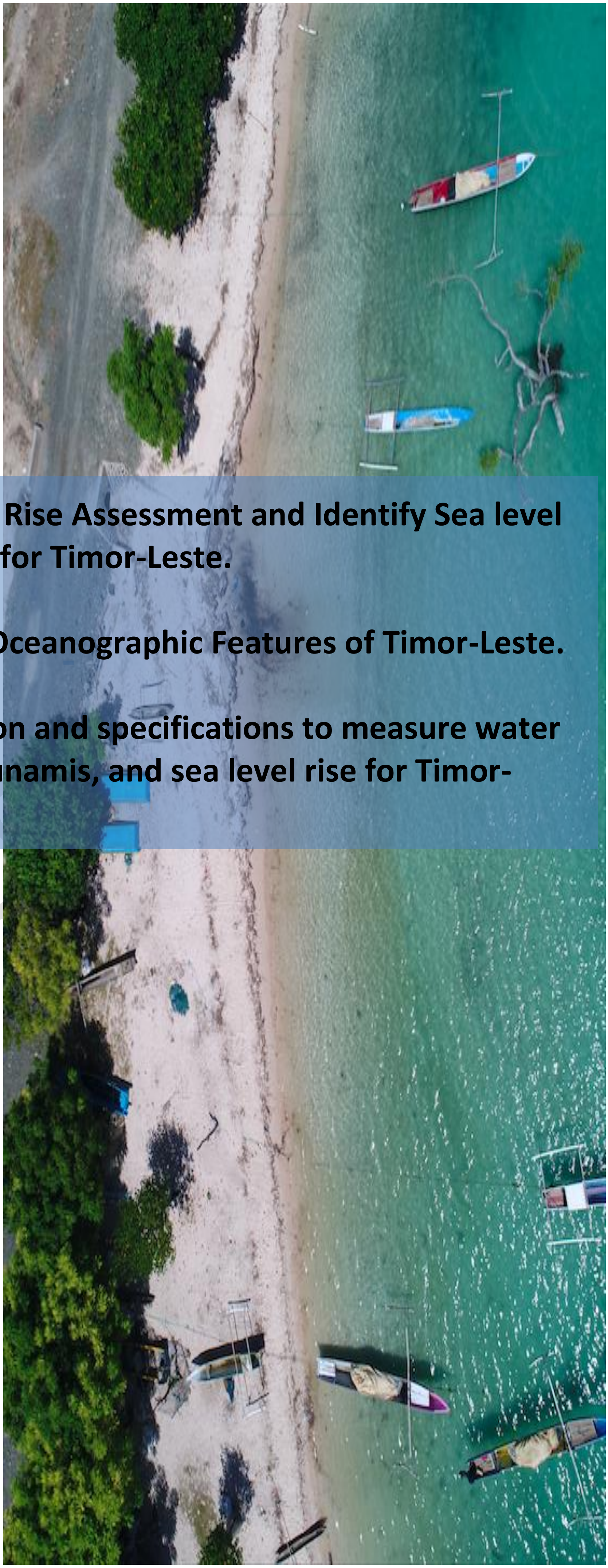

Rapid Shoreline and Sea Level Rise Assessment and Identify Sea level Rise/Tidal Gauge Instruments for Timor-Leste.

Rapid Assessment Report on Oceanographic Features of Timor-Leste.

Recommended instrumentation and specifications to measure water levels due to tides, storms, tsunamis, and sea level rise for Timor-Leste.

confide

PREPARED BY:
Dr Serena Blyth Lee

May 2017

Griffith UNIVERSITY
Centre for Coastal Management

United Nations Development Programme(UNDP) UN House Caicoli Street Dili, Timor-Leste	Draft received on 16/05/2017 Final report received on 11/06/2017

Synopsis: This report has been prepared to provide information regarding appropriate sites and appropriate instruments for measuring ocean and coastal processes in Timor-Leste which are capable of providing information to determine the processes that influence water level variations at the coast, including the contribution due to sea level rise. After conducting a rapid assessment of the coastal environments of Timor-Leste, appropriate locations where tide and sea level rise instruments can feasibly be installed were determined. The recommendations regarding instrument placement and setup are based upon the most recent recommendations for organisations wishing to participate in the Global Sea Level Observing System (GLOSS). As such, these recommendations align with best international practice.

Keywords: Sea level rise, water level, mean sea level, tides, tidal processes, ocean processes, currents, temperature, tidal gauge, monitoring, waves, wave climate, storm surge, extreme events, tsunami, coast, coastal zone, coastal communities, infrastructure, beach, vulnerability.

REVISION/CHECKING HISTORY

REVISION NUMBER	REPORT DATE	CHECKED BY		ISSUED BY	
1	16/05/2017		SBL, RT,		SBL
1	23/05/2017		SBL, RT		SBL
2	11/06/2017		SBL, RT		SBL

© UNDP 2017
This document was prepared by the Griffith Centre for Coastal Management of Griffith University contracted by United Nations Development Program (UNDP) and Ministry of Agriculture and Fisheries, Democratic Republic of Timor-Leste under the Coastal Resilience Project. The Copyright of the report is the property of UNDP

confidential draft

Contents

Executive summary 6

1. Background: Ocean and Coastal Conditions 10

1.1 What causes tides? 10
1.2 Investigating ocean and coastal processes in Timor-Leste 12
1.3 Tides in the Timor Region 15
1.4 Waves in the Timor Region 16

2 Site Selection 20

2.1 International Oceanographic Commission (IOC) Site Selection Recommendations 20
2.2 Hera Naval Port, Dili Province 24
2.3 Mahata Port, Oecussi Province 27
2.4 Site Selection Summary 30

3 Instrument Setup 30

3.1 Recommended Instrumental Setup 30
3.2 Tide Gauge instruments 33
3.3 Radar Gauges 35
3.4 Radar Gauge Manufacturers 37
3.5 Pressure Gauges 37
3.6 Pressure Gauge Manufacturers 40
3.7 Visual Tide Staff 40
3.8 Data loggers and Telemetry 42
3.9 Data Management 45
3.10 Quality Control Software 47
3.11 Data Transmission to the IOC Sea Level Monitoring Facility at VLIZ 48
3.12 Benchmarks used for Datum Control and Levelling 51
3.13 Tide Gauge Benchmark 55
3.14 Additional Benchmarks 56
3.15 Instruments to measure vertical land motion 56
3.16 Bedrock GPS 58
3.17 Tide gauge CGNSS 58
3.18 Absolute Gravimeter 59

4 Instrument Installation 59

5 Future Leverage of Tide and Sea Level Observation Instruments 61

6 References 63

Executive summary

The recommendations regarding tidal and sea level instruments provided in this report align with the International Oceanographic Commission 2016 guidelines detailed in JCOMM Technical Report No. 89. The principal purpose of the recommended instruments is to provide monitoring of water level variation due to tides, storm systems, tsunamis and long-term sea level changes. The data obtained by the instruments will relay data for display in near-real time, and the instrument setup recommended is designed to perform to the standard required of participants in the Global Sea Level Observing System (GLOSS) network. If the recommendations are met, the data obtained by the Timor-Leste tide and sea level observing system will contribute both to stakeholders within Timor-Leste, and to the international scientific research community. The coasts and oceans environments of Timor-Leste represent an under-studied part of the earth. Open access to the water level data collected in Timor-Leste will facilitate further scientific research by international scientists to better explain the ocean conditions that affect the coastal areas of Timor-Leste.

A graphical overview of the instrument setup for tide and sea level observing systems recommended for Timor-Leste is depicted in Figure A. The individual components depicted in Figure A are briefly outlined in this summary, with more detailed information describing instruments and their use is presented in the report.

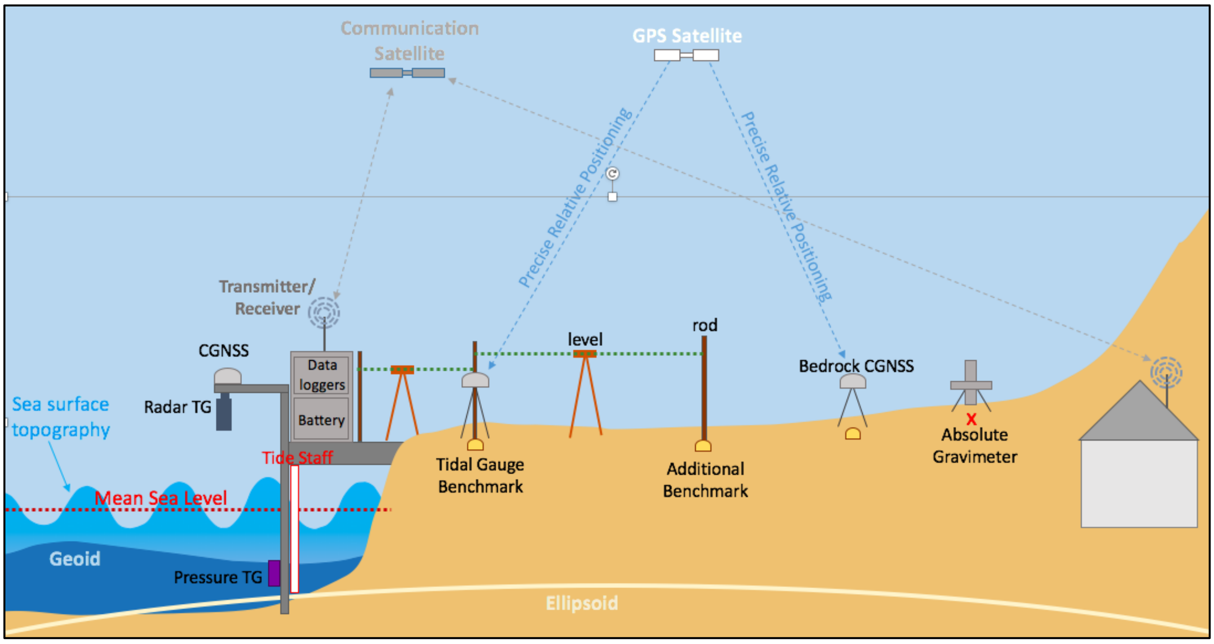

Figure A. Graphical display of instrument setup. Equipment displayed assumes the full suite of desirable equipment is available and affordable.

The tide gauges discussed in this report measure water level variations due to all processes, not just tides. The ability of an instrument to detect changes in sea level associated with non-tidal processes such as storm surges or sea level rise, is determined by the frequency with which they record water level, the period of time over which measurements are acquired, and the ability to remove distortions in data caused by vertical land movement which obscure measurement of long time scale processes like sea level rise.

Following the site selection criteria detailed in IOC, 2016, JCOMM Technical Report No. 89, two locations in Timor-Leste are deemed to adequately meet the selection criteria governing appropriate site selection for tide and sea level observing systems. The two locations are Hera Naval Base, Dili Province, and Mahata Port, Oecussi. These two locations contain stable support structures (newly constructed wharves) that extend over deep water (> ~10m depth). The first of these criteria was the most difficult to satisfy and the absence of such support structures limited site selection in Timor-Leste. In the event that future infrastructure projects build sturdy wharves that extend into deep water, these sites should be investigated to determine if they are suitable locations for further tide and sea level observing systems. During the course of this project, it was identified that Hera Naval Base has a tide gauge in place, however it is presently not operating despite the value this information could add to the functioning of the Naval facility. It is recommended that a tide gauge be placed at both Hera Naval Base and the Mahata Port, not only for the benefit of improving understanding of ocean processes, in Timor-Leste, but also to assist the efficient operations of these two facilities whose activities are intrinsically affected by ocean conditions.

When selecting a company responsible for installing, calibrating and maintaining tide and sea level observing instruments it is recommended that companies who have a long track record of performing these functions over many years be given preference over newer companies. While new companies may have the capacity to install instruments, given the long (multi-decadal) nature of the instrumentation, the company engaged must be capable of maintaining their commitments with respect to providing support and instrument maintenance. It is vital to check the track record of the operator. Organisations who install and maintain instruments that are presently part of the GLOSS network would also be preferable. While these established companies are likely to incur higher costs, they are more likely to be in a position fulfil the long-term commitment required to support Timor-Leste in maintaining the instruments, which is an essential requirement of the overall tide and sea level observing system. In the past national organizations such as the National Tidal Facility, in Australia have established tide and sea level observing systems in the Pacific Island region. The National Oceanographic and Atmospheric Administration (NOAA) have also undertaken similar activities in the Caribbean region. The German institution GFZ was involved in the institution of tide and sea level rise instrumentation in Indonesia as part of the German Indonesian Tsunami Early Warning System (GITEWS) project (Rudloff et al., 2009). The Institut de Physique de Globe de Paris (IPGP) has installed tide instruments in the Caribbean region. The University of Hawaii Sea Level Centre is also responsible for multiple sea level stations in the Caribbean and nearby regions. The Chilean Hydrographic and Oceanographic Service of the Navy is responsible for the tidal observations along the Chilean coast. These are some of the institutions how have contributed to the establishment of some of the sea level observing systems currently within the GLOSS network. The private company Metocean services performs similar work in remote regions, most commonly for the oil and gas industry, however it is not known if they have installed instruments for the purpose of long-term sea level rise measurements. Given the high involvement of oceanographic institutions and national facilities in installing and maintaining tide and sea level observing systems, it is recommended that Timor-Leste attempt to establish a similar level of involvement with a National or State government organization who are already involved in long-term sea level measurement programs. This way Timor-Leste can best benefit from the experiences gained when instituting similar instrumentation and associated data communication, analysis and management platforms. The Timor-Leste data may also be able to integrated into an established system with attended data quality controls.

With respect to instrument recommendations, a combination of three instruments are recommended for measuring water level variations, one radar gauge and two pressure gauges. The recommended radar gauge is a stainless steel, K-band, Pulse radar gauge with a data logger capable of interfacing with two-way communication telemetry systems. The two most commonly used manufacturers in the world are VEGA (7 countries) and OTT (6 countries). Both manufacturers make robust instruments that are appropriate for deployment at Timor-Leste sites. The next most frequently used radar manufacturers are MIROS (3 countries), Sutron (two countries) and Waterlog (two countries).

The radar gauge previously used at Hera Naval Facility is a Vegaplus 61 instrument. If this instrument is found to be functioning, and is able to be updated to interface with a two-way communication system, it is recommended that this radar gauge be repositioned at this site. Repositioning is required in order to better comply with the IOC 2016 site selection and instrument installation recommendations. In addition to the radar the manufacturers will supply display units that sit on top of, or nearby the radar gauge. In this way a visual check can easily be made to ensure the instrument is reporting the same level as that observed on a nearby tide staff. The manufacturer also provides an appropriate data-logger capable of interfacing with two-way telemetry systems (for communication, relaying data from the instrument to a web-based platform). The selected radar manufacturer should be consulted by the installation company, regarding the components best suited for telemetry needs.

Two-way communication to the radar instrument is required for instrument maintenance. Two achieve this a combination of two telemetry systems is recommended, a two-way satellite telemetry system and a General Packet Radio System (GPRS) telemetry system for backup communication. The combination of the satellite and GPRS systems will act to secure communication.

Either a vented pressure gauge, or a synchronized pair of absolute pressure gauges, one recording atmospheric pressure and one recording in-water total pressure be installed. The advantage of the vented pressure gauge is the instantaneous correction for atmospheric pressure due to connection to the open air. This disadvantage is the potential damage to the instrument if the venting tube is damaged and the instrument is flooded. This issue is removed by using the combined synchronized absolute and atmospheric gauges, however the disadvantage of this method is the need to perform the correction to remove the influence due to changes in atmospheric pressure on the reported water depth. The pressure gauge setup provided backup water level measurement during normal conditions but is the principal tsunami measurement device, due to the potential for a tsunami wave to flood the radar gauge. The two principal manufacturers recommended for these instruments are RBR and Sea-Bird. Both companies have been in operation for over thirty years and are the leaders in the field of in-water oceanographic instruments. The instrument components for these instruments are to include the pressure gauges, waterproof cables, display monitor, and telemetry device.

It has become common practice (and a GLOSS requirement) for tide and sea level instrumentation to include a GNSS instrument located within close proximity of the bedrock survey benchmark (or ideally at the tide gauge benchmark if it is also a bedrock site), and the installation of these instruments is recommended at both tide and sea level observations sites in order that the data can contribute to the Global Sea Level Observation System network. These instruments were employed in Indonesia, principally to measure earthquakes effects (Schöne et al., 2011), however in the Timor-Leste context it will principally be employed to correct long-term sea level records for vertical land movement. The instrument used in Indonesian locations was a high-precision L1/L2 geodetic type Pola Rx2 receiver manufactured by Septentrio, which utilized a choke ring antenna. By installing a CGNSS near tide gauges, not only will Timor-Leste gain a better understanding of the relative sea level rise affecting Timor-Leste, these data will be able to contribute to improving global understanding of the rates of land movement. To this end, it is recommended that these data be relayed to organization collating these data across the world, the International GNNS Service (http://www.igs.org/).

While an independent determination of vertical land movement employing technologies such as absolute gravimetery is desirable, it is recognized that these instruments are very expensive, and thus are unlikely to be affordable at this time. In the event that an absolute gravimeter instrument is already available from one of the government departments within Timor-Leste, it is recommended that a campaign of several days be undertaken at a bedrock location near to the tide gauge, but far enough away from the wave break zone to prevent the action of breaking waves distorting instrument measurements. These data will provide verification of vertical land movement determined from the GNSS instruments.

Given the inter-relationships that exist between ocean and atmospheric processes it is recommended that weather stations be positioned close to or as part of the tide and sea level instrument setup. Weather stations may already be in place at Hera Naval Base and Mahata Port given that such systems are commonly placed at these sites for operational purposes. In the event that weather stations are not in place at these site, their institution would assist both the tide and sea level observing system and the port and naval base operations. Robust weather stations are required at coastal locations, and instrumentation with few small parts that may be easily damaged in storm conditions are recommended.

To facilitate the effective operation of all tide and sea level instrumentations it is recommended that a small tidal hut be constructed. This hut could serve the dual purpose of protection battery supply and data logger equipment from the elements and interference, while providing an elevated surface from which the radar gauge can more easily be mounted, and where the weather station and telemetry transmitting devices can be placed.

1. Background: Ocean and Coastal Conditions

1.1 What causes tides?

While there are many processes that influence how tides vary around the world, the major forces that create the tides we see are **Gravity** and **Inertia**.

Gravity is the force of attraction that exist between all masses. The amount of attraction between two objects is proportional to the mass of the objects and is inversely proportional to the square of the distance between the two objects. This means that the larger the objects are, the larger the gravitational force between them. Also the closer two objects are, the larger the gravitational force between them. For large objects like the Earth and Moon, the gravitational force between these two bodies is strongest on the sides which face each other (where the distance is smallest) and weakest on the sides that face away from each other (where the distance is greatest).

Inertia is the property of matter that causes it to resist changes in velocity (speed and/or direction). The amount of inertia an object or material has, is proportional to its mass. As gravitational forces act to pull the Earth and moon toward each other, Inertia acts to resist this motion and maintain the Earth and Moon in their present state.

The reason tides exist is because the gravitational force is not uniform around the world. The gravitational attraction between the Earth and moon is strongest on the side of Earth facing the moon (closest to the moon). As gravitational force acts to draw water closer to the moon, the inertial force of the water attempts to resist and keep the water in place. On the near-moon side of the Earth however, the gravitational force is stronger than the inertial force, and water piles up causing a bulge on the side nearest the moon.

On the far-side of the Earth, the gravitational force of attraction exerted by the moon is less because the distance is greater between the moon and the far-side of the Earth. On this far-side, the inertial force of the water is greater than the gravitational force exerted by the moon, and the water largely maintains its original trajectory moving away from the Earth, creating a second bulge on the opposite side.

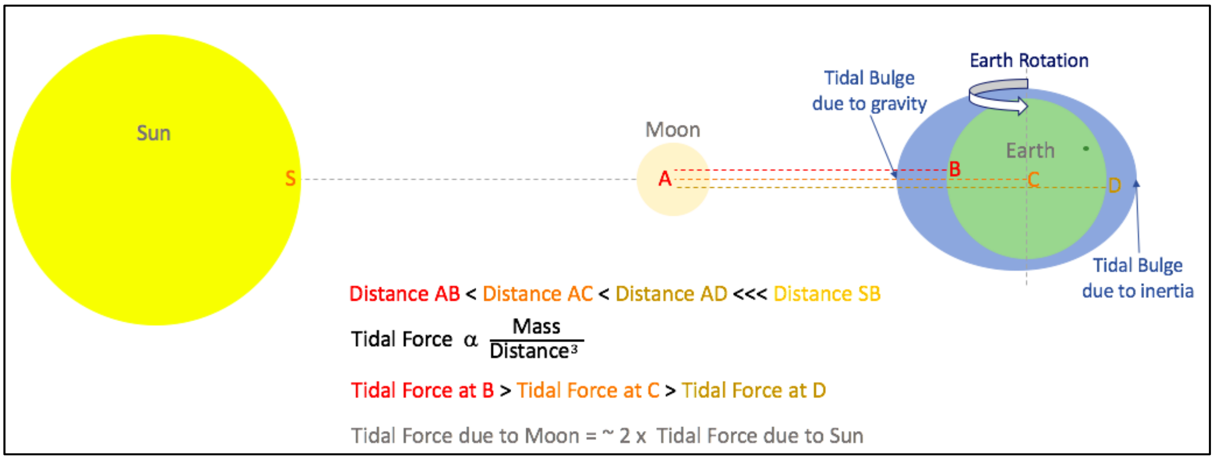

Figure 1. Two tidal bulges occur on opposite sides of the Earth due to the moons gravitational force and the counterbalance due to inertia. In this diagram the sun is also aligned with the moon and Earth. Under these conditions high tides water levels are higher than the average position of high tide and low tide water levels are lower than the average position of low tide. These conditions are known as Spring tides. If the sun was instead positioned above the Earth, while the moon was oriented to the side of the Earth (e.g. in the same position as shown above) Neap tides occur because the gravitational force between the Earth and sun counteracts the gravitational force between the Earth and moon. Under Neap conditions high tide levels are lower than average high tide levels, and low tide levels are higher than average low tide levels.

