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# Absolute height of sea surface by trajectory of GPS antennae over submerged pressure gauges

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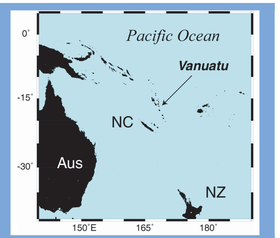
OS 42A




## Abstract :

**Water height data provided by seafloor tide gauges is a combination of sea-level variations and ground motion. Both of these signals are of scientific interest, but they must be separated in order to be useful. Estimating ground motion is specially important in very tectonically active areas such as the Pacific Ocean rim. One promising method to separate the two contributions is to use satellite altimetry data which gives absolute water height, but these data must be calibrated using " ground truth " measurements. Once different components of the signal are separated, bottom pressure gauges can be used to detect vertical movements of the seafloor such as co-seismic or slow inter-seismic motions.**

**The Vanuatu archipelago is part of the Pacific " ring of fire ", where plates are rapidly converging. In the area, movements are very rapid and the seismic activity is intense, which gives a good opportunity to study deformation and seismic cycle. To get an integrate picture of vertical deformation over one plate and between the two plates, one needs to be able to monitor vertical movements on both underwater and emerged areas. We conducted an experiment in the Vanuatu archipelago, South-West Pacific, to compare measurements from bottom pressure gauges located beneath altimetry satellite tracks with sea surface altitude measurements from GPS. Two bottom pressure gauges are immerged since Nov. 1999 on Sabine bank (15.90°S, 166.14°E) and Wusi Bank (15.34°S, 166.55°E), West of Santo island, Vanuatu. In order to perform absolute calibrations of satellite altimeters that overfly the Wusi and Sabine banks, respectively, we performed GPS measurements of instantaneous sea surface altitude. We present results of GPS computations in kinematic mode. We compare the results with the sea level variations recorded by the tide gauges.**

## Long term objectives of the project : vertical deformation of submerged areas.

**Bottom pressure is directly related to water depth : Pb - Pa =ρw g h**
**h varies with sealevel or seafloor altitude changes.**
**In this study, we compare sealevel variations observed with different measurements methods : seabottom pressure (BPG), shipboard GPS, satellite altimetry (Topex Poseidon).**
**The ultimate goal is to be able to detect vertical motion of the seafloor, using a combination of sealevel and ocean depth measurements methods.**

## Why are we interested in the Central Vanuatu area ?

- The Vanuatu archipelago is part of the Pacific ring of fire, known to be a particularly active zone on a volcanic and seismogenic point of view.

- In a regional framework where plates are converging very rapidly (9cm/yr, Calmant et al. 2003), the arrival of a submarine ridge (D'Entrecasteaux Ridge) into subduction slows locally the convergence rate in Central Vanuatu down to 3cm/yr (Calmant et al., 2003). Vertical movements induced by this phenomenum are responsible for a strong seismic activity in the area (numerous seisms with magnitude>7).

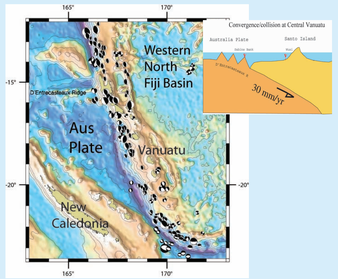



Figure 1 : Bathymetry of the New Hebrides archipelago (Vanuatu). Focal mecanisms are from Harvard catalogue

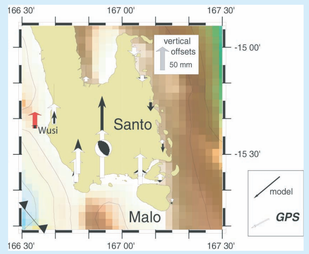



Figure 2 : Vertical movements due to a magnitude 6.9 seismic event on October 4th, 2000, recorded by GPS on land (white arrows) and at the Wusi BP(red arrow).

