INDONESIAN REAL TIME SEA LEVEL MONITORING NETWORK SUPPORTING TSUNAMI WARNING

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Abstract

Lessons learned from the 26th December 2004 Sumatra Tsunami have prompted efforts by Indonesia, with support from donor countries, to establish an Indonesia Real Time Sea Level Monitoring Network to support tsunami early warning systems (TEWS) both in the Indian Ocean and for Indonesian Sea waters. The German, USA, and Indonesian Governments, and the Intergovernmental Oceanographic Commission (IOC), have committed to support the establishment of 10, 10, 60, and 3 real time sea level stations, respectively. The stations should be in place by the end of 2008 and these will complete the Indonesia Sea Level Monitoring Network of 120 stations. The extensive network will use different communication channels such as Very Small Aperture Terminal (VSAT), the Global Telecommunication System (GTS) supported by the World Meteorological Organisation (WMO), the Broadband Global Area Network (BGAN), and the Global System for Mobile Communications (GSM) data, which will all run independently, if possible. This will provide a more robust system to ensure that data are received in the event of emergencies. The use of satellite based data communication, with solar cells for independent power supply, should be the most reliable option for the vast archipelagic region. The USA and IOC support stations are assigned to use GTS and BGAN, while all German and 30 Indonesia support stations use VSAT and GSM data, if signal coverage is available. Progress has been made, and there are a total of 11 operational stations (as of March 2007) supporting TEWS in the region, with data transmitted via GTS and available online via internet. The most critical point for the Indonesian TEWS is to provide reliable response to local tsunami events in which the tsunami waves could hit the nearest coast in about 15 minutes. To meet this challenge, redundant sensors and communication channels as well as effective computer applications must be available for collecting, processing, and displaying data information for the watch standees to maintain situational awareness.

1. Introduction

The Indonesian Sea waters play an important role in ocean monitoring and climate studies. It is realised that to have a better understanding of the regional and local oceanography and climate of the region, a set of well distributed continuous sea level stations in the region is necessary. The demand for sea level monitoring has been increasing after the recent tragedy of the 2004 Sumatra Tsunami. The tsunami was the most catastrophic in recorded history, causing great loss of lives with more than 120,000 fatalities in Indonesia and thousands more over 9 countries in Asia. If an early warning system were available in the region, many lives could have been saved.

Considering the tectonic setting of the Indonesian region, where the epicentres of earthquakes generating tsunamis are mostly located close to the archipelago, the distribution of the proposed TEWS in the Indian Ocean should be designed to be capable of guiding the fast issuance of warnings. Realising the great loss in the tragedy and in support of the early warning system in Indian Ocean initiated by the United Nations, Indonesia has allocated national funding for establishing the Indonesian Tsunami Early Warning System (IdnTEWS). As sea level monitoring is an important component of TEWS with its role for confirming to evacuate or not to evacuate, Indonesia in joint efforts with international partners under the coordination of IOC/UNESCO agreed to establish real or near real time sea level monitoring stations starting from mid-2005 until the end of 2008.

This paper reports on the grand design of the real time sea level network development supporting IdnTEWS and the latest progress towards its realisation. Programs to improve the quality of the sea level network in Indonesia such as minimising drift, regular precise geodetic levelling from tide staff to bench marks, and continuous GPS monitoring are also presented.

2. Status Before the 2004 Sumatra Tsunami

The 26th December 2004 Sumatra Tsunami, which devastated the coastal area of Aceh and the surrounding countries in the Indian Ocean, can be claimed as a turning point in the development of sea level monitoring in Indonesia. Since then, the appreciation of the importance of sea level monitoring has been increasing, resulting in funding by the Indonesian Government for 2006 - 2008 fiscal years for modernising the network with new instrumentation and real time communication tools.

The Indonesian Sea Level Monitoring Network before the 2004 Sumatra Tsunami consisted of 60 stations, of which 35 stations were using analogue graphical chart recorders and 25 stations were using digital recorders with Public Switch Telephone Node (PSTN) data connection. Figure 1 shows the distribution of the stations (some stations located in several river estuaries cannot be seen). The network distribution is, however, considered less than adequate for representing tidal characteristics along the entire country coast line. Assuming that one tidal station represents a tidal regime of about 100 km of coast line length, an ideal number of permanent tidal stations for the whole country should be about 810 stations.