In this way gravity and inertial forces interact to create two bulges of water, one on the side of Earth closest to the moon and the other on the side of Earth furthest from the moon. Because water is fluid, the two bulges remain aligned with the moon as the Earth rotates. These bulges of water create the high tides. Rather than the bulges changing position around the Earth, it is actually the Earth that changes position as it spins on its axis relative to the bulges. As the Earth rotates on its axis a specific location, say a city, moves relative to the bulges and when the Earth has rotated such that the city is on the near-side of the moon, it experiences a high tide. As the Earth continues its rotation by 90 degrees (~ 3 hours after high tide), the city moves through the minimum in the water level and experiences a low tide. Then as the Earth rotates another 90 degrees, so that the city is now on the opposite side to the moon, the city experiences a second high tide and so on. If the moon was stationary, the timing of tides would be equal to one solar day (24 hours) however the moon itself rotates around the Earth over the period of 28 days, so a lunar day is 24 hours and 50 minutes. This is why the timing of high and low tides changes every day by about 50 minutes.

There are many other processes that influence tides, and how they vary around the world, however for brevity we will not address these in this report. For more information and explanation regarding tides, the National Oceanographic and Atmospheric Administration (www.oceanservice.noaa.gov/education/tutorial_tides) provide excellent resources.

In addition to tides, there are other forces that cause water levels to vary around the world. Meteorological influences, such as high and low atmospheric pressure and winds are two of these processes. In areas where the air temperature is warm, the atmosphere exerts lower pressure on the ocean than areas where the air temperature is cold. This means that the ocean bulges up slightly in areas where air temperature (low pressure) occurs and is depressed slightly in areas where air temperatures are cold (high pressure). When wind blows across the ocean surface frictional drag causes water to move. If winds are steady and blow for an extended period of time from a particular direction a wind-driven current will develop. On a non-rotating Earth, the wind-driven current would be in the same direction as the wind, however because the Earth rotates wind-driven currents are deflected to the right of the wind direction in the Northern Hemisphere and to the left of the wind direction in the Southern Hemisphere. These wind-driven currents actually result in the large ocean currents and gyres seen in the worlds ocean basins. For more information, describing ocean currents the NASA Ocean Motion website (www.oceanmotion.org) is an extremely helpful resource.

1.2 Investigating ocean and coastal processes in Timor-Leste

Sea level rise in the Timor-Leste region is predicted to range between 5 and 7 mm/year. These estimates are based upon satellite altimetry data and global atmosphere/ocean models. There is however an absence of on-the-ground measurements describing water level variations in the Timor region which can be used to verify these estimates. As a consequence, it is difficult for Timorese government departments to make informed decisions regarding the management of the coastal zone, particularly with respect to managing the impacts of climate change, including sea level rise on coastal communities and coastal infrastructure. To remedy this gap in data and understanding the UNDP facilitated the Rapid Shoreline and Sea Level Rise assessment and identify Gaging Instruments for Timor-Leste Project. The project involved a partnership between researchers at the Griffith Centre for Coastal Management, from the Gold Coast, Queensland, Australia, and UNDP Coastal Resilience Unit staff, based in Dili, Timor-Leste.

Following an inception meeting to discuss the project aims and objectives both among the work team and with key stakeholders, namely the Ministry of Agriculture and Fisheries, including the ALGIS Department, a strategy for conducting the coastal assessment determined and enacted. Over a two-week timeframe coastal environments in ten of the 11 coastally connected provinces were assessed (Figure 2). The one province where on-the-ground assessments were not conducted was Ainaro, due to difficulty accessing this section of the coast. In the absence of on-ground assessments, a remote assessment has been undertaken to determine coastal characteristics and coastal vulnerability to assist fill this gap.

Timor-Leste is located in a region known to experience complex tidal behaviour and strong currents. This is in large part due to its position, at the intersection between the Indian, North and South Pacific Oceans (Figure 3). Consideration of these complexities and the need to improve the understanding of ocean and coastal processes in this complex region informs the recommendations made in this report.

Figure 2. Locations where site measurements and site data were collected are identified by red and orange dots in Google Earth. Additional site assessments (not displayed on the map) were undertaken between locations depicted, through the collection of site photos, where road access provided close access to the coast.

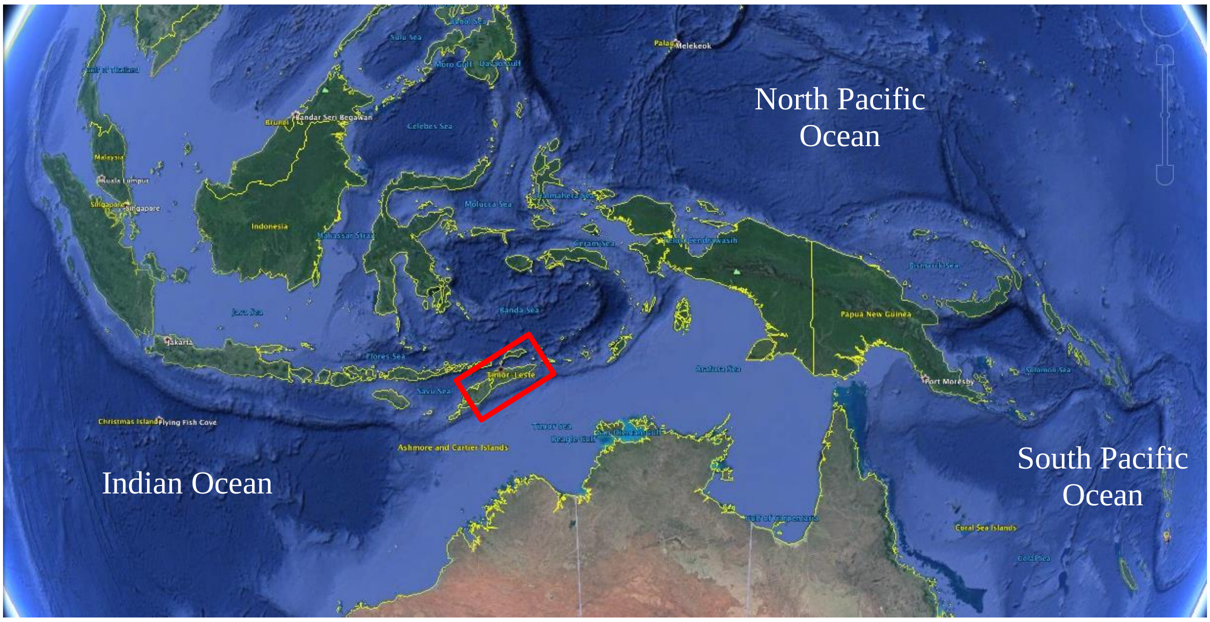

Figure 3. The three ocean basins (Indian, North Pacific, South Pacific) that contribute to the complex movement of marine waters around Timor-Leste (shown highlighted in the red box). The map image was generated using Google Earth.

To gain a preliminary understanding of water level variations due to tidal processes in Timor-Leste, a tidal gauge was deployed at the Pertamina Jetty in Dili. This jetty extends over deep water (water depth > 10 m). The pressure tide gauge was fixed in place, approximately 4 m from the water surface, for a period of 17 days, recording water level every 10 minutes. The water level measurements obtained by the pressure gauge are displayed in Figure 3. The time series in Figure 4 shows the vertical variations between high and low tide during both a neap and spring tide cycle. In this display water level is displayed with respect to the mean water level, where the water level at the mid-point of the tide is assumed to be the mean sea level (MSL) and so is represented as 0 m on the y-axis. From this time series, the maximum tidal range (the largest difference between successive high and low tide water levels) was 2.29 m. Longer time series data provided by the permanent tide and sea level instruments recommended in this report will enable similar measurements to be continuously obtained. By capturing such measurements over long periods of time, researchers will be able to describe the coastal processes that influence beach and shoreline environments in Timor-Leste with improved accuracy. By recording measurements over long time frames (years to decades), Timor-Leste will have the data necessary to measure how much sea level rise is occurring in the region, and how sea level rise is likely to affect coastal communities.

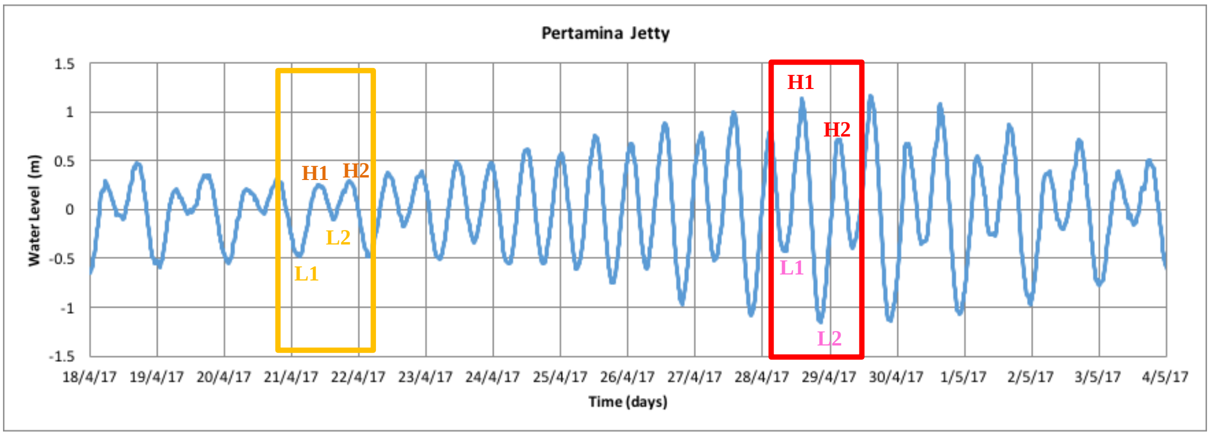

Figure 4. Water level time series collected using an in-water pressure tidal gauge at Pertamina Jetty, Dili. On the y-axis, 0 m represents mean sea level (MSL), which is approximately equal to the average position of water if no tides occurred (mean sea level). As the tide comes in, water is raised above mean sea level. At high tide, the maximum water level is reached, and the tide turns and recedes. As the tide recedes water level drops back to mean sea level and then continues to drop below mean sea level to the low tide level. The difference between the high tide level and low tide level varies due to the relative position of the moon, sun and earth. To describe these variations in tides we use the terms Neap Tides and Spring Tides. The section selected in the yellow rectangle shows the water level variations during neap tides (when differences between high tide and low tide is the smallest). The section selected in the red rectangle shows water level variations during spring tides (when differences between high tide and low tide are greatest). Additionally, this time series shows a strong diurnal variation between successive high and low tides. That is the first low tide (L1) of the day is either lower or higher than the second low tide of the (L2), and similarly for the first (H1) and second (H2) high tides.

1.3 Tides in the Timor Region

Because there are few tidal measurements in the Timor region tides have been estimated by using measurements of sea surface height from satellite observations. The changes in sea surface height measured during the satellite fly overs has provided some insight into the broad variations expected for the region. From this data the mean amplitude of the semidiurnal (two high/low water levels per day) variations (M2) caused by the moon-earth system, and the diurnal (one high/low water level per day) variations (K1) caused by the moon-earth system have been estimated (Figure 5).

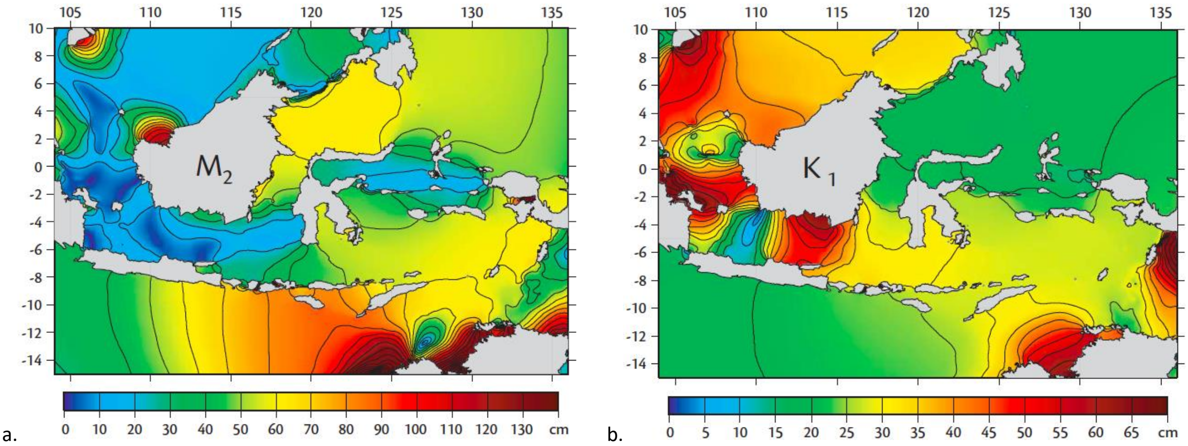

Figure 5. Amplitude of the tide wave due to the principal semidiurnal lunar constituent, known as the M2 constituent (a) and due to the principal diurnal lunar constituent, known as the K1 constituent (b). (Maps reproduced from Ray, Egbert and Erofeeva, 2005, A brief overview of tides in the Indonesian seas).

The maps in Figure 5 show the complicated, highly variable nature of tides in this region. While the maps displayed in Figure 5 give an indication of the likely variation in high and low tides, there is a need for more detailed information to better describe water level variations around Timor-Leste by measuring water levels at permanent tidal stations. This is because tides in deeper waters are modified as they move over shallower water and as they enter coastal bays of different shapes and sizes. Accurate tidal information is particularly necessary in order to understand the potential impacts brought about by storm activity, tsunamis, ENSO cycles and other multi-year processes, including changes in sea level due to climate change.

A literature review undertaken to determine the state of understanding of ocean and coastal environments in the Timor region revealed fast tidal currents (up to 30 cm/s) are experienced in the Ombai Strait, between the Timor-Leste provinces of Bobinaro, Liquicia, and Dili, and the Alor Archipelago (yellow/orange area seen in the Ombai Strait in Figure 6). Further east, in the Wetar Strait coast tidal currents fall below 10 cm/s, but ramp up around the south-eastern tip of Timor-Leste, approaching 20 - 30 cm/s. Along the southern side of Timor-Leste M2 tidal currents typically range between 3 and 10 cm/s (yellow, lime and green areas shown in Figure 6).

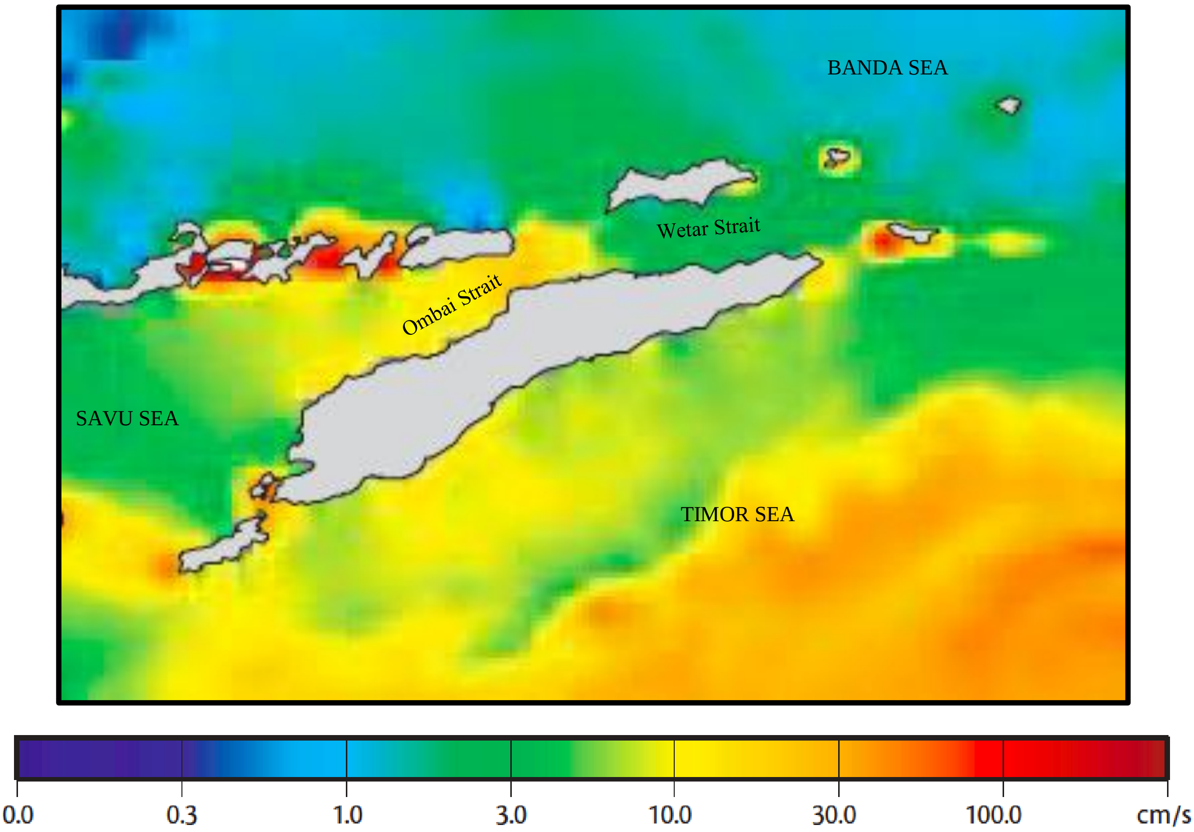

Figure 6. Maximum current velocity due to the M2 (semidiurnal lunar) constituent, which is the major constituent broadly responsible for tidal water level variations. (Map reproduced from Ray, Egbert and Erofeeva, 2005, A brief overview of tides in the Indonesian seas).

1.4 Waves in the Timor Region

While no wave measurements were located during the literature review, wind-wave estimates have been calculated for the region using numerical wave models forced by observed wind conditions. These models predict the offshore wave climate and give an indication of the maximum wind-wave heights in deeper water. As wind-waves encounter shallow water they break and dissipate so wave heights indicated may differ from those experiences at the coast. The results of model simulations discussed below in this report are from CAWCR Technical Report No. 068. PACCSAP wind-wave climate: High resolution wind-wave climate and projections of change in the Pacific region for coastal hazard assessments.
From model simulations, the offshore wind-wave climate on the southern side of Timor-Leste is higher than that on the northern side of the island. This is due to the larger expanse of open water adjacent to the southern shores, compared to the northern shores, which are protected by the presence of the string of islands immediately north of Timor-Leste.

On the southern shorelines predicted significant wave height, which represents the wind wave height of the top 10% of waves, reaches approximately 1m from the South-west during December to March. During the period from June to September predicted significant wave height reaches up to 1.5m from the South (Figure 7). Extreme storm driven wind-waves reach between 2 and 3 m on the southern shores. These wave heights have a predicted recurrence interval of 4-6 years.

