# MONITORING SEA LEVEL USING GPS

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**_Abstract_**

*GPS (Global Positioning System) is a passive, all-weather satellite-based navigation and positioning system, which is designed to provide precise three dimensional position and velocity, as well as time information on a continuous worldwide basis. The ability of GPS for providing high-precision vertical component of relative coordinates could be exploited for monitoring, and hence mapping, the sea level. In this case, the local nature of GPS measurements could nicely supplement the temporal and spatial resolution of satellite altimetry measurements which has a more or less global nature.*

*This paper would describe and discuss the concept and method of monitoring sea level using GPS, and the technical and operational aspects that should be taken into account in implementing this technique. The paper would also discuss the prospect of using this GPS-based approach for monitoring sea level in Indonesia, along with its potential related applications. The paper would be sum up with some concluding remarks and recommendations.*

## I. INTRODUCTION

Information about sea level and its variations are important for various purposes, such as navigation, bathymetric survey, marine construction works, fishing industry, military operations, oceanography, and climatic study. Due to its important and strategic values, there are several techniques that have been used to monitor the sea level and its variations, such as tide gauge and satellite altimetry. Nowadays GPS based technique is also being implemented for that task.

GPS (Global Positioning System) is a passive, all-weather satellite-based navigation and positioning system, which is designed to provide precise three dimensional position and velocity, as well as time information on a continuous worldwide basis [*Hofmann-Wellenhof et al.*, 1997]. The ability of GPS for providing high-precision vertical component of relative coordinates could be exploited for monitoring, and hence mapping the sea level and its variations. In general the roles of GPS for sea level study are quite numerous such as :

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- ? Altimeter Calibration.
- ? Supplementing the satellite altimetry. measurements with finer temporal and spatial resolution features.
- ? Monitoring sea level in local area.
- ? Offshore tide measurement.
- ? MSL (Mean Sea Level) transfer

In this case, the local nature of GPS measurements could nicely supplement the temporal and spatial resolution of satellite altimetry measurements which has a more or less global nature. At the same times, the GPS measurements could also be used to calibrate the altimeter measurements, as illustrated in the following Figure 1. The calibration in principle is based on comparison between the altimeter measurement of the sea level distance below the satellite with the distance computed from GPS derived coordinates of the buoy and the satellite. For the purpose of calibration, both altimeter satellite and the buoy have to be equipped with GPS receivers.

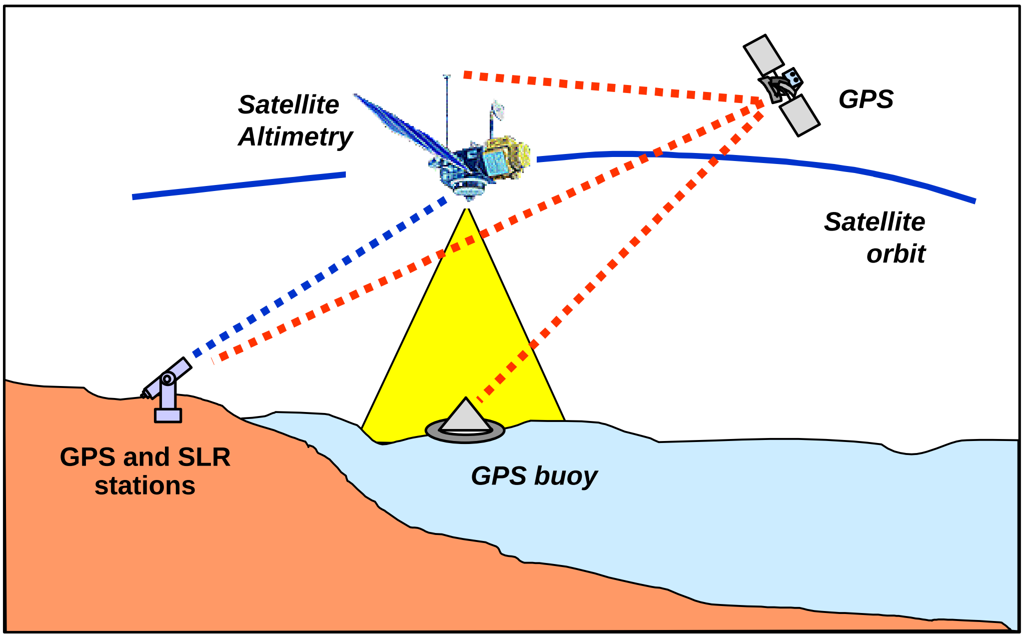


Figure 1. Altimeter calibration using GPS buoy system.