Progress on the development of the sea level network before the tsunami was relatively slow and it was initially designed for survey and mapping purposes, such as providing mean sea level height for the national height system in the main islands. The early implementation was started by BAKOSURTANAL with 8 analogue stations. The number of new stations increased by about 2 per year, except for a significant increase of 25 digital stations in 1998 to support the bathymetric mapping of the exclusive economic zone and sea line passages in Indonesian waters.

The network operation is fully centralised under the responsibility of BAKOSURTANAL in terms of budgeting, maintenance and data processing. However, the contribution of the local port authorities is considerable by assigning at least one of their staff to operate the station on a daily basis.

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Figure 1. National Sea Level Monitoring Network of Indonesia, operational before the 2004 Sumatra Tsunami

Optimal sea level observations still require local operators to routinely check and maintain the station. BAKOSURTANAL assigns local operators, recruited from the local port authority office where the stations are located. The operators play a very significant role in maintaining the stations to ensure the full operation of the instruments. This is because the recording instruments used in the network have been based on float gauge technology and the stations are mostly located in busy ports which are prone to damage by traffic in the harbour and vandalism. Training workshops for improving the operator's skill on station maintenance have been conducted since 2003 with a capacity of 10 trainees per year. The results of the training have been encouraging, as indicated by a significant improvement in data quality and data return from an average of 60 to 90%.

3. Grand Design of the Indonesia Sea Level Network Supporting IdnTEWS

Efforts have been made to build joint cooperation with international, inter-related government institutions and local governments in Indonesia to implement the warning system. Indonesia, as one of the most vulnerable countries to tsunami hazards, has shown a high commitment on the establishment of the system. International efforts on the establishment of the Indian Ocean Tsunami Warning System are coordinated under the leadership of the IOC/UNESCO.

There are five sources of funding available at present that have contributed to the upgrade and installation of tide gauge stations in support of tsunami warning in the Indonesian region. The sources of support and number of agreed stations are as follows:

- German Government - Indonesia TEWS (GITEWS) program supports 10 sea level stations. Each station consists of continuous GPS monitoring, a ground meteorological sensor and VSAT communication.
- USA Government under NOAA/University of Hawaii Sea Level Centre (UHSLC) joint collaboration and with financial assistance from USAID, has

partnered with BAKOSURTANAL to support 10 stations using GTS communication.

- Indonesian government under the IdnTEWS program supports funding for 60 stations using multiple platforms of data communications.
- The IOC has provided funding for 3 tide gauge station upgrades.
- OTT Messtechnick GmbH & Co. KG, a manufacturer of tide gauge sensors from Germany, with PT Trisari Tiga Putra, their sole agent in Indonesia, donated a complete set of sea level sensors consisting of pressure, float, and radar gauges including a communication tool with GSM data.

As the result of these new developments, the Indonesia Sea Level Network can be classified as follows:

- **First Order Sea Level Network** consisting of 80 planned real time stations supporting IdnTEWS. This is designed to use multiple communication tools such as GTS, VSAT and GSM data.
- **Second Order Sea Level Network** consisting of 20 operational digital stations using PSTN and GSM data connections
- **Third Order Sea Level Network** consisting of 30 operational analogue (graphical chart) stations.

Figure 2. Proposed real time sea level monitoring stations for the TEWS both in the Indian Ocean and Indonesian Internal Waters.

3.1. Network Design

According to The State Ministry of Research and Technology (2006), the Indonesian region requires at least 80 real time stations to properly detect tsunamis in the Indian Ocean and within parts of the internal waters of Indonesia. The sea level network has recorded four tsunami events in just two years. The first was the Sumatra Tsunami in 26th December 2004, known as the most destructive tsunami waves ever recorded by modern instrumentation (Rabinovich and Thomson, 2007). The tsunami waves were be recorded by sea level stations world wide. The Sibolga tide gauge station, the nearest Indonesian station from the epicentre, recorded wave heights over 2 meters (Merrifeld et al., 2005). The second event was the Nias Earthquake which occurred on 28th March

2005. Fortunately, this sea bottom earthquake with Mw = 8.3 generated only a small scale tsunami with wave heights of about 20 cm as recorded by the Sibolga station, again the nearest to the epicentre. The third event was the South Java Tsunami, which occurred on 17th July 2006, with wave heights over 2 meters recorded at the 3 nearest tide gauge stations. The last was a local tsunami, which occurred on 25th January 2007, with wave heights of about 10 cm in the Molucca Sea, in the eastern part of Indonesia. Although these four events were recorded by graphical chart stations, the data are still important for tsunami source reconstruction and research.