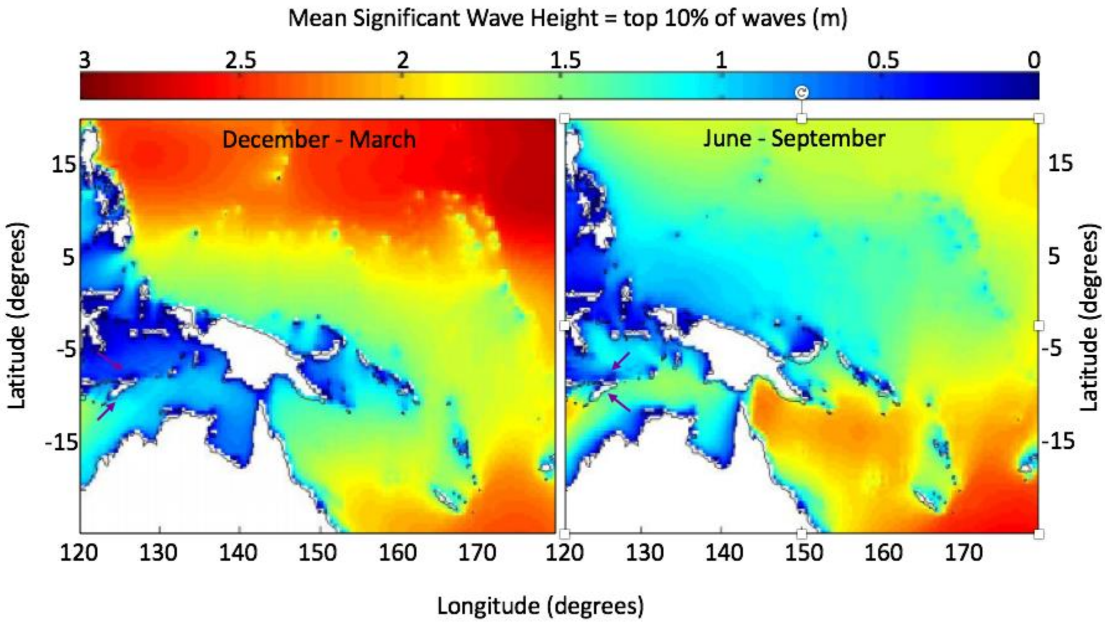

Figure 7. Maps displaying predicted wave climates for the region. These results are based upon an analysis of model hindcasts for the period from 1979 to 2009. Note that the maps show the predicted significant wave heights which represents the upper 10% of waves. The maps in this figure are reproduced from those reported in CAWCR Technical Report No. 068, http://www.cawcr.gov.au/publications/technicalreports.php)

On the northern shores predicted significant wave heights during December to March fall below 0.5 m from the North-west. During June to September, significant wave heights also fall below 0.5 m but come from the North-east (Figure 7). Peak wave heights during extreme storm events reach up to 1m on the northern side of Timor-Leste, and have a recurrence interval of around 2 years.

While not sufficient for detailed coastal hazard assessments, the data reported above, from the literature review demonstrate the different processes that influence different sections of the Timor-Leste coasts and show how these processes vary spatially around Timor-Leste. For this reason, it would be ideal if tidal and sea level infrastructure be put in place to monitor to capture this spatial variability. The rapid coastal assessment undertaken for this project confirmed the benefit of having instruments placed around Timor-Leste to capture information to improve understanding of how sea level rise and climate change may impact the different coastal communities. Additionally, this information will help guide decisions about the placement of critical infrastructure such as roads and electricity generation facilities, diesel plants, and gas and oil facilities. If new ports are proposed, an understanding of the ocean processes that these facilities will be exposed to, both in the present and future, will enable these facilities to be designed in such a way as to improve their longevity and minimise damage. A map displaying how tide and sea level infrastructure might be placed to enable variations in coastal and ocean conditions and processes to be more fully captured around Timor-Leste is shown in Figure 8.

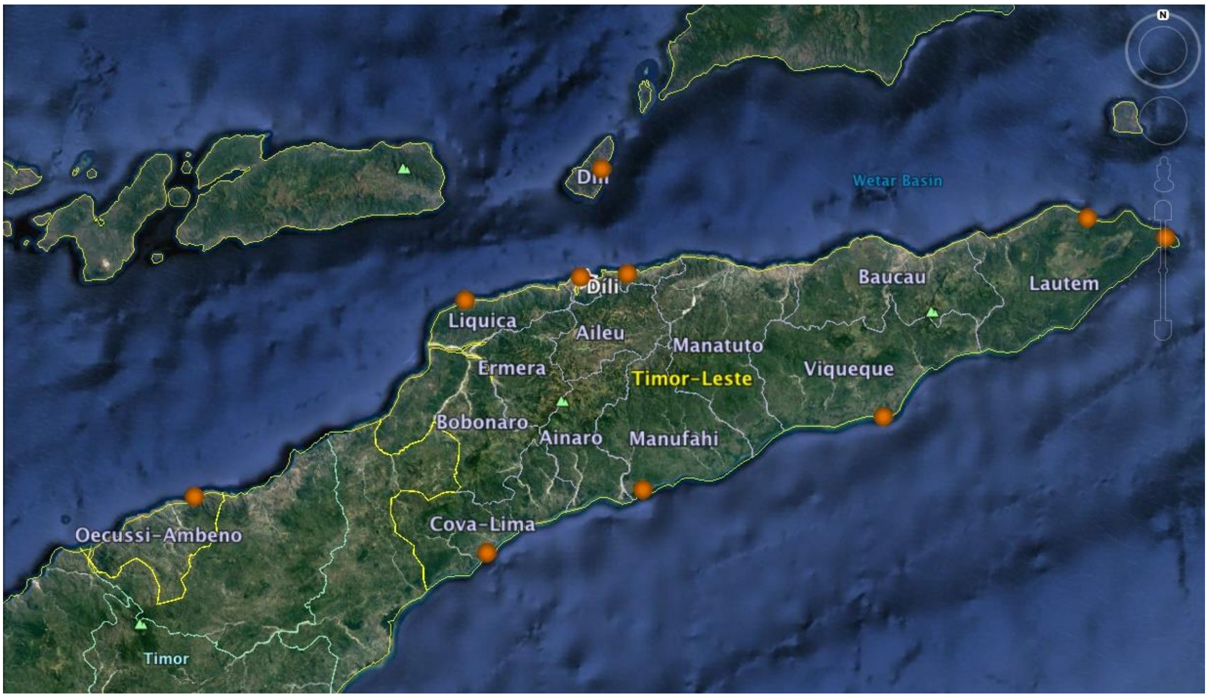

Figure 8. Orange dots indicate ideal positions for tidal and sea level rise instruments if site selection conditions were met. Distributing instruments around the coast would enable increased understanding of regional differences in ocean and coastal processes. (Image generated using Google Earth).

It is recognized that some of the sites indicated may not be feasible due to budget limitations and staffing and maintenance constraints. Additional limitations relate to site accessibility and lack of appropriate structures such as a jetty or port on which to place the instruments. However, in the absence of such restrictions, distributing instruments in locations similar to those displayed would capture the majority of ocean processes and their variation around the Timor-Leste coast.

Having undertaken a comprehensive assessment of the locations suggested in Figure 8, of the ten locations recommended only five site presently have jetty or port facilities where instruments could easily be positioned at present. These locations are Mahata Port, Pante Macassar in Oecussi Province, Tibar Port, Liquicia Province, Dili and Hera in Dili Province, and Com in Lospalos Province. These five locations are all on the northern side of the island. While the port at Com is well positioned, being close to the eastern end of Timor-Leste, this port is in need of repair. Similarly, the facilities in Tibar are in need of significant repair and at present are not suited to instrument placement. The Maritime Port in central Dili, Pertamina Jetty in near Arbiru Beach, Dili, are in much better condition, however the facilities are showing signs of age-related damage and will likely need to undergo some level of upgrade or repair in the near future. Given these limitations, the two locations that are most likely to meet the recommendations pertaining to site selection are the Hera Naval Base, Dili Province, and the Mahata Port, Oecussi Province. The international recommendations for site selection, and the compliance with these standards for these two locations are presented in the following section of this report.

The information generated by obtaining measurements at these two locations will provide valuable data which will help facilitate improved understanding of tides, storms, sea level rise and other ocean and coastal processes. This information will support studies investigating coastal communities and ecosystems and will facilitate the development of more accurate models for predicting coastal hazards and coastal processes in Timor-Leste.

Similar information would also be valuable for northern-eastern and southern coasts. This is because different regions experience differing tidal processes and wave climates depending upon their orientation and ocean exposure. In the event that the Port at Com is upgraded such that it provides a stable supporting structure, placing instruments at this location is recommended. Similarly, while presently there are no jetties that extend off the coast on this side of Timor-Leste, there are gas hubs proposed for Beaco Beach, Betano Beach and Suai. At present it is unclear if these hubs will include the building of ports or jetties over deep (> 5m) water, or if ships would moor offshore and utilise flexible hose connections. If jetties/ports were to be part of the future infrastructure at any of these locations, it is recommended that tide and sea level rise instruments be installed. The installation of these instruments would not only provide valuable information with respect to better describing the ocean processes, the presence of these instruments would assist the port operators better understand and monitor the ocean conditions affecting their infrastructure. The data obtained from tide and sea level instruments could then be used to assist the operators manage risk and associated insurance.

In the absence of permanent monitoring stations on the southern shorelines, it is recommended that some monitoring of tides and waves form part of investigations undertaken when conducting feasibility studies for the gas hub facilities. Additionally, it is highly likely that any oil and gas operators who undertake extraction in this region will have collected some form of ocean data, be it water level data, current (water speed) data or wave measurements, in order to meet requirements placed upon their operation by insurance companies covering their operation. In order that Timor-Leste may make use of this data, these companies could be contacted to determine if they would be willing to provide these data the ALGIS department, the department to whom responsibility for the tide and sea level data for Timor-Leste will be transferred to in the near future (~ 2021). While the data oil and gas operators may have collected will be over relatively short periods (days to weeks), these data could assist build up a library of measurements which can be used by researchers to assist develop models which can then be used to fill in the time gaps and then project conditions into the future.

If the recommendations provided in this report are followed with respect to site selection, instrument selection, and instrument installation and setup, the data collected by the tide and sea level instruments will be of a standard acceptable to the Global Sea Level Observing System. In this way the information collected can not only improve understanding of these processes for the benefit of the people of Timor-Leste, but can also contribute to improved understanding about both regional and global coastal and ocean processes.

2 Site Selection

2.1 International Oceanographic Commission (IOC) Site Selection Recommendations

Selection of appropriate sites for instrument placement is critical for the acquisition of accurate sea level measurements and is vital for the success of tidal and sea level infrastructure. This report includes the recommendations for appropriate instrument placement, guided by recommendations detailed in the Intergovernmental Oceanographic Commission detailed in the Manual on Sea Level Measurement and Interpretation Volume V: Radar Gauges (2016). These recommendations regarding instrument placement are synthesized into the points listed below. After each recommendation, the implications of the recommendation with respect to instrument placement in Timor-Leste are summarized.

1. Sites should be connected by relatively deep water to the open sea in order that the instruments reflect the tidal regime of that section of the ocean. It is best to avoid sites close to headlands, or site within harbours with restricted entrances, or sites that are subjected to high rates of siltation.

There are numerous sites around Timor-Leste where coastal waters have a continuous connection to the open ocean, and where headlands are sufficiently far as to not unduly influence water-level measurements. There are presently no restricted entrance harbours in Timor-Leste. While these considerations do not heavily restrict instrument placement the recommendation is important and was taken into consideration when recommending appropriate site locations in this report.

2. The instrument must be positioned where water is sufficiently deep and does not dry out during low tides. Water depth should be > 2m deep during lowest astronomical tide and must be sufficiently deep that the seafloor is not exposed by wind-wave activity.

Given the tidal range at Dili, is around 2.5 m (from the Pertamina measurements and tidal predictions for Dili Port), it would be best to place instruments in areas with water depth > 4.5 m above Mean Sea Level.

There are very few locations in Timor-Leste with any facilities that extend beyond the intertidal zone and over water, thus the small number of ports and jetties in Timor-Leste significantly limits the locations where instruments can safely be placed. While instruments can be placed directly on the shoreline of cliff coasts where there is a sharp drop off to deep water, other considerations regarding ease of access listed below are not presently satisfied at these locations. This consideration is a major limiting factor that had to be taken into consideration when selecting appropriate tide gauge sites in Timor-Leste.

3. Tide gauges are best placed at sites minimally exposed to tidal streams or currents exceeding 0.5 knots (~26 cm/s), river discharge effects, and high wave energy.

At present there is little information describing near-shore current speeds for Timor-Leste, however current speeds off the coasts adjacent to Dili, Liquicia and Bobinaro Provinces are likely to reach 26 cm/s. Closer to shore currents speeds may be more moderate, however it is recommended that some measure of tidal currents be undertaken if fast currents obviously affect a site selected for tidal gauge placement, or if locals with knowledge of the site report the presence of fast currents.

Given Timor-Leste experiences rapidly varying freshwater discharge, it is best to place instruments at locations as far as possible from river outlets to minimize the potential for riverine flow to influence marine water level measurements. In some instances, instruments may have to be placed within 1 km of a river outlet due to other limitations governing site selection. In such a situation, in order to determine if riverine flow has an impact on water level measurements at the site any hydrological measurements that might be available for the nearby river should be compared with water level data to determine if there is a residual influence on water level height that cannot be attributed to marine influences such as tide, regional circulation, atmospheric pressure, storm surge etc, but that matches river behaviour.

The wave climate is relatively low around Timor-Leste, with significant wave heights typically falling below 0.5 m. As such waves are unlikely to influence instrument placement at most locations. During extreme weather events wind-waves up to 1m (north) and 1.5 m (south) do occur for short periods, however their influence can be removed through appropriate filtering of measured data in post-processing.

4. The site should be located in tectonically/geologically stable locations.

Given Timor-Leste is located on the Pacific Rim, the country experiences vertical land movement associated with tectonic activity. In order to remove the influence of tectonic and geological processes from shifts in water level due to ocean processes, Global Navigation Satellite System (GNSS) receivers are recommended in the instrumentation. A GNSS instrument should ideally be positioned immediately next to the tide gauge, with an additional GNSS instrument set into bedrock at a nearby site. The relative positions and variations reported by the GNSS instruments will enable vertical land movement signals to be removed from changes in mean sea level due associated with ocean and atmospheric processes, including sea level rise due to climate change.

5. Instruments should be placed on stable supporting structures, at locations were future construction work that may necessitate the relocation of the tide gauge thus interrupting sea level time series is unlikely.

This requirement is the second most significant consideration limiting the placement of tidal instruments in Timor-Leste. Of the facilities with structures that extend beyond the shoreline, only two are presently built within recent years, such that future construction work to upgrade the facility is unlikely or unnecessary. Despite this challenge, Timor-Leste is a rapidly developing country with the capacity to build high quality infrastructure, and as such more locations appropriate for housing tidal infrastructure may become available in the future.

6. The site must have sufficient space to place a hut housing the gauge's electronic equipment next to the tide gauge and must have access to continuous mains power. In the absence of mains power solar panels and storage batteries may be used. Additionally, there must be continuous telephone or satellite access for near real-time data transmission.

The conditions with respect to access to mains power are easily satisfied due to the extensive electricity network present in Timor-Leste, however it is recommended that a storage battery is installed as a back-up power source in the event of disruption of the electricity network. Satellite coverage in Timor-Leste is sufficient for data transmission purposes.

7. Instruments should be placed in close proximity to existing, or specially installed high stability survey benchmarks and should have easy access high-precision level connections to stable survey benchmarks.

The GPS coordinates of permanent survey benchmarks will need to be obtained from the Department of Justice. The PMS network for Oecusi is documented in the report Rede Geodesica Nacional Regiao Administrativa Especial Oecusse Ambeno (Raeoa) SNC RG_OEC/2016. On obtaining the benchmark positions, the three benchmarks closest to sites selected for potential instrument placement need to be checked, and all information relating to the position and benchmark type recorded. If adequate permanent survey benchmarks are not available at the proposed sites for tide and sea level instrument placement, additional PSM benchmarks will need to be put in place before the tidal instrumentation is installed. At present, there is a dense network of permanent survey marks for Timor-Leste, however the marks need to be checked to ensure they have not been built over, and the information relating to the marks needs to be updated. These benchmarks are vital as they determine the relative position of the land with respect to the water level and provide a common reference point against which water levels are measured and against which mean sea level is established. In order to determine if water levels are changing over time, water level has to be measured against a common point on land. A GPS base station is being established in Timor-Leste and this base station will act as a common point against which all PSMs are referenced. The institution of the GPS base station will facilitate the accurate establishment of new PSMs and will enable all existing PSMs to be rapidly updated.

It is important that the GNSS network is maintained and regularly checked (annually) as this information facilitates the measurement of vertical land movement due to tectonic or geological activity. These processes cause subsidence or uplift of the land and the common reference points against which the water levels are measured. For this reason, the tidal instrumentation recommended for the Timor-Leste includes a minimum of two GNSS receivers, one CGNSS (Continuous Global Navigation Satellite System) associated with the tidal gauge, and one with the bedrock permanent survey benchmark (PSM).

8. Minimize exposure of instruments to marine growth.

The recommendation is accounted for by using a RADAR tide gauge as the principal water level measurement instrument. In warm tropical waters marine growth is rapid and will interfere with in-water instruments. However, an in-water pressure tide gauge is recommended to be used in concert with the RADAR tide gauge to both act as a quality check, and a backup instrument during periods when maintenance is required, or in the event that the RADAR gauge is damaged during an extreme storm event. To minimize the impact of marine growth it is recommended that the in-water instrument be housed in such a way that it may be easily brought to the surface, cleaned and replaced at regular intervals. Three monthly intervals may be sufficient however this may need to be revised by the staff responsible for maintaining the instruments.

9. Place instruments where there is minimum risk of vandalism or theft.

The sites where appropriate structures extend over deep enough water are locations that already have high security in-place and thus vandalism or theft of instruments is unlikely. This recommendation however limits the potential for using cliff-coastal sites as at present there are no manned facilities in such locations and thus any instruments placed at these sites would be at a higher risk of damage or theft.

10. Locations where shipping activities might generate short-lived, large, high frequency sea level oscillations are to be avoided.

This recommendation is not feasible in Timor-Leste, as sites that are used for shipping are the only locations with stable structures extending over water deep enough for instrument placement. As a consequence, oscillations associated with shipping activities will have to be removed at the post-processing stage.

11. Ensure ease of access for the purpose of servicing instrumentation.

For sites located on land used for government or military purposes, access to the site for the purposes of instrument maintenance will have to be negotiated with the relevant stakeholders. If easy access is not able to be obtained to ensure instruments can be maintained as needed, this recommendation may further restrict the number of locations where instruments may be placed. In this event, it would be necessary for coastal land to be set aside specifically for the purpose of building an appropriate facility that could house tidal sea level infrastructure as there are only two locations that fit the other ten criteria and if these were not accessible there would be no locations available for the infrastructure at the present time. There are multiple benefits to any port, shipping and naval facilities of housing tidal infrastructure however, and as such, with communication between the appropriate stakeholders, arrangements should be able to be put in place so that instruments placed on an existing stakeholder's structures can be readily accessed for the maintenance purposes after following an agreed upon protocol.

Applying the full set of recommendations, there are two potential locations that are presently suitable locations for the placement of tide gauge and sea level measurement instruments, Hera Naval Base, Dili Province, and Mahata Port, Oecusi Province. These two locations are discussed in detail.

2.2 Hera Naval Port, Dili Province

Recommendations 1-3 regarding the site having a relatively deep connection to the ocean, sufficient water depth through the tide cycle, and being situated away from headlands and riverine flow etc. are mostly satisfied at this site. This is supported by the fact that this location was found to already house a tide gauge capable of capturing tidal water level variations. The instrument was installed for the purpose of assisting delineate coastlines and not expressly for investigating water level variations due to multiple processes from tides to sea level rise. As such the position of the instrument does not presently satisfy all recommendations pertaining to tide and sea level instrumentation and as such it is recommended that the instrument be repositioned and retrofitted. Prior to repositioning the instrument, it is recommended that two temporary pressure gauges will be put in place, one at the current gauge location and one at the proposed location (see Figure 9). The radar gauge and two pressure gauges will record water level measurements for a minimum of 28 days and the three datasets compared. These comparisons will allow differences in water level associated with gauge position to be accounted for if in the future, data from the prior period of tide gauge operation is sort. It is important to note that a river outflow appears to discharge on the western side of the Hera Naval Facility. An understanding of the river discharge this location is thus needed in order to understand if riverine influences may affect water level measurements.

The tectonic and geological stability of the site (Recommendation 4) needs to be clarified. As with many harbours, this modified shoreline environment is likely to have been constructed using a combination of reclamation of previously intertidal or marine areas, and dredging to increase the bathymetry (water depth) so larger ships are able to dock at the site. If tide gauge instruments are placed on a support structure constructed on relatively newly acquired and modified land, the site may experience sediment compaction over time. These processes can be accounted for using GNSS instruments, and any vertical shifts due to compaction can be removed. The same instrument setup can also be used to detect uplift of land due to tectonic activity.

Figure 9. Aerial image of Hera Naval Port. The location recommended as a potential location for tide and sea level instrumentation is indicated the red arrow , while the orange triangle indicates the location of the present tide gauge.

Recommendations 5 and 6, relating to the stability of the support structure and space availability for the placement of a tidal hut close to the position of the tidal gauge instruments is likely to be able to be met at this location, however the stakeholder needs to be engaged in order to assess the stability of the jetty and port facilities, and to determine if any refurbishment activities are planned at this location. Additionally, the placement of instruments as well as access to a continuous power supply, needs to be discussed with the stakeholder. The present tide gauge located at Hera Naval base has a stand-alone solar panel which may be a sufficient power supply, negating the need to connect to the mains power supply however it is advisable that more a back-up power source be available to ensure the instrument continues operating if one power source fails. Discussions should be held with the persons previously responsible for this tidal gauge to discuss the reliability of the power and battery system presently in place.

Access to communication satellites is likely to be adequate at this location, however at present the tide gauge located at this site does not appear to have the capacity to transmit measurements at near real-time and as such this capacity needs to be added. The transmission of measured data in near-real time is a vital to the success of tide and sea level measurement project, and will enable data to be disseminated to multiple users and stakeholders.