Considering that satellite altimetry could provide various important information on global and regional ocean dynamics, the need for good and reliable altimeter calibration mechanism is quite obvious. In the *Workshop on Methods for Monitoring Sea Level*, held in Pasadena, California, 17-18 March 1977, Mitchum (1997) has proposed a kind of altimeter calibration network, which its proposed stations are shown in Figure 2 below.

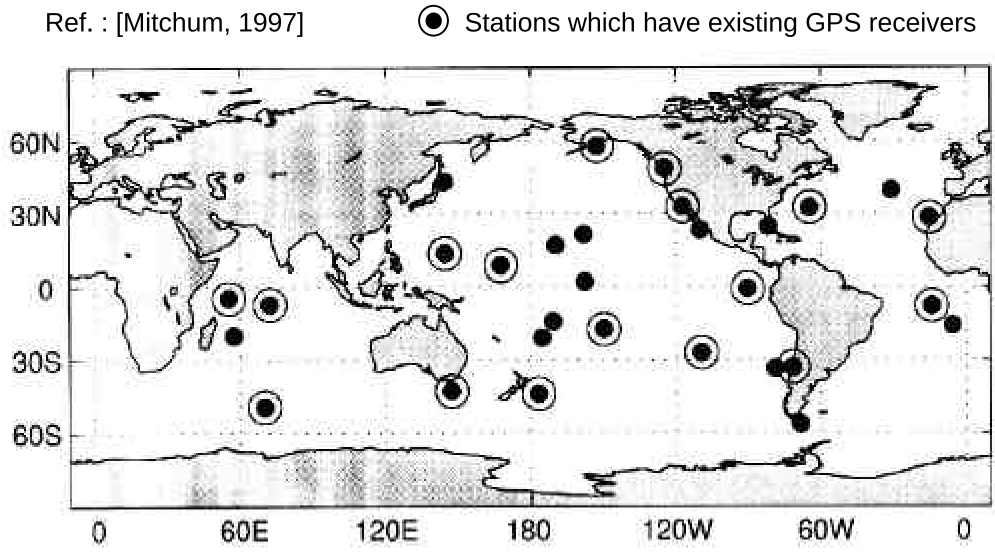


Figure 2. Stations proposed for Altimeter calibration.

GPS could also supplement tide gauge measurements, especially in the areas where the tide gauges measurements could not be performed, such as in rough coastal areas and offshore. In other word, offshore tide measurement could be performed by using GPS buoy system. This buoy system could also be utilized to study and map sea level variations in a local area, to serve various studies and works. Moreover, mean sea level (MSL) transfer between stations on shore could also be done by the help of GPS measurements.

Since sea level monitoring using GPS is basically the problem of height determination in temporal domain, in the following the principle of height determination using GPS is explained in general.

## II. HEIGHT DETERMINATION USING GPS

GPS provide the position of a point in three dimensional coordinate system. It could be in geocentric cartesian system (X,Y,Z) or in geocentric geodetic (ellpsoidal) coordinate system (?,?,h). Height determination using GPS is therefore inherent in GPS positioning task. It should be noted in this case, however, that the height determined by GPS is an ellipsoidal height. This height is not the same with the height being used in practice (academically called orthometric height). Ellipsoidal height is referred to the used reference ellipsoid (i.e. WGS84 in the case of GPS), and orthometric height is referred to geoid. Geoid itself is an equipotential surface of Earth's gravity field, which for practical purposes is assumed to be very close to global mean sea level (MSL). The geometric relation between the two heights is shown in Figure 3 below.

