A key point for making PPPs work is the need for both the public and the private sector participants to gain from the partnership—a one-sided arrangement will not be sustainable, whichever party is favoured. Fortunately, there are significant potential benefits for both public and private participants in partnerships for hydromet services, as identified below.

Beyond the mobile telecommunications industry, there are many examples of win-win partnerships that can be developed with the sectors of the economy in greater need of more complete and accurate weather and climate data sets. For example, the banking industry, which makes loans to farmers, and the agricultural weather-index insurance industry, which provides crop insurance to the same farmers, are both industry groups that rely on hydromet data to make financial decisions that impact their bottom line. Indeed, bundling a loan to a farmer with indexed crop insurance and a service providing agricultural hydromet information to the farmer via cell phone reduces the risk to the bank and the insurance company while helping the farmer to operate his farm more profitably. (Agricultural supply products such as seeds and fertilizers are also sometimes bundled as well.) Note that crop insurance requires good climatological data to estimate risk, an essential step in setting premiums, and then verifiable weather data so as to know when a payout is necessary. (See Agricultural Insurance in Africa, p78.)

While on the surface there may appear to be limited commercial opportunities in the issuance of early warnings and extended crop forecasts—the valuable information that smallholder farmers need to improve their livelihoods—expanded customer bases, brand loyalty, reliable workforces and more climate-resilient productive infrastructure all point to some lasting possibilities to connect enterprises with people. In the case of EcoNet in Zimbabwe, new partnerships are forming between the Ministry of Agriculture and the cell-phone service to connect farmers to agricultural extension workers (p100).

Lightning information is also valuable to a wide range of users for the protection of assets such as electrical utilities, logging operations and airfields. In each case, because of the nature of these businesses, there is also exposure of personnel and thus a significant potential for injury or death due to lightning strikes, as well as damage to key equipment, as illustrated in the case of Brazil (p97).

Table 5.2 PPPs for Weather Services: A Potential Win-Win Opportunity.

PUBLIC SECTOR BENEFITS	PRIVATE SECTOR BENEFITS
Access to latest technologies	New profitable markets
Financial and human resources	Potential for services in high demand—weather information
Greater development benefits through support of more components of the economy	Access to more complete, government-managed data sets
Increased resilience to climate change	Potential new products and services to retain existing customers for telecoms
Potential for revenue generation	Opportunity to show social responsibility (communicate emergency warnings)
Enhanced status and public support	Increased productivity in agriculture and other weather-dependent sectors

PUBLIC-PRIVATE PARTNERSHIPS FOR TELECOMMUNICATIONS IN AFRICA

Engagement with cell-phone companies is one of the strongest opportunities for NHMS.[93] Not only can they provide secure locations to site AWS, but they can also aid in the distribution of valuable life-saving messages to a wide, diverse audience. From the perspective of the NHMS, this can occur in a variety of ways:

- **Directly**, carried out by the NHMS, who pays the cell-phone company to do so, or if the material to be disseminated is critical but infrequent, such as storm warnings, the cell company may disseminate the warnings without charge as a public service.
- **Indirectly**, carried out by the telephone company, who develops a business in which a package of routine weather information, say a daily morning agricultural forecast, is provided for a (very) small fee to the user, in this case a farmer or herdsman. While the fee for each user could be small, there are many potential users, so the revenue could become sufficient to justify the service, as is the case with EcoNet and the numerous mobile banking platforms available in Africa.
- **Through a third party** that serves as an intermediary between the NHMS and the phone company. This might be a for-profit branch of the NHMS, in much the same way the UK Met Office and several other NHMS in developed countries have some elements supported by the central government and other elements supported through business activities. The third party could add value to the meteorological information through additional analysis, tailoring and personalization before passing it on through the phone system to a paying customer base.

Combinations of the above are also likely; situations with all three arrangements can be found in countries in the developed world. In each possibility, it is a win for all the parties. The NHMS accomplishes its mission, the telephone company generates new revenue and goodwill, and the users receive timely hydromet information to better secure their lives and improve their livelihoods.

In best case scenarios, a revenue stream may come back to the NHMS. For this to be realized, the NHMS must be proactive in developing new business ventures with the phone company and with others that value hydromet information in their decision processes. For example, Human Network International's 3-2-1 programme (p85) works with NGOs and government ministries to create local feature-phone content across a range of development topics, including public health, agriculture, education, water and sanitation, family planning, microfinance, early warnings and other important areas of interest.

[93] Opportunities to use the rapidly growing network of cell-phone services in Africa for developmental purposes are being identified for a growing range of applications including health, education and disaster relief. There are also some successful examples of programmes to help small farmers by providing them with a range of support for planting, harvesting, and selling their crops. See, e.g., Kofi Annan and Sam Dryden, 'Food and the Transformation of Africa', *Foreign Affairs* (November/December 2015).

IDENTIFYING RISKS

PPPs are also not without risks, which include legal challenges and delays when contracts are awarded without sufficient transparency,[94] inappropriate allocation of risks to the public,[95] and a lack of the public skills and leadership necessary to effectuate complex transactions.[96] Issues also arise and vary by country (e.g., regulations pertaining to the awarding of contracts, the sharing of data, and the dissemination of disaster warnings.)[97] A requirement or policy of many nations is to make all publicly funded data (which includes most computer-generated outputs and publicly funded forecaster products) freely available for all to use. This creates a potential for competition and conflict if an NHMS develops new products and services that were previously provided by the private sector to niche markets. At the same time, the availability of private services should not in any way undermine the improvement of public weather services and emergency warning systems. A collaborative relationship between the NHMS and private weather service providers is therefore fundamental to a successful public-private partnership. A careful, country-specific approach is essential, as discussed in greater detail in Section 6.

COSTS AND BENEFITS OF EARLY WARNING SYSTEMS

One of the major barriers to public investment in the modernization of hydromet services is the perception that other public needs such as roads, health and education are more urgent and important from a development perspective. This said, modern weather

Table 5.3 PPPs for Weather Services: Potential Risks.

PUBLIC SECTOR RISKS	PRIVATE SECTOR RISKS
Mission and scope creep (the expansion of a programme beyond its original mission or goals)	Higher financial risk profile in developing economies
Internal capacity development	Legal and regulatory hurdles provide obstacles to achieving objectives
Legal and regulatory challenges	Infrastructure deficiencies for sustainable security, power, communications
Allocation of responsibilities	Cultural gaps
Departure from the status quo	Language gaps
Data ownership and IP challenges	Lack of successful models

94 Trefor Moss, 'Philippines Strives for Public-Private Solution to Infrastructure Woes', *Wall Street Journal*, 22 January 2015 (competitive bidding for highway construction cancelled and rerun due to transparency concerns).

95 Michael Laris, 'Va. spends $260 million on unbuilt road, says it could have been worse', *Washington Post*, 2 July 2015, www.washingtonpost.com/local/trafficandcommuting/va-spends-260-million-on-unbuilt-road-but-says-it-could-have-been-worse/2015/07/02/638d9b62-20d2-11e5-aeb9-a411a84c9d55_story.html (taxpayers required to pay for road that could not be built due to inability to obtain construction permits).

96 Diann-Yi Lin, 'Can Public Private Partnerships Solve Indonesia's Infrastructure Needs?', McKinsey & Company, October 2014, www.mckinsey.com/global-locations/asia/indonesia/en/latest-thinking (48 PPP projects worth US$57 billion announced in Indonesia stalled due to lack of effective public skills and leadership).

97 Rogers and Tsirkunov, 'Weather and Climate Resilience', p. 110. A potential concern identified by the authors—the possibility of insufficient competition leading to a quasi-monopoly if there are few qualified private firms—would not appear to be an issue in the hydromet context based on the expression of interest in the CIRDA programme reflected in a diverse group of business participants at a private sector expo at the kick-off workshop on 13–14 April 2014 in Addis Ababa, Ethiopia (www.undp-alm.org/sites/default/files/downloads/final_agenda_ci_wkshp.pdf).

services can, in fact, enhance the delivery of other public services and in multiple ways contribute to economic development. A growing body of economic analysis, as illustrated in the case of the Netherlands and South Africa, is showing how these benefits can be quantified. This can help make the case for investment by cash- and credit-strapped governments—especially if some of the costs can be offset by revenue generation.

One significant source of benefits is the availability of effective early warning systems to mitigate the impact of storms and extreme weather events. Natural disasters impede growth in multiple ways. Most obviously, the loss of human lives has a devastating social and economic impact on communities. Natural disasters can cause households to descend into poverty traps. Countries have to spend large sums of money on reconstruction after disasters, money that could be otherwise spent on development.[98]

A recent case study in Uganda showed the cost-benefit ratio of investments in early warning systems to be five- to tenfold (for more information on Uganda, see p124), and these figures are in line with other case studies.[99] It is this combination of the potentially very high effectiveness and the decreasing associated costs that makes a very compelling case for investments in climate information and early warning systems.

Quantifying the Benefits

The benefits of early warning systems can be grouped into three categories: a reduction in asset losses from disasters, a reduction in human losses from disasters, and other economic benefits. The first of these benefits, avoided disaster losses, are difficult to accurately assess without a very thorough analysis. As a pragmatic approximation, Hallegatte (2012)[100] assumes that all countries can obtain the same relative benefits, and that these benefits amount to between 0.003 and 0.017 percent of the country's GDP.

The quantification of a reduction in human losses requires one to attach a monetary value to a (priceless) human life. Economists have developed several useful ways to assign a monetary value to a statistical reduction of fatal risks, such as the Value of a Statistical Life (VSL) or the Disability-Adjusted Life-Year (DALY) approach. The VSL and DALY approaches give useful indications on how much money a country is willing to spend to reduce mortality risk (without making an ethical judgement as to the actual value of life).

Reductions in human and asset losses are benefits from early warning systems alone. However, the economic benefits from weather and climate information during normal conditions can be much greater. Rogers and Tsirkunov (2013) point out how national meteorological and hydrological services benefit most sectors of society. In addition to the direct impact of early warnings, these other benefits can generate an additional 6 to 10 percent in economic benefits per year.[101]

Assessing each country's vulnerabilities to natural hazards, combined with estimates on the potential effectiveness of early warning systems for specific hazards, can give a good indication of the total monetary benefits of an early warning system. For example, flash flood early warnings are particularly effective, as the evacuation (i.e., movement to higher ground) for a flash flood is very cheap and extremely effective. Consequently, flash flood early warning systems can yield a high reduction in flash flood fatalities. Drought forecasts are another example, as they can be used to supply food in advance to those areas where droughts are forecast, thus significantly reducing the impact of the drought.

Required Components

For the development of early warning systems, a number of components have to be in place. First, a local observation system has to be developed and operated for a sufficient period of time to establish

98 Stéphane Hallegatte, 'Early Warning Weather Systems Have Very Real Benefits', 23 July 2012, on the 'Let's Talk Development' World Bank blog, blogs.worldbank.org/developmenttalk/early-warning-weather- systems-have-very-real-benefits.

99 See, e.g., A. R. Subbiah et al., 'Background Paper on Assessment of the Economics of Early Warning Systems for Disaster Risk Reduction', World Bank Group, Global Facility for Disaster Reduction and Recovery (GFDRR), 1 December 2008; Thomas Teisberg and Rodney Weiher, 'Background Paper on the Benefits and Costs of Early Warning Systems for Major Natural Hazards', World Bank Group, GFDRR, 18 March 2009; and the Independent Evaluation Group (IEG), World Bank, 'Adapting to Climate Change: Assessing World Bank Group Experience', ieg.worldbankgroup.org/Data/reports/cc3_full_eval_0.pdf.

100 Stéphane Hallegatte, 'A Cost Effective Solution to Reduce Disaster Losses in Developing Countries: Hydro-Meteorological Services, Early Warning, and Evacuation', World Bank Policy Research Working Paper, 2012.

101 Ibid.

CONNECTING SMALLHOLDER FARMERS WITH INSURANCE HELPS REDUCE RISK. PHOTO BY UNDP.

baseline information. Forecasting capacity in most African countries has to be significantly strengthened. Meteorologists and hydrologists have to be capable of interpreting model outputs, and translating these into forecasts and warnings. Communication tools for the dissemination of the early warning messages are required. And, last but not least, the people who receive the warnings need the information and support necessary so they can effectively respond to early weather warnings.

The cost of deploying an end-to-end early warning system is decreasing. New, innovative sensors (e.g., Lightning Detection Systems) can cost-effectively provide similar benefits to those traditionally received in developed countries from expensive traditional sensors like weather radars. The price of automatic weather stations, capable of transmitting data in real time, is going down as well. At the same time, the sensors are becoming more robust and less prone to malfunctions, and cloud-based computing solutions are now widely available, reducing the need for expensive servers and computer rooms.

AGRICULTURAL INSURANCE IN AFRICA

Lowering risk and building resiliency are essential components of public-private partnerships. They constitute a huge win for both the public and private sectors, with increased productivity and market stealth, improved risk thresholds for smallholder farmers, and the potential for greater market stability.

Many of the least developed countries in the world are rural and the majority of the population relies on agriculture as a form of livelihood. Farmers face a slew of risks, from those related to markets and financing, to disease and pest issues. Most risks and impacts faced by farmers, however, are weather-related. Fluctuations in temperature, the severity and frequency of storms, or rainfall can impact crop yields dramatically, which threatens household welfare and, ultimately, local food security and political stability on the national level. (See p35 for a discussion on climate-related productivity loss).

The traditional financial tools available to small-scale rural farmers are often non-existent or unaffordable, or, if they are provided by the state, these instruments will be focused on recovery. As a result of this uncertainty, farmers tend to fall back to traditional methods of risk management, which include saving money and planting lower-risk crops.

Crop and Index Insurance

In traditional crop insurance, indemnity payments are linked to individual farmer yields or cover multiple perils (i.e., hail, pests, diseases, etc.). In order to determine the payout, a loss assessment is performed through costly and time-consuming individual farm visits that evaluate the impact of an event on the farmer's yield. In the case of developing countries, these insurance instruments tend not to be subsidized enough to be sustainable (see p101 for an examination of Sovereign Risk Insurance).

Index insurance links payments to an independently observable outcome, such as local rainfall, which is assumed (based on modelling results) to be highly correlated with yields. Such an approach could solve many of the cost and informational problems associated with traditional crop insurance.

LINKING SMALLHOLDER FARMERS TO INSURANCE

By Diana Rodriguez

The Agriculture and Climate Risk Enterprise, better known as Acre Africa, links farmers to insurance products so that they can confidently invest in their farms and protect their futures. The company seeks to foster equity, fairness and innovation in the agricultural sector through localized solutions that reduce climate-associated risk.

Acre Africa is not an insurance company, but rather a service provider working with local insurers and other stakeholders in the agricultural insurance value chain. The company is registered as an insurance surveyor in Kenya, an agent in Rwanda, and it has applied for registration as a microinsurance agent in Tanzania.

The Acre Africa team undertakes risk assessment, product development and risk monitoring to facilitate access to insurance products for smallholders. With tailored microinsurance products, farmers can feel comfortable investing in quality inputs, increase their productivity, and access agricultural loans. The team has developed insurance products to cover a variety of crops against weather risks like drought, storms, floods and erratic rains, as well as other production risks.

At the core of Acre Africa's operations is access to weather data to build effective and suitable index-insurance products. Without accurate, consistent and accessible weather data, the development of relevant weather-risk-transfer tools is not possible.

As a consumer of quality data, Acre Africa continues to face challenges in accessing reliable weather data. These include the following:

- **Limited capacity among technical personnel** to accurately model weather data;
- **Inconsistency in available data** sets, whereby missing and short series data limits capacity to model trends;
- **Deficiencies in available data parameters** (e.g., long-term temperature data) curtail the types of insurance policies that Acre Africa can develop to cover a wider variety of agricultural risks such as pests and crop diseases;
- **Slow availability of improved technologies** to better approximate the on-the-ground experience and reduce instances where existing data do not give a true reflection of ground conditions;
- **Emerging and dynamic business applications of weather data are often hindered by the slow progress of enabling and regulatory environments to support them** (e.g., National Meteorological Agencies are often primary custodians of weather data and they are often not equipped or allowed to work with the private sector).

Acre Africa's ability to develop and scale agricultural insurance products for smallholder farmers depends on increased research and development across the African continent to ensure the provision of quality hydromet data. In this respect, there is a need to foster cross-sectorial partnerships to optimize data usage and spread technologies that have already been developed. For this reason, Acre Africa welcomes collaborative approaches with government, private sector and other partners to transform agriculture into a more professional, productive and food-secure system for smallholder farmers.

Acre Africa evolved from the Kilimo Salama project, established in 2009 and funded by the Syngenta Foundation for Sustainable Agriculture and the IFC's Global Index Insurance Facility (GIIF). To learn more, visit www.acreafrica.com.

Establishing index-based insurance, however, is not as simple as installing a rain gauge. A weather index can be constructed using any combination of measurable weather variables over any period of time, but only once a credible baseline has been established. The parameters chosen must be those that best represent the risk to the agricultural end-user. This implies that good quality meteorological data must be used to correlate its influence on agricultural yield over time.

In LDCs, some of the main limitations for the implementation of index-based weather insurance include the following:

- The limitation on good quality historical and current weather information that is spatially representative (or sufficiently dense to cover the national landmass);
- The lack of historical agricultural yield data;
- The lack of cost-effective and reliable data communications (reaching both insurers and end users with reliable and easy-to-understand data);
- Cultural impediments to the adoption of new technologies, products and services.

Without these parameters in place, commercial insurance providers might not be able to provide a cost-effective insurance solution. There are a fair number of successful index insurance projects throughout the world that are fully commercialized, but government subsidized, most notably in India and Kenya. The key to the success of these projects is the participation between the public and private sectors to fund the installation and maintenance of real-time weather observation stations and the participation of the NHMS in data quality control.[102]

BETTER WEATHER AND CLIMATE INFORMATION MAKES FOR BETTER RISK-MITIGATION ON THE FARM.

[102] For an expanded discussion on insurance, visit www.undp-cirda.blogspot.com.

THE ROLE OF METEOROLOGY IN AVIATION

The impact of weather on the aviation industry is far-reaching. Weather patterns and conditions affect decisions on runway orientation, the management of aircraft operations, ground handling, en-route planning and overall aviation safety. Quality, accurate and timely weather information improves efficiencies, provides the data for informed decision-making in the air, and protects both property and human life.

SAFETY

The aviation industry relies on agreements with NHMS to provide daily weather forecasts, usually issued every six hours for a five-mile radius around the airport, known as Terminal Aerodrome Forecasts (TAFs).[103] These forecasts play a critical role in ensuring safe flight planning, while pilots use hourly METAR (Meteorological Aerodrome Forecast) forecasts and onboard satellite systems to measure wind speed, visibility, etc., during take off and landing. With limited resources, capacity and political support for NHMS, challenges exist in providing accurate TAFs in some sub-Saharan African countries.

On a global level, weather is cited as the cause of roughly 23 percent of all aviation accidents, both fatal and minor.[104] Even though the impact of weather-related aviation accidents is comparatively low, it is a factor that can be mitigated through quality real-time information and skilled decision-making. This could mean the difference between saving lives and a catastrophic event.

While planes are designed to be struck by lightning and to handle most forms of severe weather, flying into very bad weather can cause instrumentation and aircraft malfunctions with severe consequences. At altitude, planes must fly in a very controlled 'envelope', and anything that can take them elsewhere can be very dangerous. Onboard systems will not always give pilots enough warning or information about the extent of an oncoming storm, and forecasts provided to pilots can be hours old. Flying at 500 miles per hour, pilots will find themselves in a potentially dangerous situation in which they are surrounded by a storm and cannot manoeuvre around it or turn around. The U.S. National Transportation Safety Board (NTSB) evaluated the role of total lightning data in identifying and tracking storms to avoid flying into severe weather and has clearly recommended the use of total lightning data to help pilots steer clear of oncoming severe weather.[105]

MAXIMIZING EFFICIENCY

Good weather forecasts can also support aviation operations by maximizing airline efficiency and lowering overall operating costs. For example, Qantas Airways is using Terminal Aerodrome Forecasts to maximize fuel savings. By using TAF weather data, pilots are able to determine if they will need additional fuel before take off to provide contingencies for thunderstorms or other bad weather at their destinations. If the TAF shows an all clear, pilots are not required to load the previously mandated extra fuel. The total estimated savings to Qantas with the use of TAFs was roughly US$16 million annually in 1995. It was projected that an increase in TAF accuracy of 1 percent would increase the savings by an additional $1.2 million annually.

Airlines plan for contingencies in the event of irregular operations (IROPS). This process takes a holistic approach by integrating existing plans with new information. Airlines have to develop measures to address operational events driven by disruptions in air travel. If the TAFs provided have a high confidence and accuracy in predicting low visibility at the arriving aerodrome at least 24 hours in advance, the airlines can notify the passengers ahead of time that the flights are delayed. This principle is applicable to any significant atmospheric event that can be accurately predicted with a high degree of confidence. Taking the lessons from Qantas, along with outlying factors, the use of high-quality meteorological information by airlines could prevent unnecessary expenses in the millions of dollars annually.

ACCURATE FORECASTS NOT ONLY MAKE FLYING SAFER, THEY CAN MAKE IT MORE PROFITABLE.

[103] TAFs are a requirement of the International Civil Aviation Organization, and are used by pilots, air-traffic control and ground operations to help planes take off and land safely.

[104] Twelve percent of fatal aviation accidents are weather-related (http://www.planecrashinfo.com/cause.htm).

[105] National Transportation Safety Board, Safety Recommendation, 18 May 2012, earthnetworks.com/Portals/0/NTSB_Safety_Recommendation.pdf.

STRUCTURING EFFECTIVE PUBLIC-PRIVATE PARTNERSHIPS

TRAINING AND THEN UTILIZING INSTALLATION TEAMS DRAWN FROM THE MAINTENANCE AND CALIBRATION STAFF OF THE NHMS TO DEPLOY AWS BUILDS VALUABLE SKILLS APPLICABLE TO FUTURE MAINTENANCE AND INSTILLS A SENSE OF OWNERSHIP IN THE SYSTEMS. PHOTO BY ADCON.

Creating effective public-private partnerships (PPPs) requires a conducive regulatory framework and business environment, sustained financial and political support, transparent and effective procurement processes, clear allocation of risks, and continual monitoring and evaluation. There is no one-size-fits-all blueprint to structuring effective PPPs within the hydromet services sectors. The individual political structures, socio-economic realities and business environments will define individual narratives. The single common thread is one of trust, shared risk and mutual benefit. The end goals remain the same: to bridge the last mile to bring valuable public-information alerts to vulnerable communities across Africa, to build new revenue streams for National HydroMeteorological Services (NHMS), and to create a true value proposition that fosters the long-term sustainability of climate information endeavours.