The recommended position of the tidal gauge is on the eastern side of the jetty, outside of the rectangular shaped port (Figure 9). This position is recommended in order to avoid distortion of water level measurements associated with wave reflection or resonance within the port. At present, the radar gauge in place is located on the other side of the wharf. The instrument has been mounted directly on the wharf at foot height (Triangle mark in Figure 9, Figure 10 images). Based upon the report documenting the radar gauge placement, the sensor is positioned approximately 0.5 m above highest astronomical tide (HAT). While this placement may have been sufficient for the purpose the initial project this instrument was used for, it is positioned too low for the purpose of collecting long-term tide and sea level observations. This is because storm surges, tsunamis or extreme storm wind-waves may result in water levels which are several meters above Highest Astronomical Tide. If such an event occurred and the instrument was left at its current position, the instrument would be flooded and thus would be damaged. Such conditions are exactly the conditions where measurements are vital. While it is not possible to position the instrument to avoid all possible extreme events, placing the instrument at least 2 m above HAT would limit the possibility of damage due to storm surge and storm waves and some tsunami events. For this reason, it is recommended that this instrument be repositioned so that it sits on the other side of the wharf where fewer ships are likely to come into contact with the instrument, at a height at least 2 m above HAT.

Figure 10. Site photos of the Orinoco Vega Plus Radar tide gauge at the Hera Naval Base. This instrument is equipped with a Vegaplus 61 sensor (inset photo). These images were sourced from the Relatorio Technico Dos Trabalhos De Campo 2014 Report. From the instruments shown in the right panel, it appears care was taken to survey the elevation of radar gauge sensor so that data from the gauge could be accurately referenced to a land benchmark.

Based upon visual comparison of the benchmark map provided in SNC RG_OEC/2016 report (Figure 21 in the benchmark section of this report), there is one 2nd order Permanent Survey Mark (PSM) at Hera, and three 3rd order PSMs in the higher elevation lands surrounding

Hera. To determine if Recommendation 7 is satisfied, the precise locations of these PSMs needs to be confirmed, and the benchmarks need to be re-surveyed to validate their positions. If the third order PSMs are situated too far from the 2nd order PSM at Hera, two additional PSM benchmarks need to be established within closer proximity of the proposed location for tide and sea level instrumentation. All PSMs to be included in the tide and sea level measurement infrastructure must use the common datum utilized by the recently established Timor-Leste GPS base station.

Given the warm tropical waters surrounding Timor-Leste there is little that can be done to minimize marine growth (Recommendation 8). To remove the potential for marine growth to interfere with accurate water level measurements, any in-water instruments must be periodically cleaned (approximately once every two to three months).

Being a naval facility, there is little risk of instrument vandalism or theft at this site (Recommendation 9). Being a naval site, ships frequently dock and depart from this site, consequently, any influence ships may have on water level measurement need to be filtered from the time series data in order to address the concerns associated with Recommendation 10. The potential for ship activity damaging the instruments will be minimized by placing the instruments on the eastern side of the facility. The location of this site is within a thirty-minute drive of the capital Dili, and road access is relatively good. As such the site may be easily accessed for maintenance purposes (Recommendation 11), however access to the actual naval port needs to be negotiated with the stakeholder, as it is a high security location.

2.3 Mahata Port, Oecussi Province

Recommendations 1-3 which relate to the depth of water, connection to the open ocean environment, and distance from headlands and river outlets are satisfied at this site. Based upon sighting during the rapid assessment, water depth drops rapidly immediately from the shoreline. The Mahata Port (Figure 11) is a recently constructed facility and thus there is likely to be recent bathymetric measurements at this location with which to confirm the sites compliance with recommendations 1-3.

As with the Hera site, the tectonic and geological stability of this site needs to be verified (Recommendation 4). In the absence of this knowledge the GNSS instruments can be used to record potential vertical land movement. These instruments are required for any system of tidal and sea level measurement before they are accepted as part of the Global Observation Sea Level System.

The support structures on which instruments will be placed are in extremely good condition at Mahata Port, as the site has recently been constructed and appears to be a very resilient structure (Recommendation 5). There is adequate space at the port to position a tidal hut close to tidal gauge instruments (Recommendation 6) with easy access to continuous electricity supply and communication infrastructure. Confirmation that recommendations 5 and 6 are easily met should be obtained through discussions with the stakeholders operating the port facility. To account for marine growth (Recommendation 7) it is necessary to temporarily remove and clean the exterior of in-water instruments every two to three months.

Figure 11. Mahata Port, Oecussi Province. The red dot on the eastern side (right-side) of the port is the suggested location for tide and sea level instrumentation.

There are known survey benchmarks established for Oecussi province. A 1st order Geodesic permanent survey mark is located in central Pante Macassar, and a 3rd order permanent survey mark is located close to Mahata Port. It is recommended that three PSMs are located within close range of the tide and sea level instruments. To this end it is recommended that the PSM already placed close to the port be resurveyed and upgraded to a first order PSM. Additionally, two new PSMs should be instituted within close range of Mahata Port including a tide gauge benchmark within the port facility. The much needed institution of a permanent GPS base station in Timor-Leste will assist in the establishment of accurate PSMs and will facilitate the accurate measurement of sea level rise and the referencing of water levels against a common vertical datum.

From a security perspective Mahata Port fulfils Recommendation 9 due to the presence of an active security service who manage access to the facility. As a consequence, there is little risk of damage, vandalism, or theft of the instruments (Figure 12).

Figure 12. Site photos of Mahata Port, taken during the rapid coastal assessment 10th April – 5th May, 2017. The red X indicates the proposed location of tide and sea level instruments. Large concrete shapes called tetrapods are used to protect some sections of the port from waves.

While shipping activities do take place at this facility, the activity is relatively low and any distortion of water level measurements due to ship movements can be removed by appropriate filtering of the data in post-processing, in order to address Recommendation 10. Finally, the facility can be easily accessed for maintenance purposes by coordinating with the Port Authority responsible for the site. The Port is located within an easy 15-minute drive of central Pante Macassar.

2.4 Site Selection Summary

At present the two locations able to satisfy the criteria with respect to appropriate sites for the placement of tide and sea level instruments are Hera Naval Base, Dili Province and Mahata Port, Oecussi Province. While there is a radar gauge installed at Hera Naval Base, this instrument has not been assessed to determine its operational status (whether it is still in working order). Additionally, the radar gauge does not appear to be made of marine-grade stainless steel. To ensure the longevity of the instruments and thus the viability of long-term tide and sea level monitoring stations in Timor-Leste it is recommended the new radar gauges at both locations use marine-grade stainless steel. Finally, radar gauges at both Hera Naval Base and Mahata Port should be positioned at locations over deep water (~10 m deep), where they are unlikely to come into contact with vessels accessing the wharfs, at a height no less than 2 m above the position of Highest Astronomical Tide (HAT), and at a distance from the wharf such that the structure does not interfere with the radar signals.

When the planned activities with respect to the construction of gas hubs are finalized, the ability for these sites to satisfy the site selection criteria (recommendations 1-11) should be revised to determine if instruments may be placed at these locations. In the event that the port at Com in Lospalos province is refurbished such that the supporting structure is stable, and if instruments will be at little risk of vandalism or theft, it is recommended that tide and sea level instruments be installed at this location, as this site satisfies all other criteria.

3 Instrument Setup

3.1 Recommended Instrumental Setup

The setup recommended in this document aligns with the international practices for monitoring tides and sea level rise as described in IOC Manuals and Guides 14, JCOMM Technical Report No. 89, 2016. The instruments recommended for Timor-Leste are intended to measure water level variations due to multiple processes, including: tides, storm surge, tsunami, and sea level rise due to climate change. To achieve this a suite of instruments are required (See Table 1 and Table 2, and figures 13 and 14 for a graphical summary of the instrumental setup). It is important to note the instruments in this setup are tsunami detection instruments. The setup can be used to measure the height of tsunami waves as they pass over the instruments, assuming the stable structure holding the instruments in place are not damaged and the instruments stay in place.

The principal instruments recommended at each site include: a radar gauge, a pressure gauge, data loggers, data communication platform, antenna, backup solar power supply and battery, weather station (if there is not an existing station on-site) CGNSS instruments, gravimeter. Yearly surveys of these benchmarks are required to ensure the relative position of instruments relative to stable points on land. In order to participate in the GLOSS network a GNSS instrument must be positioned at a bedrock location within close proximity of the tide and sea level instruments to facilitate accurate determination of vertical land movement. This required equipment is summarized in Tables 1 and 2. A graphical depiction of the instrumental setup recommended for Timor-Leste is contained in Figures 13 and 14.

Instruments to measure water level variations
Radar Gauge (stainless steel K-band, Pulse type)
Pressure Gauge (vented type if feasible)
Atmospheric Gauge
Tide Staff (also known as Tide Board)
Weather station: wind meter, solar radiation, temperature,
Power and communication cables
Data loggers
Telemetry Communication Instrumentation including Antenna
Solar Panel for backup power
Batteries
Tide hut to store out of water instrumentation
Monitor to display data in near-real time onsite
Marine quality steel or aluminium mounting arm for radar gauge
Marine quality steel or aluminium mounting for pressure gauge

Table 1. Water level instruments recommended to obtain water level variation data. This data needs to be referenced to stable benchmarks and require the equipment/instruments listed in Table 2 to ensure water level data can be properly analysed to provide accurate measurements of sea level rise.

Equipment/Instruments to measure vertical land movement
Stable bedrock benchmark/s
Continuous Global Navigation Satellite System (CGNSS) (advisable)
Absolute Gravimeter (if budget allows)
Tidal benchmark (if no bedrock available as stable as possible, re-survey annually)
Rods and levels for surveying benchmarks and the vertical position of the radar and pressure sensors relative to the stable bedrock benchmark (only needed during surveying, not permanent)

Table 2. Equipment recommended to accurately determine vertical land movement which obscures measurement of sea level rise if not accounted for. In the absence of a CGNSS instruments capable of regularly reporting vertical position, the vertical position of the tide gauge must be annually surveyed relative to the bedrock benchmark. A GNSS must be located at the bedrock benchmark or close by in order for the tide and sea level observation system to participate in the GLOSS network.

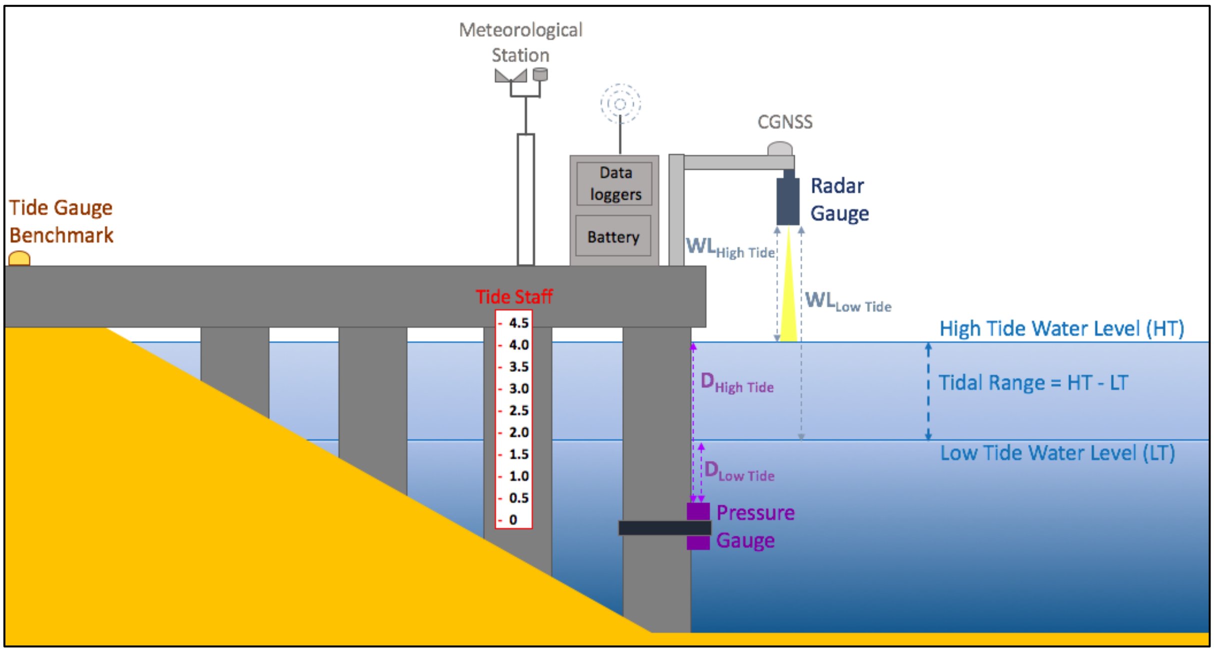

Figure 13. Instruments setup to measure marine water level variations and meteorological conditions, including equipment to transmit measured data in near-real time. The tide hut beside the tide gauge holds the data logger, battery and cable connections which form part of the radar control unit, which links to the telemetry device which in this diagram is shown onto of the tide hut.

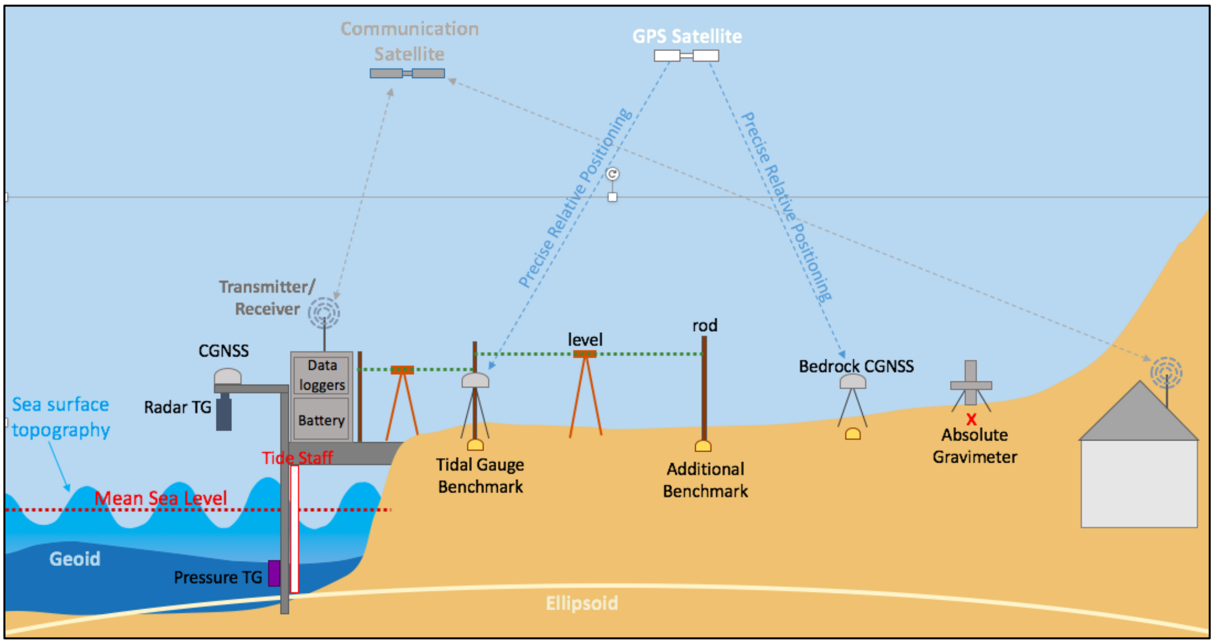

Figure 14. Instrumental setup to obtain water level variations and vertical land movement. The data provided by this combination of instruments will enable the description of tides, storm surge, tsunami, and seasonal water level variations and sea level rise.

A brief description of each instrument is provided below. Further details regarding the instruments and the various applications can be found in IOC Manuals and Guides 14, JCOMM Technical Report No. 89. The different setups employed in range of different countries and regions, is also provided in the appendices of the aforementioned report. While there are some variations in the setups employed by different countries, the instruments employed remain similar, with small variations to allow for variations in the environment and processes of interest at each location.

While it might be considered that the instruments listed in Table 1, related to the measurement of water levels are the most important component of a sea level rise study, these instrument can only provide accurate data if they are accurately reference to a fixed stable benchmark on land. Furthermore, it is vital that this benchmark is situated on bedrock and that this benchmark is regularly surveyed every year. The bedrock benchmark should be connected to a number of supplementary marks to prevent its movement or destruction. Connections between the Tide Gauge Benchmark, the supplementary marks, and the level determined as the tide gauge zero mark, should be made annually, to an accuracy of a few mm. This work falls under the category termed datum control and levelling. Datum control is vital for all gauges intended for use delivering long-term sea level data for scientific research and for data intended to be included in data banks such as the Permanent Service for Mean Sea Level (PSMSL).

The reason why it is vital to maintain a stable benchmark is that sea level rise is a gradual process, which causes shifts in the mean sea level of a few mm/year. In order to detect such small changes, we have to be able to compare the position of the sea level against a stable point. However, land is not as stable as one might assume. Soft sediments like sand and silt can compact over time. This is why the stable benchmark must be placed on bedrock. Furthermore, tectonic activity may cause even bedrock to rise or sink. For this reason, the benchmarks have to be re-surveyed every few years. By resurveying the benchmarks any gradual shifts in the land, known as vertical land movement, can be calculated. If any tectonic events such as earthquakes occur in the Timor-Leste region, it is advisable to re-survey bedrock benchmarks around the country at the earliest opportunity following the event. These events may cause a sharp uplift or depression in the land. In this event the vertical position of the tide gauge relative to the benchmark will have to be adjusted to reflect the sharp step.

By conducting annual surveys of all stable benchmarks in Timor an understanding of how the land mass of Timor-Leste shifts (up, down, neutral) will be gained and the relative sea level rise can be determined. An array of CGNSS instruments that continuously relay vertical position data would enhance the capacity to accurately monitor vertical land movement. These data can be relayed in real-time to the International GNNS service (http://www.igs.org/).

3.2 Tide Gauge instruments

In the past, coastal water levels measurements used mechanical float gauges. These instruments were then surpassed by electronic and digital devices that calculated water level either based on the measurement of subsurface pressure (pressure is proportional to water depth) or on the measurement of the time of flight or an acoustic or radar pulse. To evaluate the accuracy, precision, and instrumental stability of the newer technologies experiments were undertaken comparing the performance of the different instruments in the laboratory and in the marine environment (Woodworth and Smith, 2003; Martin Miguez et al., 2005; Martin Miguez et al., 2008b; Blasi, 2009). From these studies radar gauges emerged as the stand out option with respect to accuracy, stability, ease of operation, ease of installation, ease of maintenance and cost effectiveness (Martin Miguez, et al., 2008a). While radar gauges provide cost-effective technology with the added benefit of being relatively easy to install and maintain, there are also fewer potential sources of radar measurement error (e.g. they are not affected by changes in gas composition, pressure and temperature). For these reasons the Global Sea Level Observation System Implementation Plan (UNESCO/IOC, 2012) recommended that new tide stations be equipped with radar gauges as the primary sea-level sensor, with pressure gauges acting as the primary tsunami sensor.

This setup, using a radar gauge, backup pressure gauge, and tide staff, with a CGNSS atop the radar gauge is recommended for Timor-Leste. This combination of instruments will provide a robust system for measuring variations in marine water levels due to the full range of processes potentially influencing Timor-Leste coastal regions. In addition to the diagram of the instrument setup recommended (Figures 13 and 14) examples of instrumental setup at existing tide and sea level instrumentation or shown in Figure 15.

Figure 15. Site photos of instrumental setup in the Caribbean (left) and France (right) to obtain water level variations. From these images we see radar gauges, with accompanying power source (solar panels). From the Caribbean setup the box containing the data logger and shown set off the ground as well as the communication antenna. From the France example, in addition to the radar gauge (the white instrument mounted on the concrete wharf pylon) an example of tide staff or tide board is shown.

Some considerations relating to radar and pressure gauges and the associated instrumentation are detailed below. It is important to note that in order to obtain accurate water level measurements both radar and pressure gauges must be properly calibrated. Radar and Pressure gauge calibration is addressed in a separate section toward the end of this report.

3.3 Radar Gauges

The two principal types of radar gauges presently in use for tidal applications are:

I. Time Domain Reflectometry (TDR) radars also referred to as Pulse radars (hereafter referred to as Pulse radars)
II. Frequency Modulated Continuous Wave (FMCW) radars.

Pulse and FMCW radars employ different methods to use the reflection of the radar signal from the water surface to calculate water level. Pulse radars calculate distance between the radar sensor and the surface of the water using the transit time of the radar signal, while FMCW radars use the difference between the transmitted and reflected signal frequencies. Both Pulse and FMCW radars capture the water level variations with errors in the 1-3 mm range. Typically, FMCW radars capture more data, however they require more power and more data analysis, and thus Pulse radars are recommended for Timor-Leste. Pulse systems have a long history of successful use for tidal applications. While they have a high power requirement during the pulse itself, transmissions occur during short intervals, and thus they have much lower overall power requirements, compared to FMCW devices which transmit continuously. Pulse radars can experience difficulties accurately determining water level at short ranges due to the short signal travel time and thus it is recommended that the gauge be installed at least 2 m above Highest Astronomical Tide. This requires the construction of an arm for instrument mounting at the two recommended Timor-Leste sites (e.g. Figure 16).