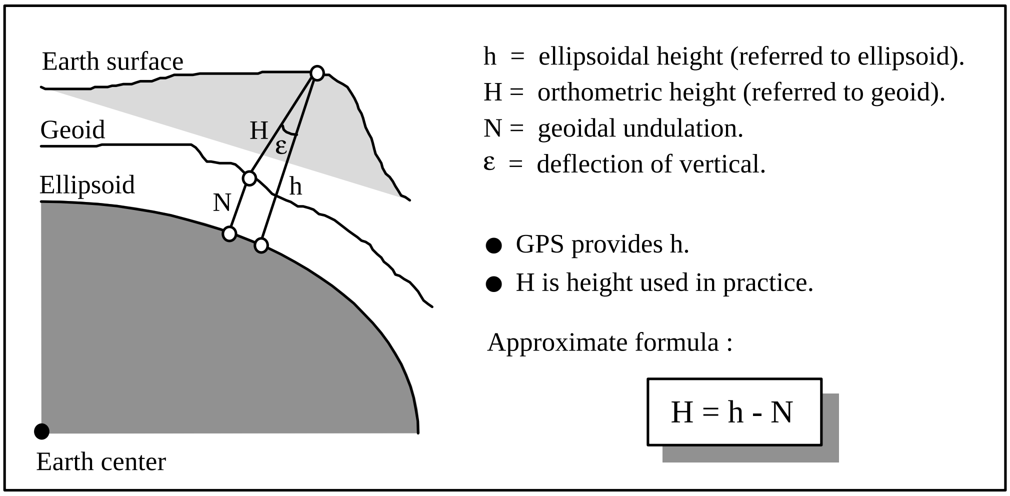


Figure 3. Ellipsoidal height and orthometric height.

From Figure 3 above it can be seen that to transform the ellipsoidal height provided by GPS into the orthometric height, the information about geoidal undulation is required. This information could be estimated using gravity data or could be roughly computed using global geoidal model.

The accuracy of height component estimate using GPS would depend on the positioning method being applied (absolute or relative), and the data being used (pseudorange or phase). The typical accuracy (one standard deviation) of the GPS derived height is shown in Table 1 below. From this Table it can be realized that for accurate sea level monitoring using GPS it is preferable to use the relative positioning and dual-frequency phase data.

| | **Pseudorange** | | **Phase** | |
|---|---|---|---|---|
| | *P-Code* | *C/A-Code* | *Single Frequency* | *Dual Frequency* |
| **Absolute Positioning** | 10 - 20 m | 50 - 70 m | - | - |
| **Relative Positioning** | 1 - 2 m | 1 - 5 m | cm to dm | cm level |
| | Achievable accuracy depends on the baseline length | | | |

Table 1. Typical accuracy of GPS derived height
(for baseline length up to about 100 km)

It should be noted however that in using the phase data for precise positioning, its cycle ambiguity has to be first resolved. Unfortunately, this cycle ambiguity resolution is not an easy task to accomplish. Successful ambiguity resolution requires good quality data, good satellite geometry and sophisticated resolution algorithm. The impact of ambiguity resolution performance on the accuracy of height estimates could be seen in Figure 4 below.

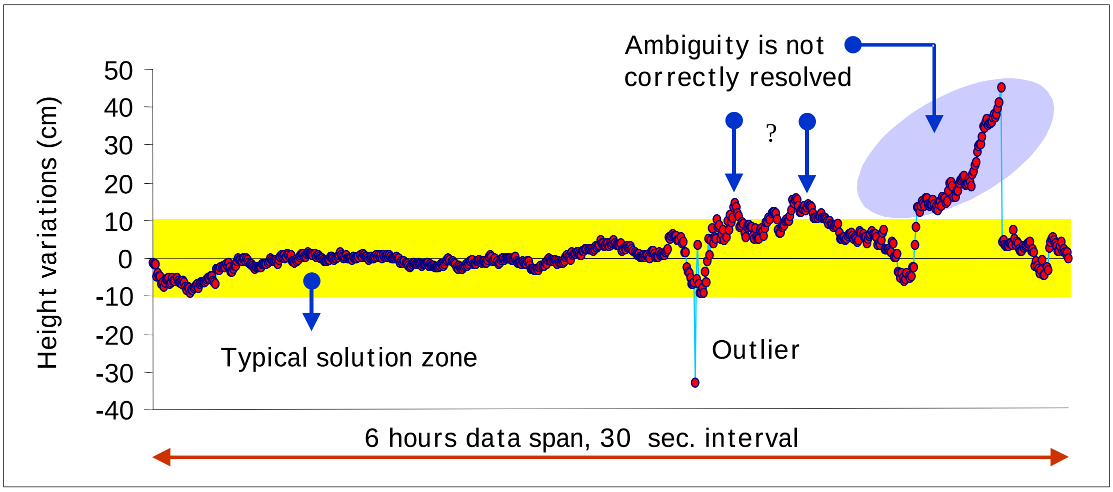


Figure 4. Height Variations derived from GPS data
(on-the-fly ambiguity resolution solution, 2 km baseline)