STRUCTURING EFFECTIVE PPPS

Billions of public and private dollars have been invested in the form of PPPs in recent decades, and the use of such structures has increased worldwide in response to fiscal constraints on public borrowing and the recognition that private sector engagement can bring multiple benefits in the form of innovative approaches as well as financial and human resources. Consequently, there is a substantial body of information on the effective structuring of PPPs, pitfalls to be avoided, and the conditions necessary for success. There are also several international organizations, including the International Finance Corporation (IFC), with units dedicated to providing technical assistance to countries interested in the design and implementation of PPPs. Drawing on this extensive body of knowledge, the following requirements provide an overview of some of the elements critical for successful PPPs and a baseline for the consideration of PPPs for hydromet services.

AWS INSTALLATION.

- **Legal and regulatory framework.** Despite the importance of appropriate legal and regulatory frameworks for the effective operation of hydromet agencies, many developing countries lack such laws.[106] Some of the issues most relevant for PPPs include a clear statement of the types of information to be provided as a free service;[107] obligations for radio and television stations to provide weather information and warnings; and the authority for revenue generation and the retention of funds. The *Public-Private Partnerships Reference Guide* provides extensive guidance on and examples of PPP laws from many countries.[108] According to a report from the World Economic Forum, "In many countries unilateral liberalization of the telecommunications sector has developed not only the use of mobile phones, but also a range of services based on telecommunications infrastructure now offered by the private sector. This expansion has required the development of a policy framework capable of encompassing new and perhaps unforeseen developments in the sector." [109] South Africa's establishment of a PPP unit (p71) offers a good framework to be considered in this space.

- **Skilled, highly trained staff.** As emphasized in earlier sections, a key issue in many developing nations is both attracting and then retaining trained staff with the necessary expertise in meteorology. An additional set of skills is necessary for the design and management of PPPs. Drawing on its experience with PPPs, the IFC makes the following observation: "The quality of teams is particularly important given the potential technical, economic and political complexities inherent in PPPs, and having the right balance of global and local expertise is critical. Global experts can bring critical knowledge and best practices from other sectors or geographies—expertise that is not easily obtained elsewhere. Yet perhaps even more important is the presence of local, on-the-ground capabilities. Again and again, IFC project teams note

[106] David Rogers and Vladimir Tsirkunov, 'Weather and Climate Resilience: Effective Preparedness through National Meteorological and Hydrological Services' (Washington, D.C.: World Bank, 2013), pp. 112–117.

[107] "For example, in most developing countries, the agricultural sector should receive information to support smallholder farmers." Ibid., p. 114.

[108] World Bank, 'Public-Private Partnerships Reference Guide Version 2.0' (Washington, D.C.: World Bank, 2014), pp. 80–82.

[109] World Economic Forum, 'The Africa Competitiveness Report 2015.' The report notes that favourable policy frameworks were key to the successful growth of Safaricom service in Kenya, and a basis for the rapid development of mobile money platforms.

the importance of both global and local expertise and presence."[110] For example, many non-profit climate information projects, such as the Human Network International Program (p85) and Trans-African HydroMeteorological Observatory (p90), leverage universities and crowd-sourced technology—along with the power and support of African institutions such as schools—to deliver robust systems for the collection of data and dissemination of information.

- **Political support.** Many reviews of lessons learned from PPPs point to the importance of high-level political support. A recent review by the IFC made the following conclusion: "Any project requires a champion: someone to articulate and refine the vision, guide progress, and advocate for support. For PPPs, political champions are particularly vital, given the significant public stake in them. Our teams repeatedly cite the importance of political champions, and it is rare for major projects to survive without them. . . . A strong champion or multiple champions can make all the difference, as in a recent successful hospital project in Africa, where the team cited the strong support of both the minister of finance and the minister of health as a key reason for the project's success."[111]

- **A transparent, competitive procurement process.** As noted earlier, one reason PPPs sometimes fail is insufficient transparency in bidding and contracting. As noted by the IFC review, "Not only is it good business practice, but also anything less risks undermining long-term public support of the partnership." This issue is particularly important for large awards and has led to significant guidance on good practice by international institutions.[112] Conversely, the perceived absence of transparent, fair bidding processes has been among the most frequent sources of problems when implementing PPPs. As discussed earlier in this publication, new UNDP Long-Term Agreements for the procurement of meteorological equipment and services offer expanded opportunities to ensure transparency and streamline procurement processes.

- **Clear allocation of risks and responsibilities between the public and private partners.** One of the most challenging issues for the design of PPPs is anticipating risks and assigning them to the government or private party. A frequently cited principle is that risks should be assigned to whichever party can manage them best—a concept more easily stated than applied. A more detailed formulation identifies the appropriate party as the one that can (i) best control the likelihood of the risk occurring; (ii) best control the impact of the risk on project outcomes; and (iii) absorb the risk at the lowest cost.[113] In the context of weather services, perhaps the biggest risk is the failure to properly anticipate and communicate warnings of storms and other extreme events. The allocation of risks is often a country- and programme-specific issue that must be thought through case by case. The country profiles at the end of this publication give a deeper look into how individual countries are tackling this challenge.

- **Ongoing monitoring and review to identify and address problems** (including dispute resolution procedures). For several reasons, incorporating a formal programme for monitoring, reporting and evaluating system performance is important. While true for hydromet services generally, the need is even greater in a PPP with the separation of responsibilities between public and private parties and the need to establish new relationships that include revenue sharing.[114] The dynamic nature of weather technologies and services also implies the need to continually monitor opportunities for improved weather products and services. Thus, regular and periodic reporting on experiences, with clear metrics to measure successes and failures, is highly desirable. Ideally, a neutral, expert group should also be identified in advance for dispute-resolution purposes.

[110] Richard Florizone, Emile Joseph and Laurence Carter, 'A Winning Framework for Public-Private Partnerships: Lessons from 60-Plus IFC Projects' (Washington, D.C.: World Bank, 2013), documents.worldbank.org/curated/en/2013/04/18197590/winning-framework-public-private-partnerships-lessons-60-plus-ifc-projects.

[111] Ibid.

[112] See, e.g., International Monetary Fund, 'Manual on Fiscal Transparency (2007)', www.imf.org/external/np/pp/2007/eng/051507m.pdf.

[113] 'Public-Private Partnerships Reference Guide Version 2.0', p. 150, summarizing Timothy Irwin, 'Government Guarantees: Allocating and Valuing Risk in Privately Financed Infrastructure Projects' (Washington, D.C.: World Bank, 2007).

[114] 'Public-Private Partnership Reference Guide Version 2.0', pp. 207–210.

3-2-1 INNOVATION

Human Network International Program Goes 'The Last Mile' to Bring Public Alerts to Cell Phones

By David McAfee

Most people in the developed world take the weekly weather forecast for granted. Their daily routine can include making reference to multiple sources of real-time, highly localized data on temperature, wind speed, precipitation and projections of expected hourly and ten-day forecasts. Impending storms produce automated (and sometimes loud) warnings. More specialized business needs for weather data are also increasingly being met with tailored products and mobile communications.

But for smallholder farmers and vulnerable communities in Africa, getting the daily weather report and important public service announcements has been an untenable pipe dream for years. But imagine the impact a good weather report, accurate health information, emergency alerts and information on finance and risk protection could have on the 33 million smallholder farmers in sub-Saharan Africa?

The 3-2-1 service from Human Network International (HNI) seeks to remedy this challenge by bringing free, highly accessible information that can be shared on a simple cell phone or feature phone simply by pressing 3-2-1.

THE CHALLENGE

The challenge is one of connectivity and capacity. In a continent with limited Internet accessibility and stubbornly high illiteracy—five in 10 women in sub-Saharan Africa cannot read—new solutions need to be created to leverage both new technology and expanded data that comes from improved weather forecasts, large databases on public health and farming, as well as up-to-date information on finance, agriculture, insurance and more.

The cell phone is the perfect delivery device for this information. There are 720 million cell phones in use in Africa today. By using the 3-2-1 interface, where farmers dial in and are prompted with numbers to hear information on everything from public health alerts to family planning and microfinance, we ensure this information is accessible to all. As we've learned through years of practice, information is one of our greatest tools for empowerment and economic development.

SCALING UP AND ACCESSIBILITY

By partnering with local telecommunications providers, 3-2-1 is providing a ready market and a valuable public good. The programme is already up and running in Madagascar and Malawi, and has achieved impressive usage and growth. Contracts have been signed with Burkina Faso, Ghana, Mozambique, Uganda, Nigeria and Tanzania.

HNI works with NGOs and government ministries to create local content across a range of development topics, including public health, agriculture, education, water and sanitation, family planning, microfinance, early warnings and other important areas of interest. The current content covers seven topics, 40 subtopics and shares 400 messages. In order to achieve maximum distribution, this content is then given to telecoms that agree to make it available to their subscribers, free of charge, via voice (IVR), SMS, USSD and the Web.

The goal was to reach 20 million callers within the first 12 months of launch and 100 million callers within the first three years. By the end of 2014, 3-2-1 was servicing 200,000 voice queries, 800,000 text queries and 200,000 USSD queries per month. Every month, 200,000 people in Madagascar make 1 million information requests . . . for free.

THE 3-2-1 SERVICE HAS THE POTENTIAL TO BRING LOCALIZED ALERTS TO MILLIONS OF PEOPLE. PHOTO BY IFAD/MWANZO MILLINGA.

A call-back survey of 300 men and women who listened to gender content reported that the information had changed lives or behaviours for 62 percent of users, improved the ability to make household decisions for 91 percent, and added value to the lives of 96 percent of respondents.

Weather alerts are not currently shared via the service—the content is simply not available. Consequently, we have been exploring ways to address this need and found the discussion at the CIRDA Kampala workshop in March 2015 encouraging. With better weather data and relevant local forecasts, the 3-2-1 service and public-private partnerships between telecommunications firms and national meteorological services offer a promising opportunity to provide the poorest of Africa's farmers with valuable information that can boost productivity and save lives from fast-acting natural disasters and local weather events like flash floods, high winds and lightning.

DAVID MCAFEE is the President, CEO, and Co-Founder of HNI. He has over 20 years of development experience and a proven record of social entrepreneurship. He was a Peace Corps volunteer in Gabon from 1991–1994. He joined Population Services International (PSI), the world's largest social marketing organization in 1996 and held various positions including Country Representative in Rwanda and Madagascar and Regional Director for Southern Africa. In 2008, he left PSI to promote the use of technology in development as the leader of HNI. David has a BA in Economics from the University of Chicago. Learn more about HNI at www.hni.org.

ESTABLISHING HYDROMET BUSINESS STRATEGIES

The justification for the continued funding of an NHMS (from either the state or the commercial sector) is based on the ability of the NHMS to generate quality hydromet information in a timely manner. Such information—coupled with related services—can be used to inform public and private decision makers to make weather- and climate-smart policies that improve human welfare, increase economic value to the state and industry, and improve efficiencies and lower weather- and climate-related losses. There is no definitive listing of government agencies or commercial enterprises, or economic choices or outcomes that could benefit either directly or indirectly from improved and tailored hydromet information. Each country and their respective industries absorb, consume and act on this information differently. However, we can say that in least developed countries, the sectors most often affected by weather-related shocks are disaster management (government) and agriculture (private/personal enterprises).

In spite of the strong guidance provided by WMO Resolution 40,[115] NHMS commercialization has sometimes resulted in weakened efforts towards meeting international commitments. Examples of such weakened efforts include the absence of essential weather and climate data exchanged through the WMO, key climate data being withheld from international data archives, and research and education communities that are either not receiving data or are being charged burdensome amounts.

The push by governments for the commercialization of NHMS cannot succeed in the face of economic realities and uneven-handed application of competition policies. The practice of withholding meteorological data—with the intent of 'protecting' the market for a NHMS product—has unfortunately become widespread. However, this strategy has questionable returns, as the value of the withheld data is set by the NHMS based on a desired return on investment and subsequent profitability, and not on affordability and value to the market. This method of pricing often causes a barrier to entry into the market for small and medium enterprises. The strategy eventually results in the stagnation of a nation's private meteorological consumer base and therefore, ultimately, a loss in revenue to the NHMS. The socio-economic rationale for policies that cause higher costs and a lower user base has been unsuccessful in the context of meteorological information.

In contrast, having open data-sharing policies has the potential to foster significant economic benefits to society. The state, together with the NHMS, has an obligation to balance the interest of the public with that of its own economic goals. With supporting policies and legislation, governments can achieve financial gains from multiple sources when they balance the mandate between public and commercial good. For instance, well-balanced approaches could produce increased indirect tax revenue from the sale of publicly produced information, or they could produce higher income-tax revenue and lower social security payments with net gains in employment and reduced risk to economic shocks.

Valuing Meteorological Information

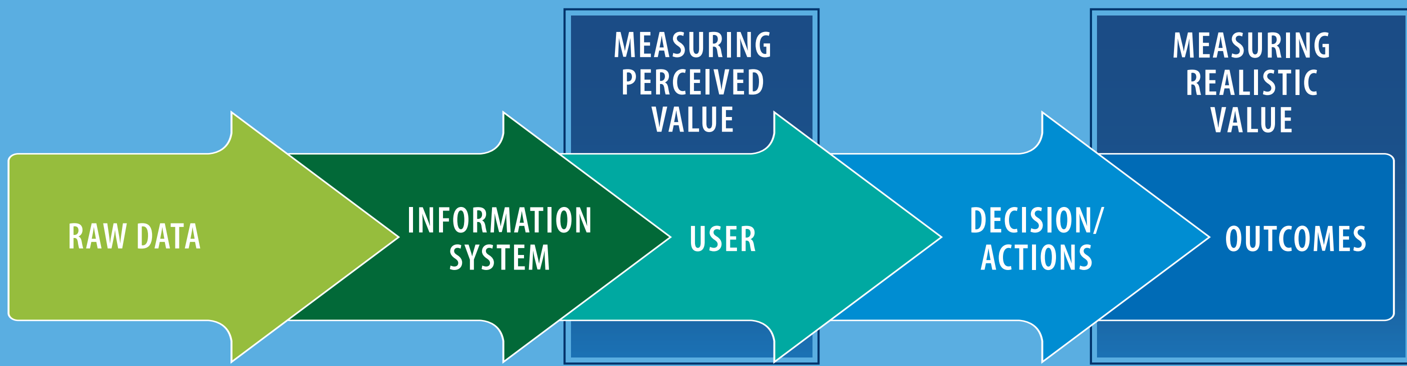
There is a complex chain of communications, analysis, understanding and decision-making that operates between the provision of hydromet services and the realization of the potential benefits. When executed well, this supply chain can produce positive outcomes for decision makers, NHMS, business, and society as a whole. The challenge is that each actor in the information supply chain perceives the value differently. The raw data provider, typically the NHMS, perceives and realizes the value of the information before it is utilized by downstream consumers like banks, resource extraction enterprises and aviation. With this in mind, the information can only be accurately valued by properly understanding the information's specific quantifiable outcomes and impacts.[116]

[115] World Meteorological Organization (WMO) Resolution 40 covers 'WMO policy and practice for the exchange of meteorological and related data and products, including guidelines on relationships in commercial meteorological activities', http://www.wmo.int/pages/prog/www/ois/Operational_Information/Publications/Congress/Cg_XII/res40_en.html.

[116] For a more detailed discussion on valuing weather information, refer to WMO, 'Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services', WMO-No. 1153 (2015), www.wmo.int/gfcs/sites/default/files/wmo_1153_en.pdf.

FIGURE 6.1 Perceived and realistic value of information, modified from Ahituv, 1989.

Valuing meteorological information



Typically, NHMS focus their business development and revenue-generating efforts on the sale of raw data, or specialized services that include provisions of information on past conditions—the historical record—and the current state of the atmosphere, ocean, land surface and surface water. They can also include forecasts of future conditions—warnings of severe weather and climate events, and general forecasts for the community at large and for a range of specialized users—along with long-range forecasts such as seasonal, inter-annual or longer-term fluctuations, and projections on human-induced climate change.

The key to the commercial viability of NHMS is to increase the reach and impact of weather information by packaging the raw information appropriately for specific sectors. Globally, the most common consumers of weather information are those within the following sectors: agriculture, aviation, banking and financial services, construction, energy, environmental protection and disaster management, fisheries, forestry, health, insurance, leisure, manufacturing, military, port and harbour management, retaining, transport, sport, urban planning, and water resource planning and management. Each industry defines value based on the attributes of the information provided (i.e., accessibility, content, resolution, validity, timeliness, cost, etc.). It is up to the local NHMS to determine the order of qualifiers for each individual customer. This is, however, not a trivial task. While market prices for specialized hydromet information exist, the determination of fair prices will be location- and application-specific and will often require the facilitation of specialists in the particular field.

An outcome of the facilitation process should be the realistic valuation of end-user information, which includes a measurable impact and demonstrable utility for the users. On the societal or socio-economic scales, the impact of the hydromet system performance must be measurable and quantifiable. If the transport industry utilizes weather information to better inform the behaviour of the drivers, operators or consumers, then this must be quantifiable in terms of financial or performance gains (i.e., reduced accidents, reduced loss of life, improved on-time performance, etc.).

Conclusion

NHMS have a unique value proposition in the national context, specifically from a public good perspective. It is difficult to quantify the total benefit of the combined infrastructure, the climatological record, or the public forecasts and warnings provided to society at large. The benefits on a commercial scale can be quantified together with the end user once the valuation logic and decision-making paradigms of the hydromet information are well understood. The overall benefit of the NHMS will be the sum of the benefits for all the end users. This can be used on an annual basis during the national budget allocation process to demonstrate the true value of hydromet services to the national economy. As we have seen, in many developing countries, limited data, capacity and technology, combined with weak political and financial support, have come together to create a non-virtuous cycle for NHMS. By underscoring the value of this public good and looking towards new commercialization models and synergies with the private sector, this non-virtuous cycle may be broken.

UNDP CLIMATE ACTION HACKATHON ACCELERATES INNOVATIVE APPROACHES TO PROVIDE WEATHER INFORMATION TO VULNERABLE COMMUNITIES IN AFRICA

The UNDP's Climate Action Hackathon, hosted in Livingstone, Zambia in 2016, brought together young software developers from around the world to develop innovative data and communications technologies to share weather and climate information with communities and help them better prepare for the realities of climate change.

"By connecting energetic young application developers with National HydroMeteorological Services and Disaster Management Units across sub-Saharan Africa, we are working to bridge the last mile to bring actionable weather information to vulnerable communities across the region", said Bonizella Biagini, Programme Manager for UNDP's Programme on Climate Information for Resilient Development in Africa (CIRDA). "In most of sub-Saharan Africa, farmers are facing increased risk as a result of a changing climate. Severe weather, flash floods and lightning kill farmers on a regular basis. The applications developed in this hackathon have the potential to both save lives and protect livelihoods."

More than 100 people applied for scholarships to attend the Climate Action Hackathon in person. A total of 23 hackers were awarded scholarships. With only three days to learn about the persistent challenges in bringing weather and climate information to African communities and build the apps themselves, the hackers worked around the clock to create prototype models, data visualization tools and end-to-end product designs.

Data sets were provided to the hackers by aWhere, Earth Networks, Geonetcast, the International Research Institute for Climate and Society's Data Library, Ubimet, and the Zambia Meteorological Department. With these data streams in hand, hackers began to tackle the challenges presented to them by event organizers.

Experts from UNDP, the Brown Institute for Media Innovations of Columbia and Stanford Universities, and the International Research Institute for Climate and Society (IRI) were on hand to facilitate discussions, help hackers understand the nuanced approaches necessary, and connect broad sets of data with the unique needs of end users.

"The Hackathon is about creating African-built high-tech solutions for Africa's challenges in adapting to climate change. By leveraging mobile communications, text messages and other new-generation technologies, African nations have a great opportunity to share improved weather reports with the communities that need it the most," said Catherine Vaughan, IRI Senior Staff Associate.

The hackers presented their products to delegates from 10 African National Meteorological and Hydrological Services on the closing day of a larger UNDP-supported multinational workshop on increasing resiliency with tailored weather information services, supported through the CIRDA programme.

The app most voted for by the African country representatives used a design and processes that were simple and provided farmers with a call-in mobile app that provided real-time weather information voice messages in local languages. Other applications included a visualization and risk-management app that agricultural extension workers could use to easily analyze weather data, a mapping app that African pastoralists could connect with to avoid hazards such as floods and wildfire, and a text app that would allow agricultural extension agents to register farmers to receive tailored texts on weather conditions.

Learn more about the Hackathon at www.adaptation-undp.org/climate-action-hackathon.

PHOTO BY VADIM PETRAKOV/SHUTTERSTOCK.COM.

A PROCESS FOR MOVING FORWARD

Finding all of the elements described above may be difficult in African countries. Nevertheless, as the experience with PPPs in other sectors illustrates, it is possible to start with less than ideal conditions and improve over time. The challenge is to identify PPP arrangements consistent with the existing legal and institutional constraints, many of which restrict or even preclude private ownership of weather data while at the same time restraining the public sector from generating sustainable income from commercialization efforts.

Another prerequisite to progress will be to assess in some detail the range of potential business relationships with entities such as cell-phone companies, cell-phone-tower companies, aviation organizations, agricultural companies, banks, mining companies, port operators and other potential off-takers for weather information.[117] An unfortunate reality is that in many African countries today the hydromet services have very little credibility with the private sector for the simple reason that they have failed to meet user needs, forcing businesses to find alternative (frequently imperfect) sources of information such as data produced by developed countries or private vendor services. Outreach to the business community will therefore have several objectives, beginning with helping to trigger a cultural change in terms of the negative perceptions of the NHMS. More specifically, outreach to the private sector will help identify the range of data needs in a particular country and how they are being met today. This information is essential for knowing what types of data could be useful, and for assessing the feasibility of installing the specific equipment required to collect it.

Equally important will be engaging relevant businesses in a conversation about their needs and interests, as they may be sources of support and information in creating the vision for a more modern and reliable system. This support may be political as well as technical, in that the interest of major businesses will help to advance the status of the NHMS within the government. Finally, there is the potential for discussion on some cost-sharing for businesses with specialized weather information needs that can be met more efficiently by a public agency.

While international organizations, particularly the IFC, have helped bring about PPPs for health and education services, structuring such arrangements in Africa for hydromet services will involve different technical and institutional issues and there are no real precedents on the continent, save for the example provided by EcoNet (p100). The help of knowledgeable international organizations and other experts will be needed to inform the design of such partnerships, to engage private sector partners, and to implement new institutional arrangements. Given the magnitude of potential benefits, strong donor interest and support should be possible. However, the ultimate success of such efforts will depend on strong national support and leadership in order to find solutions consistent with local needs and circumstances.

[117] The CIRDA project is supporting a regional market assessment and several participating countries are doing such studies individually.

LEAPFROGGING TECHNOLOGY

Trans-African HydroMeteorological Observatory Aims to Install 20,000 Weather Stations in Africa

By John Selker

PHOTO BY ARTUSH / SHUTTERSTOCK.COM.