Figure 16. OTT Kalesto gauge in Alexandria (left). The arm is retractable for easy access during installation and maintenance activities. The image on the right shows an example arm from the UK with a WaveRadar Rex mounted to extend approximately 1 m from support structure (source IOC Manuals and Guides 14, JCOMM Technical Report No. 89, 2016).

In low energy, relatively low wave environments both TDR and FMCW radar gauges use a K-band microwave signal (~ 26 GHz). For sites situated within high energy environments where large waves and regular storms occur low frequency C-band sensors are recommended. In low-energy environments sampling frequencies typically employed ranges from 1 – 4 Hz. Integration periods (data averaging intervals, or smoothing intervals) typically range between 15 s and 2 minutes in low wave environments, increasing to between 2 and 4 minutes for high wave environments.

Having consulted the instrumentation deployed for multiple international projects that form part of the GLOSS network, K-band sensors (~26 GHz) are expected to adequately capture water level variations at the Hera Naval Base and Mahata Port sites. Radar gauges should be setup applying sampling frequencies from 1 – 4 Hz, with integration periods ranging from 15 – 120 s. These instruments are deemed appropriate given the relatively a low-wave climate (significant wave height < 0.5 m). In Mahata Port there are significant shoreline protection measures in place, on the eastern side of the port where a few rows of tetrapods (large concrete moulded shapes seen Figure 9, bottom left image) are placed in front of the concrete wall. The installation of these measures indicates wave interact with the shoreline at this location. This is further supported by anecdotal reports from Mahata Port security guards who mentioned overtopping occurring during storm conditions in the sections of the port where no tetrapods have been installed. Overtopping is the term used to describe waves hitting a coastal barrier and spilling onto the land behind the barrier. However, compared to other locations (e.g. Brest, France) where K-band radar gauges have been successfully employed for extended periods (over 5 years), the wave climate at Port Mahata is relatively low and so should not require the use of lower frequency (C-band) instruments.

Figure 17. Multiple examples of different radar gauges and radar gauge setups. The first image on the left shows the multi-component setup typically employed for radar tide and sea level observation systems. Three different examples of radar gauges are shown in the central and right images. (IOC Manuals and Guides 14, JCOMM Technical Report No. 89, 2016)

3.4 Radar Gauge Manufacturers

To provide some guidance for the selection of appropriate radar gauge manufacturers, Table 1 lists the principal manufacturers whose instruments have been utilized to measure tide and sea level processes around the world. Beside each manufacturer is a list of the countries where instruments have been successfully installed and utilized. The manufacturers most commonly employed are VEGAPLUS and OTT. The tide gauge currently in-place, but inactive in Hera Naval Base is a VEGAPLUS 61 sensor. VEGAPLUS sensors have been employed for numerous installations in Queensland and they form part of the tide and storm surge measurement network. For more information, describing the locations where different instruments have been implemented see the IOC Manuals and Guides 14, JCOMM Technical Report No. 89, Manual on Sea Level Measurement and Interpretation, Volume V, Radar Gauges, 2016.

Radar Gauge Manufacturers	Agency/country where radar gauges are understood to be part of the tide and sea level rise infrastructure, as of April 2016
VEGAPLUS	Australia, Chile, Germany, Peru, Spain, UK, USA
OTT	Bahrain, Brazil, Germany, Italy, South Africa, UK
MIROS	Israel, Norway, Spain
Sutron	Oman, USA
Waterlog	UK, USA
Endress and Hauser	Denmark
GEONICA	Peru
Krohne	France
Radac	Netherlands
Rosemount	UK
Tokyo Keikei	Japan

Table 3. Radar gauge manufacturers and applications across the world, as reported in IOC Manuals and Guides 14, JCOMM Technical Report No. 89, IOC 2016.

3.5 Pressure Gauges

Pressure gauges have a fast response time and can be used to measure wave heights at periods of a few seconds or storm surges at periods of a few hours. This instrument allows a great deal of flexibility as it can easily be reconfigured to suit the type of process being investigated, and the reconfiguration may be performed remotely if the instrument is setup in such a way that it is connected to the communication network.

In tide gauge applications, the instrument is typically setup to record a 1 minute or so burst of measurements every 6 to 10 minutes. The instrument measures pressure every 0.25-1 second over a 1-minute interval. The pressure measurements recorded in that 1-minute burst are averaged, removing any variation in water level caused by high frequency wind-waves. If wind-waves monitoring is required, the pressure gauge can be configured to report the raw pressure data without averaging. For the purpose of measuring tides, storm surge, tsunami, and long term changes in sea level, 1-minute averaging, every 6 minutes is deemed acceptable, and meets the recommendation of the GLOSS network.

Pressure gauges are fixed directly in the sea and monitor pressure changes as water levels change. As with all in-water instruments, it is vital that the position of the pressure gauge is accurately recorded relative to the same benchmark used to level the radar gauge and tide staff. The vertical distance between the pressure sensor and benchmark must be accurately measured and recorded. This distance should be intermittently checked to ensure the pressure gauge does not shift. In Timor-Leste it is recommended that the pressure gauge we placed approximately 2m below lowest astronomical tide. This will enable the instrument to remain underwater during all tidal conditions and during storm conditions.

Pressure gauges are often deployed as a first measure to obtain an understanding of the potential tidal range or wave conditions present at a site. For these temporary deployments the instruments run off batteries, and log the data which is retrieved when the instrument is removed from the site. For permanent setups, the pressure gauge maintains a power connection via a cable that carries power and signal lines to a control and logging unit. This connection allows data from the instrument to be obtained in near-real time.

In marine environments the pressure sensor is usually placed inside a copper, titanium, or a thick moulded plastic housing. These copper and titanium materials tend to limit marine growth, while thick plastic mouldings are robust. The connecting cable is attached via a watertight gland. The instrument and cable are placed in an outer protective tube which is fixed to a sea wall, or in the case of the sites in Timor-Leste, to the wharf support columns (depicted in Figures 13, and 14). An example of a plastic moulded tide gauge and power/communication cable is shown in Figure 18.

Figure 18. RBR tide gauge and cable to provide power supply and communication. An RBR tide gauge was deployed at Pertamina jetty, Dili, to record water level variations over a 17-day period. The data from this deployment is shown in Figure 3. Typically pressure gauges are cylindrical-shaped instruments. Their lengths range from between 20 and 40 cm, and diameters range from ~2 – 10 cm.

There are two principal types of pressure gauges, absolute or differential pressure gauges, also known as vented pressure gauges. The difference between the two instruments relates to how they account for pressure variations that are not due to changes in water depth, but rather are caused by changes in atmospheric conditions. Differential pressure gauges maintain a vent to the water surface which allows the instrument to self-correct, to account for changes in pressure due to the atmosphere. Absolute transducers provide the total pressure due to the ocean and atmosphere. Therefore, a separate barometer is used in concert, and this data is subtracted from the absolute pressure data to provide the pressure changes solely due to changes in water level. This procedure occurs in the data processing stage, after measurements are relayed. While the vented gauge is preferable, if the venting tube were damaged during an extreme event the pressure gauge would be flooded. If there is little risk of damage to the venting tube, this instrument is preferable, however if the site is subject to extreme weather and wave conditions or is located in a tectonically active region the absolute pressure gauge, used in concert with a time-synchronized atmospheric gauge, is recommended as the secondary instrument for measuring water levels at Timor-Leste sites. This gauge is intended as a back-up instrument that will continue recording if the principal radar gauge is damaged during an extreme event. While barometers already form part of the weather station equipment associated with the tide and sea level rise instrument assembly, if an absolute pressure gauge is selected for use, a separate atmospheric gauge, from the same company is advisable for ease in processing the data and synchronizing the two instruments. The atmospheric pressure gauge and the absolute pressure gauges must be synchronized to the same clock, so the data readily be subtracted to yield sea level. This setup is the system most frequently employed in remote locations where instrument maintenance is less frequently employed.

All pressure transducers are sensitive to temperature and it is recommended that the pressure sensors have an in-built temperature sensor to allow compensation of the pressure signal. It is important to note that even for high-quality low-pressure sensors commonly employed for coastal work, instrument drift on the order of 1 mm per year can occur. For this reason, it is recommended that the instrument be recalibrated on an annual basis and a log be kept to record calibration activities. It is recommended that training with respect to instrument calibration be undertaken by the organization contracted to install and maintain the tide and sea level instruments. It is also recommended that an additional two or more absolute pressure gauges be obtained, to act as back up instruments that can be deployed in the event of unforeseen events that cause damage to tide and sea level instruments. These instruments are relatively low-cost and they may be easily deployed for up to a year using battery storage for temporary sites such as Com or southern shoreline sites, where the absence of, or state of the wharf, presently precludes the sites acting as a permanent station at this time.

3.6 Pressure Gauge Manufacturers

The RBR and Sea-Bird Scientific are the primary manufacturers of pressure gauges. (https://rbr-global.com/products) (http://www.seabird.com/products/pressure-sensors) Both RBR and Sea-Bird have a long history of producing robust reliable oceanographic equipment. Other companies including OTT, who also make radar gauges, are also likely to supply pressure gauges. From experience, using other smaller companies who manufacture oceanographic equipment can become problematic in the years after instruments are purchased. Difficulties typically arise if the company changes focus or is absorbed into a larger company. In this situation, often the software needed to login to the instrument is not updated. This means that computers using window programs specific to the era the instrument was made must be kept, in order for the software to run. In-water oceanographic equipment is generally very robust and designed to have a shelf life of one or more decades, much longer than the period between windows software updates. Given the measurement of sea level rise requires multi-decadal measurements, it is best to invest in instruments from a company who is likely to be operating into the distant future, who are present to provide support regarding software updates and instrument maintenance.

3.7 Visual Tide Staff

Visual tide staffs are the simplest instrument used for measuring tides. They are installed in water near the coast and as water level rises and falls the level can be measured by reading its position on the tide staff using one's own eyes. While small adaptations can be made to tide staffs to assist easy reading of water level, at the two Timor-Leste locations a simple tide staff should be sufficient. The zero of the tide board must be levelled to a benchmark on the land nearby (Figure 19).

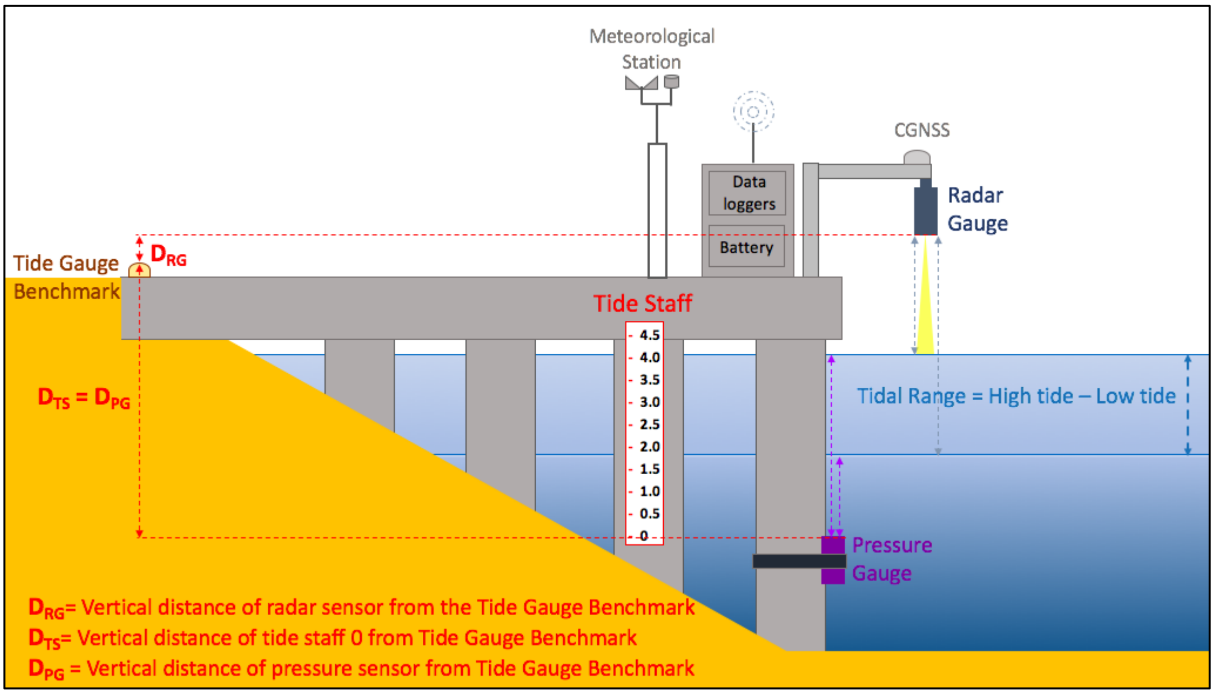

Figure 19. Instruments to measure marine water levels including tide staff shown levelled to a benchmark.

Figure 20. Examples of tide staffs. The top images show tide staffs in the U.K. The top left image is from Cowes Harbour (http://www.cowesharbourcommission.co.uk/) and the top right image is from the Severn Estuary, where tides range over several meters. The bottom image shows a tide staff being installed during a NOAA mission in Kodiak Island Alaska, U.S.A (https://noaateacheratsea.blog/category/2014/page/21/)

Due to their low-tech nature tide staffs can be installed at any location where they are able to be fixed to solid structures including bedrock or coral platforms. So long as the staff is stable and is correctly referenced to a benchmark, this instrument can be monitored by local staff, who simply need to record the water level, date and time, every few hours or a few times a day. Such tasks may be able to be performed by maritime police, if a tide staff is installed near a coastal maritime base. This method is unlikely to be able to provide an accurate measure of long-term sea level rise, however if clear and accurate records are maintained installing tide staffs may enable some measurement of ocean and coastal processes, such as tides, to be obtained at unmonitored locations.

For the present locations at the Hera Naval Base and Mahata Port, the tide staff is required to provide a visual reference by which the radar and pressure gauges can be checked. During the installation procedure measurements obtained from the radar and pressure gauges will be compared with the water level shown on the tide staff at regular intervals, to ensure the instruments are representing the visually observed change in water levels.

Tide staffs are also an easy way to demonstrate how water level varies when communicating to local stakeholders and educators exactly what the radar gauge and pressure gauge are recording. Because the tide staff relies upon a person manually collecting water levels, it can be explained that the instruments installed are able to perform this task continuously and automatically, during all hours, and all weather conditions.

3.8 Data loggers and Telemetry

While pressure gauges typically have internal data loggers, radar gauges typically require external data loggers. If the Hera Naval Base and Mahata Port operators wish to access to the real-time data, the data logger may relay the data via radio or Wi-Fi if there is clear line of sight between the transmitting antenna on the tidal hut, and the receiving antenna. If feasible the antenna on the tidal hut should be positioned to facilitate clear communication. Alternative communication methods may be employed if this is not feasible. With respect to the data logger, the company who provides the radar gauge will provide appropriate compatible data loggers. When the company undertakes in-situ calibration of the instrument the radar gauge must be connected to the data logger to ensure the whole system is accurately calibrated. Examples of a gauge control unit and telemetry system are shown in Figure 21.

The International Oceanographic Commission recommend radar data be transmitted via two forms of telemetry to prevent data losses if one telemetry platform fails. This recommendation was principally intended for regions affected by tsunamis however the recommendation has been more broadly applied. Example satellite system coverage is graphically displayed in Figure 22.

To facilitate instrument maintenance, the data logger must be able to interface with satellite telemetry for 2-way communication. The company contracted to install the and maintain the instruments, will recommend appropriate data logging and telemetry systems to best facilitate remote maintenance of the instruments. As with the selection of pressure gauge manufacturer, it is highly recommended that reputable companies or institutions with a long history installing and maintaining tide and sea level observation instruments for government or similar organisations, be given higher consideration in the selection process. Given the lack of capacity in Timor-Leste with respect to oceanographic measurements, and the high level of expertise required to maintain these instruments, it is vital that the company is able to perform its duties well into the future. Experience gained during similar projects over the past 30 or more years will also assist the selection of the best telemetry methods for local data transfer and international communication.

Figure 21. Example of the internal components of the radar gauge control unit (left) which included data logger and connections to telemetry instruments. The radar gauge control unity is connected via cable to the telemetry systems antenna (right).

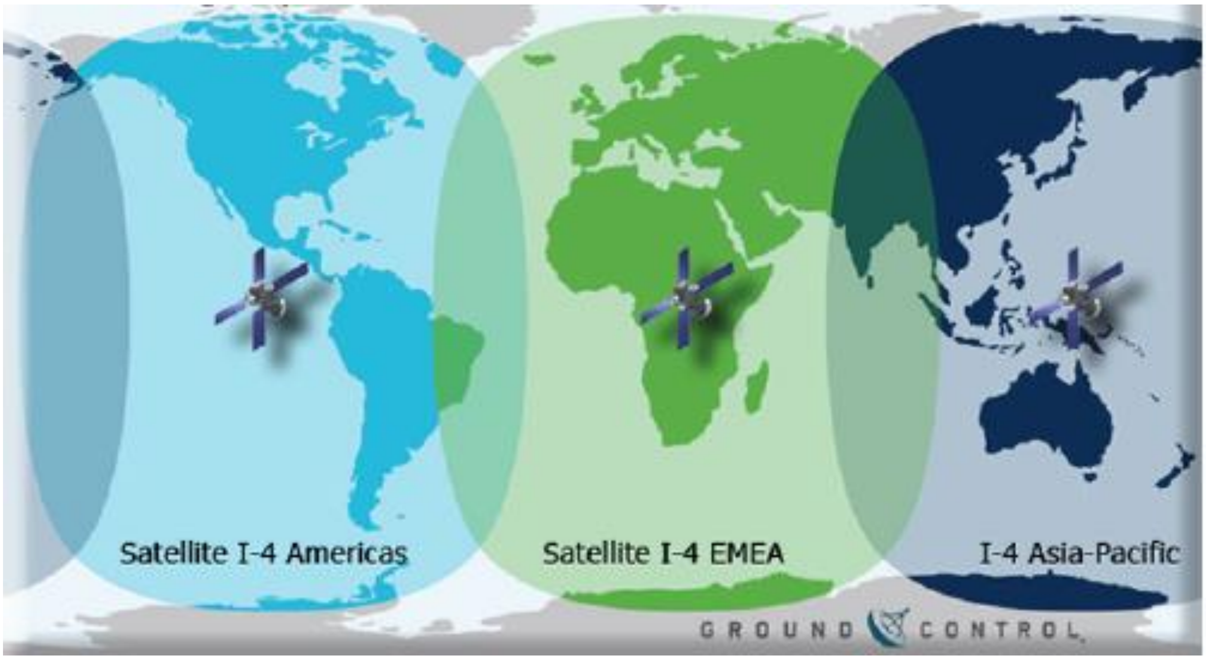

Figure 22. Image depicting satellite coverage for the INMARSAT BGAN system. This satellite system is employed for communication from tide and sea level instruments in Indonesia. (IOC Manuals and Guides 14, JCOMM Technical Report No. 89, 2016)

In addition to providing two-communication with the instruments, satellite telemetry systems are the most appropriate for sending data to a data processing centre for emergency management and scientific purposes. There is a plethora of public and private satellite systems available, with each system having its pros and cons relating to coverage and frequency of transmission. Satellite systems already employed for telemetry at tide stations are summarized in Table 4. Only systems capable of two-way communication are reported in Table 4. In addition to satellite systems the GPRS system which relies on the telecommunication network is also documented in the table due its capacity to act as a relatively reliable secondary telemetry system.

Satellite System	Bandwidth	Delay in transmission	Approx. costs (USD)	Recurrent Data Costs	End Point of Data	Potential Problems
ORBCOMM	< 50 KB/day	Several hours	$200 - $300 for modem terminals	$60 / month	Email Server	Appears to have been largely superseded.
IRIDIUM	1 MB/hr	Near zero	$2000 for modem and antenna	$22/month + $1.2/minute for data only mode	User Modem	Some reports indicate IRIDIUM and GNSS signals can interfere in some circumstances, and this possibility should be check for each installation.
INMARSAT BGAN	492 KB/s	Near zero	$1000 for antenna	Depends on contract	Internet	Potentially subject to interruption during emergencies
VSAT	4 KB/s - 16MB/s	Near zero	$3000 for antenna modem and cables	Rate dependent on data volumes	Internet	Has been applied in Indonesia and India however Indonesia ceased using this satellite system.
INMARSAT Global Xpress	50 MB/s download, 5 MB/s upload	Near zero	Unknown	Unknown	Internet	High capability but need to check cost and coverage over Timor-Leste
GPRS (used for backup telemetry)	56-114 KB/s	Seconds	$350 for handset and modem	Comparable to mobile rates in country	Internet	Relies on land-based internet. Well used method for backup communication.

Table 4. Two-way telemetry systems used in past tide and sea level observation systems (adapted from IOC Manuals and Guides 14, JCOMM Technical Report No. 89, IOC, 2016)

Timely access to sea level data can be as important as the accuracy of a tide gauge for some applications. Tide gauge information can be provided in real time, near real time or in delayed mode. Storm surge warning system typically require data to be relayed to authorities in a very short time and thus real time data is recommended. In contrast some scientific research investigating long-term variations may only need to recover data annually, in which case data may be stored on site and can be extracted by replacing the memory card in the data logger during periodic site visits with no need for telemetry. For Timor-Leste data transfer in real-time or near-real time is recommended for both data transmissions to local platforms and to an international data management facility. Some examples of different devices used to receive and transmit from tide and sea level observation sites are shown in the pictures in Figure 23.