## III. MONITORING SEA LEVEL USING GPS

In principle, monitoring the sea level using GPS is based on differential (relative) positioning. It involves two (2) GPS receivers and the phase data is used instead of psudorange data. In this case one, GPS receiver is located at reference station on the shore, and the other is on the buoy, as illustrated in Figure 5.

With this technique, the *sea level variation* is studied through *the variation of the vertical component* of GPS antenna coordinates on the buoy. If the information of sea level variations is required in real-time, then the buoy data should be transmitted to the shore, through a certain communication link. In its operation, this technique could be implemented by using one reference station and multi GPS buoys.

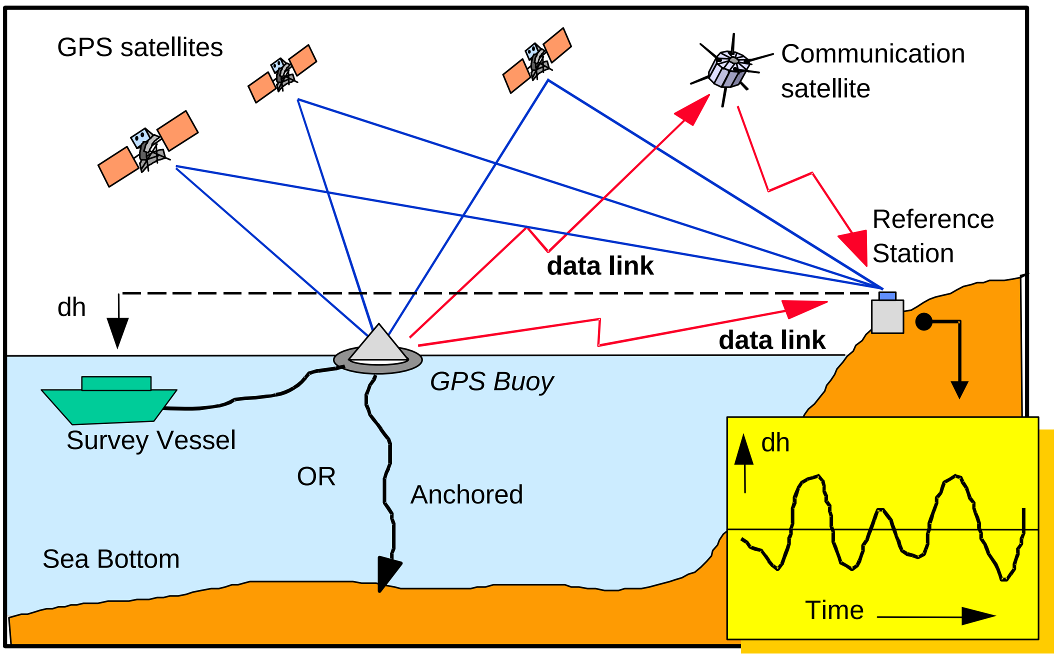


Figure 5. Principle of Sea Level Monitoring Using GPS

If we referred to Figure 5, it should be noted that from GPS data of the buoy and reference station, the height differences dh(t) could be estimated at each observation epochs. These ellipsoidal height differences could be transformed into orthometric height differences, dH(t) through the following relation :

$$dH(t) = dh(t) - dN(t), \quad (1)$$

where dN(t) is geoidal undulation differences between the buoy and the reference station. Since the time variations of undulation, dN(t), are usually very small and therefore can be safely assumed to be negligible, then the following relation is obtained :

$$dH(t) \approx dh(t), \quad (2)$$

Therefore the GPS derived height differences could be directly used to characterize the sea level variations.