A proposal for upgraded and new sites for the tsunami early warning system, both in the Indian Ocean and Indonesia territorial waters, is shown in Figure 2. The basic considerations for site selection are:

- Stations situated on both sides of the Western Outer Island Arc of Sumatra are assigned the highest priority. These stations must provide fast detection of tsunami waves generated by subduction zone earthquakes with epicentres located along the fore arc and back arc zones. Because the stations are located far offshore, it will be possible to provide enough time for the evacuation of the population along the western coast of Sumatra.
- The dense station distribution along the western coast of Sumatra and the southern coast of Java is meant to provide early detection of tsunami waves generated from epicentres located near coastlines.
- Additional stations located in the inner water coastline are designed to detect local tsunamis generated by earthquakes with epicentres located in the internal waters.

3.2. Sea Level Instrumentation

Important considerations for sea level instrumentation in support of TEWS are low power consumption and high reliability in the design of the field unit. The field unit shall be a stand-alone, unattended (if possible), data acquisition and transmission device capable of acquiring, storing and reporting water level measurements from remote locations.

To provide back-up and redundancy, each field unit should consist of three types of water level sensors capable of providing continuous observations during extreme water levels and long term satisfactory performance for at least 12 months. The three types of level sensors are as follows:

1. **Float gauge digital recording** with one minute data sampling rate, allowing real time monitoring that can cover extreme sea level changes for relatively short time durations.
2. **Pressure gauge digital recording** with one minute data sampling rate and high capability in detecting quick changes of water pressure caused by tsunami.
3. **Radar gauge tidal recording** with 10 second data sampling rate enabling monitoring of sea level with high time resolution recording.

The three types of sensors should be capable of operating independently and have a 0.5 millimetre height resolution over a range of 0 to 15 meters.

3.3. Data Communication Plan

IdnTEWS consists of seismic, sea level and buoy components, operating under the responsibility of different institutions. They are the Geophysical and Meteorological Agency (BMG) responsible for seismic monitoring, BAKOSURTANAL for sea level monitoring, and the Agency for the Assessment and Application of Technology (BPPT) for buoy monitoring. The real time sea level data from the BAKOSURTANAL Sea Level Centre should flow continuously to BMG designated as the responsible national Tsunami Warning Centre. The data of some real time stations will also be available online via the website of the BAKOSURTANAL Sea Level Centre. The flow of the sea level data can be seen in Figure 3.