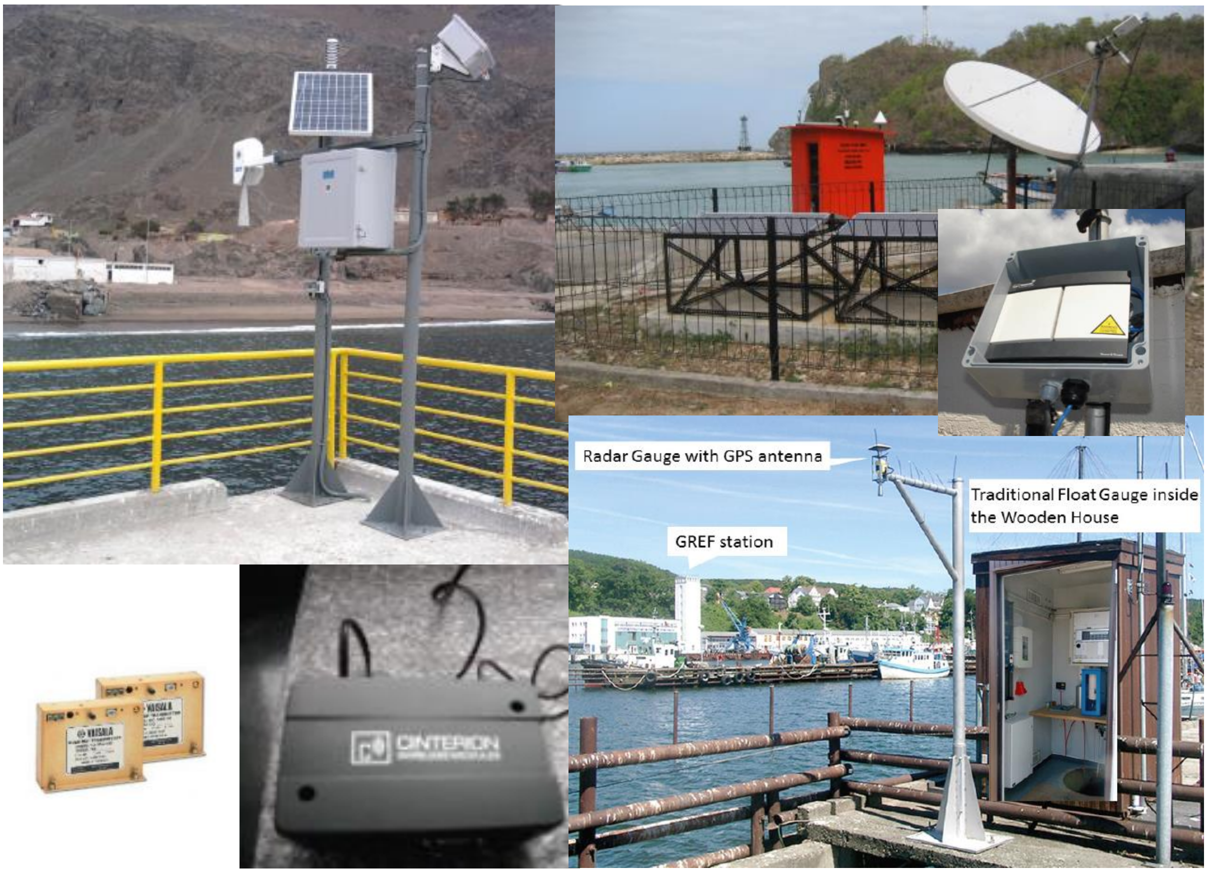

Figure 23. Images of various telemetry instruments, including stand-alone satellite receivers, modems, antennas and GOES transmitters. (IOC Manuals and Guides 14, JCOMM Technical Report No. 89, IOC, 2016).

3.9 Data Management

There are three principal modes of data management typically employed for sea level observations, Rapid, Fast and Delayed mode. The methods employed for data quality control depend upon the purpose the data is required for, which is reflected by the mode. At present Timor-Leste does not have in-country expertise regarding the management and interpretation of tide and sea level data. For this reason, it is recommended that data from measurement instruments be relayed in real-time to the IOC Sea Level Monitoring Facility at VLIZ. This facility can be tasked with the job of managing sea level data, particularly during the early stages of the establishment of the Timor-Leste sea level observing system. The IOC Sea Level Station Monitoring Facility provides access to continuously-updated time series plots. The daily inspections undertaken at the facility will identify gauge malfunctions as soon as possible, leading to overall better long term data sets with which to determine sea level rise. Given the high level of expertise at this international facility it would extremely valuable to leverage their knowledge and expertise in the management of the Timor-Leste sea level observation data.

While data will be relayed to the IOC Sea Level Monitoring Facility, it will also be relayed to a computers and data storage systems within Timor-Leste. The company contracted to install the tide and sea level instruments can assist in the setup of these platforms. Via the web data provided by the IOC SLMF can be compared with the local display in Timor-Leste display providing a check on the in-country data quality control procedures.

In addition to transmission of data, storage cards must be periodically replaced (annually or more frequently if needed) and securely stored in a readily accessible location, in order to maintain a secondary record of data. Accurate records must be kept for each storage card that reflect the time of deployment and parameters measured.

It is recommended that one of the well-known quality control software programs UHSLC, or TASK be used for quality control as these packages are well used by other GLOSS participants. The sections below expand upon the different data modes, briefly explain quality control and expand upon the benefits offered by utilizing the IOC Sea Level Monitoring Facility as principal repository of tide and sea level data.

Real Time Mode: In recent years there has been increased emphasis placed on the display of real-time and near-real time data (rapid mode) from as many gauges as possible. This data is typically used for port operations and emergency management purposes where real-time or near-real-time data are required. These data display measurements within minutes. These data can be used to make immediate decisions regarding the safe operation of a port facility, and can be relayed to ships to assist aid navigation. Real-time data can be used within storm surge flood warning systems (Pugh and Woodworth, 2014), examples of which are seen in Australia and the U.S.A. Real-time data is also used as part of the alert mechanism in the Tsunami warning systems employed around the world. In addition to helping provide alerts, measurements of water level can assist emergency responders identify areas likely to be most in need of assistance. Because these data are required within short time frames there is little need or opportunity to perform any quality control on these data, however several operators of these systems have developed some measure of quality control which is able to quickly screen test the veracity of the data without stalling its rapid distribution. Often specialized operators are employed to oversee this data in order to detect if there are anomalies which indicate potential instrumental error. For operators such as the port or navy, over time, familiarity will be gained by the users of this data, and they also will be able to detect if there are anomalies in the data that do not coincide with its normal operation. Anomalies that cannot be attributed to an extreme event such as a storm or tsunami, can alert the maintenance providers of the need to check the instruments. The real-time and near-real time display of data has enabled instrument errors to be more quickly identified, facilitating improved operation of these instruments.

Fast Mode: This data mode is typically used to ensure the instruments are operating accurately. One method for checking instrument operation is to compare coastal observations with measurements obtained from satellite altimetry. Fast mode employs some measures of quality control which typically involves filtering of the data to remove residual water levels due to processes such as wind waves, which are already smoothed in the satellite altimetry data. While the data from the coast are likely to differ by some measure from the satellite altimetry data, there are likely to be similar trends from both data sets. If one set of observations is suddenly out of step, this can indicate potential events such as a tectonic event which may have local effects near the coast instruments which are not picked up in satellite altimetry data. Alternatively, it might show a potential error in the operation of the tide and sea level instruments. For example, if the instrument mounted on a wharf was bumped and dislodged from its normal position. The time delay between measurement and supply of this data to the public is on the order of days to weeks for this mode of data. Often fast model data are used by scientists who are performing hindcasting experiments using numerical models of a particular section of the ocean and coast.

Delayed Mode: The highest level of quality control is applied to delayed model data (DM). These data have been thoroughly inspected. The principal application for these data is scientific research. The time delay between measurement and provision of these data can range from several weeks to months, depending upon the facility performing the quality control. These data are typically used for long-term sea level rise studies.

3.10 Quality Control Software

For national tide gauge agencies that do not have their own quality control software, or who do not have individual analysts allocated to undertaking quality control, software packages are available capable of performing this task. The two packages listed by the IOC (2016) with which the IOC has the most experience are **the UHSLC (University of Hawaii Sea Level Centre) package and the Tidal Analysis Software Kit (TASK-2000) package.**

Because the instruments will detect anomalies, quality control is needed to remove the influences due to non-ocean processes, or due to processes that are not of interest. For the purpose for which the tide and sea level instruments are intended, wind-wave heights are not of concern. Their influence on water level heights can largely be removed by averaging measurements over an ~ 1-minute timeframe. In high wave regions larger averaging times are recommended using lower-frequency radars than is required for the Timor-Leste sites. Despite these procedures the data may still retain higher frequency variations. There are numerous methods and computer programs which can be used to remove unwanted signals.

3.11 Data Transmission to the IOC Sea Level Monitoring Facility at VLIZ.

The capacity to transmit raw data to the IOC Sea Level Monitoring Facility can be performed by the company contracted to install the instruments if this is stipulated in the contract. It is recommended that data be made available to all interested users on the Global Telecommunications System (GTS), as recommended by IOC (2011) in accordance with the UNESCO/IOC Oceanographic Data Exchange Policy under the Mauritius Declaration of 2005. Sensor observations can be readily transmitted via the GTS in real-time using the WMO CREX formats for sea level data (for more details see Chapter 7 of IOC Manuals and Guides 14, JCOMM Technical Report No. 89, 2016). Where difficulties are encountered the World Meteorological Organization (WMO) can provide assistance to GTS users.

Operators should ensure radar data are sent in real time via satellite, internet or other appropriate telemetry method, to the IOC Sea Level Monitoring Facility at VLIZ (http://www.ioc-sealevelmonitoring.org). This facility provides an efficient means for monitoring the status of sea level measurements worldwide. In the event that there are gaps or telemetry errors in the real-time data, data should also be stored on local loggers which are regularly downloaded.

For Timor-Leste, information from instruments must be provided in manner that can be useful on a day to day basis. In addition, the long term record of data must be maintained. For day-to-day operations it is recommended that the display show radar, pressure, and predicted tidal water levels (see Figures 20 and 21 for an example display). The images in Figures 24 and 25 are adapted from the National Oceanographic and Atmospheric Administration (NOAA) website, which is accessible to the general public (internationally). Figure 18 displays near-real time data which has not yet passed all quality control checks. The preliminary nature of these data in the display by utilizing a specific colour for preliminary data in addition to a PRELIMINARY watermark in the graph background. These measures are taken to inform the user that the full quality control procedures have not been applied to these data because they are real-time data. The blue line in the graph indicates the predicted water levels. These data are generated using computer programs which predict water level variations at the gauge location due solely to tidal processes. By comparing the red and blue lines we see that the red data is slightly higher than the blue data. This may indicate that there are non-tidal ocean processes elevating the water level at the coast, shifting it above the normal tidal water levels. The predicted tides (blue line) provide a guide against which the instrument data can be checked. Measured data will vary somewhat from predicted data because tides are not the only process that influence marine water levels.

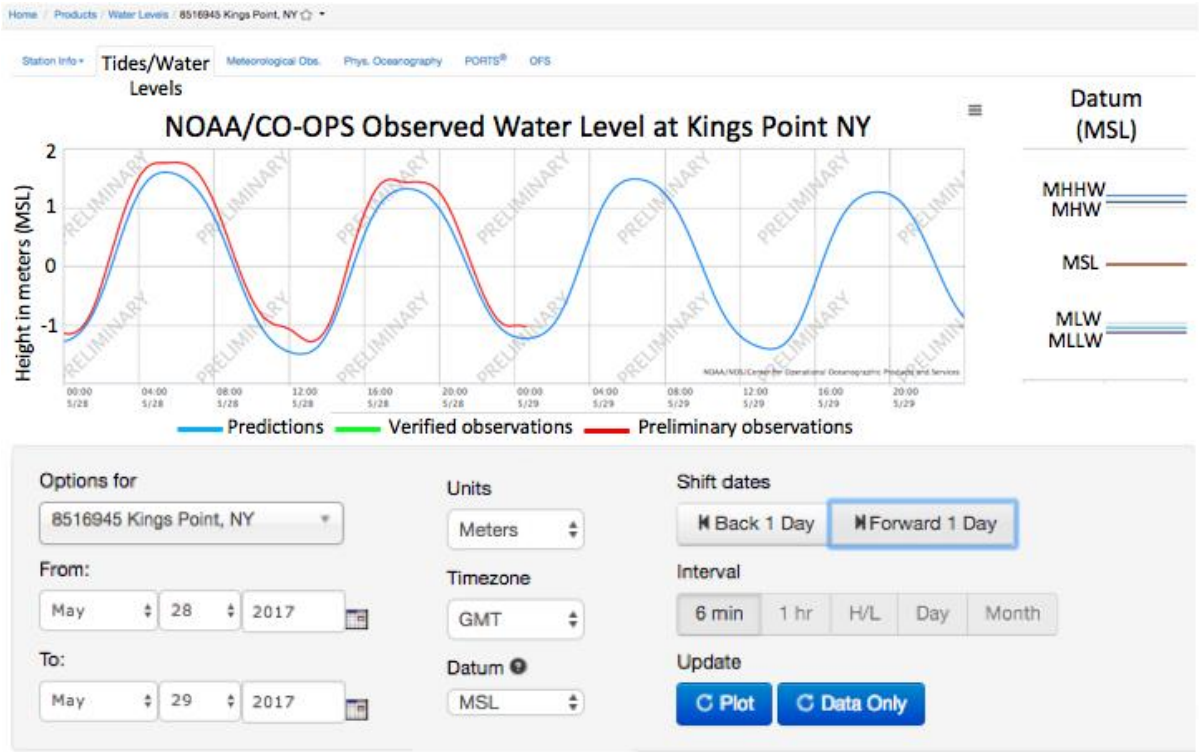

Figure 24. Example of real-time data display from the National Oceanographic and Atmospheric Administration (NOAA) U.S.A. (https://tidesandcurrents.noaa.gov/waterlevels.html?id=8516945), for a site in New York State.

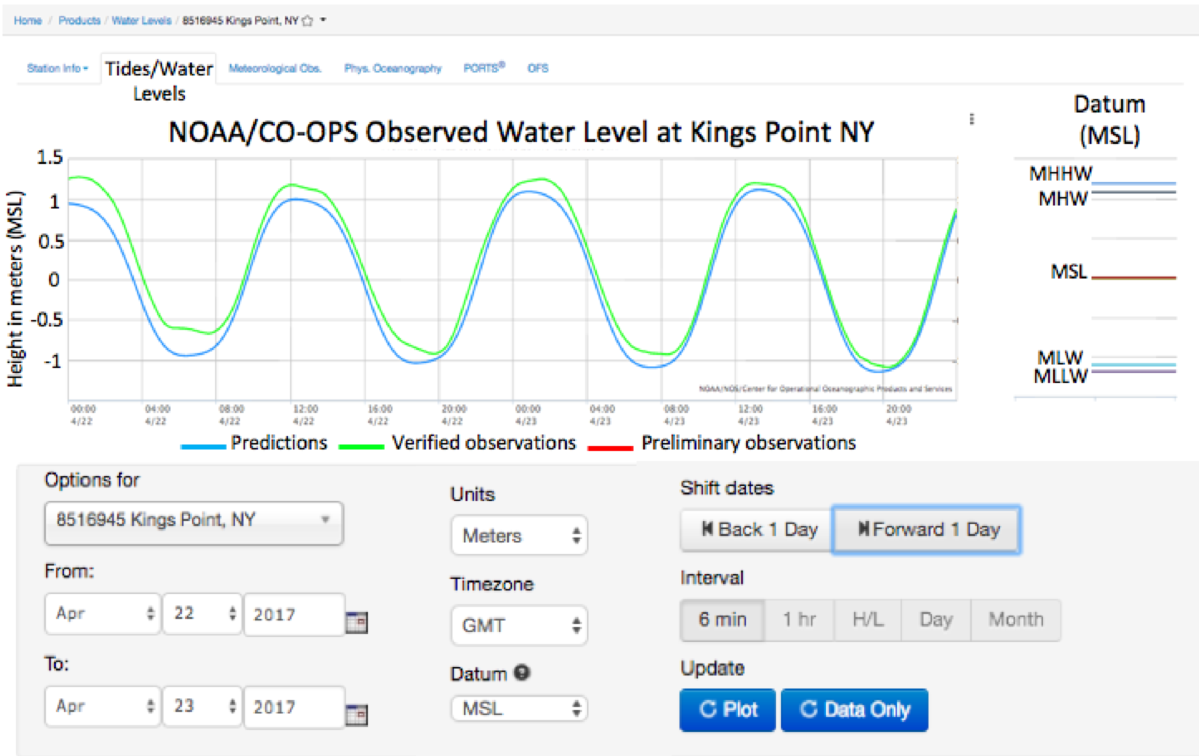

Figure 25. Example of fast mode data display from the National Oceanographic and Atmospheric Administration (NOAA) U.S.A. (https://tidesandcurrents.noaa.gov/waterlevels.html?id=8516945), for the same site in New York State as that in Figure 18. In this display the red data (labelled Preliminary) is replaced by a green line (labelled Verified).

Figure 25 shows the same location as Figure 24, however it displays Fast mode data obtained about one month before the data in displayed in Figure 20. During the intervening month, the measurements have been put through quality control checks. After being evaluated, the data which passed the quality control checks is deemed “Verified”, and is indicated by the green time series. Differences still exist between the predicted and verified water levels. This is likely for two reasons, the first being the influence of non-tidal processes which are not accounted for in numerical tidal predictions but which are detected by the instruments, and the second being the limitations of tidal prediction models. Numerical models that include more processes than simply tides are likely to obtain closer agreement with the measured data.

For Timor-Leste we recommend that water levels from both the radar and pressure instruments are included in the data display in order to assist detect any error with either instrument.

To show how wind-waves affect water level data an example of real-time data taken from a site in Chile that experiences high wave activity is displayed in Figure 26. While these wave conditions are not representative of Timor-Leste coastal environments, this figure is included to provide some context to show the different time scales that pertain to wind-waves compared to tides. The top panel in Figure 26 shows the tidal trend with scatter due to wind waves. The time between successive peaks in the tide are ~ 12 hours, While the time between successive peaks in wind-waves is on the order of seconds to minutes.

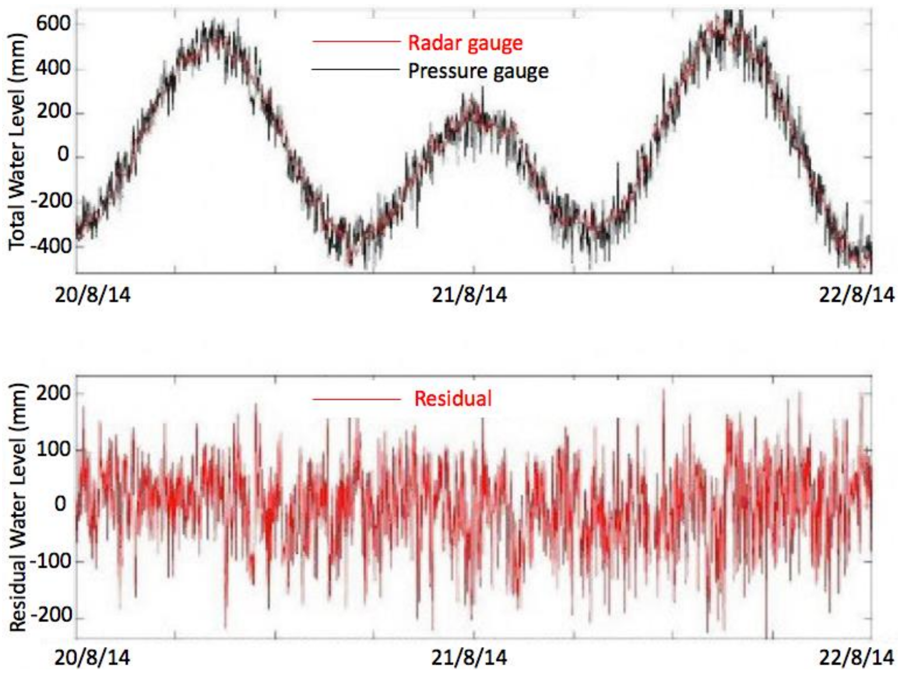

Figure 26. Water level data from Constitucion, Chile. The tide trend can be seen through the overall curves in the upper panel which move through three peaks and two troughs. The more rapid variations are due to wind waves, termed residuals. Residuals, after removing the tide data are shown in the lower panel. Graphs were adapted from IOC Manuals and Guides 14, JCOMM Technical Report No. 89, IOC, 2016,

3.12 Benchmarks used for Datum Control and Levelling

Benchmarks are clearly identifiable reference points that define the level of land near a tide gauge (IOC, 2016). Benchmarks are used to provide a common datum for data from different sources. They can be installed on any stable surface such as a quayside, a sizeable building, a sturdy harbour wall, or directly into bedrock. As previously mentioned it is essential that tide and sea level observations are appropriately referenced to stable benchmarks on land, and that the vertical and horizontal positions of these benchmarks are regularly checked, to ensure any land motion can be taken into account when determining long-term sea level measurements.