Africa is ready for a next-generation of weather, water and climate information solutions. The goal of the Trans-African HydroMeteorological Observatory (TAHMO) is to install 20,000 on-the-ground sensing stations across the African continent, providing high-tech automatic weather stations that will produce rainfall, temperature, and other critical data with robust redundant sensors and real-time cell-phone uplink. TAHMO plans to make high-quality data freely available to governments, scientists and farmers in real time via the Internet from stations installed at 30 km spacing.

It's no easy task, but all the right elements are falling into place to make this once lofty dream a reality. By leveraging a large mobile telecommunications platform, crowdsourced technology that is both durable and cost-effective, and a network of rural schools, TAHMO is already making strides in achieving its goal.

TAHMO is currently piloting projects in Chad, Democratic Republic of Congo, Ghana, Kenya, Nigeria, Senegal, South Africa and Uganda, with stations being prepared for installation in Malawi, Rwanda and Togo. Most notably, TAHMO was selected to move into the second stage of funding for the Global Resilience Partnership Challenge, and it is working with Earth Networks, Human Network International, Climate Change Adaptation Innovation, and African Centres for Lightning and Electromagnetics to create an early warning system around Lake Victoria, where an estimated 5,000 people die each year due to erratic weather.

TAHMO installed six automatic weather stations in southern Uganda with the support of the Ugandan National Meteorological Authority. These stations measure over a dozen weather parameters and are self-powered by matchbook-sized solar cells. They transmit data via a built-in cell-phone modem. In the next phase, over 100 stations will provide a dense observation network.

School-2-School

Stations will be located primarily at schools and universities, with TAHMO providing science curriculum materials and connections between schools and others in the network. Hosted by science teachers who will receive stipends for their caretaking of stations, the data collected by stations will also provide a foundation for scientific education.

For example, in March 2015, TAHMO installed a weather station at a high school near the coast of Lake Victoria as part of their School-2-School Programme. The students will be comparing data with a sister school in Idaho, USA. This activity not only supports the gathering of accurate, real-time weather data; it also helps build a next generation of scientists and raise awareness of climate change and environmental stewardship.

Crowdsourcing Innovation

Under the auspices of the Delft University of Technology—a public-private consortium comprising 14 universities and several small and large businesses—TAHMO is looking towards crowdsourced solutions to provide low-cost hydrological and meteorological sensors.

For the past two years, the organization has hosted a senior design competition to gather top thinkers to create low-cost, durable and highly advanced next-generation solutions. According to *The Guardian*, "TAHMO offers the prospect of cost-effective hydro-meteorological measuring stations that are low maintenance. The stations will cost only $500, but will be technologically innovative by deploying low-cost sensors (as found in objects ranging from washing machines to cars and smart phones) marshalled to serve as weather or water sensors. For instance, the simple piezo buzzer (costing $1), which is used in fire alarms, will be used to measure rainfall intensity."[118]

TAHMO developed a prototype of an acoustic disdrometer (rain gauge) that can be produced for €10, less than 1 percent of the cost of a commercial equivalent with the same specifications. The disdrometer was developed in the Netherlands and tested in Tanzania for a total project cost of €5,000.

JOHN SELKER is a Professor of Hydrology at Oregon State University and the Co-Director of TAHMO. His research and development work on sensing applies to irrigation, hydrology and water systems. To learn more about TAHMO, visit www.tahmo.org.

[118] Nick van de Giesen, 'To strengthen Africa's green revolution, look to the skies', *Guardian*, 22 August 2013, www.theguardian.com/global-development-professionals-network/2013/aug/22/weather-stations-agricuture-data-africa.

PROMOTING FINANCIAL SUSTAINABILITY

The absence of sufficient resources is a pervasive shortcoming that underpins and exacerbates almost all the problems of hydromet services in Africa, which include, among others, inadequate and poorly maintained equipment; an inability to attract and retain technical staff; and the absence of effective public communications programmes. Public financing is, and will always be, needed, but given the competing and often higher priorities such as public health, and the issue of inadequate revenue collection, it will rarely be sufficient. Donor support helps, but it cannot be viewed as a regular source of funding.

International experience, including models from countries such as the Netherlands, the United Kingdom, Brazil and South Africa, illustrates the potential for going beyond aviation (a source of revenue for weather services in many countries) to a much more diverse and significant contributor to NHMS budgets through fee-for-service arrangements. This of course presumes that NHMS can respond to needs for customized weather information on a consistent and reliable basis—a challenge which is increasingly realistic in technical terms but which will require effective institutions and management. Such arrangements will therefore not be quickly or easily established, as the absence of credibility cannot be overcome overnight. This supports the argument to leverage private weather services as a bridge to build revenues, improve reliability, and foster trust and credibility.

Revenue expectations should also not be unrealistic. Private contributions most likely will never provide the majority of funding for national weather services. However, business support may be equally important as a source of status and credibility within national budget processes as it demonstrates economic value and a larger role in development. At the end of the day, this enhanced status may be the most effective basis for sustainability.

CELL TOWERS STRETCH ACROSS RURAL AFRICA, PROVIDING SECURITY, POWER AND COMMUNICATIONS FOR WEATHER MONITORING EQUIPMENT. PHOTO BY SOLOMON MANGENI.

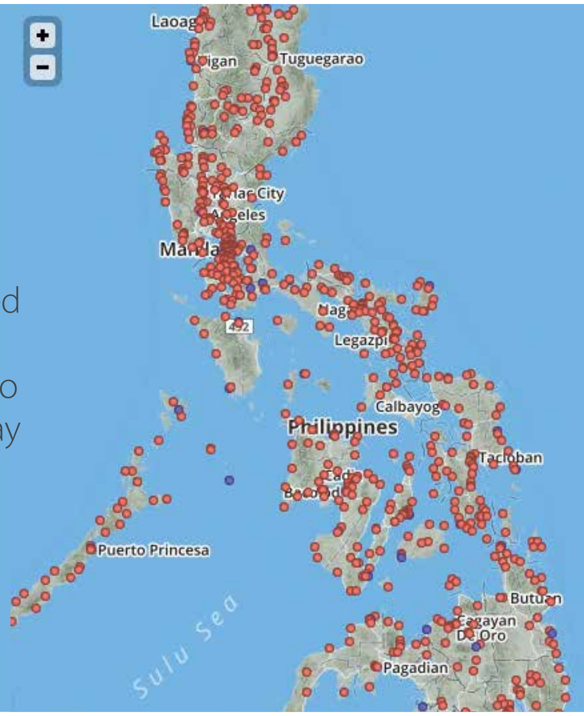
CONCRETE EXAMPLES

SMALL BOATS ARE USED BY MANY FISHERS ON THE CHAIN OF LARGE LAKES IN WEST AFRICA. THESE DO NOT PERFORM WELL IN LARGE WIND-DRIVEN WAVES.

The vision outlined earlier in this publication gives a glimpse of working models where public sector interests collide with private sector know-how and technology to create lasting synergies for the deployment and support of integrated hydromet systems. These new models are being approached from different angles by governments and private sector interests across the globe, and they will need to be tailored to fit the unique needs, challenges and opportunities in Africa today. The examples presented in this section explore how the Philippines has deployed a network of 1,000 Automatic Weather Stations (AWS), how partnerships with telecommunications providers are offering new options for farmers in Africa, and how private weather companies are working in Brazil to provide a total lightning detection network that supports public goods and protects private interests.

FIGURE 7.1
An image from the Weather Philippines Foundation (weather.com.ph), the local weather information portal for the Philippines, operated by MeteoGroup.

This map shows some of the AWS installed across the northern Luzon island group. Each dot is interactive, providing access to the most current observation and five-day forecast for that station.



WEATHER WISER IN THE PHILIPPINES:A NETWORK OF 1,000 AWS

By deploying hundreds of Automatic Weather Stations (AWS), leveraging innovative public-private partnerships, and creating systematic community engagement and outreach strategies, the Weather Philippine Foundation (WPF) is providing the 100 million citizens of the Republic of the Philippines with free, accurate and localized weather information. This extensive AWS network is an essential element of a model Early Warning System (EWS) that can save lives, build resilience and improve livelihoods.

Installing such an extensive AWS network in the Philippines is a major task. The nation occupies an archipelago of some 300,000 km^2 spread across 7,100 islands. Many of the islands where people live are mountainous, covered with tropical forests and contain active volcanoes. But as the Philippines is particularly vulnerable to high-impact weather, the need for local weather information and emergency warnings is great.

Most of the Philippines experiences strong thunderstorms throughout the year. These bring high winds and torrential rains. The rains, in turn, produce flooding and lead to frequent landslides. The Philippines also sits astride the western Pacific typhoon belt. In a typical year, around 19 typhoons come near the islands; six to nine of these will usually make landfall, bringing even stronger winds, heavier rain and more widespread flooding.

While the majority of typhoon near-misses and landfalls occur on the northern Luzon island group, recent events show that no part of the Philippines is immune. Recent major disasters include Super Typhoon Bopha/Pablo in early December 2012, which resulted in 1,901 reported deaths and US$1 billion in damages across the southern Mindanao island group, and Super Typhoon Haiyan/Yolanda in early November 2013, which caused catastrophic damage with 6,241 reported deaths and more than US$2 billion in damages across the central island group of Visayas.

In recent years, providing emergency services in response to the annual cycle of typhoon- and other weather-related disasters has strained the resources of the Government of the Republic of the Philippines. One consequence is that it has proved difficult for the National HydroMeteorological Service (NHMS)—the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA)—to modernize many of its weather observing systems and forecasting processes, and to retain or upgrade key staff. This has left the Philippines without some of the modern weather observation and localized weather forecasting systems being utilized in other developing countries that have far less exposure to high-impact weather events.

Weather Philippines Foundation

In 2012, the non-profit Weather Philippines Foundation (WPF) was established by AboitizPower—a major energy supplier in the Philippines—in partnership with UnionBank, in order to partially meet the country's needs for better surface weather observations, localized forecasting, and effective early warnings of weather and climate hazards across the archipelago.[119] The goal set for WPF is to deliver free, accurate, localized weather information so that Filipinos can make better, more informed decisions during life-threatening weather events as well as about more routine weather-influenced matters in their daily lives.

WPF is chartered to work with the private sector, individuals, and federal, regional, provincial and local governments to develop and operate weather observation, forecasting and early warning systems for the Philippines on a non-governmental basis. Given the innovative nature of WPF, obtaining a license to operate was difficult as there were legal and political issues that had to be addressed at the outset. These were resolved in WPF's favour early on, with the network and range of services provided by WPF continuing to grow ever since.

A publically stated goal of WPF is to install approximately 1,000 automatic weather stations and (at selected locations) lightning detectors to ensure nationwide monitoring of the weather in locations where people live and work. Starting with the installation of 82 stations in 2012 (one in each province), WPF has continued to install between 200 and 250 AWS per year. As of late 2015, WPF had about 750 AWS installed and was set to grow the network to about 1,000 stations by June 2016.

Since its establishment, WPF has focused on industry-targeted fund-raising to support network development and operations, as well as the development of collaborations with regional, provincial and local governments. As a result, it has several major donors that have each pledged approximately US$54,000 (which is sufficient to support 20 AWS), to be paid over a 10-year period. Other companies have committed to smaller amounts of funding. These donors include major industrial and commercial enterprises, such as SM Supermalls, Vista Land, LBC, Nickel Asia Corp., and International Container Terminal Services, Inc. Some of these donor companies also provide sites for AWS. WPF is a member of the League of Corporate Foundations, through which it has been successful in obtaining additional sponsors. Many local governments also contribute small amounts of funding as well as in-kind support for installations. WPF sustains its operations through innovative barter agreements. For example, it provides detailed weather information for free to Cebu Pacific Airlines in exchange for flights for its technical staff to install and service AWS in distant locations.

To carry out its mission, WPF has developed strong partnerships with public sector agencies and the umbrella organizations of such agencies at the regional, provincial and municipal levels. These include the League of Provinces, the League of Cities, and the Presidential Assistant for Rehabilitation and Recovery. These public sector partners help WPF identify municipalities to receive AWS free of charge.

WPF also has developed strong public outreach programmes to assist the population of the Philippines in becoming 'weather wiser', that is, knowing what weather information is available from WPF, understanding how such information can be used in a variety of situations, and then taking appropriate actions on the basis of that information, especially in times of severe weather. The outreach programmes include training community leaders and individuals on local emergency preparedness; promoting planning for business continuity in a disaster; fostering a junior meteorologist programme for students; passing out information at local fairs, service club meetings and other events; and developing a strong presence on social media. A Weather Philippines software application has been developed and is available for free download on the Apple iPhone.

[119] The Weather Philippines Foundation has received numerous awards for its work to date. These include 1st Runner Up, Product Innovation—ASEAN Corporate Sustainability Summit and Awards 2014; Accounting for Climate Change CSR Award—CMO Asia 2014; and the Yahoo! Internet for Good Award—Gold Standard Awards, Public Affairs Asia.

FIGURE 7.2
The background image from the Facebook page of the Weather Philippines Foundation (https://www.facebook.com/weather.com.ph).

Making a Non-Governmental Weather Service Work

WPF engaged MeteoGroup Philippines, Inc., in a long-term arrangement as an operating partner and content provider. MeteoGroup is charged with deploying, maintaining and operating the AWS network and producing a highly localized forecast for each AWS site. MeteoGroup supplies WPF with the technology for EWS operations and provides the interactive web portal (monitored by Google Analytics to provide data on its users) for disseminating weather information to the Filipino people. The web portal provides current conditions from local AWS (updated hourly); local and national forecasts for five days out; and severe weather warnings according to postal code level. Additional items offered for free on the portal include detailed satellite analyses, films, access to webcams, and a weather TV station. Under its arrangement with WPF, MeteoGroup retains more detailed data for use in its global commercial weather enterprise.

FIGURE 7.3
An example display from the Weather Philippines Foundation iPhone application.

FIGURE 7.4
An example of current conditions for 8 a.m. Monday 21 September 2015, as reported by the AWS and the localized weather forecast for the Caramoan-Tawog site in the Weather Philippines network of AWS. The current condition data, the forecast and the display are prepared by MeteoGroup. (The forecast extends for five days, but was truncated in the interest of readability.)

Assigning Ownership and Roles

Ownership of deployed AWS is retained by WPF. Each local government agency or commercial/industrial entity receiving an AWS signs a memorandum of understanding (MOU) in which it agrees to protect, clean and provide proper first-level maintenance of the AWS. Prior to installation, WPF asks the receiving agency to submit a description of the proposed location and its surroundings, together with 360° pictures of the proposed site. WPF provides training to the personnel of the agency and involves them in the installation of 'their station', thus developing a sense of local ownership for each AWS. Municipal leaders also play important roles in securing the safety of their AWS.

During the training of agency personnel, and in its public communications, WPF stresses that its efforts are intended to "complement the government's efforts in reducing weather-related disaster risks in the country, enabling timely response to variable weather conditions to avoid loss of life and property". Further, WPF indicates that the Foundation wants local communities to "understand the basic concepts, processes and effects of different weather disturbances and rain-producing weather systems", so local people can plan and make their own disaster preparedness programmes to reduce the impact of future severe weather. WPF also takes care to indicate that its services and warnings are 'unofficial' and points to PAGASA as the source for official data and warnings.

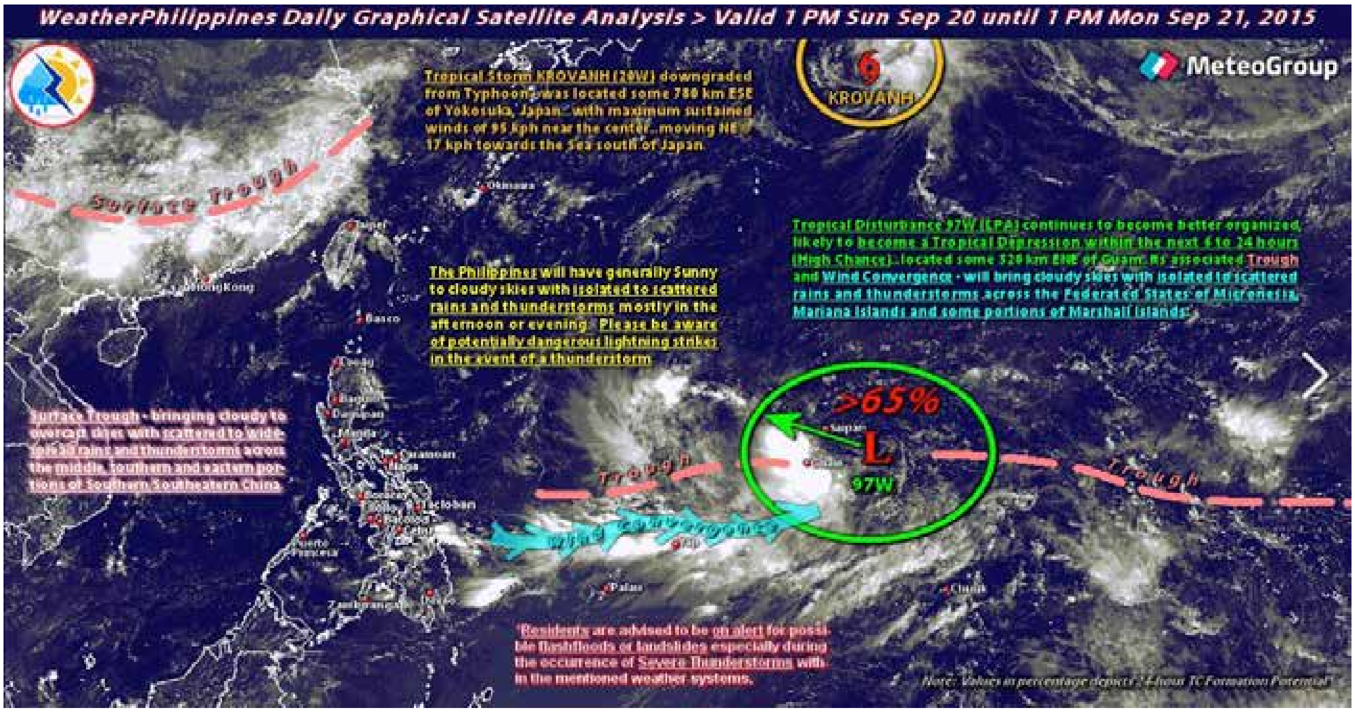
Lessons Learned that are Potentially Applicable to Africa

To learn more about the AWS network being installed in the Philippines, the UNDP Programme on Climate Information for Resilient Development in Africa (CIRDA) sent five representatives from three participating African countries (Tanzania, Uganda and Zambia) to the Philippines to gain first-hand knowledge of the efforts of WPF and MeteoGroup. Based on the follow-up report from the South-South Cooperation mission, and a review of online materials regarding WPF and MeteoGroup, high-level lessons learned from the Philippines include the following:

- Current technology is sufficient to provide highly localized weather observations, forecasts of future weather, and early warnings of severe weather. This information allows individuals to make better, more informed decisions during life-threatening weather events as well as in more routine weather-influenced matters in their daily lives.
- Successful installation of a national, highly localized Early Warning System, such as that operated by WPF/ Meteogroup, requires careful end-to-end planning and tightly monitored execution: from sensor selection, to telecommunications provision, through to delivery mechanism(s) to users.
- It is possible to install an extensive local observing network using good-quality equipment at relatively

FIGURE 7.5

Visible satellite image and overlain analysis and discussion for 20 September 2015 from the WPF web portal (also posted to the Foundation's Facebook page). This visible image is accompanied by the corresponding infra-red (IR) image (not shown). The visible image, its analysis and discussion, and the associated IR image are prepared by MeteoGroup.



modest cost. There appear to be definite economies of scale when the number of instruments to be deployed is large. Local fabrication of components, in-house assembly of the stations from components, and the use of labour from the receiving communities (with some training) to install and maintain the stations further reduces cost.

- Effective outreach to the diverse user communities is essential for political and financial support and to reach those most affected by high-impact weather.
- In the Philippines, a non-profit foundation (established by major industrial and commercial interests) and an established private-sector weather company have together produced a model (non-governmental) early warning system for the islands. This happened because of the synergy between the local support provided by the Foundation and the technical knowledge and skills provided by the private-sector weather company. Is this a model for the future?

BRAZIL'S TOTAL LIGHTNING DETECTION NETWORK

Brazil's efforts to create a total lightning detection network through public-private partnerships provides a working model of how effective PPPs can be structured to meet the needs of NHMS agencies, private-sector partners, industry partners and end-users of Early Warning Systems (EWS).

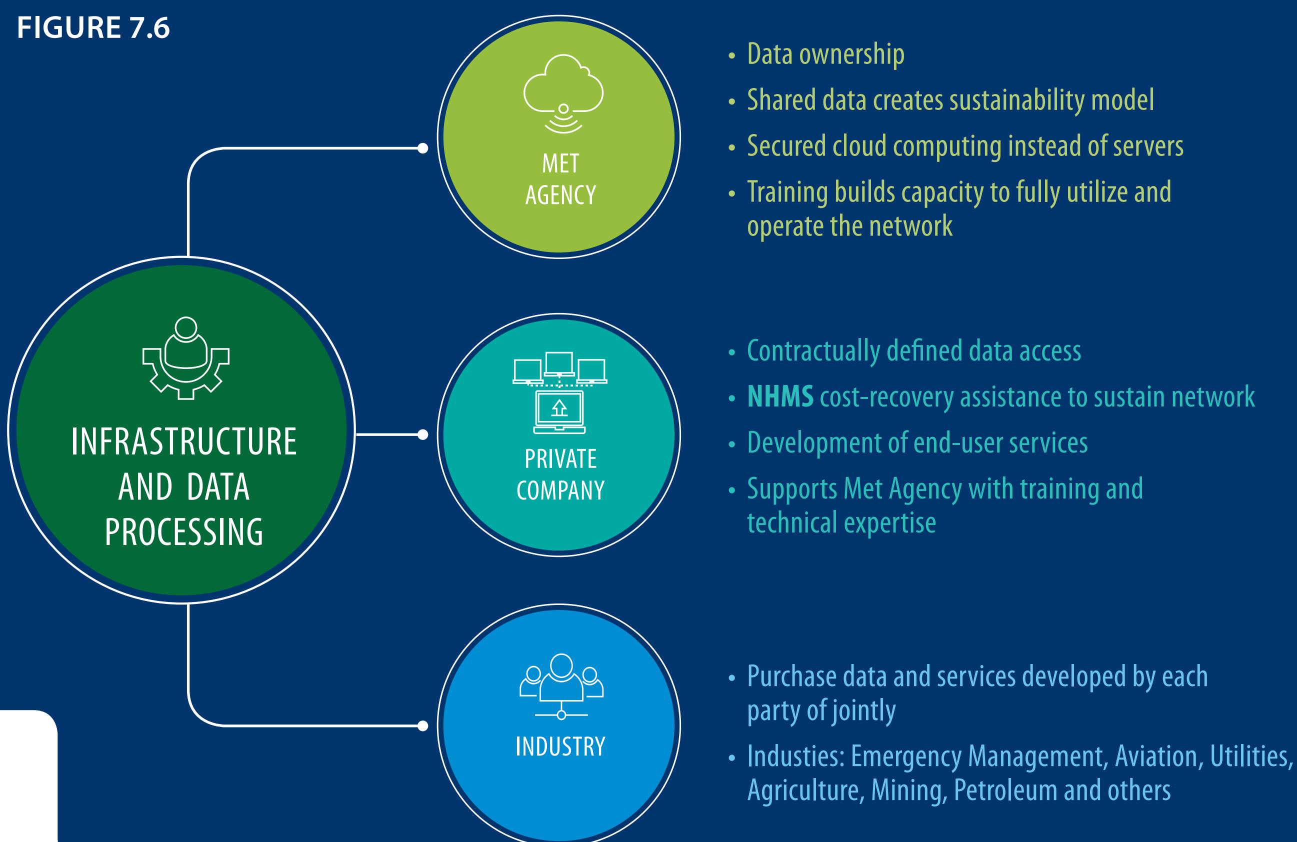
Brazil frequently experiences very intense thunderstorms, with lightning strikes concentrated in densely populated southern areas, including São Paulo and Rio de Janeiro. The resulting floods can trigger lethal mudslides. In January 2011, flooding and mudslides killed more than 900 and left thousands homeless. One year later, in January 2012, flooding claimed more than 250 lives. Timely weather alerts are crucial to preventing future tragedies. The prevalence of lightning, which is often a precursor to severe weather events, and the need to better track and alert people to major storms led to the deployment of BrasilDAT (Sistema Brasileiro de Detecção de Descargas Atmosféricas), the Brazilian Lightning Detection Network.