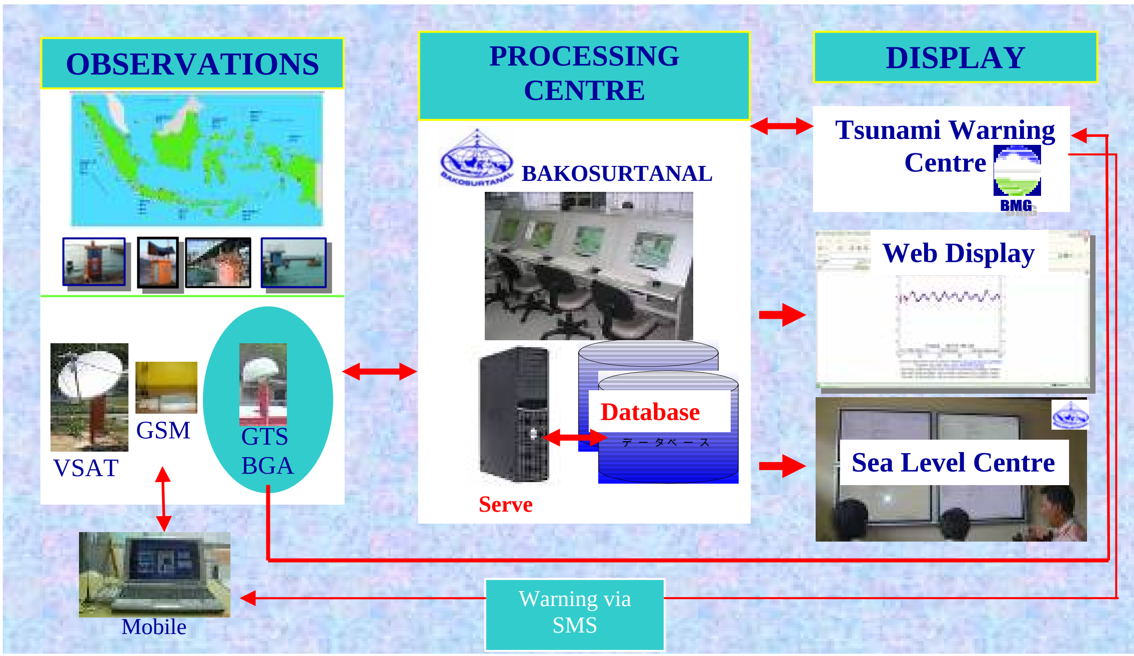

Figure 3. Real time sea level data flow from remote sensors to the data base server in the sea level centre (BAKOSURTANAL) and its distribution to the Tsunami Warning Centre (BMG).

Communication is one of the main bottlenecks in the development of an early warning system in terms of maintenance and airtime cost. The operational demands driving the data communications system requirements are: i) Reliable real time data streaming (every minute), ii) system stability, iii) system versatility and two-way communication capability, iv) ability to expand usage, and iv) affordable cost. The demands would only be fulfilled by using different communication channels such as VSAT, GTS/Meteosat, BGAN, and GSM data, which are all running independently, if possible. This provides a more robust system to ensure that the system is able to receive data during emergencies. The use of satellite based data communication with solar cell for a self-supporting power supply should be the most reliable option for the vast archipelagic region.

In a normal situation when the required data transmission rate is not that high, use of Meteosat or Japanese geostationary satellites and GTS provides the most reliable option for data transmission. This approach allows for data transmissions every 15 minutes, the satellite link modem consumes low energy, and the transmission air time is free access due to the generous support of WMO. However, Indonesia is located in the potential tsunami risk front lines where the time needed for tsunami waves to reach the nearest coastline is 15 minutes on average. This communications option is not meant for facilitating an extreme mode with faster data transmission requirements, such as one minute transmission rates when a tsunami occurs. This high transmission rate often requires that the system trigger the stations, located close to the tsunami source, to continuously transmit data in the event of a major earthquake. This allows the experts on duty at the Indonesia Tsunami Early Warning Centre to make a decision to evacuate or not to evacuate.

Therefore, we require a system capable of transmitting the data from related stations in an extreme mode. The use of VSAT is the high priority option since this is the best solution at present for real time data communication. It is becoming more cost effective and reliable for a vast area such as Indonesia with an archipelagic condition where mostly very minimal terrestrial communication infrastructure is available. The VSAT instrumentation should have a high standard technical specification, such as all connectors should be hermetically sealed to protect the electronics from water, dust and particularly high salinity in outdoor and marine environments.

Public Switch Telephone Node (PSTN) had been extensively used for the digital stations established in 1998. The PSTN access is a two-way system so that it can be also used for remote maintenance of a station. However, because the PSTN is placed on the ground, it is susceptible to local weather events such as storms or other outages caused by traffic in the port. In fact, we have found that for PSTN-stations in remote areas, the cable line was mingled with the radio connections resulting in some problems in transmitting data with a modem.

Considering the limitation of PSTN and the better coverage of GSM data in the archipelago, we have started to replace the PSTN connections in the Second Order Sea Level Network with GSM data. We have also started using power supplied by solar panels in early 2007. The upgrade is expected to be completed by the end of 2007. The self-supporting power supply and wireless communication will enable us to set a batch job for a daily data download and possibly at a desired time from a laptop computer, in case of an emergency. However, as is common for a terrestrial-based communication, a disadvantage of GSM data technology is that it can fail during an earthquake and during storms or other events that disrupt land-based systems.

Other means of communication technology such as radio becomes less effective in archipelagic geographical condition and networks with inter station distances over 200 km, although the air time cost is no logger required except for maintenance and the cost of the base stations. Another issue with this system is that the communication equipment occasionally fails to function properly due to corrupted commands, lightning strikes, and unhandled data overloads.

The USA and IOC support stations are designed to use GTS and BGAN, while those of all 10 German and 30 Indonesia support stations use VSAT and GSM data, if signal coverage is available. The remaining Indonesia support stations will be equipped with GSM data. To provide a back up, we will use GSM data connections provided by two different cellular operators.

4. Progress of Real Time Sea Level Network Development

The present (May 2007) progress of the installation is encouraging. 11 out of 80 stations have been installed, namely 3 out of 10 of the USA/NOAA-support stations, 3 out of 3 of the IOC support stations, 2 out of 10 of the Germany-support stations, and 4 out of 60 Indonesia-support stations. The location of the installed real time stations can be seen in Figure 4.