Benchmarks are typically flat, or round-headed brass bolts that are concreted or permanently adhered into horizontal solid rock (see Figure 27 for examples). Countries and organizations participating in the Global Sea Level Observation System (GLOSS) network, are required to have at least five Benchmarks located within a few hundred meters (up to 1 km) of tide and sea level instruments (also referred to as tide stations in this section). Additionally, the benchmarks must be clearly identified and their details recorded in the tide station metadata. The metadata details must include benchmark name or number, description (e.g. brass plate, or brass dome in bedrock or on seawall etc.), photo, national grid reference, position on local map, and latitude, longitude and elevation using a global datum (e.g. WGS 84). The relative heights of the benchmarks must be measured annually using high precision levelling instruments and these annual surveys must be documented in the tide station metadata.

Figure 27. Examples of standard brass benchmarks from different locations around the world (source: OC Manuals and Guides 14, JCOMM Technical Report No. 89, IOC, 2016; https://noaateacheratsea.blog/tag/tide-gauge/; https://www.sa.gov.au/__data/assets/image/0016/239101/permanent-survey-mark-brass-plaque.jpg)

Benchmarks have been established at various locations around Timor-Leste. These permanent survey benchmarks (PSM) are discussed in the report conducted for Oecussi, (see Rede Geodesica Nacional Regiao Administrativa Espeical Oecusse Ambeno (Raeoa), 2016). It must be noted that some of the PSMs reported in this document may have been destroyed or relocated due to large scale engineering works undertaken in recent years. In the two sites where tide stations are recommended at present there does not appear to be an adequate number of benchmarks within the close range of where instruments will be placed. In order to meet the GLOSS criteria, it is recommended that the existing benchmarks near Hera Naval Base and Mahata Port are resurveyed. Once the number of benchmarks within 1 km of the tide station has been determined and their details have been properly documented, the additional benchmarks can be put in place in locations where they are unlikely to be destroyed or moved in the future. The details of the newly installed benchmarks must also be documented in the tide station metadata. These benchmarks should also be added to the national benchmark dataset.

In addition to resurveying the benchmarks it would be advantageous GNSS instruments are required at a bedrock benchmarks close to the tide station, for reasons expanded upon in the section relating to vertical land movement. The present distribution of PSMs around Timor-Leste is displayed in Figure 28.

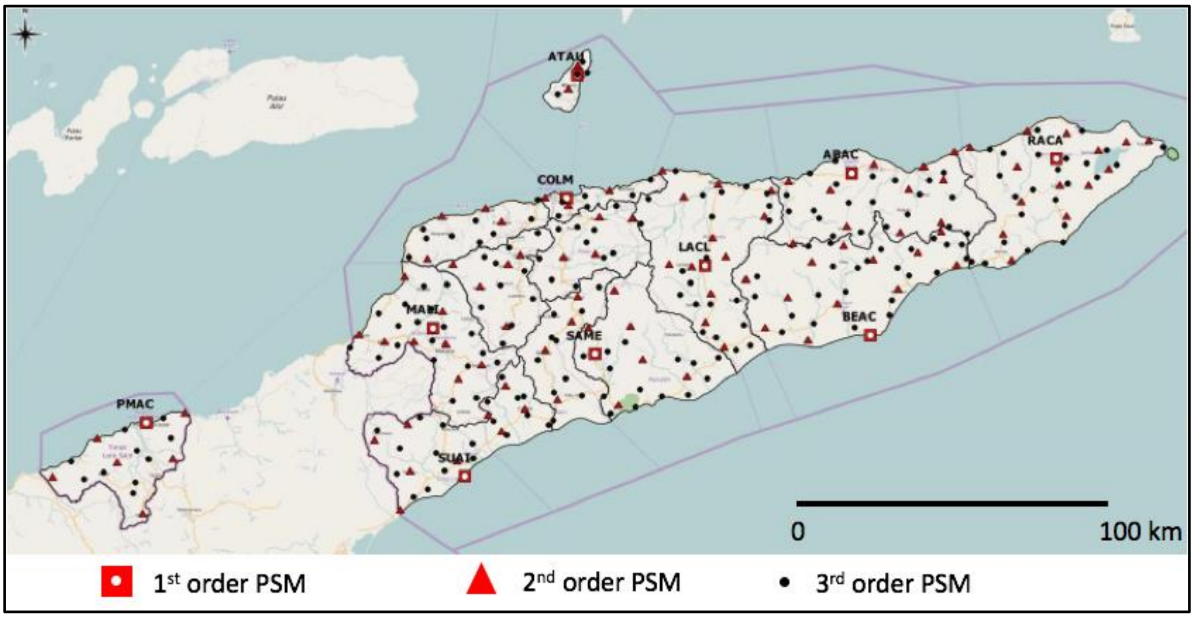

Figure 28. Locations of Permanent Survey Marks/Benchmarks (PSM) in Timor-Leste. There are three classes of PSM reported, 1^{st}, 2^{nd}, and 3^{rd} order. 1^{st} order benchmarks have a measurement error of 1 cm over distances of up to 100 km. 2^{nd} order benchmarks are accurate to within 3 cm over distances of between 20 to 50 km. 3^{rd} order benchmarks are accurate to within 5 cm over distances of up to 10 km.

With respect to tide and sea level observations we need to establish an agreed point on land with which water levels can be measured against. If there is not a common datum which both ocean scientist and land surveyor or coastal engineers reference their measurements to difficulties can arise. For example, if an ocean scientist reports high tide reaches 1.5 m, without making clear that 1.5 m is referenced to MSL, a land surveyor may assume it is referenced to LAT which the point of lowest astronomical tide. The surveyor may then advise an engineer constructing a road near the coast that it is safe to build in an area that is actually within the tidal zone, because LAT is below MSL (see Figures 29 and 30). The images in Figure 29 show shorelines on the northern side of Timor-Leste. In both images, the extent of a recent high tide can be seen on the sandy shoreline. These images were taken from two different locations, during the rapid assessment of the Timor-Leste coastal environments undertaken from 10thApril – 5th May, 2017.

Figure 29. The top image was taken near Balac, Manatuto. The lower image is from a drone survey conducted at Watabo Beach, Bacau. The high tide can be picked out by the lines of debris (leaves, twigs, litter) which collect at the high tide mark. The buoyant debris material is picked up by ocean water and when the tide recedes the material is stranded on the shore.

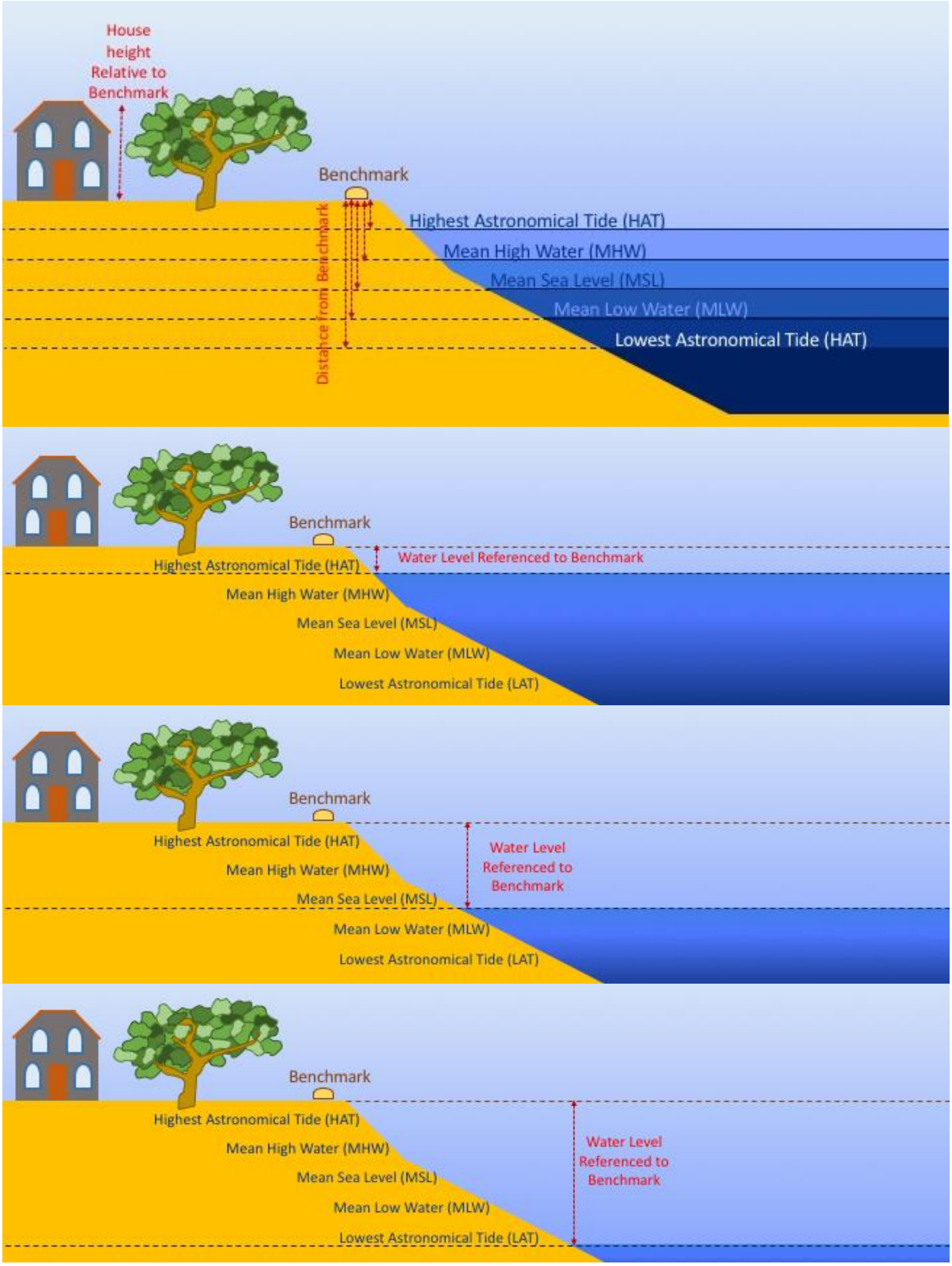

Figure 30. Profile diagrams showing the various water level positions and common terms used to describe the different stages of the tide. These terms are also known as tidal datum. The average positions of high tide and low tide over an 18.6-year tide cycle are termed Mean Higher Water (MHW) and Mean Low Water (MLW) respectively. Two additional terms Mean Higher High Water (MHHW) which falls between MHW and HAT, and Mean Lower Low Water (MLLW) which falls between MLW and LAT, are not shown for simplicity. Timor-Leste water level cycle through two high tides and two low tides during a lunar day (24 hours and 50 minutes).

Figure 30 shows a series of graphic diagrams depicting a shore profile. The top panel summarizes the different stages of the tide and the different terms used to describe the water level at these different tidal stages. The three additional panels depict the water level dropping from Highest Astronomical tide (2nd panel) down to Mean Sea Level (3rd panel), and then down to Lowest Astronomical tide (4th panel). In all panels the common benchmark from which water levels and land elevations are referenced is depicted near the shoreline.

3.13 Tide Gauge Benchmark

The tide gauge benchmark (TGBM) is the principal benchmark for the tide station and it serves as the datum to which sea level from instruments are referenced (as illustrated in Figure 19, and Figure 30). The benchmark will be selected from the set of five benchmarks based upon its stability, longevity and proximity/adjacency to the station instruments. In some instances, redefinition of the tide gauge benchmark may be required if it is destroyed during refurbishments or local development. This is one reason that additional benchmarks are necessary. Note the additional benchmarks must be able to be connected with the each other via levelling equipment.

Figure 31. The photo on the right shows a team using levelling equipment to determine the correct position of tide instruments relative to the tide gauge benchmark (https://noaateacheratsea.blog/tag/fairweather/). The image on the right shows the position of two tide instruments (red and purple triangles) and the position of the tide gauge benchmark (yellow filled circle) in Trinidad, California, U.S.A (http://www.hbv.cascadiageo.org/)

For Timor-Leste it is recommended that if not already in place, benchmarks should be installed within the Hera Naval Base, and the Mahata Port, to act as the tide gauge benchmarks. Both sites are likely to have solid stable structures upon which tidal gauge benchmarks may be installed. Also, it is unlikely that these facilities will be altered by development as they are both established critical infrastructure.

3.14 Additional Benchmarks

As previously mentioned, in order to meet the GLOSS criteria, and to ensure instruments are able to be referenced against a common datum into the future, a minimum of five benchmarks are required to be positioned within 1 km of the tide station. These stations must be well-documented with the information held by in the metadata for each tide station.

3.15 Instruments to measure vertical land motion

Relative sea level rise is the measure of the position of marine water in specific regions or countries. Relative sea level rise is affected by changes in the position of ocean water and also by changes in the land. The earth is a dynamic environment and while it may appear that land is fixed and stationary, it is in fact gradually shifting, both horizontally (Figure 32) and vertically (Figure 33), due to processes such as plate tectonics and glacial isostatic adjustment. Plate tectonics basically describes the movement of the large plates upon which countries sit, while glacial isostatic adjustment is the slow ongoing movement of land in response to the retreat of past ice-age glaciers which covered much of the Northern Hemisphere approximately 16,000 years ago. Timor-Leste is little affected by glacial isostatic adjustment and thus this process is not discussed further in this report, however tectonic activity may contribute to vertical and or horizontal land movement, which may influence the relative rate of sea level rise. In addition to gradual movement associated with shifting plates, sudden changes in land elevation can result from earthquakes caused when plates interact with one another.

These movements of land can interfere with calculations of sea level rise if they are not accounted for. In some coastal areas the land is relatively spongy and unconsolidated. In these regions over time the land may compact over time and sink. The Delmarva Peninsula on the U.S. East coast is an example of a region where land is sinking and as such the region is recognized as a sea-level rise hotspot (an area where the relative sea level rise is higher than the global average). In contrast some regions such as the U.S. northwest coast, experience uplift and the land is moving upward faster than the sea level is rising (Figure 33).

For Timor-Leste, geodynamics, geodesy and geophysics are relatively new areas of research, and little is known about the vertical and horizontal land movements beyond the estimates determined for the wider region (see Figure 33). This lack of data will in part be remedied by the institution of a new permanent GPS in Timor-Leste, through a collaborative initiative between the Institute of Petroleum and Geology, Timor-Leste, the University of Southern California, and the Australian National University. In order to build upon these efforts Timor-Leste would greatly benefit from the placement of additional GPS instruments in order to determine differences in vertical and horizontal land movement across the country.

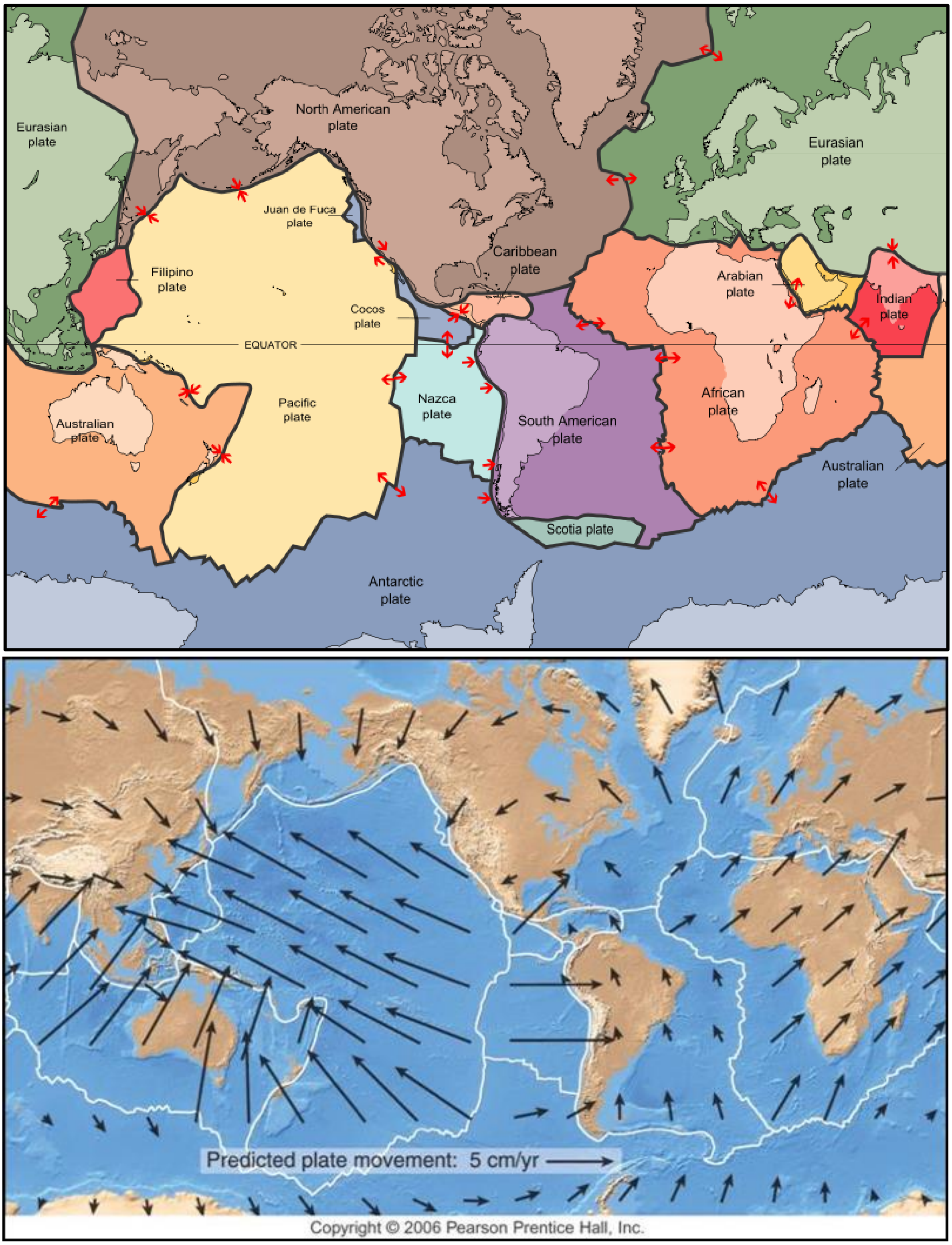

Figure 32. The tectonic plates upon which countries sit atop (top). The red arrows indicate the direction of motion of the plates. The most tectonically active regions of Earth lie at the interface between two plates. In the case of Timor-Leste, the country is located at the interface between the Australian plate and the Eurasian plate. The velocity of plates can be measured using GNSS instruments (bottom). Measurements obtained from nearby countries indicate that the Eurasian plate is moving in a south-eastward direction at a speed of 1 to 2 cm/year, toward the Australian plate, which is moving to the North East, into the Pacific Plate at a speed approaching 10 cm/year. (top image source: USGS, https://pubs.usgs.gov/gip/dynamic/dynamic.html; lower image source: Pearson Prentice Hall, http://xenon.colorado.edu/spotlight/index.php?action=kb&page=3).

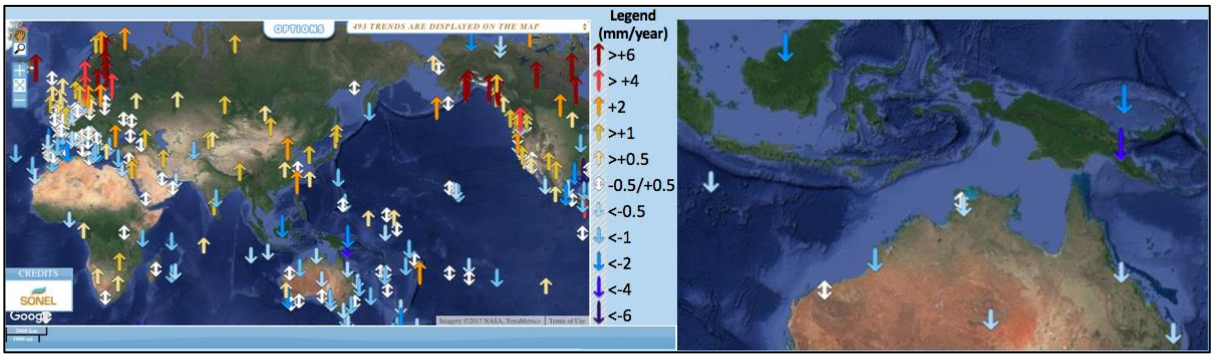

Figure 33. The maps display vertical land movement estimates across the globe. These maps were obtained from (http://www/sonel/org/-Vertical-land-movement-estimate-.html) and are derived from the work of Satamaria-Gomez et al., 2012). The image on the right displays the measurements obtained nearest to Timor-Leste. The new GPS instrument may potentially assist fill the large gap in vertical land movement data across the Timor region.

It is highly recommended that a GNSS be positioned at benchmarks near tide stations. These additional instruments would provide real-time measurement describing land movements which would contribute to the efforts underway at through the Institute of Petroleum and Geology initiative.