The detection network was created through a public-private partnership. In December 2010, Earth Networks, a private weather service products provider, entered into a joint research and evaluation partnership with the National Institute for Space Research in Brazil (INPE). Along with local partner company Simtech, Earth Networks and INPE deployed a dense network of total lightning sensors throughout Brazil.[120]

The overall impact is far-reaching and substantial. Advanced weather content is cross-cutting in nature, and the resultant products and services are broadly useful for the public and almost every sector of the economy, including transportation, agriculture, energy, water resource management, insurance and emergency management. In sum, the benefits of the system are expected to be wide-ranging on both national as well as regional levels:

- **Protection of Life and Property**—supporting the overarching mission of the NHMS and the like
- **Climate Change Adaptation**—alerts for the increasing incidence of high-impact climate-induced hazards
- **Disaster Risk Reduction**—ability to automatically alert at the local level in real time
- **Food Security**—early warning of severe weather damage to agricultural production
- **Flood and Drought Warning**—long-term rainfall totals in remote areas with no radar

FIGURE 7.6



[120] The BrasilDAT network is expanding throughout the country with additional sensors for detecting both cloud-to-ground and in-cloud lightning, known as total lightning. The vast majority of lightning is in-cloud, and high rates of it often precede extreme weather, making it a vital part of the severe weather monitoring and alerting process, which can enable effective early warnings. Currently, the BrasilDAT network covers about half of Brazil.

- **Water Resource Management**—monitoring impact of storms on water levels downstream
- **Energy Security**—electrical grid stability, power outage management, demand response
- **Hydropower**—operation of power plants, localized real-time rainfall totals without radar
- **Development of Infrastructure**—inclusion of localized rainfall and storm statistics in planning
- **Regional Aviation**—flight safety, air traffic control, ground crew safety at airports
- **Sustainable Operation**—revenue from provision of information to sustainability partners

The business model to deploy and support the EWS has several components to ensure it is sustainable: shared initial investment with seed funding, shared operational responsibilities and data rights, revenue sharing from ongoing data services to target market, and funding allocated to ensure reliable network operation. A Business Plan and Total Addressable Market (TAM) analysis to enable the long-term sustainability of the EWS was developed to ensure its sustainability. In Brazil, the new infrastructure generates roughly US$1 million in annual revenue for the partners.

Tracking Benefits to Energy, Aviation, Mining and NHMS

Brazilian weather and climate data and content service customers include the largest electrical utility companies EDP, Coelba, CELG and several others. These companies invest in the generation and usage of severe weather data because it helps them improve power quality; prevent and manage outages; and improve their overall operations. As Brazil continues to grow economically and technologically, large industry players such as utility companies advance into smart grid applications, with weather data becoming an integral part of the process.

Notably, around the world one of the other key sustaining supporters of meteorological agencies and research institutes is the aviation sector. For instance, aviation provides a large proportion of the operating budgets of national meteorological agencies in the European Union and the United States, and it is the key driver behind the advanced service delivery observed

Figure 7.7 Market segments from Brazil for specific weather data, monitoring and applications.

	MARKET SEGMENT								
PRODUCT	Oil and Gas	Renewables	Utilities	Aviation	NHMS	NHMS	Public Safety	Consumer	Other
Data Feeds									
Lightning	X	X	X	X		X		X	X
DTA's	X	X	X	X		X		X	X
PulseRad			X	X		X		X	X
ENcast	X	X	X			X		X	X
Professional Visualization Tools	X	X	X		X	X	X		
Mobile Alerting	X	X	X		X	X	X		X
Outdoor Alerting	X				X		X		
Consumer Aplication			X				X	X	X

in French-speaking African countries, members of the Agency for Aerial Navigation Safety in Africa and Madagascar (ASECNA). Aviation is acutely dependent on information about the changing weather and increased occurrences of high-impact climate-induced hazards, such as the growing prevalence of rapidly developing severe storm systems in the region.

In Brazil, as well as globally, lightning data is used by airports, airlines, civil aviation authorities, air force commands and others. Uses range from basic ground crew safety enabled with proximity alerting applications, to the more advanced air traffic control applications enabled with severe weather tracking and alerting applications. For instance, Brazilian oil company Petrobras uses the data for their airplane and helicopter fleets that deliver goods and staff to and from offshore facilities.

Mining is an industry that is very sensitive to the weather and associated hazards. In particular, severe weather and lightning safety are key concerns for the mining companies. This is because mines often perform operations such as blasting that need to cease immediately if there is any possibility of inbound severe weather, which represents a risk to equipment, the risk of injury, possible loss of life, and, ultimately, financial losses. Mining companies have many operating sites and use real-time proximity alerting services on a routine basis.

Furthermore, in Brazil the data have enabled the local commercial weather service providers to enhance the services they provide to government and private sectors via GIS-based applications, as well as to the general public via mobile applications and broadcast media. Companies like Climatempo have developed brands and levels of trust among the population.

While Brazil's political, economic and regulatory environment is distinct from much of Africa, the lessons learned from this large middle-income country underscore the need for shared risk, specific avenues for revenue generation and unique takeaways on a functioning early warning system created through a public-private partnership.

ECONET IN ZIMBABWE

In Zimbabwe, the market-leading telecommunications provider EcoNet Wireless is packaging and distributing valuable information such as farming tips, health advice, weather information and mobile banking options to engage with rural customers, build brand loyalty, and support the overall image of the company. The company has launched a wealth of feature phone-enabled subset brands, such as EcoCash, EcoHealth, EcoSchool and EcoFarmer.

"EcoFarmer is a revolutionary way of farming using mobile technology. It is Zimbabwe's first micro-insurance product designed to insure inputs and crops against drought or excessive rainfall. In addition, the insured farmer will also receive daily weather information, farming tips and information on when and where to sell, and the best price for their produce," according the platform's website.

The EcoFarmer platform includes the following information:

- Daily weather data from a weather station linked to the field of the respective user
- Farming and market tips
- Free daily rainfall advice
- Free weekly best farming prices
- Free weekly crop data
- Free monthly market pricing requests
- Crop information
- Credit rating
- Free adverts and marketing links
- Financial linkages

There are three basic levels of subscription: General Farmers get very basic information for free, Registered Farmers provide some information (a monetizable asset for telecommunications firms) and receive expanded information, while Insured Farmers receive all the information, plus a supporting insurance policy.

TARGETED, LOCALIZED PLANTING AND HARVESTING INFORMATION FOR CANADIAN WHEAT PRODUCERS

While much of LDC Africa is engaged in low-productivity, sustenance, rain-fed farming practices, the agricultural sector still dominates the economy throughout the region. Therefore, the introduction of even tiny improvements in efficient or more productive farming practices and techniques could have an immediate impact on economic development.

Substantial development efforts for the agricultural sector in Africa have focused on financial products through the creation of crop or index insurance for individual farmers or sovereign risk products for government use at the national level, but additional effort on the development of more efficient operational practices at the local level might also contribute to sustainable economic development.

While mechanization and land management policies have rapidly advanced agricultural productivity around the world, developed economies have also begun to establish richer and more relevant weather and climate data sets to further improve crop yields. The introduction of similar techniques could have an impact on food security and rural livelihoods within Africa as well.

One such example is a service called Weatherfarm, an online weather data and agricultural information resource operated on behalf of farmers throughout Western Canada by Weather Innovations Consulting and Glacier Media. Originally introduced as a public-private partnership between the Canadian Wheat Board (a public agency of the Canadian national government) and WeatherBug (a private weather services firm), Weatherfarm deployed a network of more than 1,000 weather stations delivering real-time weather observations to wheat farmers in Canada. This network of low-cost, automatic weather stations provided growers throughout Western Canada with weather observations much closer to, if not directly on, their farms than ever before. Additionally, this rich data set was used to enhance the quality of weather forecasts, and as input into basic models for planting, irrigation and harvesting decisions, and more advanced models for pest and disease management.

Today, each automatic weather station in the Weatherfarm network is managed by a farmer or an organization that has a vested, economic interest in keeping the data flowing to the broader community. The community is further supported financially through the sale of sponsorships to agricultural input providers, which in turn help sustain and enhance the products, services and operations of Weatherfarm. This community-based model for the creation and distribution of weather information could be one way for LDC African countries and their respective NHMS to sustainably establish weather and climate networks and enhance economic development for the agricultural sector and the national economy.

By subscribing to the services for 8 cents per day for 125 days, Insured Farmers are said to be guaranteed a harvest or at least US$100 for every 10kg of seeds planted. In an obvious partnership with a sponsor, the seeds have to be SeedCo brand. They provide this micro-insurance "regardless of the weather conditions," meaning this is not true index-based insurance, but rather a smart marketing scheme designed to engage customers. It's working, however, and the modality is an interesting one for other African nations. There are currently an estimated 300,000 subscribers. They spun-off the EcoFarmer service in 2015 to launch a separate, new service called 'Dial-A-Mudhumeni', a partnership with Zimbabwe's Ministry of Agriculture that connects smallholder farmers with agricultural extension workers.

Where does the weather information come from? EcoNet has developed a network of cell-tower-based stations to monitor weather patterns including rainfall, temperature and humidity. More specifically, "Zimbabwe operator EcoNet has inked a partnership agreement with the Metrological Services Department (MSD) to provide weather information to smallholder farmers. The MSD issues weather forecasts to the public, and EcoNet provides the data platform for distribution. The MSD's new weather station automatically records the parameters and transmits the data to MSD remote stations and its offices in Harare via SMS. The data received at the MSD in Harare will be relayed to the Ministry of Agriculture, Mechanization and Irrigation Development for policymaking. The new system for weather measurement and monitoring will be installed throughout the country to assist smallholder farmers in accessing information."[121] They locate the farmers using a smart application connected with the seeds. The seed packs hold a small, plastic container with a specific number that the farmer must send to the network via SMS. As soon as the number is received, the farmer's location will be noted, and rainfall in the area will be monitored.

[121] 'Econet Zimbabwe launches weather data platform,' *Telecompaper*, 15 October 2015, www.telecompaper.com/news/econet-zimbabwe-launches-weather-data-platform--972950.

CONCLUSIONS

EARLY WARNINGS COULD PROTECT FISHERS ACROSS AFRICA.

Finding next steps is the challenge for everyone. While this report serves as a catalyst for change—articulating a new vision for the acquisition, distribution and application of reliable hydromet information across Africa—it is the role of African governments, donors, thought leaders and business enterprisers to leverage this knowledge to create customized, tailored, integrated and long-lasting solutions that will propel the development agenda forward and positively impact the lives and livelihoods of the 3 billion people worldwide living in poverty today.

This report began with a description of the challenges facing hydromet services in Africa today, highlighting the many damaging consequences of this reality for everyone from poor farmers to major businesses. Every year, people die unnecessarily due to the absence of effective warnings of lightning and severe storms. Meanwhile, businesses—from smallholder enterprises to larger agricultural companies to transportation firms to power companies—make do with imperfect weather information, losing out on the productivity badly needed for economic development, market stealth and long-term sustainability. This failure to provide essential information comes despite considerable support from donors and multilateral development banks over the years, not to mention the dedicated efforts of many conscientious public servants within government agencies. It has also created a self-reinforcing non-virtuous cycle: as public weather services came to be viewed as unreliable, support for public funding diminished, leading to yet further inability to maintain systems much less to make improvements.

In contrast, the new technologies and partnerships outlined in this publication hold the promise of a virtuous circle. As services improve, public and business support will increase and the case for greater public resources—partially offset by revenue from private services—will steadily strengthen. This process need not require long periods of time as the technologies required are modular and can be installed in days, although the training of staff and the integration of information with existing systems will take somewhat longer. Moreover, insofar as timely and more reliable weather information can provide benefits to other agencies, such as those in disaster planning, agriculture, tourism, energy, etc., there is a further likelihood of growing internal support for National HydroMeteorological Service (NHMS) budgets.

It should be evident that the hopeful vision outlined in this report is tantalizingly close but still some distance from realization. Initial funding has been secured, collaboration with at least the 11 countries supported through the UNDP's Programme on Climate Information

INSTALLING IMPROVED WEATHER MONITORING TECHNOLOGY IS THE FIRST STEP TO CREATING AN INCLUSIVE END-TO-END SYSTEMATIC APPROACH.

for Resilient Development in Africa (CIRDA) has begun, market studies are uncovering new opportunities, and technical support is being offered through workshops and a technical support team.[122] Numerous other international development agencies are joining in support of nationally driven resiliency efforts, with continued increases in funding for climate change adaptation. However, the ultimate commitment to make the necessary changes will require buy-in, leadership and persistence from Africa's leaders, continued discussion by thought leaders and knowledge brokers, and flexibility, adaptability and humanity.

[122] Interested readers are invited to check the CIRDA website (www.undp-alm.org/projects/cirda) periodically for progress reports and more detailed information on technologies and specific country programmes. To share your reactions and reflections, visit the CIRDA blog at www.undp-cirda.blogspot.com.

COUNTRY PROFILES

Applying a new vision to hydromet services in Africa will require adaptability, flexibility, ingenuity and custom tailoring. Unique and varied social, political, environmental, economic and legal frameworks will necessarily drive the way as new weather, water and climate services are put into place within individual African countries. The brief country profiles in this annex point to some of the existing strengths, weaknesses, opportunities and challenges within the 11 National HydroMeteorological Services supported by the UNDP Programme on Climate Information for Resilient Development in Africa (CIRDA). The profiles were informed by a market study of the 11 countries, as well as by progress indicators and other relevant monitoring and evalution efforts by UNDP and the UNDP-supported Climate Information and Early Warning Systems Projects (CI/EWS). They have also been reviewed by country teams and development experts.

Each profile provides a summary metric in the form of a public-private partnership viability index created by the research firm that conducted the market study: C4 EcoSolutions. The viability index uses red to indicate 'least ready', orange as 'progressing', and green as 'most ready.' Conducting a market analysis and review of existing challenges is a helpful starting point to dentifying markets, political support, and legal frameworks conducive to the pursuit of public-private partnerships in the climate and weather services space. However, it will be the work of individual African governments to identify key areas where public-private partnerships can be effectively leveraged to support the overall sustainability of the climate information and early warning systems and achieve the opportunities created by this new vision.

BENIN

Benin is one of the most stable democracies in Western Africa. It ranks 166th out of 188 countries on the UNDP Human Development Index (2015). Persistent economic challenges remain, however, as does its vulnerability to climate change and severe weather. In a nation where 70 percent of the workforce relies on agriculture, changes in precipitation could have severe impacts on both food security and income. Sea-level rise threatens the country's fishing activities, tourism and ports, and cyclical floods affect human lives, crops, livestock and productive infrastructure.

The UNDP-supported Climate Information and Early Warning Systems Project (CI/EWS) seeks to significantly improve climate services in Benin. By tailoring revenue-generating forecasts for various socio-economic sectors, the project strives to set the foundations for financially sustainable weather and climate monitoring in Benin. Together with satellite imagery used for land-use planning and monitoring, tailored climate products will provide significant environmental benefits at the local level, for example by detailing the best coastal management practices to help in Benin's fight against coastal erosion.

Weather and climate monitoring equipment has been procured and rehabilitated, including rain gauges, Doppler flow meters, oceanographic buoys and synoptic weather stations. A mix of manual and automatic stations is being used to support a gradual transition to a fully automated information collection system. Sea-level and coastal erosion monitoring equipment has also been purchased, including spare parts and tools to facilitate future maintenance. Technical institutions are receiving training on data storage and analysis, as well as on how to manage and properly budget for the expanded observation network and associated recurring costs.

The project also facilitates inter-agency and cross-boundary data sharing. This is particularly critical for Benin, as all of its watersheds cross into neighbouring countries. In order to build effective hydrological and weather forecast models, data exchange from upstream is required.

The country has the legal framework required to monetize weather and climate data, but it has had little success to date in packaging relevant information for use by the private sector.

Benin issued early warnings for flooding through a multiagency committee in 2014 and 2015 by using manual monitoring of river levels, data processing and information analysis. The country has also adopted a standard operating procedure for the diffusion of alerts through the National Disaster Management Agency. Additionally, Benin has the technical and institutional frameworks in place for climate modelling.

Telecommunications and Public-Private Partnerships

Benin has 10.8 million cellular subscribers, and there is a phone for every inhabitant of the country. This doesn't mean that every person in Benin has a phone; some people may have two or three. Benin has five active mobile phone companies. MTN

BIG PICTURE

Per Capita GNI (2014): US$810

Living in Poverty (2011): 36.2%

Persistent Challenges: Coastal encroachment and sea-level rise, insufficient electrical supply, reliance on subsistence agriculture, cyclical floods, a volatile economy due to reliance on climate-sensitive sectors that are insufficiently adapted.

HYDROMET PPPS

Conducive Policies: Yes, in the form of a draft law to allow NHMS to charge for services and a recently approved meteorological bill (2015) to encourage PPPs to develop meteorological services.

Existing Legal Framework: Yes

Overall C4Ecosolutions Viability Index: Orange

NHMS CHALLENGES

- Sparse network of observation stations;
- Slow transmission of data from the manual hydrometeorological stations;
- Poor long-term planning of budgets;
- Insufficient skilled human resources;
- Limited collaboration between different localized early warning initiatives;
- Inconsistent cross-sectorial data sharing and dissemination;
- Limited tailoring of weather and climate information to user needs.

REVENUE GENERATION

National Met Budget: US$50,000

Current revenue generation: There are regulations that enable the Meteorological Department to sell data, however, the income generated from these sales does not cover the costs of providing the information.

Use of Private Weather Data: None

USE OF WEATHER DATA

Benin does not use radars, rather, its system is comprised entirely of AWS. The installation of Early Warning Systems (EWS) based on lightning sensors could bolster the new efforts to monitor and report early warnings and have positive economic and social impacts. Farmers now have better information for planting, and they receive warnings to move their livestock out of harm's way. The private sector has improved information for decision-making, and the Government has a new agency that models the impacts of climate change. Ongoing partnerships between the Meteorological Department and the agribusiness sector are being evaluated by a National Adaptation Programme of Action (NAPA) project.

is the largest, with 45 percent of the market. Other telecommunications companies included Bell Benin Communications, Benin Telecoms, Libercom, Globacom and Moov. The project is pursuing relationships with telecommunications providers, and has placed special emphasis on the packaging of data for the private sector. Forecasts will be tailored to various sectors such as small-scale rain-fed agriculture and large-scale cotton cultivation to improve production and reduce susceptibility to food insecurity.

Industries that could benefit from custom-tailored weather information include the following:

- **Agriculture.** Agriculture, especially cotton production, accounts for much of Benin's economic production. Crop reports, flood and drought warnings, and tailored reports for cotton production could benefit this sector. The shea and pineapple industries could also benefit.
- **Livestock.** Flood and drought warnings could reduce losses.
- **Fisheries.** Severe wind and rough sea warnings would protect human lives.
- **Banking and Insurance.** Tailored reports could be provided for weather index–based insurance.
- **Transportation.** Information could inform decision-making on road closures.
- **Tourism.** This is a growing industry that could benefit from both seasonal forecasts and tailored advisories on high seas and wind.

Institutional Structure

Benin's Meteorological Department is the sole provider of weather and climate information in the country. Climate warnings are also produced by the Water Department, the regional aviation agency (ASECNA), and the Ocean Institute. The Disaster Management Agency, along with a cross-functional committee, issues warning bulletins.

Conclusion

To increase income generated from products and services, Benin's Meteorological Department should conduct user-needs assessments. With the automatic weather stations (AWS) acquired through the CIRDA project, a relatively dense local observation network is in place, but the data collected are not yet used to create the high-value data needed to commercialize the information produced by the Meteorological Department. Although challenges in the areas of human resources, effective fiduciary controls and cross-departmental sharing may hinder progress, the issuance of recent early warnings, the availability of conducive legal and regulatory frameworks to sell data, and recent forays into private sector engagement point to overall progress.

OCEANOGRAPHIC AWS IN BENIN.

BURKINA FASO

Burkina Faso ranks 183rd out of 188 countries on the UNDP Human Development Index (2015). The level of persistent poverty in the country is compounded by the spread of mosquito-borne illnesses and exposure to high-impact climatic events like floods and recurrent droughts, among other factors.

Flooding in September 2009—with the heaviest rainfall ever recorded—and also in August of 2015 and July of 2016, along with civil unrest, have taken their toll on the nation's ability to prioritize and maintain hydrometeorological observation systems.

Through the UNDP-supported Climate Information and Early Warning Systems Project (CI/EWS), the Government of Burkina Faso is seeking to improve its monitoring systems, develop public-private partnerships (PPPs) to increase revenues for National HydroMeteorological Services (NHMS), build partnerships with telecommunications companies, further develop activities related to weather index–based insurance, create strategies to mobilize funds from the national budget, build integrated communications strategies to aid in the issuance of early warnings, and improve overall climate data sharing with neighbouring countries.

The country has no existing legal framework for the monetization of weather and climate data, and it has had little success to date in successfully packaging relevant information for use by the private sector.