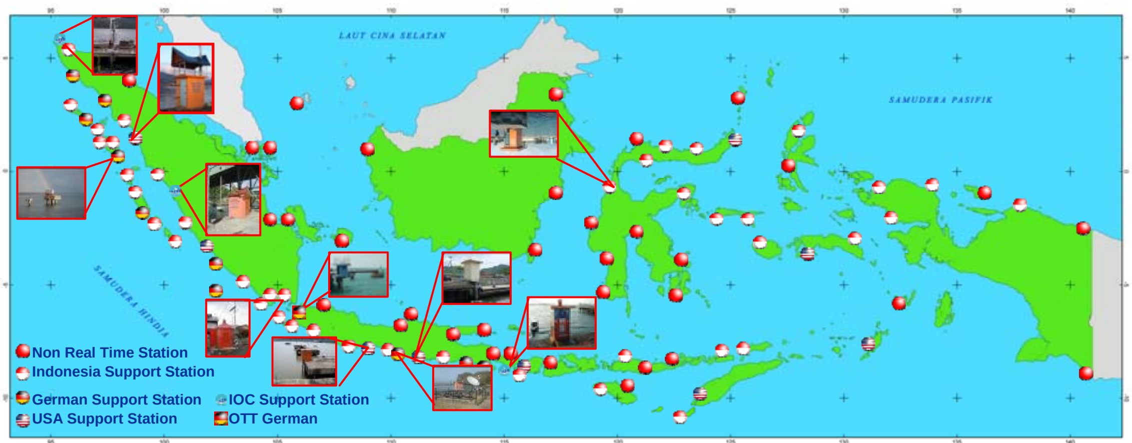

Figure 4. Present progress of the real time station establishment supporting IdnTEWS by May 2007.

4.1. USA/NOAA-Indonesia Action Plan

BAKOSURTANAL and the UHSLC, with financial support from the IOC and USAID, have taken the first initiative to install real time stations in the Indian Ocean region. The first installation was made in 22nd – 24th April 2005 in Sibolga on the western coast of North Sumatra Province. The next installation was carried out in Padang 16th – 22nd December 2005. The installations were continued in January 2006 at Benoa (Bali) and Sabang (Aceh) and the latest ones were done in Cilacap and Prigi in early February 2007. Four additional stations will be installed before the end of December 2007. All the stations are equipped for 15 minute data transmission using GTS/Meteosat. Later, BGAN communication capability will be added to the stations.

Data from all stations have been available on line with free access via the UHSLC website since the stations were completely installed.

4.2. Germany-Indonesia Action Plan

Site surveys for several of the planned stations were carried out by GeoforschungZentrum (GFZ) and BAKOSURTANAL in February 2006. The main objectives were i) to investigate site and physical oceanographic conditions of candidate sites in the outer arc islands off the western coast of Sumatra, ii) to determine whether existing sea level stations could be used with upgrades to real time communications, iii) to collect ancillary information such as site accessibility, mobilization strategy, constructions, etc.

Germany committed to install up to 7 units by the end of 2007. The remaining stations are planned to be installed in 2008. Data communication will be facilitated with VSAT plus PASTI, an Indonesia satellite communication provider, enabling data stream in real time mode to IdnTEWC.

At present, 2 stations under the GITEWS programme have been installed. One is the station in Sadeng Gunungkidul, Yogyakarta, that is equipped with sea level, GPS and ground meteorological sensors, installed on 28th August – 9th September 2006. The other is the station in Teluk Dalam Nias, North Sumatra, installed on 14th – 18th September 2006. At a later time, VSAT communication was installed at the two stations from 20th November to 10th December 2006 (refer to Figure 5). The data of the two stations have been streaming to the BAKOSURTANAL server since that time.