3.16 Bedrock GPS

It is recommended that a GNSS instrument be installed at the bedrock benchmark nearest to the tide gauge. The extra information provided by these instruments is proving extremely valuable determining the relative sea level rise of individual countries, islands and states, which can only be determined by combining measurements from tide and sea level instruments with measurements on land. The Implementation Plan for the GLOSS network requires that every gauge in the network be equipped with a nearby CGNSS receiver (IOC, 2012).

3.17 Tide gauge CGNSS

It has been demonstrated the Continuous Global Navigation Satellite System (CGNSS) technology provide a mature technique for monitoring the ellipsoidal heights of Benchmarks. In tide and sea level monitoring work, the technique is often denoted as CGNSS@TG. The installation of a CGNSS allows mean sea level at the gauge to be defined in the same global geocentric reference frame as that used for satellite altimetry data. The main advantage however is the ability to isolate the contributions due to sea level and land level changes on relative sea level. The cost of these instruments has dramatically reduced in recent years making their use common. At busy ports, radio interference can pose difficulties of the transmission and receiving of GNSS data, in which case nearby sites where this interference does not pose a problem need to be utilized. The radio activity at Hera Naval Base and Mahata Port need to be evaluated to determine any potential interference which might affect the positioning of CGNSS instrumentation. A first pass assessment of activity at these two locations indicates that there is likely to be little interference, however confirmation is required before installing the CGNSS at the location within these facilities.

3.18 Absolute Gravimeter

While it would be ideal to verify CGNSS measurements of vertical land movement with data from an absolute gravimeter this would only be feasible if an instrument was already available, as these instruments are very expensive. In the event that such an instrument is available, a survey over the period of several days would provide very valuable data to assist understanding of the contribution vertical land movement makes to the relative sea level rise in the Timor-Leste region.

For clarity, and to summarize the different processes the tide and sea level rise instruments are intended to measure, a graphical summary of the processes leading to relative sea level rise is displayed in Figure 34.

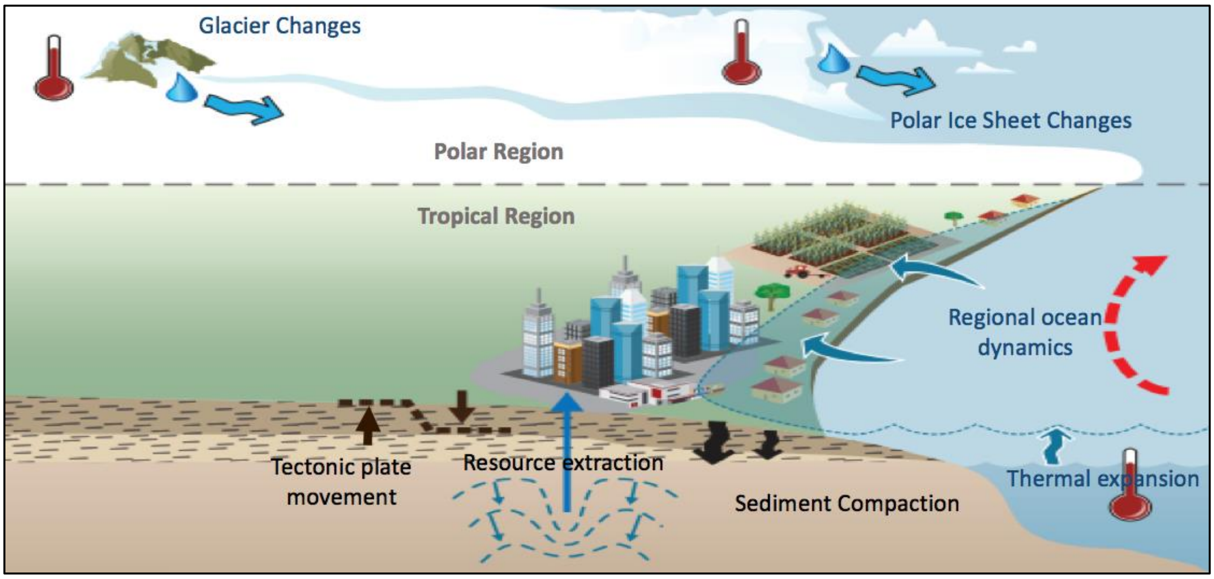

Figure 34. Processes contributing to relative sea level rise, that is the variation in rates of sea level rise around the world. The processes that relate to sea level rise are labelled blue, while the processes affecting vertical land movement are labelled black. The four processes relating to sea level rise are likely to contribute to higher than global rates of sea level rise in Timor-Leste due the role played by regional ocean dynamics. While both resource extraction and sediment compaction lead to negative land movement (sinking of land), tectonic plate movement can cause uplift or subduction of land. At present it is not clear if Timor-Leste is experiencing uplift or subduction or if it is relatively stable. This information is needed to determine if the relative sea level rise in the region is similar or vastly different to the present predictions from global models and satellite altimetry analysis. (The image in this figure was adapted from https://www.pwrc.usgs.gov/SeaLevelRiseProjections.pdf)

4 Instrument Installation

The company contracted to install the tides and sea level instrumentation, including CGNSS instruments will be familiar with the successful installation of all instruments recommended for Timor-Leste. Regardless some short notes are included here to guide installation.

- When fixing instruments onto the support structure, they must be positioned such that the supporting structure does not interfere with measurements.
- The radar gauge must be placed at a height that is within the range specifications of the instrument.

- For radar gauges, there is a limit to how close the instrument can be to the water surface, as there is a dead zone, close to the radar sensor where no accurate measurements can be obtained. This dead zone is accounted for when determining the sensor offset. This offset can be determined during instrument calibration.
- The radar gauges should be positioned sufficiently high to avoid overtopping of the instrument by storm surge or tsunami events.
- The instruments must be calibrated in-situ as part of the installation procedures. For radar gauge calibration typically a metal plate is positioned at a known distance below the radar sensor. The difference between the reported distance and actual distance is the offset. This process is repeated using different distances to determine that the offset is constant. (See figure 35 for example calibration instrument setups). Calibration of pressure gauges is undertaken by the manufacturer prior to issuing the instrument, however the instrument will also be checked in-situ. By placing the pressure gauge, a known distance below the water surface and comparing the reported depth with the actual depth (measured using a ruler or similar), any offsets can be determined.
- Any offsets must be documented and the position of Mean Sea Level relative to the Tide Gauge Benchmark must be dated and documented.
- Any mounting arms must be constructed using marine-grade stainless steel or similar marine grade materials and the mounting arm itself must not interfere with the instruments. A guide to safe mounting distances is shown in figure 36.
- The installation procedures must comply with the procedures outline in IOC Manuals (IV and V). More detailed instructions regarding all instruments and their setup are provided in these manuals, along with additional experience from previous Tide and Sea Level Observation installations.

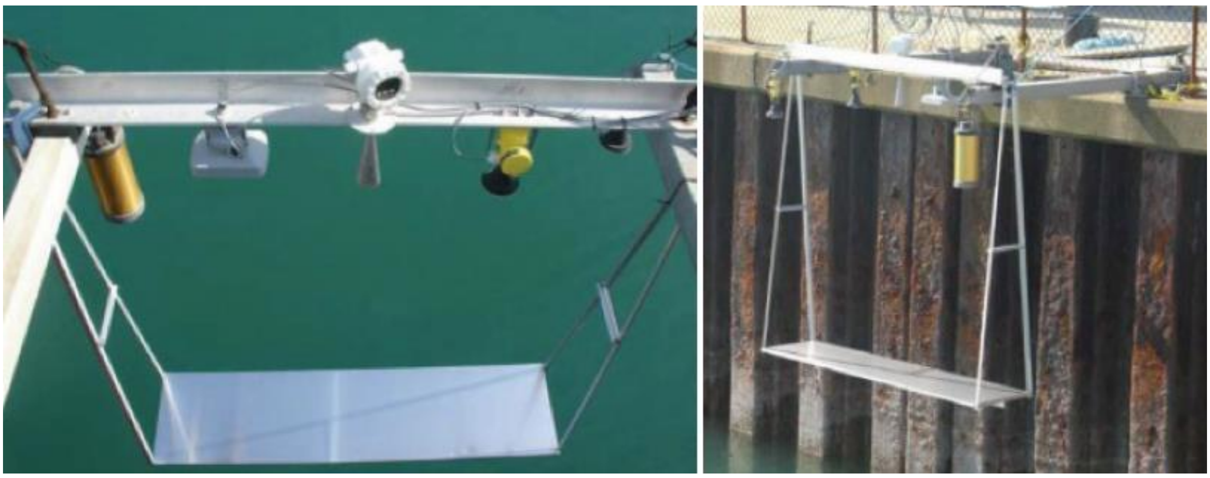

Figure 35. Two images displaying different radar gauges undergoing calibration, using a metal plate to reflect the signal emitted by the gauges at a known distance. (IOC Manuals and Guides 14, JCOMM Technical Report No. 89, IOC, 2016).

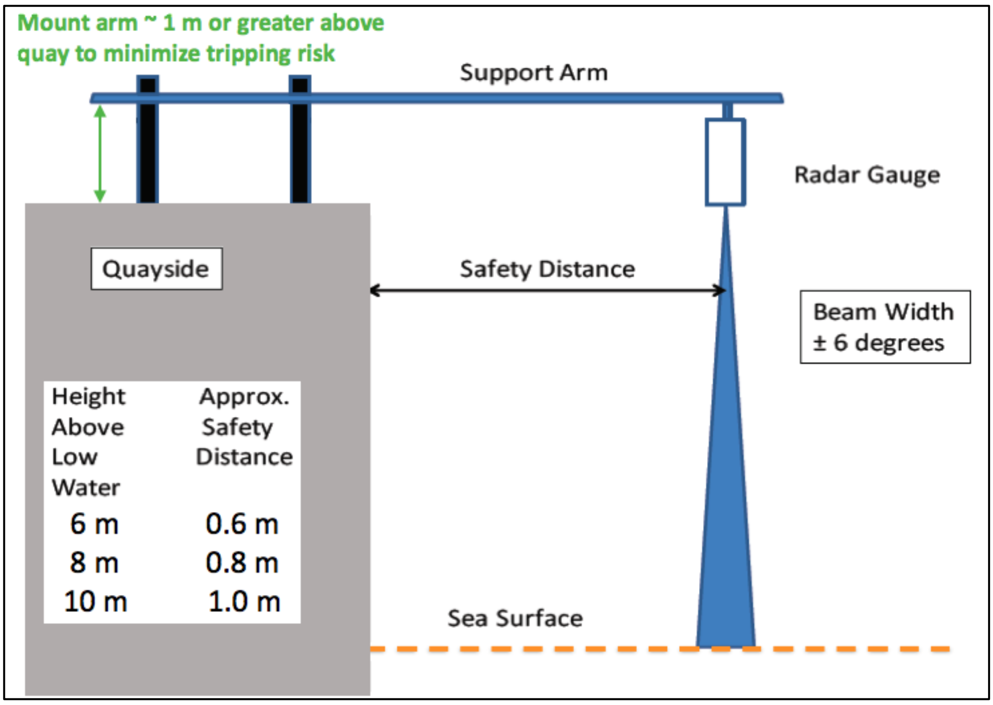

Figure 36. Position of radar gauges to ensure the radar gauge beam does not experience echoes or false reflections from the quayside or other structure it is mounted on.

5 Future Leverage of Tide and Sea Level Observation Instruments

The installation of tide and sea level observation systems represents a major step forward for the management of both natural and urban coastal environments in Timor-Leste. The water level measurements collected will facilitate the development of more accurate models for predicting coastal processes, including the impact of coastal hazards in Timor-Leste.

At present understanding of the ocean and coastal environments in Timor-Leste is limited by a lack of data describing basic marine conditions, including water level and water temperature. Presently the only data available for the region are obtained from satellite measurements, which have limited applicability near the coast. When Timor-Leste has a tide and sea level observation system in place, the data collected will be enable numerical models (also called ocean models, coastal models, or hydrodynamic models) to be constructed and verified. Numerical models provide powerful efficient tools for investigating many processes in ocean and coastal environments.

An example of a numerical model grid constructed to predict ocean and coastal behaviour along the U.S. East coast is shown in Figure 37. The grid displayed is called a flexible mesh grid. Models such as this are used the world over to better understand the ocean environment, marine and coastal ecosystems, and the impact of coastal hazard such as storm surges and tsunamis. Numerical models can also be used as engineering tools to better understand how development projects at one coastal location will affect nearby areas along the joining coastline.

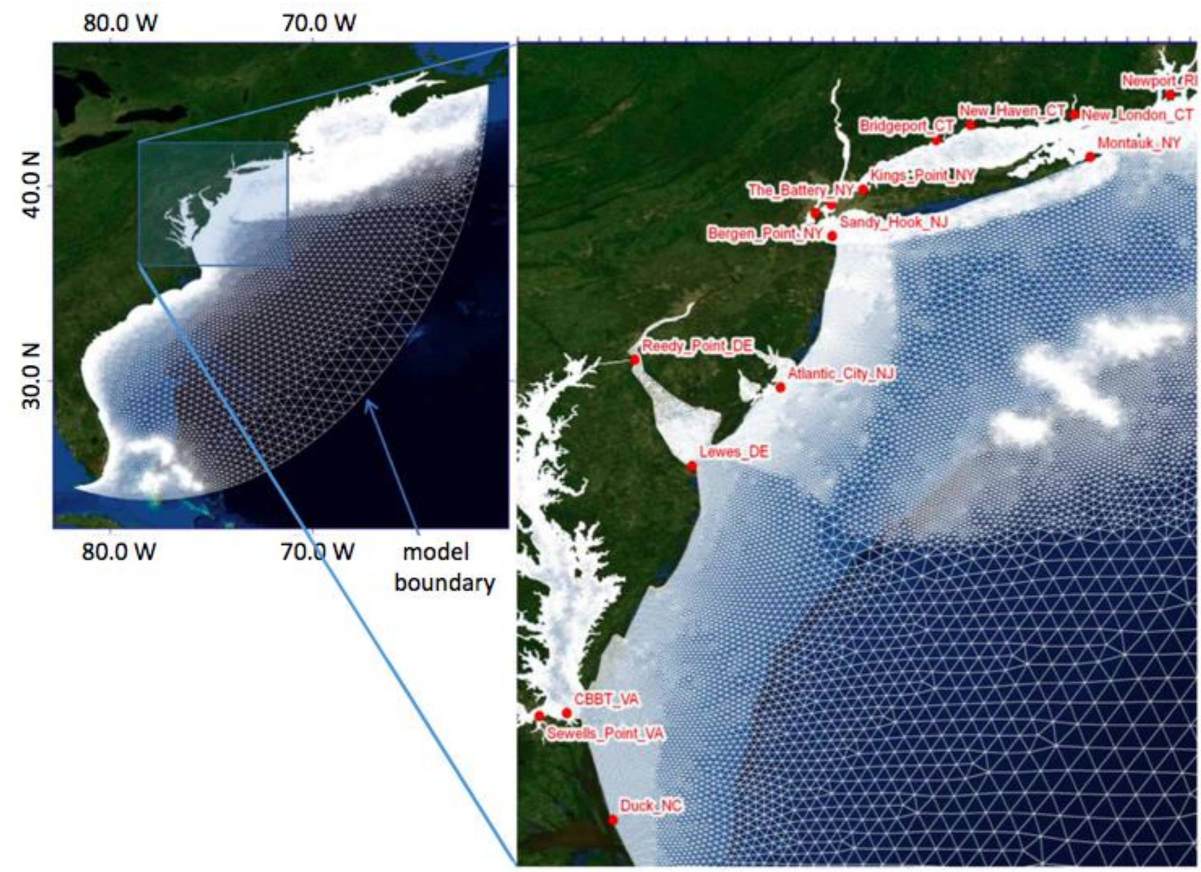

Figure 37. Numerical model covering the U.S. East coast and adjacent Atlantic Ocean. These images show the grid used by the numerical model. The model performs mathematical calculations and reports predicted conditions at each corner of every grid cell (each triangle is known as a grid cell). In this model the grid cells are larger in the deep ocean but become smaller in the coastal areas where the coastline has a more complicated shape. Smaller triangles are also used in an area of the ocean known as the shelf break which is the section of the ocean where the continental shelf ends. The regions with smaller grid cells appear as white areas in the images above, because they are so close together they cannot easily be shown without zooming in. The smaller the triangles the more accurately the model is able to represent the actual shape and behaviour of the environment being modelled.

Along the coast displayed above, instruments are permanently installed at the locations indicated by red dots and labels. Measurements are compared with model predicted water levels. If the predicted water levels agree with the water levels measured at these locations, then the model is said to be verified. That is, the model represents the behaviour of the ocean with a high degree of accuracy. This verified model can then be used to predict water levels at other locations beyond those where instruments are in place. The verified models can also be used to predict the impact of sea level rise on coastal communities across large regions, where no instruments are positioned. In the example grid shown in Figure 37, water levels can be predicted at every grid point (every corner of every individual white triangle). Models such as this are used to investigate ocean and coastal environments all over the world to overcome the difficulty of not being able to collect measurements everywhere. The data to be collected by the tide and sea level instruments recommended for Timor-Leste, will enable oceanographers to construct and verify models similar to that shown above for the Timor-Leste region, for the benefit of the Timor-Leste people.

6 References

Blasi C.J. 2009. A new technology for the measurement of the sea level and the sea state. *Environ. Geol.* 57: 331-336

IOC, 2016, Manual on Sea-level Measurements and Interpretation, Volume V: Radar Gauges. Paris, Intergovernmental Oceanographic Commission of UNESCO. 104 pp. (IOC Manuals and Guides No.14, vol. V; JCOMM Technical Report No. 89; (English)

IOC, 2006/09, Manual on Sea-level Measurements and Interpretation, Volume IV, An update to 2006. Paris, Intergovernmental Oceanographic Commission of UNESCO. 78 pp. (IOC Manuals and Guides No.14, vol. IV; JCOMM Technical Report No.31; WMO/TD. No. 1339) (English)

Martín Míguez B., B, Pérez, E. Álvarez Fanjul, 2005, The ESEAS-RI sea level test station: reliability and accuracy of different tide gauges. *Int. Hydrogr. Rev*. 6: 44-53.

Martín Míguez B., R. Le Roy, G. Wöppelmann, 2008a. The use of radar tide gauges to measure the sea level along the French coast. *J. Coast. Res*. 24: 61-68.

Martin Miguez B., L. Testut, G. Wöppelmann, 2008b. The Van de Casteele test revisited: an efficient approach to tide gauge error characterization. *J. Atmos. Ocean. Technol*. 25: 1238-1244.

Pugh, D., and P. L. Woodworth, 2014, Sea-level Science: Understanding Tides, Surges, Tsunamis and Mean Sea-level Changes, Cambridge Univ. Press, Cambridge, U. K.

Ray, R.D., G.D. Egbert, and S.Y. Erofeeva. 2005. A brief overview of tides in the Indonesian seas. *Oceanography* 18(4):74–79, http://dx.doi.org/10.5670/oceanog.2005.07.

Rede Geodesica Nacional Regiao Administrativa Especial Oecusse Ambeno (Raeoa) SNC RG_OEC/2016

Relatorio Tecnico dos Trabalhos de Campo, Timor-Leste 16th March, 3rd April, 2014.

Rudloff, A., J. Lauterjung, U. Münch, and S. Tinti, 2009, Preface "The GITEWS Project (German-Indonesian Tsunami Early Warning System)", *Nat. Hazards Earth Syst. Sci*., 9, 1381-1382, doi:10.5194/nhess-9-1381-2009.

Santamaria-Gomez, A., M. Gravelle, X. Collilieux, M. Guichard, B. Martin Miguez, P. Tiphaneau, G. Wöppelmann, 2012, Mitigating the effects of vertical land motion in tide gauge records using a state-of-the-art GPS velocity field. *Global and Planetary Change*, Vol. 98-99, pp. 6-17.

Schöne, T., Illigner, J., Manurung, P., Subarya, C., Khafid, Zech, C., and Galas, R., 2011, GPS-controlled tide gauges in Indonesia – a German contribution to Indonesia's Tsunami Early Warning System, *Nat. Hazards Earth Syst. Sci*., 11, 731-740, doi:10.5194/nhess-11-731-2011, Trenham, C. E., M. A. Hemer, T. H. Durrant, and D. J.M. Greenslade, 2013, PACCSAP Wind-wave Climate: High resolution wind-wave climate and projections of change in the Pacific region for coastal hazard assessments CAWCR Technical Report No. 068 June

UNESCO/IOC, 2011, Tsunami Early Warning and Mitigation System in the North-Eastern Atlantic, the Mediterranean and connected seas. First Enlarged Communication Test Exercise (ECTE1). Exercise Manual and Evaluation Report. IOC Technical Series No 98.

UNESCO/IOC, 2012, Global Sea-Level Observing System (GLOSS) Implementation Plan – 2012. UNESCO/IOC, 41pp. 2012. (IOC Technical Series No.100) (English)

Woodworth, P.L., D.E. Smith., 2003, A one-year comparison of radar and bubbler tide gauges at Liverpool, *International Hydrographic Review*, Vol 4, 3.