The met service has acquired 150 automatic weather stations (10 synoptic, 40 agro-climatic and 100 rain gauges), bringing the national coverage from 25 up to 75 percent for rain gauges. The Hydrology Department has acquired 16 hydrological stations, three acoustic Doppler current profilers, 100 mires mist, one data server and software for Early Warning Systems (EWS) and data transmission and processing. The RADAR (Radio Detection and Ranging) in Ouagadougou is being rehabilitated to support nowcasting at the met service. The project aims to establish a Standard Operating Protocol for the issuance of early alerts.

Telecommunications and Public-Private Partnerships

The telecommunications industry is competitive in Burkina Faso, with three main operators vying for customers from the 12.5 million estimated national subscribers.

The CI/EWS Project in Burkina Faso is actively pursuing PPPs with Telmob Burkina, Airtel Burkina and Telecel Faso, and is seeking to create a Short Message Service (SMS) early warning system using weather data similar to the 3-2-1 Service. A pilot project on the collection and dissemination of lightning information is being finalized by the General Directorate of Meteorology (Direction Générale de la Météorologie, DGM).

BIG PICTURE

Per Capita GNI (2014): US$710

Living in Poverty (2009): 46.7%

Persistent Challenges: High exposure to extreme weather and climate change, floods, droughts, mosquito-borne illness and Ebola, civil unrest.

HYDROMET PPPS

Conducive Policies: No

Existing Legal Framework: There is no dedicated PPP unit in Burkina Faso. However, the private sector can approach the chamber of commerce to indicate they are interested in a partnership. Also, if the private sector directly approaches the NHMS and can come to an agreement, this process is not needed and the private sector and NHMS can develop a MoU.

Overall C4Ecosolutions Viability Index: Green

NHMS CHALLENGES

- Limited hydrometeorological monitoring equipment;
- Limited automatic weather stations, particularly synoptic and agrometeorological stations;
- Limited budget to maintain equipment;
- Timely dissemination of weather information in the local language;
- Accessible NHMS data for potential users.

REVENUE GENERATION

National Met Budget: NA

Current revenue generation: The main source of income for met services in Burkina Faso is the aviation sector. This income is used to maintain the network of observation stations and pay DGM staff. The products and services that generate profit for the DGM are climate databases and maps that indicate average rainfall.

Use of Private Weather Data: None

USE OF WEATHER DATA

Burkina Faso has a network of approximately 150 meteorological observation stations. Since 1980, data generated from these stations have been digitized. These data are used to produce 10-day agrometeorological bulletins, which include information on humidity, evapotranspiration and solar radiation. These data, along with parameters on rainfall, temperature and wind, are presented in graphs and tables. In addition, the DGM provides forecasts on precipitation and temperature at the beginning and end of the rainy season.

Data produced by weather stations are used to generate forecasts and warnings, which are regularly transmitted through radio and television. However, the low density of weather stations suggests that the accuracy and quality of forecasts need to be improved.

Industries that could benefit from custom-tailored weather and climate information include:

- **Cotton.** Accounting for a third of GDP, this is a mainstay industry. Soil moisture, humidity, the number of sunny days and night-time temperatures all affect the overall quality of cotton production.
- **Mining.** While the mining industry is relatively small, mines could benefit from localized early warnings, lightning forecasts and monitoring that protects roads.
- **Infrastructure.** Burkina Faso has a relatively good road system, and a railway that runs south to the Atlantic Ocean. Protecting this productive infrastructure with working monitoring systems can be used as a value proposition within the Government.

Institutional Structure

Meteorological Agency Structure: The DGM of Burkina Faso is responsible for overseeing all meteorological matters. The DGM is mandated with regulating, planning and implementing Burkina Faso's policy on weather and climate activities. The General Directorate of Water Resources (DGRE) is mandated with monitoring water resources and is in charge of implementing policies related to water resources in Burkina Faso. The Permanent Secretariat of National Emergency Council and Rehabilitation (SP-CONASUR) is mandated with information dissemination in the field of early warnings in collaboration with the General Directorate of Civil Protection (DGPC) and Government Information Service (SIG).

Conclusion

If it is able to withstand civil unrest, along with ongoing challenges related to endemic poverty, Burkina Faso is well poised to become an important presence in Western Africa in terms of public-private partnerships within the weather and climate sectors. The biggest challenge will be creating a true value proposition. The demand for these products and services can be increased by improving their quality, as well as by increasing awareness of met services and government involvement.

The next steps will include the finalization of the installation of automatic weather stations (AWS) and their use to improve forecasting and early warning systems, and pursuit of the dialogue between the hydromet directorates and the telecommunication operators with the objective of establishing a win-win partnership.

PHOTO BY JOOST HOEDJES.

ETHIOPIA

The UNDP Human Development Index ranks Ethiopia 173rd out of 187 countries (2013). The 2015 El Niño brought drought to the region, producing one of the most severe food security challenges faced by the nation since the 1980s. In a country prone to drought, the lack of effective weather and climate monitoring systems hinders long-term decision-making and adds risk to the nation's smallholder farmers.

The country currently has US$26.4 million in adaptation-focused multilateral funding, with multilateral projects funded through the Forest Carbon Partnership Facility, Global Climate Change Alliance, Least Developed Countries Fund (LDCF), MDG Achievement Fund, Scaling Up Renewable Energy in Low Income Countries Program (SREP), and the Special Climate Change Fund. Ethiopia is also a pilot country for the USAID-supported Climate Change Resilient Development (CCRD) project.

The UNDP-supported Climate Information and Early Warning Systems Project (CI/EWS) in Ethiopia has the overall objective of increasing the capacity of the country's hydrometeorological services to monitor and predict weather events and climate change.

The project aims to strengthen the capacity of national and subnational entities in Ethiopia to monitor climate change, generate reliable hydrometeorological information (including forecasts), and be able to combine this information with other environmental and socio-economic data to improve evidence-based decision-making for early warning and adaptation responses as well as planning.

The project has enhanced the capacity of the National Meteorological Agency (NMA) and the Hydrological and Water Quality Directorate in the Ministry of Water, Irrigation and Electricity by the commissioning, procurement and installation of, among other instruments, 40 automatic weather stations (AWS) and 60 automatic hydrological gauging stations to monitor extreme weather events and climate change. Additionally, hydrometeorological and environmental information for early warnings and long-term adaptation has been improved through the establishment of equipment and other instruments that will increase the efficiency and effectiveness of early warning systems.

This project allowed NMA to produce tailored products for specific sectors by (i) creating an enabling environment for NMA to produce and use weather and climate forecasts; (ii) identifying markets for tailor-made early warning products; (iii) increasing the country's capacity to incorporate climate and weather data into its Climate-Resilient Green Economy Strategy and Growth and Transformation Plan II; (iv) creating channels to distribute early warnings to communities; and (v) establishing partnerships between the public and private sectors to support the financing of early warning and climate information systems. Recent efforts by NMA have served to enhance food security by providing farmers

BIG PICTURE

Per Capita GNI (2014): US$691

Living in Poverty (2010/2011): 29.6%

Persistent Challenges: Droughts and floods; food, water, energy and economic insecurity.

HYDROMET PPPS

Conducive Policies: Currently, the NHMS charges for some data, but it has to return this income to the Ministry of Finance and Economic Cooperation, who controls the division of revenues. Towards changing this, the NHMS has put in a proposal for a law to form public-private partnerships (PPPs).

Existing Legal Framework: No

Overall C4Ecosolutions Viability Index: Orange

NHMS CHALLENGES

- Lack of representative meteorological station network in the country;
- Limited budget for managing and administering station network;
- Limited capacity and budget for expanding and maintaining existing meteorological stations network;
- Inadequate channels to communicate weather and climate data;
- Limited technical capacity of NMA staff;
- Limited capacity to introduce modern technology;
- Inefficient network lines between head and branch offices;
- Gaps in data;
- Faulty equipment and slow maintenance services, with limited budget to improve instruments and provide training to staff;
- Limited digitization of historical climatological data;
- Limited capacity to provide meteorological forecasts, aviation meteorology, and for the needs of the development meteorology service.

REVENUE GENERATION

National Met Budget: NA

Current revenue generation: NA

Use of Private Weather Data: None

USE OF WEATHER DATA

Currently, NMA has over 1,000 conventional weather stations, 70 automated weather stations (AWS), an upper air observation station and automated weather observation systems at the different airports in Ethiopia. In addition, NMA receives satellite images every 15 minutes from the Meteosat Second Generation (MSG) satellite launched by the EU. Products generated by NMA are disseminated through broadcast, print and online media. In addition, NMA's observed data are disseminated to WMO member countries, with which it exchanges information.

Through a project implemented by the World Food Programme in 2010, NMA received an additional 37 AWS. These collect data on environmental variables, including air temperature, rainfall, relative humidity, solar radiation, wind speed and wind direction. These data are transmitted to a central base station every 15 minutes, thereby removing the need for field visits. Forecasts are delivered daily, every three days, every 10 days, monthly and seasonally. In addition, risks associated with hazardous and extreme weather events are forecasted, thereby enabling farming communities to prepare for the negative effects of hazardous climate and weather events.

AN EXAMPLE OF A WELL-LAID OUT, WELL-MAINTAINED SYNOPTIC OBSERVING STATION USING TRADITIONAL EQUIPMENT AND HUMAN OBSERVERS TO RECORD DATA.

with valuable weather information, connecting farmers to insurance, and providing health bulletins.

Telecommunications and Public-Private Partnerships

Ethio Telecom is the state-owned monopoly that runs both fixed-line and mobile telecommunications. There are about 30.5 million cell-phone users in the country, but overall saturation is low, with about 32 phones for every 100 inhabitants. Private companies that install meteorological stations are legally required to share the data that is collected with NMA. However, this law is rarely enforced, thereby limiting the extent to which the NMA gains access to privately collected weather data. Investment in NMA by the private sector could increase the density of the meteorological observation networks.

Industries that could benefit from custom-tailored weather information include the following:

- **Energy.** While agriculture is still the main economic driver, the Government of Ethiopia is seeking to diversify into manufacturing, textiles and energy generation. Energy enterprises could benefit from long-term climate modelling to balance costs and benefits.
- **Agriculture.** While monetizing agricultural information will be a challenge in a country of smallholder farmers, the opportunity to leverage better climate information for weather index–based insurance, and to use customized reports for growing export enterprises like the coffee industry, may offer some opportunities.

Institutional Structure

The mission of the National Meteorology Agency (NMA) is to collect, analyze and study climate data to provide weather forecasts and early warnings on the negative effects of weather and climate in Ethiopia. To achieve its mission, NMA has developed the following strategic objectives: (i) fulfil national needs and international obligations relating to meteorology; and (ii) establish and operate a national network of meteorological stations. In addition, NMA is mandated with preparing and disseminating AgroMeteorological Advisory Bulletins to assist planners, decision makers and farmers. NMA also provides monthly, seasonal and annual Climate Bulletins and annual HydroMeteorological Bulletins. The Government of Ethiopia has always supported the National Meteorological and Hydrological Services (NHMS) and as a result the NHMS does not experience problems with funding. There is therefore no urgency for the NHMS to engage with the private sector to increase revenues.

Conclusion

There is a possibility to generate revenue through the sale of weather and climate products to private sector enterprises. The revenue generated for NMA will increase with the improvement of private sector awareness of the benefits of weather and climate information. For instance, the insurance sector needs weather data to appraise insurance claims made by smallholder farmers. However, the current recovery fee does not cover the cost of the service.

THE GAMBIA

This small country (ranked 175th on the UNDP Human Development Index as of 2015) faces unique challenges in terms of economic factors and from climate change. Given its geographic location, coastal erosion and salinization can be aggravated by heavier rains, more intense coastal storms and droughts. The country relies heavily on remittances and international aid, with limited developed industries. The agricultural sector employs three quarters of the population and makes up almost one fifth of GDP. Agriculture has untapped potential with just half of the country's arable land currently being cultivated, but it is threatened by a lack of good weather and climate information and changes in weather patterns. Tourism is another economic driver with growing potential.

Public-private partnerships already exist between the National HydroMeteorological Services (NHMS) and advertisers, and a proposed act would pave the way for more partnerships with the private sector, including in the fishing, marine, construction and aviation sectors.

The Gambia Chamber of Commerce and Industry is the lead for private sector engagement on climate change, and a Climate Change Forum has been created to bring together national partners. A planned market analysis, cost-recovery policy and overarching business plan are part of the project's proposed actions to build sustainability and generate revenue.

The objective of the UNDP-supported Climate Information and Early Warning Systems Project (CI/EWS) is to strengthen early warning systems and the climate monitoring and adaptation capabilities of the Gambia. To achieve this objective, the project will promote the following measures: (i) support for transitioning the NHMS towards financial sustainability; (ii) the installation, upgrading and maintenance of the hydrometeorological infrastructure of the Gambia to meet the needs of an optimal performance early warning system; (iii) the training of staff to operate early warning systems, as well as to plan for medium- and long-term climate adaptation; and (iv) effective communication of climate information to local communities and other stakeholders. In addition to increasing the capacity of the Gambia to monitor and forecast extreme weather and long-term climatic changes, this project will increase the technical capacity of NHMS staff. The capacity of forecasting institutions to monitor and deliver mandates will also increase.

The CI/EWS project has thus far purchased nine automatic weather stations (AWS), with installation slated for the near future. The procurement process for the acquisition of two PILOTSONDE systems is underway. An early warning system is also being procured.

Telecommunications and Public-Private Partnerships

There are four mobile operators in the Gambia, including Gambia Telecommunications (partially privatized in 2007), Africell, Comium and QCell. With 2.3 million mobile users (119 subscriptions for every 100 inhabitants), mobile saturation

BIG PICTURE

Per Capita GNI (2014): US$440

Living in Poverty (2010): 48.4%

Persistent Challenges: Coastal erosion and salinization, droughts, floods, storms, limited natural resources, reliance on remittances, fiduciary controls.

HYDROMET PPPS

Conducive Policies: There is an act under consideration that will enable the NHMS to form a partnership with the fisheries and marine sectors, as well as with cell-phone companies. This partnership will assist NHMS with improving the quality of their products and services.

Existing Legal Framework: No

Overall C4Ecosolutions Viability Index: Orange

NHMS CHALLENGES

- Limited capacity to develop sector-specific services and products;
- Limited capacity of NHMS to communicate products to end users, especially in rural communities;
- Obsolete and inadequate climate monitoring infrastructure, thereby limiting data collection as well as the analysis and provision of meteorological services;
- Shortage of skilled staff, thereby reducing the capacity of NHMS to predict future climatic events;
- Climate information is not packaged, translated or disseminated according to user demands;
- Limited use of climate information and warnings at the community level.

REVENUE GENERATION

National Met Budget: NA

Current revenue generation: Sponsors pay for broadcasting by advertising their product before and after the weather forecast.

Use of Private Weather Data: None

is high. There is an act under consideration that will enable the NHMS to form a partnership with the fisheries and marine sectors, as well as with cell-phone companies. This partnership will assist NHMS in improving the quality of their products and services.

Actors and stakeholders in the Gambia that require weather and climate data include the following:

- **Civil Engineering Companies** contracted to construct roads and bridges require information on rainfall distribution, temperatures and wind patterns.
- **The Tourism Management Board** requires information on temperature fluctuations, rainfall and incoming storms.
- **Civil Aviation Authority (GCAA)** for Aeronautical Services requires information for principal users of weather and climate data for the safety of air navigation.
- **The Gambia Ports Authority (GPA)** for marine navigation requires information on incoming storms, high and low tides, sea waves (rough) and wind speed.
- **Construction companies** require information on rainfall distribution, wind direction and speed, and the temperature regime.
- **The Gambia National Water and Electricity Company (NAWEC)** requires information on the quantity of rainfall distribution for each region for the purpose of borehole drilling and gauging water tables for operation.
- **The Gambia Football Federation (GFF)** requires information on incoming storms.
- **Fisher Folk Associations** require information on wind storms to avoid the loss of lives and property.
- **Farmers' Associations and Livestock Associations** require information on the time of rainfall onset, rainfall quantity and the time of cessation.
- **Poultry farmers** require information on temperature variation, which is linked to production, and rainfall quantity for drinking water.
- **Insurance companies** require information on weather variables to determine payouts.
- **Commercial banks** require information on seasonal forecasts to determine loan agreements with farmers.

Institutional Structure

Although the Gambia National Meteorological Service (GNMS) is funded by the Government, GNMS is supporting an act that will establish it as a semi-autonomous organization. This will allow GNMS to engage with the private sector and increase income for NHMS, as currently the services provided to the private sector are overseen by the central government, with GNMS receiving only a small portion of the revenue.

Conclusion

While the CI/EWS has yet to really take off, given the steps to establish PPPs, a conducive regulatory framework, and the political will to generate income through public-private partnerships, the Gambia has many of the pieces in place to begin laying out an effective PPP strategy. The limited capacity of GNMS to communicate effectively with local communities may lead to

RIVER GAMBIA NIOKOLOKOBA NATIONAL PARK. PHOTO BY ANTPUN.

inadequate use of project products and reduce sustainability. However, partnerships have been developed with existing network providers such as Q Cell, as well as with Elton petrol stations, to facilitate early warning data collection and dissemination to users. Additionally, arrangements have been made with community radios and radio listening groups in some parts of the country on the most effective way of disseminating climate information to local communities and other stakeholders. Notwithstanding, there is a need to expand these services to other parts of the country to attain nationwide coverage.

LIBERIA

Liberia has withstood numerous challenges over the years. It ranks 177th out of 188 countries on the UNDP Human Development Index (2015). A history of civil unrest has destroyed much of its infrastructure and the Ebola crisis has stretched resources thin, with funds and resources being redirected towards more pressing issues.

The country was declared Ebola-free in September 2015—with the exception of a few flare-ups the following year—and is working to rebuild its meteorological infrastructure, which fell into disrepair during the years of conflict. Many Liberians live on the coast, and sea-level rise is expected to create high levels of socio-economic and physical vulnerability. Migration from the coasts could put pressure on agricultural zones. Sea-level rise also leads to direct inundation of lowlands, beach erosion, land salinization, coastal water-table effects and the disruption of socio-economic activities. The country has rich natural resources, including iron, gold, diamonds and timber. About 60 percent of the population is employed in agriculture (2014), meaning the risks of more severe weather or competition for resources from coastal migrants could affect their livelihoods.

The Climate Information and Early Warning Systems Project (CI/EWS) seeks to promote effective climate monitoring and early warning systems. The objectives of the project are to (i) develop a streamlined, customized and consolidated early warning system informed by accurate climate information; (ii) increase the geographic distribution of meteorological monitoring stations; and (iii) establish communications channels to disseminate climate information and early warnings.

Under the project, a country-wide network consisting of 11 automatic weather stations (AWS) and 11 lightning detection systems has been acquired, with installation scheduled for August 2016. The siting of these AWS and the lightning detection sensors on cell-phone towers will help ensure the reliable and uninterrupted operation—and, eventually, the sustainability—of the observation network. As soon as the equipment is installed, cloud-based forecasting and Early Warning Systems (EWS) will provide the meteorological service with accurate forecasts and EWS for weather hazards. Through the EWS developed by this project, small-scale farmers, business owners and vulnerable communities will be able to prepare for the negative effects of hazardous climate and weather events.

The National HydroMeteorological Services (NHMS) in Liberia have been restricted in their possibilities to market tailored weather and climate information products. The proposed creation of a National Meteorological Agency will open the door for a more market-oriented approach. Initial talks with private entities to assess needs and establish the potential mandates for the proposed National Meteorological Agency indicate a private-sector need for such information products.

BIG PICTURE

Per Capita GNI (2014): US$370

Living in Poverty (2007): 63.8%

Persistent Challenges: History of civil unrest, Ebola, reliance on foreign assistance, unpredictable rainfall, coastal erosion.

HYDROMET PPPS

Conducive Policies: Draft legislation for the establishment of a National Meteorological Agency (NMA) has been validated by stakeholders and is under review for enactment into law.

Existing Legal Framework: No

Overall C4Ecosolutions Viability Index: Red

NHMS CHALLENGES

- Limited access to climate models and technology;
- Weak institutional coordination;
- Lack of environmental databases for the assessment of risks posed by weather variability and climate change;
- Lack of a national institution/entity designated for the monitoring and systematic observation of the atmosphere and for the provision of hydromet services;
- Lack of data processing and forecasting facilities;
- Lack of public weather services;
- Lack of public education and awareness on weather and climate;
- Lack of Information and Communications Technology (ICT) facilities for data processing;
- Lack of communications facilities or links.

REVENUE GENERATION

National Met Budget: US$277,000

Current revenue generation: None

Use of Private Weather Data: None

USE OF WEATHER DATA

When the new automatic weather stations and lightning detection system, combined with cloud-based forecasting and early warning services, become operational, the Liberian NHMS will, for the first time since the outbreak of the conflict in the late 1980s, have the capacity to provide accurate weather forecasts and early warnings for weather hazards. This will help vulnerable communities and businesses adapt to hazardous weather events and reduce the negative impacts thereof. Through the provision of timely and accurate information products to the public and the private sectors, Liberia's NHMS have reasserted their relevance.

TRADITIONAL SYNOPTIC STATION IN LIBERIA. PHOTO BY JOOST HOEDJES.

Telecommunications and Public-Private Partnerships

Liberia has 3.2 million cellular phone subscribers, with 79 subscriptions for every 100 inhabitants. There are four cellular phone companies, including Lonestar Cell, Cellcom, LiberCell and Comium. The siting of AWS on cell towers is an option that would provide security, power and communications.

One of the main economic activities in Liberia is the mining industry. This presents a number of interesting opportunities for public-private partnerships. For mining companies, the day-to-day decision-making on operations depends heavily on weather conditions and river levels. This presents a significant marketing opportunity for meteorological and hydrological information products, and one that has been discussed with mining giant Arcelor Mittal.

Institutional Structure

The Liberia National Meteorological Service was established in 1952 under the Ministry of Public Works, but later transferred to the Ministry of Transport. The long civil war in Liberia (1989–1997; 1999–2003) resulted in limited institutional and technical capacity to conduct research on weather and climate.

The draft legislation for the establishment of a National Meteorological Agency (NMA) has been validated by stakeholders and is under review for enactment into law. Through this law, NMA will be mandated with monitoring and observing the atmosphere, as well as providing weather and climate information and services.

The Liberia Hydrological Service falls under the Ministry of Lands, Mines and Energy (LHS). The LHS provides operational hydrological services, collects and manages hydrological data, and does water quality analysis. Water quality monitoring is especially important, as most major rivers flow into Liberia from neighbouring Cote d'Ivoire and Guinea, and large-scale mining activities in these countries pose a risk to Liberia's water quality.

Conclusion

A working monitoring system and effective capacity to analyze, package and process weather and climate information are important first steps for Liberia. In order to effectively deliver weather services to commercial users, new laws would need to be put in place allowing for the sale of information. Given that the country is starting from a relatively blank slate, the cost-efficient and innovative local observation network, coupled with the cloud-based forecasting and early warning services, provides a great stepping stone for Liberia's NHMS to provide a valuable service and solidify the newfound relevance of hydromet services to the community.