## IV. TECHNICAL AND OPERATIONAL ASPECTS

Development and implementation of a GPS based system for accurate monitoring of the sea level, which from now on would be referred as GPS buoy system, is not so easy. There are several issues that have to be properly taken into account in this case, such as :

- Optimal design of the buoy, both in term of geometry and physical features.
- Power supply for GPS receiver on the buoy.
- Remote control mechanism for GPS receiver operation on the buoy.
- The integration of the pitching and rolling sensors with the buoy system.
- Data link/communication system for command and control mechanism and also for transferring data from the buoy to the shore.
- Automatic quality control mechanism that should be had by the system, especially on the buoy.

Related to the buoy design, Figure 6 shows the example of GPS buoy that was used by CCAR, Univ. of Colorado, in Harvest platform experiment. In this experiment the buoy was connected to Turbo Rogue SNR GPS receiver on the boat with a 20-ft rope and cable [*Key et al.*,1998].

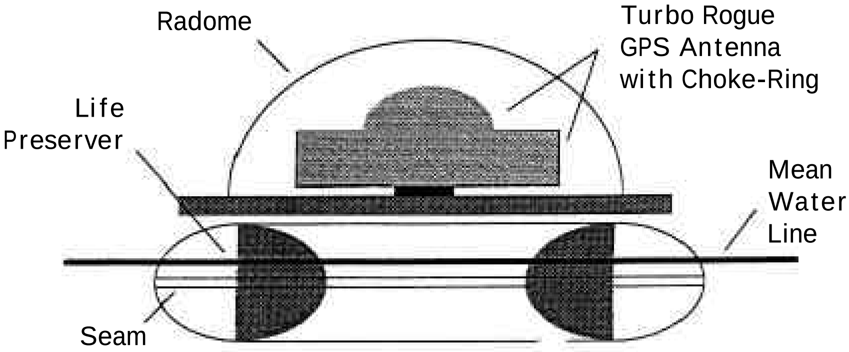


Figure 6. Example of GPS buoy.

Related to processing of GPS data for estimating the height differences between the buoy ant the station on the shore, there are several issues that should not be forgotten, namely :

- On-the-fly ambiguity resolution of GPS phase data which is required because of the continuous motion of GPS antenna.
- Coordinate transformation, which is required because of GPS antenna motion.
- Residual ionospheric and tropospheric biases.
- The effects of signal multipath caused by the sea surface.
- The occurrences of cycle slips due to antenna motion.

In order to have accurate height differences, and therefore accurate sea level variations, those issues have to be properly taken into account.

## V. IMPLEMENTATION PROSPECT IN INDONESIA

Considering the maritime continent nature of Indonesia archipelago, it can be foreseen that the implementation of GPS buoy system in Indonesia would be very beneficial and has very good prospects. From various roles of GPS buoy system for sea level monitoring that have been mentioned before, there are a few that seems to have good implementation prospects in Indonesia.

GPS buoy system would be very beneficial for enhancing the tide measurement system in Indonesia. It could be implemented not just offshore but also inshore where, due to its coastal topography and sea dynamics, the installation of tide gauge system is quite difficult, such as in several places of southern Java, Bali, and Nusa Tenggara. By using the system with multi buoys, the tide characteristics in several places could be simultaneously monitored. If equipped with the data communication system, the monitoring could even be performed in *real-time*.

GPS could also be used for transferring the MSL from a well established tide gauge station to another required station nearby. This GPS based transfer technique would be suitable for those requiring medium level accuracy of MSL in a relatively short time period, such as for coastal engineering works. Considering the relatively fast development of coastal areas in Indonesia, this GPS based technique would have a good future for implementation.

Finally, the vast maritime region of Indonesia could only be effectively studied by using satellite systems. In the context of sea level study and monitoring, satellite altimetry is the best choice to use. In this respect, the implementation of GPS buoy system becomes more important, not just for altimeter calibration but for supplementing the altimetry derived information with finer temporal and spatial resolution features.

Considering the above prospects of GPS buoy system, it is recommended that in the next generation of *SeaWatch* buoys, they are equipped with GPS receivers. Moreover, the cooperation among the related government agencies and universities in the area of sea level monitoring are necessary, not just in research and development stage, but also in operational stage. With the strong cooperation, we would understand more about our ocean, and therefore our future !!

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