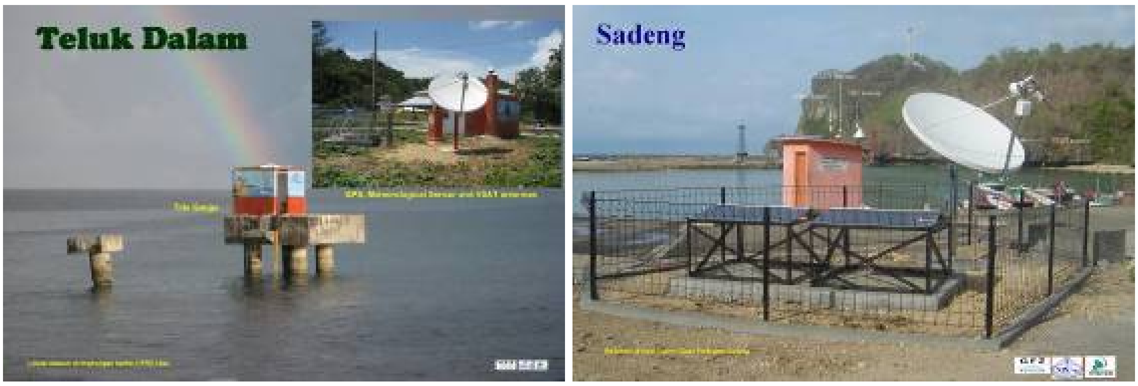

Figure 5: GITEWS Real Time Tide Gauge in Teluk Dalam and Sadeng Yogyakarta.

4.3. Indonesia Action Plan

BAKOSURTANAL, the responsible agency for the sea level monitoring, purchased 40 sets of digital tide gauges in fiscal year 2006 and these should be installed at forty locations by the end of 2007. The agency has successfully installed 3 stations in 2006 and 1 station in March 2007. The site constructions in 22 ports are still in progress, which will be followed by station housing constructions in areas where concrete jetty ports are not available.

The operation and maintenance of VSAT data communication from 30 planned stations to BAKOSURTANAL Sea Level Centre will be out-sourced to a VSAT provider company. We currently have invited several companies to make preliminary tests on the tide gauge data communication, as a prerequisite for bidding on the VSAT installation. Our main concern is to give an opportunity to the candidate companies to solve a communication problem between the VSAT instrumentation, which is IP based with Hydras3, and the sea level data downloading application provided by OTT, which is still in serial version. This difference leads to a delay in data streaming. A temporary solution to minimise the delay is that we use several PCs to download data from the remote stations. We plan to write a program enabling us to download the data from all stations simultaneously.

5. Program on Improving the Quality of Observation

To improve the quality of the observations requires a variety of considerations such as minimising height and time drifts, conducting precise levelling for monitoring height reference and testing datum stability, and applying new technology for separating the derived sea level change from ground movement, and data management. These aspects are discussed briefly in the following sections.

5.1. Minimising Height and Time Drifts

The non-real time stations consisting of analogue and digital recording instrumentation should be manually synchronised. A synchronisation of the instrument's time to the UTC and the level reading to the staff level are necessary to minimize the drifts in the recording. This synchronization is carried out by the station operators manually. Therefore the local operators are requested to provide a list of the daily time and height synchronisation records, as shown in Figure 6. Time accuracy of the digital quartz clock of the graphical chart recording OTT type R20 is at the level of about one second. The time reading of each graphical chart recording is synchronised to the time of the operator's clock. To keep the time correctly, the operators are requested to routinely synchronize their clocks to the local standard time, e.g. time broadcasted by local radio or TV. It is expected that the time accuracy would be realistically of about one second. The level recording of each tide gauge is synchronised to that of the actual sea level at the tide staff with an accuracy of about 0.5 cm.

A manual synchronisation, of course, should be improved to a digital and automatic synchronisation. Recording time should be automatically synchronised with a GPS receiver to UTC and an auto-level switch should be used for the level reading, as introduced by the UHSLC in the real time stations in Sibolga, Padang, Sabang, Cilicap, Prigi, and Benoa.