MALAWI

Malawi is a densely populated country with a high degree of vulnerability to climate change. It is ranked 173rd on the UNDP Human Development Index (2015). Massive floods at the beginning of 2015 displaced a quarter million people, increasing the risk of disease and malnutrition.

Malawi's economy is dependent on rain-fed agricultural production, which is dominated by smallholder farming. Agriculture contributes roughly 30 percent of Malawi's gross domestic product, and it supports livelihoods for over 77 percent of the population. Climate change has created erratic rainfalls, increased water scarcity, rising temperatures, and extreme weather events such as heat waves, floods and droughts resulting in hundreds of casualties every year. Decreases in agricultural production and environmental degradation as a result of climate change threaten the country's economy and the well-being of its people. Climate change also contributes to low fish stocks, unstable hydroelectric production, and rapid deforestation.

Malawi has received substantial donor support in the climate information services space. In November 2015, the Green Climate Fund approved a $12.3 million programme for 'Scaling up the Use of Modernized Climate Information and Early Warning Systems in Malawi'. Also active in Malawi is the Climate Services for Action Africa Project, part of the Global Framework for Climate Services (GFCS).

The UNDP-supported Climate Information and Early Warning Systems Project (CI/EWS) seeks to strengthen Malawi's weather, climate and hydrological monitoring capabilities, early warning systems and the delivery of available information to facilitate adaptation planning and timely responses to extreme weather. To achieve this objective, the project has assisted in procuring and commissioning 10 synoptic Automatic Weather Stations (AWS) and the COSMO forecasting model with processing infrastructure, and increased the capacity of met staff in forecasting techniques. In addition, the outcomes of the project include (i) improving the capacity of the Department for Climate Change and Meteorological Services and the Department for Water Resources to monitor and forecast extreme weather, hydrology and climate change; and (ii) efficiently and effectively using hydrometeorological and environment-related information to ensure early warnings and design long-term development plans. Through these outcomes, the project is expected to reduce food insecurity and climate vulnerability in Malawi.

The formation of a new unit on public-private partnerships points to good opportunities in the climate information space. In particular, the establishment of a network of automated weather stations will facilitate effective early warnings, thereby enabling small-scale farmers, business owners and vulnerable communities to prepare for hazardous climate events. The data from these stations and products are currently being disseminated across the Human Network International (HNI) 3-2-1 mobile service. The information is currently accessed 1.5 million times a month and accounts for almost 60 percent of the total call volume for the service. The service is in the process of being extended to agricultural-specific products targeted at the small-scale farming sector.

BIG PICTURE

Per Capita GNI (2014): US$250

Living in Poverty (2010): 50.7%

Persistent Challenges: Population growth, pressure on agricultural lands, fiduciary controls, HIV/AIDS, food insecurity, water scarcity, environmental degradation.

HYDROMET PPPS

Conducive Policies: Yes, but no 'Meteorological Act'.

Existing Legal Framework: Yes, a unit called the 'Public Private Partnership Commission'.

Overall C4Ecosolutions Viability Index: Orange

NHMS CHALLENGES

- No 'Meteorological Act';
- Limited budget, resulting in a lack of modern equipment for the improvement of information, products and services;
- Shortage of trained staff;
- Inadequate technological and marketing capacity to tailor products and services to the public and private sectors;
- Lack of research and systematic observation activities;
- Inadequate forecasting, post-processing and service production systems;
- Limited instrument calibration facility and climate database management facility.

REVENUE GENERATION

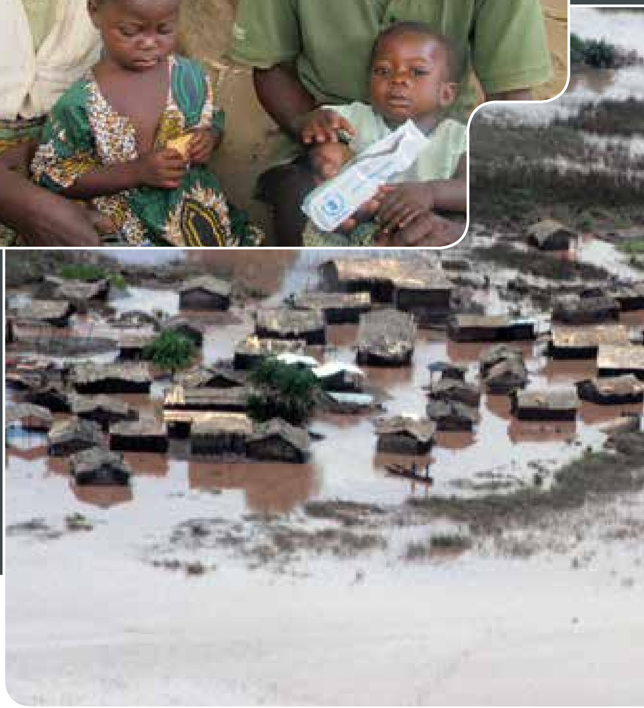
National Met Budget: NA

Current revenue generation: None

Use of Private Weather Data: Yes

USE OF WEATHER DATA

Malawi is a member of WMO and therefore follows WMO standards for meteorological observation. Currently, Malawi has 22 meteorological stations, 21 subsidiary agrometeorological stations and over 400 rainfall stations. At the meteorological stations, weather observations are made seven times a day during the week, and twice a day on weekends by fully trained Meteorological Assistants. This weather data is disseminated via radio, television, websites, emails and text messages. Currently, there is competition between the meteorological services and private weather companies as a large percentage of the population uses online sources for climate and weather information. There is potential for collaboration with the private sector to improve the products and services offered by MNMS. For example, the private sector can assist with the value addition of meteorological services, as well as for improving communication channels for climate information. In addition, since some private sector organizations own and operate their own meteorological stations, there is scope for the sharing of data. Indeed, many private sector organizations are open to working with the Government, as they already provide some services to the Government.



FLOODS IN MALAWI CAUSED WIDESPREAD DAMAGE. PHOTOS BY UNDP.

Telecommunications and Public-Private Partnerships

There are 5.1 million mobile subscribers in Malawi. This means there are 30 subscriptions for every 100 inhabitants, relatively low for Africa. The mobile cellular network is largely based around urban areas, though companies Bharti Airtel (formerly Zain) and Telekom Networks Malawi (TNM) are looking to update their networks.

Malawi has created an enabling environment for public-private partnerships (PPPs) through policies and an Act of Parliament that facilitated the creation of a dedicated PPP unit in Malawi called the Public-Private Partnership Commission.

Sectors that could benefit from custom-tailored weather information include the following:

- **Agriculture.** The large tobacco industry could benefit from specific reports. Information on crop protection, insurance and management should also be supplied.
- **Infrastructure.** Specific packaged data could benefit hydropower and water management projects, along with building, road and rail maintenance, and construction.
- **Health.** Specialized reports to predict disease outbreaks, and aid in warnings for floods and tropical cyclones would help in protecting lives and productive assets.

Institutional Structure

Malawi's National Meteorological Services (MNMS) is administered by the Department of Climate Change and Meteorological Services (DCCMS) under the Ministry of Natural Resources, Energy and Mining. The MNMS is mandated with monitoring, predicting and providing information on weather, climate and climate change to promote socio-economic development within the country. The weather services provided by MNMS are available to all socio-economic sectors at local, national and regional levels. The mission of MNMS is to provide weather and climate services to fulfil national, regional and international obligations through the dissemination of accurate and timely weather data and information.

Conclusion

To increase demand from the private sector, MNMS is improving the awareness of its products and services and the quality and resolution of the information that is generated. With improved accuracy and reliability of weather and climate services, additional revenue could be generated for MNMS through the provision of products and services. The consistent use of meteorological data provided across mobile services demonstrates the need for quality and industry-specific information, especially in the lower-income sectors. MNMS is currently expanding its product offerings to include (i) climatological data; (ii) climatological summaries; (iii) agrometeorological products; (iv) weather reports for insurance claims; (v) calibration of equipment for other institutions; (vi) the hiring of equipment; and (vii) the training of weather observers from other institutions.

SÃO TOMÉ AND PRÍNCIPE

As a small island nation, São Tomé and Príncipe is threatened by rising sea levels and regular coastal storms. Erratic rainfall may affect agricultural production, especially hurting the cacao industry. The country ranks 143rd on the UNDP Human Development Index (2015).

National Adaptation Plans illustrate the willingness of the Government to adopt a more proactive approach that moves from responding to disasters to risk prevention and management. However, the lack of hydrometeorological infrastructure, combined with the absence of an early warning system, limits the capacity of the country to issue and disseminate good weather and climate forecasts. Currently, hydrometeorological observation stations cover 20 percent of the country, with the goal to increase coverage to 60 percent, and the plans for procurement and rehabilitation would create a network of 28 automatic weather stations (AWS), including 14 automatic water-level stations, 12 agrometeorological stations and two synoptic stations.

The UNDP-supported Climate Information and Early Warning Systems Project (CI/EWS) has operations for securing, transferring and installing critical technologies, as well as for developing the necessary systems for climate change–related information to permeate decision-making processes. Furthermore, improving Early Warning Systems (EWS) also provides benefits for long-term planning and helps the National Institute of Meteorology (NIM), the General Directorate of Natural Resources and Energy (GDNRE) and other institutions to build capacity to service other needs, e.g., for land-use and agricultural planning, hydroelectric power, etc. Through a substantial communications programme, the creation and training of local committees for disaster and risk prevention at the local level is contributing to and working with other projects to relocate at-risk communities from the sea, and train journalists on disaster risk management issues related to both the public and private sectors. The project is interested in pursuing public-private partnerships and South-South knowledge-transfer opportunities.

The country has not yet succeeded in successfully packaging relevant information for use by the private sector.

Through the CI/EWS project the country has improved its network coverage, and staffs involved in Disaster Risk Reduction and local community members have been equipped and trained for communication in the early

BIG PICTURE

Per Capita GNI (2014): US$1,670

Living in Poverty (2009): 61.7%

Persistent Challenges: Coastal erosion, inundation, low-productivity agriculture, erratic rainfall, landslides, squall lines, deforestation, land tenure and political instability.

HYDROMET PPPS

Conducive Policies: No

Existing Legal Framework: No

Overall C4Ecosolutions Viability Index: Red

NHMS CHALLENGES

- Weak weather, climate and hydrological monitoring network;
- Limited infrastructure, skills and capacity to effectively produce accurate forecasts;
- Weak capacity to issue, disseminate and respond to potential warnings;
- Absence of an environmental database and lack of a national framework for data sharing.

REVENUE GENERATION

National Met Budget: US$500,000

Current revenue generation: Through aviation.

Use of Private Weather Data: None

USE OF WEATHER DATA

The National Institute of Meteorology is responsible for the management and coordination of activities on meteorology and geophysics. It also provides technical weather information required for air and maritime navigation, agriculture and fisheries.

The General Directorate of Natural Resources and Energy is responsible for water resources management and all weather-related scientific and economic activities in the country.

TOP IMAGE: A SATELLITE IMAGE SHOWING DEEP CONVECTION (THUNDERSTORMS) ILLUSTRATES THE IMPORTANCE OF USING SATELLITE INFORMATION TO OBTAIN THE 'BIG PICTURE' OF WHAT IS HAPPENING 'WEATHER-WISE' OVER A REGION.

BOTTOM IMAGE: AN ANALYZED SYNOPTIC WEATHER MAP FOR AFRICA, SHOWING THE MAIN WEATHER FEATURES ON A CONTINENTAL SCALE.

warning plan. Moreover, staffs at NIM have been trained on the installation and maintenance of hydromet equipment and the SADIS workstation has been purchased and installed to improve aviation meteorological forecasting.

Telecommunications and Public-Private Partnerships

There are around 128,000 mobile subscribers on this island nation, with about 67 subscriptions for every 100 inhabitants. CST maintains much of the mobile market share, while the Angolan operator Unitel started operations in 2014.

There has been increased interest in creating an enabling environment for PPPs since 2014. However, the legal framework for PPPs is fragile. In addition, challenges in relation to land tenure have prohibited partnerships between agribusinesses and the public sector. This partnership has the potential to be greatly beneficial to improving food security in the country by providing early warnings of hazardous weather events.

Sectors that could benefit from customized weather and climate information include the following:

- **Fishing and Maritime.** For port maintenance, fisheries protection and early warnings for bad weather.
- **Resource Extraction.** Protecting the oil exploration platforms in the Gulf of Guinea with specialized reports. The timber industry and fish processing sector could benefit by optimizing market stealth.
- **Tourism.** Seasonal reports could be leveraged for tourism promotion.
- **Agriculture.** In support of small-scale and commercial farming to reduce the risk of food insecurity due to climate change–induced variability. Recently, cacao production has declined at the national level. Information on soils and rainfall patterns could improve and boost productivity.

Institutional Structure

The Ministry of Infrastructure, Natural Resources and Environment coordinates the work of the Water Department based at the General Directorate of Natural Resources and Energy and the National Institute of Meteorology. The budget is provided through state budget allocations, while the institution is mandated to be financially independent. Revenue is generated through services provided to the aviation sector, but there is scope to increase this revenue by engaging with the fisheries, port (maritime navigation), banking and insurance sectors.

Conclusion

The monetization of climate information will be key for the long-term sustainability of the National Institute of Meteorology. The project is taking important strides in bridging the last mile, with the establishment of disaster risk management committees, and trainings on what to do in the event of an emergency and how to receive and disseminate warnings. Initial engagements with one of the telecommunications service providers have yielded some positive results. A focus on providing quality information to bridge the last mile, including fisheries products, will be among the key approaches to ensuring sustainability. Moving forward, the next steps are to improve the national forecasting system and ensure the effective use of hydromet equipment for the establishment of early warning systems.

SIERRA LEONE

The Republic of Sierra Leone was declared Ebola-free on 7 November 2015, with limited flare-ups in 2016. This humanitarian crisis, coupled with persistent challenges such as the long-lasting impacts of the civil war, rapid and unplanned urbanization, and the generally low priority, support and capacity for data collection and monitoring systems for the provision of early warning information have hampered the country's efforts to rehabilitate its climate information and early warning infrastructure.

The country ranks 181st on the UNDP Human Development Index (2015), indicating persistent poverty traps and food security challenges, as well as substantial vulnerability to extreme weather, floods, water- and vector-borne illnesses, and other stresses that challenge poverty alleviation efforts.

Weather extremes have already left a mark on the country's infrastructure and development sectors, including agriculture, the fisheries industry, water resources management and the production of hydroelectric power. Sierra Leone is vulnerable to rainfall variability, heavy precipitation, wind storms and heat waves. Heavy rainfall following dry spells often results in extensive flooding and its attendant impacts include the loss of lives and properties. The effects of these seemingly usual temperature and rainfall patterns on agriculture, water supplies and sanitation have been felt in various parts of Sierra Leone in recent years. Erratic rainfall often causes disruptions in planting seasons, which, in turn, have affected agricultural production and food security in the country.

The Climate Information and Early Warning Systems (CIEWS) Project seeks to improve the capacities of the Sierra Leone Meteorological Department (SLMD), the Disaster Management Department of Sierra Leone's Office of National Security, the Agrometeorological Unit of the Ministry of Agriculture, Forestry and Food Security, the Climate Change Secretariat of the Sierra Leone Environment Protection Agency (EPA-SL) and the Water Directorate of the Ministry of Water Resources to generate and use climate information in the planning for and management of climate-induced hazards/risks. The CI/EWS project aims to achieve this through upgrading the meteorological and hydrological observation networks, strengthening the capacity of the SLMD and support in developing weather forecasting and early warning systems.

The SLMD, with funding from the Global Environment Facility (GEF) and support from the United Nations Development Programme (UNDP) in Sierra Leone, has procured eight automatic weather stations (AWS) and five lightning detection sensors. The latter will become part of a larger lightning detection network that extends over neighbouring Guinea and Liberia and will provide the SLMD with much-needed early warning capacity for weather hazards. An accurate, cloud-based forecasting system will give SLMD the capacity to provide the public and private sectors with high-quality hydromet products, and at the same time train its meteorologists in the use of the new observation systems and real-time data flows. The water

BIG PICTURE

Per Capita GNI (2014): US$710

Living in Poverty (2011): 52.9%

Persistent Challenges: Repercussions from Ebola, civil war, rapid urbanization, climate change effects on the water and health sectors, lack of consistent fiduciary control.

HYDROMET PPPS

Conducive Policies: Sierra Leone Meteorological Services Strategic Plan (2011–2015).

Existing Legal Framework: None

Overall C4Ecosolutions Viability Index: Red

NHMS CHALLENGES

- Shortage of qualified NHMS staff;
- Non-functioning and limited number of synoptic stations and related monitoring equipment;
- Lack of appropriate infrastructure for monitoring early warnings;
- Lack of national framework to integrate climate information into other sectors;
- Lack of standardized information/ communications strategy for the delivery of reliable and much-needed climate information;
- Weak investment in climate information;
- Absence of sustainable finance mechanisms for the long-term delivery of climate information to end users.

REVENUE GENERATION

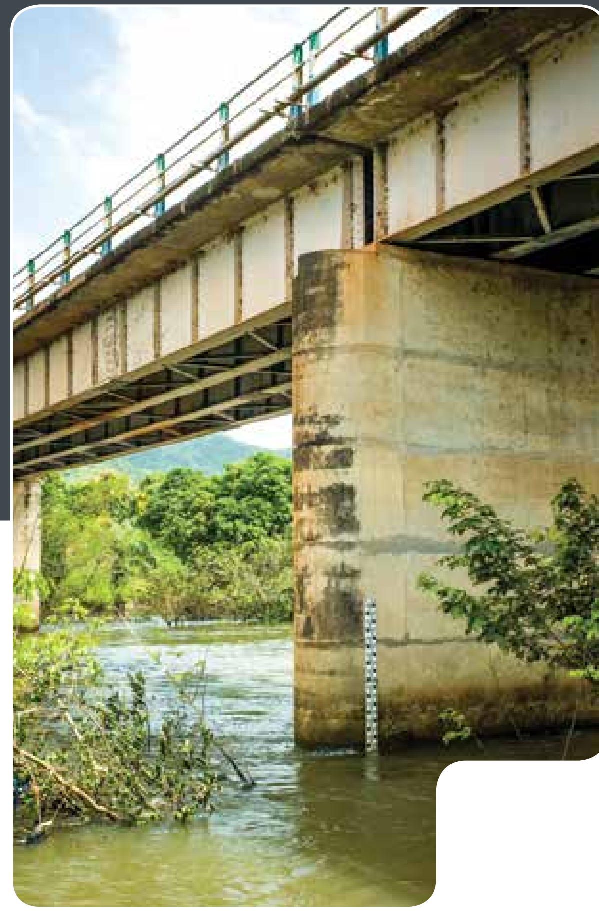
National Met Budget: NA

Current revenue generation: None

Use of Private Weather Data: Being explored

USE OF WEATHER DATA

SLMD is working towards producing aeronautical forecasts (advance 30-hour forecasts that will be validated every six hours), and tendency forecasts for aviation purposes (advance two-hour forecasts) for both domestic and international air traffic requirements. SLMD also participates in a Regional Forum (Regional Forum PRESAO 11) for seasonal forecasts (three to six months). The daily forecast for aviation will serve the wider public, but, because warnings of extreme events are given with little or no notification, adequate time for taking proper preventative measures becomes a key challenge.



TRADITIONAL RIVER STAFF GAUGE.

directorate is in the process of procuring networks of automatic hydrological stations.

Telecommunications and Public-Private Partnerships

There are an estimated 4.8 million mobile subscribers in Sierra Leone, with an estimated 83 subscriptions for every 100 inhabitants.

Through the country's telecommunications regulatory body, the National Telecommunications Company (NATCOM), the SLMD and the Office of National Security (ONS) are in the process of establishing formal partnerships with active government and private telecommunications companies for the dissemination of climate and early warning information to end-users on a cost-to-user basis.

A number of sectors could benefit from specialized climate and weather information, including the following:

- **Water Sector.** Specialized information on river flows, rainfall, droughts and floods would be useful for the maintenance of hydroelectric facilities, and protect human lives from the hazards of flooding.
- **Agriculture and Fisheries.** Over two thirds of the population in Sierra Leone engages in subsistence agriculture.
- **Mineral Extraction.** The weather at mining sites, as well as the streamflow of rivers in the vicinity, have a large impact on mining operations, and therefore accurate and timely weather and river streamflow forecasts are critical for the day-to-day management of these sites.
- **Energy.**
- **Health.** Planning processes in the health sector could benefit from longer-term climate information that could help to predict and address the spread of climate- and precipitation-related diseases (e.g., cholera, malaria).
- **Transport.** The transport sector requires detailed weather services to inform planning, as well as to take measures for the protection of infrastructure and other resources.
- **Communications.** Besides using weather information to prevent weather-induced network problems, the communications sector itself also plays an important role in the dissemination of weather and climate information.

Institutional Structure

The mission of SLMD is to provide cost-effective weather and climate services by collecting, processing, archiving and disseminating meteorological and climate information.

The Agrometeorological Unit (AU), which falls under the Ministry of Agriculture, Forestry and Food Security, is mandated to provide agrometeorological advisories to farmers in Sierra Leone.

The Water Directorate, established in 2008, was placed under the Ministry of Water Resources in 2013. Its mandates include water resources management; rural and urban water supply (through parastatal companies); and policy, research and planning.

Conclusion

As the country emerges from the shock of the Ebola crisis, steps are being taken to strengthen SLMD, the AU, the DMD, ONS and the Water Directorate as institutions, and improve their observation networks through the acquisition of cost-effective and innovative sensors, the data from which can be used to improve the reliability of their weather and climate information products. This allows them to enter into partnerships with public and private stakeholders, including telecommunications outfits, for the dissemination and sale of early warning information and products to end-users, with accrued revenue from the sales of the climate and early information products used to sustain the operations of the SLMD.

TANZANIA

With a relatively stable political history, natural resources and a growing economy, Tanzania is well positioned to continue its development and create working climate information systems. The country is ranked 159th on the UNDP Human Development Index (2013). Floods and erratic rainfall patterns threaten human lives and productive infrastructure in the country, where 74 percent of the workforce works in agriculture—mostly rainfed small-scale enterprises—and thus the risks posed by changing climate patterns and more extreme weather are high.

The goal of the UNDP-supported Climate Information and Early Warning Systems Project (CI/EWS) is to strengthen the capacity of both national and subnational authorities to monitor climate change, generate reliable hydrometeorological data, produce early warnings and compare this information with other environmental and socio-economic data to improve evidence-based decision-making. The project aims to increase the national coverage of the hydrometeorological network from 50 to 75 percent. This involves expanding the network by adding 36 automatic weather stations (AWS), 25 hydrology stations, 130 river gauges, and 35 automatic rainfall gauges, which would bring the network's national coverage to 75 percent. Under this initiative, 16 AWS have been installed and an additional 20 have been procured. Further installation is underway and scheduled for completion as of August 2016. Fifteen hydrology stations, 80 river gauges and 15 automatic rainfall gauges have been installed and the installation of an additional 10 hydrological stations, 50 river gauges and 20 automatic rainfall gauges is underway and also scheduled for completion in August 2016. The project is investing in upgrading weather, climate, hydrological and environmental monitoring infrastructure, and integrating climate information into development plans and early warning systems. Through the project's interventions—in particular the improvement of early warnings—damage to physical infrastructure, reductions in agricultural output and disruptions to livelihoods will be decreased.

With the investments in automatic hydrometeorological observation systems, the Tanzania Meteorological Agency (TMA) has started receiving real-time weather observations covering the entire country, but the system would be strengthened by the completion of the installation of the remaining equipment. By assimilating these data into its forecasts, the quality of the forecast will be greatly improved, forming a solid basis for further product development.

Likewise, the Ministry of Water's Basin Boards of the two pilot catchments are installing automatic hydrometeorological stations. Using real-time data, their integrated water resources management will become much more effective and allow the Basin Boards to work more efficiently. Among other outcomes, it will allow for water allocation planning that is much more hands-on.

Telecommunications and Public-Private Partnerships

There are 31.9 million mobile subscribers in Tanzania, with around 64 subscriptions for every 100 inhabitants. Tanzania has a highly competitive telecommunications market. Telecom operators include Airtel, Tigo, Tanzania Telecommunications Company, Vodacom, Zantel and Halotel.

BIG PICTURE

Per Capita GNI (2014): US$930

Living in Poverty (2011): 28.2%

Persistent Challenges: Effective management of natural resources, dependence on rainfed agriculture, floods, land reform.

HYDROMET PPPS

Conducive Policies: There is a national strategy under development for the exchange of weather and climate information.

Existing Legal Framework: Yes, there is an existing legal framework for PPPs as well as a dedicated PPP unit (the Tanzania Investment Centre).

Overall C4Ecosolutions Viability Index: Green

NHMS CHALLENGES

- Limited number of meteorological and hydrological observation stations;
- Ineffective channels to communicate weather, climate and early warning information;
- Stakeholders and users of the climate monitoring system are uncoordinated in their operation, maintenance and use of the system and information.

REVENUE GENERATION

National Met Budget: US$3,963,415 per annum.

Current revenue generation: Yes

Use of Private Weather Data: No

USE OF WEATHER DATA

TMA has initiated the process of developing an integrated database to accommodate climate and hydrological data, mapped weather stations across the country, facilitated the inter-institutional sharing of data, and supported data digitization.

TMA has developed a national strategy for data-sharing and is now working on the memorandum of understanding for sharing climate data within the Ministry of Water and Irrigation.

TMA provides daily weather forecasts, advisories and warnings; ten-day, monthly and seasonal outlooks; and climate change projections. These services contribute to the efficiency of the operations of various sectors such as agriculture, health and transportation. TMA provides short-term predictions of the consequences of specific weather events, along with seasonal forecasts. It also provides meteorological services for international air navigation; administers networks of surface and upper air stations necessary to capture accurate records; and provides weather and climate services and warnings to the general public and various users for reasons of safety and the protection of property, including in the areas of the marine environment, agriculture and food security, water resources, disaster management, health, the construction and industry sectors, and research institutions.

A SERIES OF STAFF GAUGES ARE USED TO MANUALLY OBSERVE RIVER LEVELS.

Sectors that could benefit from specialized climate and weather information include:

- **Agriculture.** Accounting for roughly one quarter of GDP and 85 percent of exports, products include coffee, sisal, tea, cotton, cashew nuts, tobacco, cloves, corn and wheat, among others. Cattle, sheep and goat ranchers could benefit from specialized reports to protect livestock.
- **Mining.** Diamond, gold, tanzanite and iron mining enterprises would benefit from lightning warnings.
- **Marine and Fishing.** Fishers on the coast of the Indian ocean and on Lakes Victoria, Tanganyika and Nyasa would benefit from early warnings; and ports and fisheries on both the mainland and island coasts would benefit from climate-smart policies.

Institutional Structure

The Tanzania Meteorological Agency (TMA) has been autonomous since 1997 and is a member of the Tanzania Disaster Relief Executive Committee (TANDREC). The Meteorological Agency is the sole provider of meteorological information in Tanzania. The role of TMA is to provide quality, reliable and cost-effective meteorological services, thereby contributing to the protection of life and property, as well as contributing to the national poverty reduction goal.

The Ministry of Water and Irrigation, operating through nine Basin Boards, is responsible for the sustainable development and management of water resources throughout the country. The Ministry formulates and implements the National Water Policy. The Basin Boards are responsible for the integrated water resources management within their respective basins, and report directly to the Ministry.

Conclusion

Tanzania's National HydroMeteorological Services (NHMS) are primarily funded by the Government. Although some of the costs are recovered from the private sector, the prices paid for these services are not reflective of the actual value of the products. By upgrading the observation infrastructure, the quality of the products and services will be significantly improved, opening up new market opportunities. Coupled with a conducive environment for the sale of information, the future looks bright for the country's NHMS. Better, more accurate weather and climate information products will generate more revenues, ensuring the sustainability of the modernized observation and data processing systems.

UGANDA

Uganda has continued to record strong economic growth, with substantial natural resources, fertile soils and recently discovered oil. It ranks 163rd on the UNDP Human Development Index (2015).

Nevertheless, with over two thirds of the workforce in agriculture, the country remains vulnerable to climate shocks. Over the past three decades, increasing temperatures, shifting rainfall patterns, prolonged droughts, floods and severe storms have undermined social and economic development. Extreme weather has had adverse impacts on the livelihoods of people and continues to claim human lives, particularly in disaster-prone areas. The economic impact of climate hazards on the agricultural sector is estimated to be in excess of $46.9 million annually.

The UNDP-supported Strengthening Climate Information and Early Warning Systems Project (SCI/EWS) is designed to build capacity in Uganda for weather, climate and hydrological monitoring; early warning systems; the provision of information for responding to extreme weather; and planning for climate change adaptation. To achieve this objective, the project, through its implementing partners, has installed 20 automatic weather stations (AWS), 5 Total Solutions automatic weather stations (TSAWS) and 40 hydrological stations, including 16 automatic ones. In addition, through project interventions, the technical capacities of the Uganda National Meteorological Authority (UNMA) and the Directorate of Water Resources Management (DWRM) to monitor and forecast extreme weather, hydrology and climate change are being enhanced through training and capacity-building programmes in partnership with the equipment suppliers and accredited regional training agencies.

As a key implementing partner in the programme, UNMA is leading the efforts to develop and implement early warning systems, and, in particular, improve the accuracy of weather predictions. Based on commercial needs for customized meteorological services, UNMA is considering partnering with existing commercial information companies to provide real-time meteorological information and, eventually, warning services.

The highest numbers of lightning and thunderstorm occurrences in the world take place in the Lake Victoria basin (Anyah, 2004). With the installation of lightning detection stations covering the Central, Eastern and Northern regions of the country, it is hoped that there will be a reduction in the number of lightning-related injuries and fatalities, and the integration of lightning data from neighbouring networks in Burundi, Kenya and Tanzania will result in improved regional cooperation in early warning systems.

In an effort to ensure that the stations work well, UNMA partnered with local telecommunications companies, which allowed them to install the TSAWS on their towers in the five districts of Kaliro, Sironko, Napak, Kotido and Agago (Otuke). This arrangement not only reduced installation costs but also ensures

BIG PICTURE

Per Capita GNI (2014): US$680

Living in Poverty (2012): 19.5%

Persistent Challenges: Instability in neighbouring countries, unreliable power, high energy costs, inadequate transportation infrastructure, fiduciary controls.

HYDROMET PPPS

Conducive Policies: The UNMA Act (2012) created the enabling environment for revenue generation, as it provides UNMA with the legal authority to market weather and climate information products and services.

Existing Legal Framework: Yes, the Private Sector Foundation

Overall C4Ecosolutions Viability Index: Orange

NHMS CHALLENGES

- Understaffing and limited technical and institutional capacity;
- Limited financial support to UNMA has resulted in the deterioration of the network of field observing stations and a decrease in the inspection of stations. In addition, the mobilization of funds to implement the modernization strategy has been delayed;
- Observation instruments are outdated.

REVENUE GENERATION

National Met Budget: US$3,590,486 ($1 million is earmarked towards procurement of a weather radar during the 2014–2015 financial year.)

Current revenue generation: Yes

Use of Private Weather Data: Pilot phase

USE OF WEATHER DATA

By legislation, UNMA is the sole climate information provider and therefore does not experience competition with private weather companies, although several organizations produce their own data, such as the Ministry of Agriculture, national universities, and sugar and tea plantations. However, since the AWS equipment used by these actors to generate data is not synoptic and therefore does not comply with WMO standards, there is limited opportunity to share these data with UNMA.

When private companies want to generate their own data, UNMA installs AWS stations to ensure there is consistency with international standards. Interest has been expressed by insurance and telecom organizations. Indeed, the demand for weather services by the private sector has increased as climate change has become more apparent.

With this increase in demand, UNMA is planning to include raw data on wind speed, temperature and rainfall that will become more tailored according to the needs of the target sectors, including aviation, construction and mining.

DEPLOYING AN ALL-IN-ONE AWS ON A CELL TOWER.

that the stations have a continuous supply of power and communication for monitoring as well as security from vandalism.

The UNMA Act of 2012 provides UNMA with the legal framework to market its products and services, thereby allowing meteorological information to be sold for profit. This additional revenue could then be used to improve the products and services offered by UNMA.

UNMA is in the process of discussing with development partners its aim of providing weather data and agriculture-specific information through mobile-phone services in the telecommunications sector. It has also held workshops with weather-sensitive industries and potential commercial partners to strategize on the development and implementation of customized products and services and will be partnering with stakeholders of critical relevance to furthering UNMA's mandate.

Telecommunications and Public-Private Partnerships

There are 20.4 million mobile subscribers in the country, with 57 subscriptions for every 100 inhabitants.

Sectors that could benefit from improved climate information and services include the following:

- **Fisheries.** Especially on Lake Victoria.
- **Aviation.** Since the 1990s, UNMA has had a cost-recovery agreement with Uganda's Civil Aviation Authority (CAA), though a new costing structure could be considered.
- **Agriculture.** Efforts should be made to connect private data collection on sugar and tea plantations for use as part of local observations.
- **Natural resource extraction.** Newly found oil deposits are promising. Informing decision-makers with climate-smart information would help guide investments in productive infrastructure.

Institutional Structure

Uganda's National Meteorological Authority (UNMA, formerly the Department of Meteorology) is a semi-autonomous government division that falls under the Ministry of Water and Environment.

Conclusion

Meteorological services and products can be tailored to meet the needs of users as well as enhance the revenue-generating potential of UNMA. Improved models for the costing of services will also help strengthen existing revenues. Regional cooperation will improve coverage in the Lake Victoria area, which has hazards that require the establishment of timely early warning systems.

ZAMBIA

The Republic of Zambia has seen sustained economic growth of around 6.7 percent per year over the past 10 years. Recent spikes in inflation, high birth rates, and the prevalence of HIV/AIDS are burdens on the national economy. The country ranks 139th out of 188 on the UNDP Human Development Index (2015). Several parts of the country are vulnerable to the impacts of floods and droughts, which are predicted to increase in frequency and severity as a result of climate change. Rural Zambian communities, the majority of which are comprised of small-scale farmers, are particularly vulnerable because of their dependence on rainfed agriculture and natural resources.

The aim of the UNDP-supported Climate Information and Early Warning Systems Project (CI/EWS) is to improve the availability of climate information and the effectiveness of early warning systems. While these systems are operational in Zambia, limited coordination between institutions has reduced the efficiency of the packaging and dissemination of climate information and warnings. This is exacerbated by inadequate infrastructure and equipment, as well as human resources limitations. The project objective is therefore to strengthen Zambia's climate monitoring capabilities and Early Warning Systems (EWS) while improving the information available to respond to weather shocks and adapt to climate change.

Under the CI/EWS project, Zambia is installing an additional 28 automatic weather stations (AWS), almost doubling the size of Zambia's AWS network. The 39 manual weather stations have received upgrades. The Water Resources Management Authority (WARMA) is expanding its automatic hydrometeorological observation network. Staff will be trained in the operation and maintenance of these stations, and in the integration of the new real-time datastreams into the forecasting workflow.

The Meteorological Act is expected to be passed by parliament soon. The act will allow the Zambia Meteorological Department (ZMD) to commercialize weather and climate information products, which will be conducive to the establishment of public-private partnerships. The marketing of its products and services will help ZMD in cost recovery, and ensure the sustainability of its modernized observation network.

Telecommunications and Public-Private Partnerships

Zambia has 10 million mobile subscriptions, with 69 subscribers for every 100 inhabitants. A domestic satellite system is being installed to improve telephone service in rural areas.

BIG PICTURE

Per Capita GNI (2014): US$1,680

Living in Poverty (2010): 60.5%

Persistent Challenges: Inflation, non-competitive agricultural policies, HIV.

HYDROMET PPPS

Conducive Policies: The National Meteorology Policy (NMP) (2013) promotes the integration of weather and climate information into national development plans. In addition, the Meteorological Bill (2015) will allow the NHMS to charge fees for the services it delivers.

Existing Legal Framework: Under development

Overall C4Ecosolutions Viability Index: Green

NHMS CHALLENGES

- Shortage of qualified meteorological staff and local consultants;
- Limited community engagement during the rainy season due to the inaccessibility of remote rural areas;
- Limited manpower, ICT access and/or transport to obtain data from manual rainfall stations;
- Absence of skills in some specialized branches of meteorology (e.g., hydrometeorology) to provide sector-specific services;
- Sparse network of observation stations;
- Irregular instrument repair, maintenance and calibration;
- Inadequate facilities for effective data processing, archiving and dissemination.

REVENUE GENERATION

National Met Budget: US$323,000

Current revenue generation: None

Use of Private Weather Data: No

USE OF WEATHER DATA

By upgrading their observation networks from the traditional manual stations to automatic weather and water-level stations, Zambia's National HydroMeteorological Services (NHMS) are increasingly acquiring the capacity to provide timely and accurate weather and climate information products to the public and the private sector. Whereas currently most of these products are provided as a private good, legislation has been proposed that will allow for the commercialization of some NHMS products. Furthermore, data from the automatic stations are boosting NHMS capacities to provide early warning information for weather hazards.

A MIXTURE OF TRADITIONAL AND MORE MODERN EQUIPMENT.

Sectors that could benefit from tailored climate information include:

- **Agriculture.** Seasonal crop reports and localized monitoring for weather index–based insurance would be beneficial.
- **Aviation.** The sector requires area and route forecasts, terminal aerodrome forecasts (TAF) and efficiency-building support.
- **Mining.** While some mining companies create their own reports, new partnerships could connect ZMD forecasts with these enterprises.
- **Road construction.**
- **Health.**
- **Renewable energy.**

Institutional Structure

The Zambia Meteorological Department (ZMD) is a specialized agency under the Ministry of Communications and Transport.

The Water Resources Management Authority (WARMA) was established in 2012. WARMA operates within the framework of the 2010 National Water Policy, and operates semi-autonomously.

Conclusion

Currently, the meteorological and hydrological sectors in Zambia are limited by, inter alia, the following factors: (i) poor maintenance of equipment; (ii) deteriorating observation infrastructure; and (iii) shortage of technical staff. With the installation of new equipment under the CI/EWS project, ZMD staff receive training in the installation and maintenance thereof. This is a first step to helping ensure the sustainability of the new network. The second step, facilitated by the passing of the Meteorological Act by parliament, is the generation of additional revenues through the marketing of weather and climate information. Through this innovative, much more market-oriented approach, there is a greater chance that the common pitfalls for NHMS in developing countries can be avoided.

A GROUP OF FARMERS GATHERING POTATOES FOR EXPORT. BETTER WEATHER INFORMATION CAN INFORM BUSINESS PRACTICES AND TAP NEW MARKETS. PHOTO BY AFRICA924.

REFERENCES

Footnotes are provided throughout this work to provide extended learning and corollary information. This work also referenced the following publications, references and resources:

Costs and benefits of early warning systems

Hallegatte, Stéphane, 'Early Warning Weather Systems Have Very Real Benefits', World Bank 'Let's Talk Development' Blog, 23 July 2012, blogs.worldbank.org/developmenttalk/early-warning-weather-systems-have-very-real-benefits.

Hallegatte, Stéphane, 'A Cost Effective Solution to Reduce Disaster Losses in Developing Countries: Hydro-meteorological Services, Early Warning, and Evacuation', World Bank Policy Research Working Paper, 2012.

Independent Evaluation Group, World Bank, 'Adapting to Climate Change: Assessing the World Bank Group Experience. Phase III', 2012, ieg.worldbankgroup.org/Data/reports/cc3_full_eval_0.pdf.

Rogers, David P. and Vladimir V. Tsirkunov, 'Weather and Climate Resilience: Effective Preparedness through National Meteorological and Hydrological Services', Directions in Development, Washington, D.C., World Bank, 2013.

Subbiah, A. R., Lolita Bildana, L. and Ramraj Narasimhan, 'Background Paper on Assessment of the Economics of Early Warning Systems for Disaster Risk Reduction', World Bank Group, Global Facility for Disaster Reduction and Recovery (GFDRR), 2008.

Teisberg, Thomas J. and Rodney F. Weiher, 'Background Paper on the Benefits and Costs of Early Warning Systems for Major Natural Hazards', World Bank Group, Global Facility for Disaster Reduction and Recovery (GFDRR), 2009.

Agricultural insurance in Africa

Anon, 'Agricultural Risks and Risk Management', 2010.

IFAD, NEPAD, 'Background Paper on the Platform for Agricultural Risk Management (PARM)', Inaugural Workshop of PARM, Rome, 3–4 December 2013.

Bokusheva, Raushan and Grégoire Tombez, 'Evaluation of socio-economic feasibility of pilot micro-insurance schemes for cotton producers in Mozambique', ETH/IED, Zurich, 2011.

Burke, Marshall, Alain de Janvry and Juan Quintero, 'Providing index-based agricultural insurance to smallholders: Recent progress and future promise', Berkeley, 2010.

Cole, Shawn et al., 'Systematic review: The effectiveness of index-based micro-insurance in helping smallholders manage weather-related risks', EPPI-Centre, Social Science Research Unit, Institute of Education, University of London, London, UK, 2012.

WFP/IFAD, 'Weather Index-Based Insurance in Agricultural Development: A Technical Guide', 2011.

Harwood, Joy et al., 'Managing risk in farming: Concepts, research, and analysis', U.S. Department of Agriculture, Agricultural Economic Report No. 774 , 1999, p.130, www.agriskmanagementforum.org/sites/agriskmanagementforum.org/files/Documents/Managing Risk in Farming.pdf.

Hellmuth, Molly E. et al., eds., 'Index insurance and climate risk: Prospects for development and disaster management', *Climate and Society* No. 2, International Research Institute for Climate and Society (IRI), Columbia University, New York, 2009.

Hossain, Shahadat, 'Problems and Prospects of Weather Index Based Crop Insurance for Rural Farmers in Bangladesh', *Developing Country Studies* 3, no. 12 (2013), pp. 208–21.

Murphy, Anne et al., 'State of Knowledge Report: Market Development for Weather Index Insurance, Key Considerations for Sustainability and Scale Up', Innovation in Catastrophic Weather Insurance to Improve the Livelihoods of Rural Households, GlobalAgRisk, Inc., Lexington, Kentucky, 2011.

WFP/IFAD, 'The Potential for Scale and Sustainability in Weather Index Insurance', Rome, 2010.

Mahul, Olivier and Fatou Assah, 'Agricultural Insurance', World Bank, DFRIP/GFDRR, 2012, p. 2.

Miller, Calvin, 'Risk Mitigation and Management for Agricultural Investment: Investment and Resource Mitigation', FAO, 2008, p. 17, www.fao.org/docs/up/easypol/526/3-5_risk_management_background_155en.pdf.

Miller, Kent D., 'Industry and Country Effects on Manager's Perceptions of Environmental Uncertainties', *Journal of International Business Studies* 24, no. 4 (1993), pp. 693–714.

United Nations, 'Developing Index-Based Insurance for Agriculture in Developing Countries', Sustainable Development Innovation Briefs No. 2, March 2007.

'Index-based Crop Insurance in Senegal', World Bank, Sustainable Development, Africa Region, Finance and Private Sector Development, April 2009.

Sadler, Marc and Olivier Mahul, 'Weather Index-based Crop Insurance in Malawi', GFDRR, Janurary 2011.

Shongwe, Mxolisi. et al., 'Changes in extreme weather in Africa under global warming', KNMI, 2000.

Van Zyl, Koos (Agri SA), 'The Progress on Agricultural Insurance in South Africa', 2013.

The role of meteorology in aviation

Saayman, Willie, SAA Manager on Duty, Operations Control Centre, Tambo International Airport, Johannesburg, South Africa, Presentation, UNDP CIRDA Workshop, Kampala, Uganda, 4 March 2015.

International Civil Aviation Organization (ICAO) website, 'Safety, Accident Statistics', www.icao.int/safety/iStars/Lists/Accident%20statistics/AllItems.aspx.

Commercialization of meteorological services

Anaman, Kwabena et al., 'Benefits of meteorological services: Evidence from recent research in Australia', *Meteorological Applications* 5, no. 2 (1998), pp. 103–115.

Anon, 'Policies on Public Sector Information in the Netherlands: Towards open policy'.

Freebairn, John W. and John W. Zillman, 'Economic benefits of meteorological services', *Meteorological Applications* 9, no. 1 (2002), pp. 33–44.

Frei, Thomas, 'Economic and social benefits of meteorology and climatology in Switzerland', *Meteorological Applications* 17, no. 1 (2010), pp. 39–44.

Leviakangas, Pekka, 'Valuing meteorological information', *Meteorological Applications* 16, no. 3 (2009), pp. 103–14.

Maurer, Andreas, 'The Legislative Powers and Impact of the European Parliament', *Journal of Common Market Studies* 41, no. 2 (2003), pp. 227–47.

Morss, Rebecca E., Kathleen Miller and Maxine Vasil, 'A Systematic Economic Approach to Evaluating Public Investment in Observations for Weather Forecasting', *Monthly Weather Review* 133, no. 2 (2005), pp. 374–88.

Pluijmers, Yvette, 'The Economic Impacts of Open Access Policies for Public Sector Spatial Information', 2002, pp. 1–14.

Rogers, David P. and Vladimir V. Tsirkunov, 'Weather and Climate Resilience: Effective Preparedness through National Meteorological and Hydrological Services', Directions in Development, Washington, D.C., World Bank, 2013.