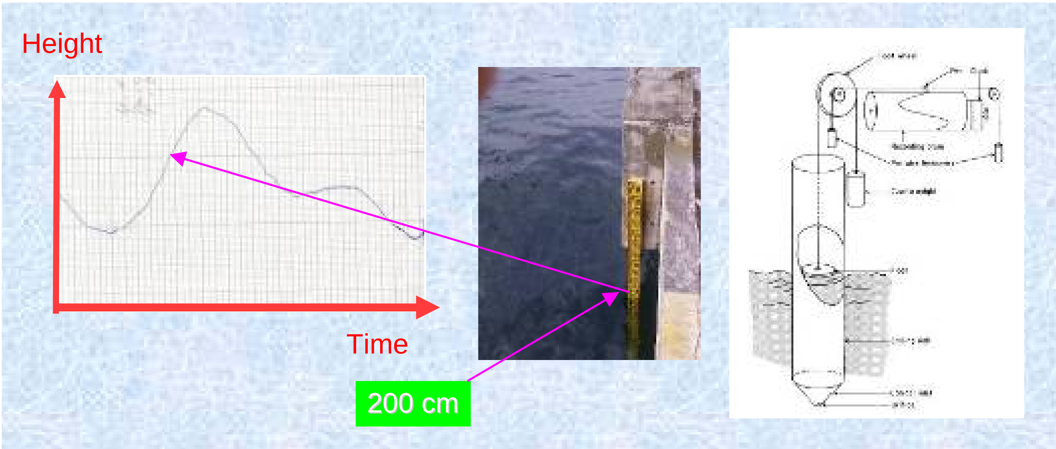

Figure 6. A manual time and height synchronisation

5.2. Precise Geodetic Levelling

Each sea level station has its own Tide Gauge Bench Mark (TGBM) with standard specification similar to that of the first order national levelling network. The tidal staff of each station is carefully referred to its TGBM with precise levelling measurements conducted regularly once each year, (International Oceanographic Commission, 1985). The regular measurements have been carried out for all stations. These measurements serve also as a valuable input for the study of mean sea level (MSL) rise due to global change effects , an issue of increasing importance nowadays.

Evaluating the MSL time series of stations with records longer than a decade, we find a lack of consistency in the MSL trends for some stations. As an example, the monthly MSL of the Jakarta station shows a significant jump at some epochs, as shown in Figure 7. It is suspected that there might be an alteration of the tide staff zero setting which is not well documented leading to offsets in the time series.

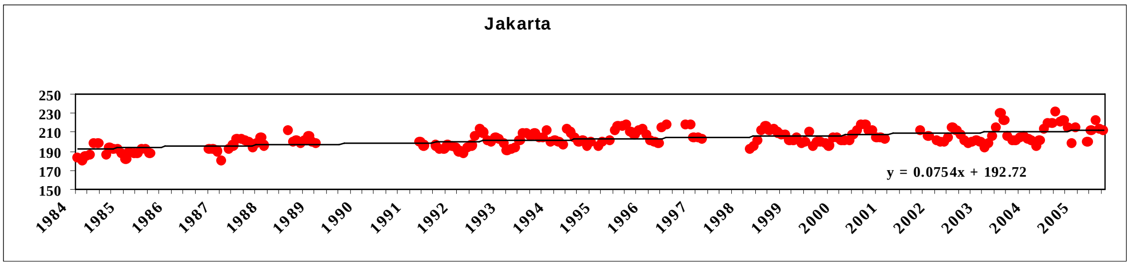

Figure 7. Monthly MSL time series of Jakarta stations, height in cm.

To protect the station against destruction caused by an extreme weather and tidal wave condition, the station buildings should be permanent and have a strong structure. The tide staff and TGBM should also be located at a very stable platform with minimum local ground displacements.

(a) (b)

Figure 8. A new designed tide staff made of fibre glass bar (yellow colour) with the reading scale covered by a strong and transparent resin layer. This is better than the sheet steel type, blue colour, (a). The tide staff was installed at Jailolo Station in Tarnate Island Eastern of Indonesia in mid-April 2006, (b).

Improvement of the tide gauge staff from sheet steel to fibre glass bar is expected to provide a high quality, and long life stable staff. We identified that the vertical staff gauges of sheet steel or aluminium may cause some errors such as discontinuity in the sea level reading time series and improper join between the sheet steels of a tide staff. Error caused by discontinuity in sea level readings may occur when the station operators mistakenly archived the data record of tide staff change. At least every one or two year replacement of sheet steels should be carried out since the reading scale is becoming deteriorated resulting from regular cleanings of the staff from coral and sea creatures. Another source of error is when the joins between sheet steel of a tide staff are not perfectly lined up during the replacement resulting in error in the reading.

Therefore, we designed a new type of tide gauge staff made of fibre glass bar with the reading scale covered by a strong and transparent resin layer, as can be seen in Figure 8. This staff bar with a dimension of 5 cm thick, 8 cm wide, and 3 meters long should provide a highly stable reading scale for more than ten years. It is expected that the high resolution observations with real time data communication, precise datum and very stable tide staffs, will contribute significantly to the improvement of the sea level monitoring in the Indonesian Archipelago.