Suarez, Pablo, Jesse Ribot and Anthony G. Patt, 'Climate Information, equity and vulnerability reduction', in Matthias Ruth and María E. Ibarrarán, eds., 'Distributional Impacts of Climate Change and Disasters' (Cheltenham, U.K.: Edward Elgar, 2009), pp. 151–65.

Viglione, A. et al., 'Barriers to the exchange of hydrometeorological data in Europe: Results from a survey and implications for data policy', *Journal of Hydrology* 394, no. 1-2 (2010), pp. 63–77.

Weiss, Peter, 'Borders in Cyberspace: Conflicting Public Sector Information Policies and their Economic Impacts', U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service (February 2002), pp. 1–92, www.weather.gov/sp/Borders_report.pdf.

The economics of hydromet information

U.S. Dept of Commerce, 'The Value of Government Weather and Climate Data', 2 September 2014, www.esa.doc.gov/economic-briefings/value-government-weather-and-climate-data.

World Bank, USAID and GFDRR, 'Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services', WMO-No. 1153, 2015, p. 18, https://www.gfdrr.org/sites/default/files/publication/SEB%20HYDROMET.pdf.

World Economic Forum, 'Multiplying Agriculture by the Power of Mobile', 2011, www3.weforum.org/docs/WEF_TC_MFS_mAgriculture_Briefing_2012.pdf.

GFDRR, 'GFDRR on Hydromet', www.gfdrr.org/sites/gfdrr/files/documents/GFDRR_Hydromet.pdf.

Country profiles

The country profiles presented here were informed by a market study on PPPs in countries supported by the CIRDA Programme. The profiles were also informed by progress indicators and other relevant project documents created through monitoring and evaluation efforts by UNDP and CI-EWS projects. They were reviewed by country teams and a team of development experts. Background research included the following sources:

Country Progress Reports as delivered in Addis Ababa, Ethiopia at the August 2015 CIRDA Workshop (www.undp-alm.org/projects/cirda/meetings-and-workshops)

World Bank Indicators (data.worldbank.org/indicator), October 2015

Economist Intelligence Unit (www.eiu.com/home.aspx)

CIA World Factbook (www.cia.gov/library/publications/the-world-factbook/)

Climate Funds Update (www.climatefundsupdate.org), November 2015

CI-EWS Country Fact Sheets

BBC Country Reports

UNDP Human Development Index (hdr.undp.org/en/data)

National Adaptation Programmes of Action, Adaptation Learning Mechanism (www.adaptationlearning.net/)

FAO Statistics Division (http://faostat3.fao.org/home/E)

Malawi Data Portal, Malawi Agriculture Sheet (malawi.opendataforafrica.org/jxkvmfe/malawi-agriculture-sheet)

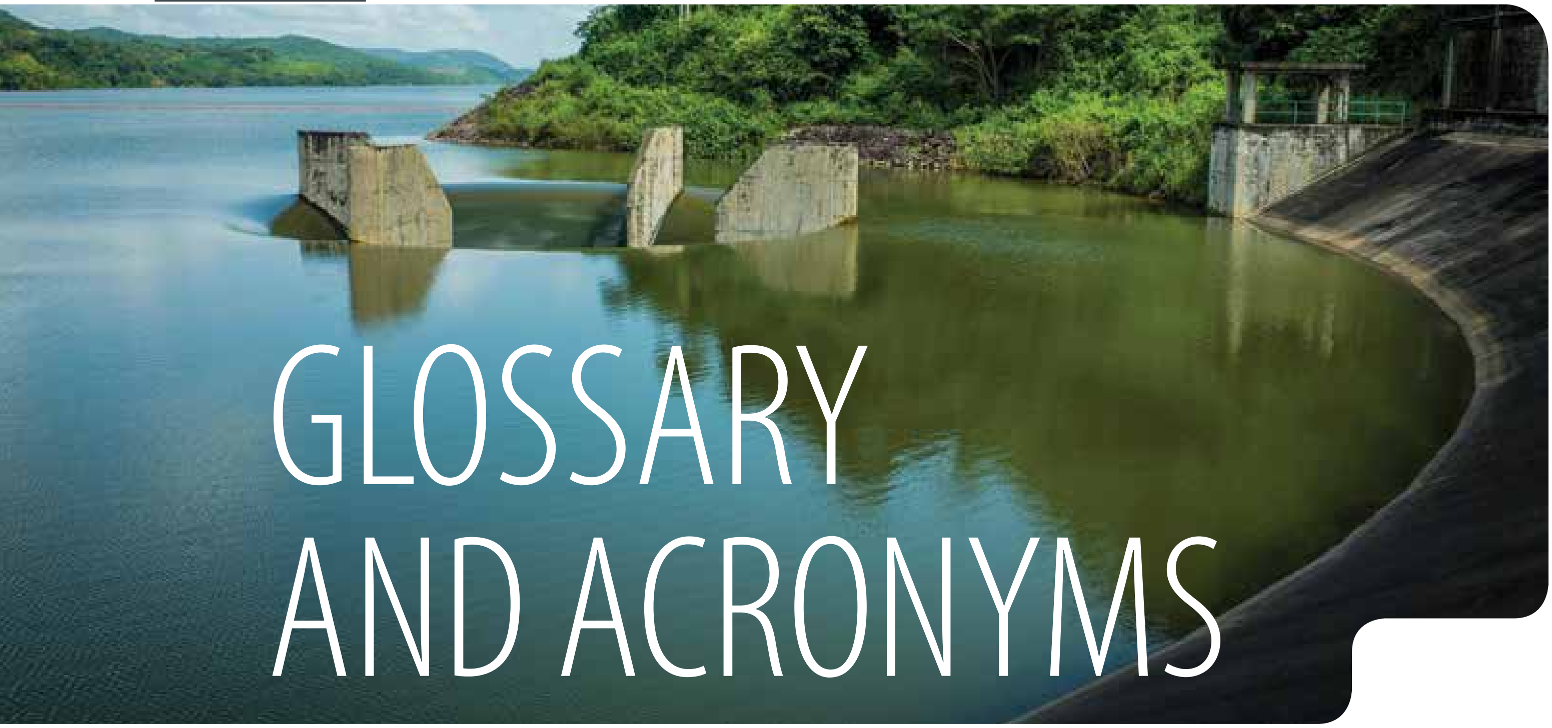
Malawi Ministry of Natural Resources, Energy and Environment, Department of Climate Change and Meteorological Services, Meteorological Station Network (www.metmalawi.com/weather/stations.php)

São Tomé and Príncipe Data Portal, São Tomé and Príncipe Agriculture Sheet (saotome.opendataforafrica.org/dwksdqe/s%C3%A3o-tom%C3%A9-and-pr%C3%ADncipe-agriculture-sheet)

Republic of Uganda, National Development Plan (2010/11–2014/15), April 2010

Thurlow, J., Tingju Zhu and Xinshen Diao, 'The impact of climate variability and change on economic growth and poverty in Zambia', IFPRI Discussion Paper 00890, 2009.

SECTION 11



GLOSSARY AND ACRONYMS

ACLE: African Centres for Lightning and Electromagnetics

AF: Adaptation Fund

AIO AWS: All-in-One Automatic Weather Station(s); all the meteorological sensors are contained in one package.

Anemometer: Instrument used to measure the speed of the wind.[123]

ARC: Africa Risk Capacity. ARC's mission is to use modern finance mechanisms such as risk pooling and risk transfer to create pan-African climate response systems that enable African countries to meet the needs of people harmed by natural disasters.

Atmospheric Pressure: The pressure exerted by the air as a result of gravity. It is measured by the barometer, and formally expressed in Pascals. Traditional meteorological units still in common use are millibars (mb) and centimetres or inches of mercury (in Hg).

Automatic Weather Station (AWS): An automatic weather station is defined as a "meteorological observing station at which observations and measurements are made and transmitted automatically".[124] The observations or collected data can be processed locally at the AWS or transmitted elsewhere for processing, for example, at the central processor of a network of AWS.[125] Automatic weather stations may be designed as an integration of individual instruments (sensors) with interfaces and processing and transmission units; in the United States, such a system is usually called an automated weather observing system (AWOS) or automated surface observing system (ASOS). AWS can also consist of a single integrated system of sensors and related electronics; such packaged systems are called All-in-One AWS or AIO AWS.

[123] The definitions here were adapted from the U.S. National Weather Service website. See more weather and meteorology terms at www.weather.gov/cae/weatherterms.html and w1.weather.gov/glossary/.

[124] World Meteorological Organization, 'International Meteorological Vocabulary', Second Edition, WMO No. 182, Geneva, 1992.

[125] World Meteorological Organization, 'Guide to the Global Observing System', WMO No. 488, Geneva, 2010.

CIRDA: UNDP's Programme on Climate Information for Resilient Development in Africa (CIRDA) connects ideas, people and technology to build resilience to climate change. This multi-country programme supports Climate Information and Early Warning Systems Projects in 11 of Africa's least developed countries in their missions to save lives and improve livelihoods. By building capacity to issue warnings of impending hazardous weather, sharing new technological advances in weather and climate monitoring and forecasting, and facilitating innovative partnerships with the private sector, the programme works to foster regional cooperation, support strong institutions and build resiliency to climate change.

CDM: Clean Development Mechanism

CI/EWS: UNDP-supported GEF-financed Climate Information and Early Warning Systems Projects

Climate: The statistical collective of weather conditions over a specified period of time (i.e., usually several decades).

Climate Change: A non-random change in climate that is measured over several decades or longer. The change may be due to natural or anthropogenic causes.

Climate System: The system consisting of the atmosphere (gases), hydrosphere (water), lithosphere (solid rocky part of the Earth), and biosphere (living) that determines the Earth's climate.

Climatological Outlook: This is a description of likely conditions (temperature, rainfall) over a given region in a coming season. It will usually include a discussion and/or graphics giving the probabilities, seasonal average temperature and rainfall in the region being above normal, normal, or below normal. Usually given a month or two in advance, a Climate Outlook is determined from climatological statistics, output from global climate models, and a consideration of regional teleconnections to such global phenomena as the El Niño–Southern Oscillation (ENSO) in the eastern equatorial Pacific.

Cloud: A visible aggregate of minute water droplets and/or ice particles in the atmosphere above Earth's surface.

Convection: In meteorology, atmospheric motions that are predominantly vertical. Usually means upward as opposed to subsidence (downward).

Critical Fire Weather Pattern: Evolving weather conditions that can quickly increase fire danger and trigger rapid fire spread.

Cumulus: A principle cloud type in the form of individual detached elements, sharp non-fibrous outlines and vertical development.

Diurnal: Daily, especially pertaining to daily cycles of temperature, water vapour and wind.

Doppler Radar: Radar that can measure radial velocity, the instantaneous component of motion parallel to the radar beam (i.e., toward or away from the radar antenna).

Drought: A period of moisture deficiency, extensive in space and time.

EAC: East African Community

EWS: Early Warning Systems

Extended or Medium Range Forecast: A forecast of general weather conditions for three through five days.

Fair: A weather term implying no precipitation and no extreme conditions of clouds, visibility or wind.

Flash Flood: A rapid and extreme flow of high water into a normally dry area, or a rapid water-level rise in a stream or creek above a predetermined flood level, beginning within six hours of the causative event (e.g., intense rainfall, dam failure, ice jam). However, the actual time threshold may vary in different parts of a country. Ongoing flooding can intensify to flash flooding in cases where intense rainfall results in a rapid surge of rising flood waters.

Flood: Any high flow, overflow or inundation by water which causes or threatens damage.

GCF: Green Climate Fund

GEF: Global Environment Facility

Global Warming: An overall increase in world temperatures that may be caused by additional energy being trapped by greenhouse gases.

GTS (Global Telecommunication System): "The coordinated global system of telecommunication facilities and arrangements for the rapid collection, exchange and distribution of observations and processed information within the framework of the World Weather Watch." –WMO-No. 49, Technical Regulations, Volume 1

Headline: A brief statement at the beginning of a forecast that highlights dangerous or changing weather conditions.

Heat: A form of energy transferred between systems by virtue of a difference in temperature.

Heat Lightning: The luminosity observed from ordinary lightning too far away for its thunder to be heard.

Heavy: In reference to precipitation, more than a half inch in forecast period.

HNI: Human Network International

Hydrology: The scientific study of the waters of the earth, especially with relation to the effects of precipitation and evaporation upon the occurrence and character of water on or below the land surface.

High Pressure: An anticyclone. An area of atmospheric pressure with closed isobars and relative high pressure at its centre. Air flows clockwise (counterclockwise) around a high in the Northern (Southern) Hemisphere.

High Clouds: Clouds composed of ice crystals, usually above 25,000 feet. Commonly called cirrus clouds.

Homogenous: In reference to an airmass having similar horizontal properties or elements.

IFC: International Finance Corporation. A member of the World Bank Group.

IFPRI: International Food Policy Research Institute

IVR: Interactive Voice Response is a technology that allows a computer to interact with humans through the use of voice and tones input via keypad.

LDC: Least Developed Country

LDCF: Least Developed Countries Fund

Lightning: All the various visible electrical discharges produced by thunderstorms. It can be cloud-to-cloud, cloud-to-ground, or cloud-to-air.

Lightning Activity Level (LAL): An objective rating system used in the National Fire Danger Rating System (NFDRS) that indicates the amount of cloud-to-ground lightning observed or forecast in a given area.

Local meteorology: The observation, analysis and prediction of local weather, that is, weather phenomena on the micro- to mesoscales. Such phenomena range in size from a few hundred metres to a few hundred kilometres in horizontal extent and form, and move and evolve, and dissipate over timescales of a few minutes to a day or two. Microscale examples include airflow through or over grain fields, dispersing plumes from industrial stacks, and microbursts from thunderstorms. Mesoscale examples are thunderstorms, squall lines, and mesoscale convective complexes. Most types of hazardous weather—from severe thunderstorms (with strong winds, torrential rains and lightning) to wildland fires to flash flooding and debris flows—are local in nature. Microscale weather events are embedded within mesoscale weather events, which in turn are embedded within synoptic weather systems. However, micro- and mesoscale phenomena are usually too small to be depicted adequately on standard synoptic weather maps, and so understanding local meteorology requires regional and local mappings and analyses by the meteorologist.

Local weather observations: These are weather observations and measurements made for the purpose of providing information on local weather phenomena. Local observations are supplementary and complimentary to synoptic weather observations, providing more detail on events occurring within a larger synoptic weather pattern. Local measurements usually are made for a specific purpose, such as the support of agro-meteorology, including planting and harvesting timing, pest management, and controlled burning; urban meteorology, including air-quality management; hydro-meteorology, including irrigation system, dam and river management; transportation meteorology, including road, railroad, and airfield and maritime/riverine operations; and emergency management, including industrial fires, toxic spills, and wildland fire operations. A particularly important use of local observations is the monitoring of the onset, evolution and movement, and demise of severe local weather events in support of hazardous weather monitoring, forecasting and warning operations. While the WMO guidelines for observations and measurements are followed to the extent possible, in local observations the instruments and their exposure are tailored to the meet the needs of the intended uses of the data. Spacing between observing sites varies with the application and terrain, and may range from a few hundred meters to a few 10s of kilometres. Observations are usually made at time intervals of 5, 10 or 15 minutes. Local observations are often of regional interest and so are shared via the WMO Global Telecommunications System or through arrangements between neighbouring NHMS.

Local Winds: Winds that over a small area may differ from those appropriate to the general pressure distribution.

Long Range: An extended forecast for a period greater than 5 days.

Mesoscale: A scale that ranges in size from a few kilometres to about 100 kilometres.

Meteorology: The study of the phenomena of the atmosphere.

Microscale: A scale that covers phenomena smaller than those in the mesoscale range.

Model Output Statistics (MOS): Statistical techniques for the generation of point-specific values from numerical model output. MOS is an objective, site-specific weather forecasting technique that consists of determining a statistical relationship between a quantity to be predicted (such as temperature) and variables forecast by a numerical model at specified forecast time(s).

Moderate: Precipitation, ranging from .21 to .50 inches in a forecast period.

National HydroMeteorological Service (NHMS): Generally used to indicate that the national meteorological and hydrological functions are in one agency, as is the case in the USA with the NOAA National Weather Service. This acronym is used throughout this publication.

National Meteorological and Hydrological Services (NMHS): Indicates two agencies, one for meteorology and one for hydrology. The majority of countries supported by the CIRDA programme fall into this NMHS category.

Normal: The average value of a meteorological element over a period of time sufficient to give a statistically stable value, usually taken to be 30 years in the United States.

Nowcast: A specialized forecast issued by the NHMS for a localized area and the near term, often in the order of minutes.

Numerical Weather Prediction (frequently NWP): The use of numerical models to produce short-, medium-, and long-range (out to 15 days) guidance in support of forecasting of the evolution of the state of the troposphere and lower stratosphere, with a horizontal resolution of typically 15–50 km and a vertical resolution of 10–30m near the surface increasing to 500m–1km in the stratosphere. Coverage can range from local to regional to global.

NWS: U.S. National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS).

PPP: Public-Private Partnership

Occasional: Occurrence of a meteorological element at infrequent intervals and for short duration.

Persistence: The tendency for the occurrence of a specific event to be more probable, at a given time, if that same event has occurred immediately preceding the time period.

Precipitation: Any or all the particles of water, liquid or solid, that fall from the atmosphere and reach the ground.

Probability: The chance that a prescribed event will occur.

Probability Forecast: A forecast of the probability of occurrence of one or more of a mutually exclusive set of weather contingencies, as distinguished from a series of categorical statements.

Prognostic (Prog) Chart: A chart depicting some meteorological parameter at a specified future time.

RADAR: "Acronym for Radio Detection And Ranging; a radio device or system for locating an object by means of ultrahigh-frequency radio waves reflected from the object and received, observed, and analyzed by the receiving part of the device in such a way that characteristics (as distance and direction) of the object may be determined." –NOAA

Radar Reflectivity: The sum of the electromagnetic energy received from all backscattering cross-sections (e.g., precipitation particles) in a pulse resolution volume divided by that volume. The radar reflectivity can be related to the radar reflectivity factor through the dielectric constant term |K|^2, and the radar wavelength.

Radiosonde (RAOB): Balloon-borne instrument for the measurement and transmission of temperature, humidity and pressure. When tracked by radar, also provides wind direction and velocity (Rawin).

SAME: "Specific Area Message Encoding"—A tone alert system that allows NOAA Weather Radio receivers equipped with the SAME feature to sound an alert for only certain weather conditions or within a limited geographic area such as a county. –NOAA

SCCF: Special Climate Change Fund

Severe: Used in reference to thunderstorm intensity. Indicates strong winds and large hail.

Severe Local Storm: This is usually a deep convective storm (thunderstorm) that usually covers a relatively small geographic area, or moves along a relatively narrow path, and which produces at surface hazardous weather conditions that threaten life and/or property. Such storms are also hazards to aviation operations, both aloft and near or at the surface. Examples of these hazardous conditions include large hail, damaging wind (straight line or in the form of outflow from downbursts), or tornadoes. A thunderstorm by definition also produces in-cloud and cloud-to-ground lightning. Although cloud-to-ground lightning is not a standard criterion for a severe local storm, it is acknowledged to be highly dangerous and a leading cause of deaths, injuries and damage. Additionally, extreme rainfall is not a standard criterion for a severe local storm, but is often a product of such a storm. Such extreme rainfall in a small watershed may result in related phenomena (flash floods) that also threaten life and property. –NOAA

Storm: In meteorology, usually refers to cyclonic storms with considerable cloud and precipitation areas.

Short Range Forecast: Weather forecast covering zero out to two days.

SMS: Short Message Service

Synopsis: A statement giving a brief general review or summary.

Synoptic meteorology: The observation, analysis, and prediction of weather phenomena that range from several hundred kilometres to a few thousand kilometres in horizontal extent and which form, move and evolve, and dissipate over time periods of several days to a few weeks. Synoptic (continental-scale) weather phenomena include mid-latitude (extratropical) cyclones and their associated fronts and jet streams, large-scale tropical and subtropical disturbances such as monsoons and tropical cyclones, polar lows, and the interactions between extratropical systems and those at high and low latitudes. Mid-latitude synoptic weather events are embedded within planetary waves, the largest (hemispheric scale) meteorological phenomena.

Synoptic weather observations: These are weather observations and measurements made for the purpose of providing information on synoptic weather phenomena. Synoptic observations are made at times and using instruments and techniques that follow to the extent possible the guidelines of the World Meteorological Organization. The observations are shared around the world using the WMO Global Telecommunications System. Synoptic observations provide information on the general weather in a region, are used as input to numerical models, and are compiled over time to provide information on the regional climate. Synoptic observations include both surface and upper air measurements. Synoptic surface weather observations are made at sites selected to be as representative as possible of the weather occurring over the surrounding region. Spacing between surface observing sites varies with the nature of the surrounding terrain, being a few 10s of kilometres in mountainous regions and around 100 to 150 kilometres in open plains. Synoptic surface observations are usually reported hourly, every three hours, and/or every six hours, depending on local policies. Upper air observations extending from surface through the troposphere and into the lower stratosphere are made twice daily at stations 200 to 300 km apart, using instruments borne aloft by balloons.

Synoptic weather maps: Synoptic weather observations, both surface and upper air, are plotted on maps and analyzed by meteorologists and computer-based display systems to reveal the 3-D structure of large-scale weather phenomena. Sequences of such maps reveal the movement and evolution of such phenomena. Such weather maps are one of the major tools of the weather forecaster.

TAF: Terminal Aerodrome Forecast

TAHMO: Trans-African Hydro-Meteorological Observatory

Temperature: The degree of warmth of an object as measured on some definite temperature scale by means of various types of thermometers.

Tropical Cyclone: The general term for a cyclone (low pressure system) that originates over the tropical oceans. They are known by different names in different parts of the tropics, e.g., hurricanes, typhoons, etc.

Tropopause: The boundary between the troposphere and the stratosphere, usually characterized by an abrupt change to a small lapse rate.

UNDP: United Nations Development Programme

UNFCCC: UN Framework Convention on Climate Change

Upper Air: Generally applied to levels above 850 mb (5,000 feet).

USSD: Unstructured Supplementary Service Data

Visibility: The greatest distance one can see with the unaided eye, as determined by light and weather conditions.

Weather: The ever-evolving state of the atmosphere, particularly that of the troposphere and lower stratosphere, usually short term, with respect to its effects upon life, property and human activities. "Present weather" refers to a snapshot of that state at a particular moment in time.

WFP: World Food Programme

WIGOS: WMO Integrated Global Observing System

Wind: Air in horizontal motion relative to the surface of the earth.

WMO: World Meteorological Organization

WPF: Weather Philippines Foundation

X-Band: A frequency band of microwave radiation in which radars operate.

Empowered lives.
Resilient nations.

United Nations Development Programme
304 East 45th Street, 9th Floor
New York, NY 10017 USA

For more information: www.undp.org