5.3. Continuous GPS @ Tide Gauge

BAKOSURTANAL has been conducting precise GPS measurements at a selected set of BMs of the tide gauge network periodically twice in a year since 2002. The selected BM's were connected to the National Permanent GPS Station Network and therefore to the International Terrestrial Reference Frame (ITRF). Monitoring of BMs and tide staffs with space techniques can improve the quality of computed MSL rises in many stations.

The Indonesian plan to deploy 20 Continuous GPS (CGPS) at sea level monitoring stations is currently being implemented. It started in mid 2007 and is expected to be completed by the end of 2008. This is a part of the multi hazard and the crustal deformation monitoring system in support of IdnTEWS.

Figure 9. Proposed CGPS @ tide gauge

5.4. Sea Level Data Processing

All of the sea level data that arrive at BAKOSURTANAL Sea Level Centre via VSAT must be decoded and then presented on graphical displays. This is necessary in TEWS to allow the experts on duty at the Tsunami Warning Centre to monitor sea level in real time after a tsunamigenic earthquake is detected. A real time display of the data collected from real time stations with data flow as shown in Figure 3 is currently under development and it is expected to be completed before the end of 2007.

A routine sea level data processing for all stations is carried out with in-house software packages, Sea Level Data Processing Software on IBM PC Compatible Computers Version 3.0, (Caldwell, 1998), and other commercial software packages. The national sea level data base is routinely updated and improved. The main content of the sea level data base is metadata, raw data, monthly and yearly tidal harmonic constants, monthly and yearly MSL trends and a description of station maintenance activities.

The tidal prediction at ports where the permanent sea level monitoring stations are located has been made to meet the increasing demand from users, mainly from the field of survey and mapping, coastal management, fisheries, tourism and water sports. We started by publishing tidal predictions in a calendar format for 5 stations in 2004. Since 2005, we have been publishing an annual tidal almanac book consisting of 60 standard ports where permanent stations are located, (Manurung et al., 2005).

6. Summary

The progress on development of the Indonesian Real Time Sea Level Network for supporting both IdnTEWS and IOTWS is encouraging. As part of an ongoing attempt to complete the deployment of 60 real time stations in 2007, there are 11 stations already in place as of March 2007. However, budgeting for the establishment of the remaining 20 out of 80 stations, as proposed in the IdnTEWS grand design, is still subject to government funding in fiscal year 2008.

The extensive network will use different communication channels such as VSAT, Meteosat/GTS, BGAN, and GSM data, which are all running independently, if possible. As Indonesia coastlines are close to tsunamigenic areas, the communication system should be capable of operating in an extreme tsunami mode where fast data transmission rate from the stations is required. The use of VSAT is a high priority option since this is the best solution at present for real time data communication in term of cost effectiveness and reliability for such a vast area like Indonesia with its archipelagic condition where mostly very minimal terrestrial communication infrastructure is available. The significant addition of new real time sea level stations is a great opportunity to improve an operational ocean observing system covering the whole Indonesia region with a better distribution.

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8. References

Caldwell, P., 1998. Sea Level Data Processing Software on IBM PC Compatible Computers Version 3.0 (Year 2000 Compliant). JIMAR Contribution No 319, SOEST, University of Hawaii, 72 pp.

Intergovernmental Oceanographic Commission, 1985. Manual on sea-level measurement and interpretation. Volume 1 - Basic procedures. Intergovernmental Oceanographic Commission Manuals and Guides No. 14. IOC, Paris, 83pp.

Manurung, P. et al, 2005. Tide Prediction Book 2006. BAKOSURTANAL, Cibinong Indonesia.

Manurung, P. et al, 2006. Tide Prediction Book 2007. BAKOSURTANAL, Cibinong Indonesia.

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Merrifield, M.A. et al., 2005. Tide gage observations of the Indian Ocean tsunami, December 26, 2004, Geophys. Res. Lett. 32, L09603, doi:10.1029/2005GL022610.

Pugh, David T., 1987. Tides, Surges and Mean Sea-Level. John Wiley & Sons, Singapore.

Rabinovich, A.B., Thomson, R.E., 2007. The 26 December 2004 Sumatra Tsunami: Analysis of Tide Gauge Data from the World Ocean Part 1. Indian Ocean and South Africa. Pure Appl. Geophys. 164 (2007) 261–308.

The State Ministry of Research and Technology, 2006. Grand Design of Indonesia Tsunami Early Warning System. The Republic Indonesia State Ministry of Research and Technology Office, Jakarta.

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