- The area is intensively studied => gives a good background knowledge on past and present day deformation (Pelletier et al., 1998, Calmant et al., 2003).
Marine data :
Several marine geological and geophysical cruises (lead by IRD in Nouméa). Long term vertical movements (over 40000 years) are studied from coral growth (Taylor et al., 1987, Cabioch, 2003, Cabioch et al., 2003)
On land data :
Repeated GPS measurements are made on a network since 1992. Also, continuous GPS recording in 3 locations (Wusi, Luganville, Port Vila ) since 1997. Vertical displacements induced by seisms have already been observed both on land (GPS network) and off-shore on the Wusi tide gauge (Figure 2, Calmant et al., 2002).

Global sea-level monitoring : Tide gauges records give accurate and often long term monitoring, but are subject to land vertical motion (Figure 3). This is known to be particularly true around the Pacific Ocean.
Satellite altimetry monitoring is more recent (no long term series) but gives global coverage and is not relative to land. Although, it requires precise altimeter calibration.

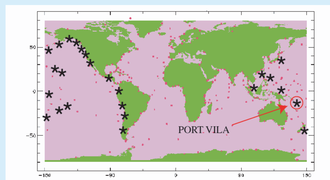



Figure 3 : red dots show the position of tide gauges from GLOSS network. Black stars highlight locations where vertical movements have been reported next to a tide gauge.

## Experimental Setting and data collection:

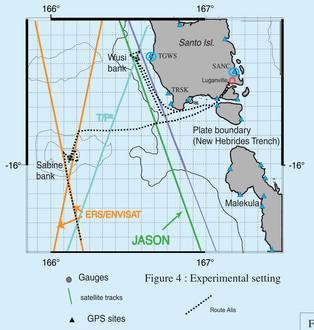



Figure 4 : Experimental setting

Photo 1: Continuous GPS station at Wusi, with the R/V Alis over the tide gauge in the background

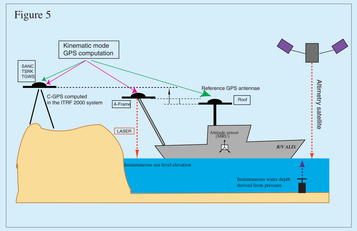
### Collected data :

Bottom pressure (BPG) at 2 locations.
Temperature and salinity on the Wusi bank (seabottom).
Continuous GPS and atmospheric pressure at Wusi (on land).
Shipboard GPS measurements at 5sec (together with ship attitude sensor data)
Satellite altimetry (Topex Poseidon, Jason, ERS and Envisat)

### BPG sites selection :

The 2 BPG sensors are installed on 2 different tectonic plates :
- Wusi site (11.6 m depth) is located on the North Fidji Basin plate, and may be subject to coseismic displacement.
- Sabine site (10.8 m depth) is located on the subducting Australian plate and is supposed to be vertically stable. This site is used as a reference to control any vertical movement that Wusi site may undergo.

Figure 5




## Pressure gauge data :

2 pressure gauges have been continuously recording since November 1999.
Installation and replacement for data retrieval and battery change is performed yearly by divers from IRD. Every other year, gauges are sent to constructor for calibration purposes.
Instruments are Seabird26.
Sampling rate is 15 minutes, corresponding to a 15 minutes average of sealevel. In addition, waves have been recorded every 3 hours.
Geodetic benchmark is a steel frame anchored on the seafloor by screws. Instrument package is installed within the frame by divers.

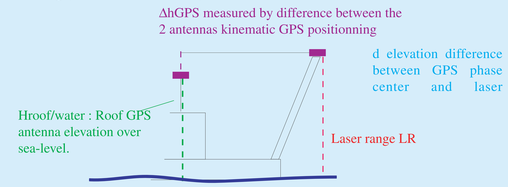
Photo 2: Underwater view of the tide gauge setting

## GPS data processing:

GPS data are processed in kinematic mode (with TRACK modulus in the GAMIT/GLOBK package (King and Bock, 2003).
2 antennas were installed on the ship (roof and A-frame), sampling rate : 5sec
Baselines from continuous GPS stations:
- calibration experiments (day 76 and 77, Luganville) : 7.6km (from Santo)
- Sabine bank measurements (days 75 and 76) : 120km (from TSRK and TGWS)
- Wusi bank measurements (days 77 and 78): 10km from TGWS and 68km from Santo
Tropospheric delays are computed in static mode from the land continuous stations and used in the kinematic computation.
Land stations are supposed fixed in the kinematic computation.
Results : standard deviation on the ship GPS positions vary from 2 to 6 cm in horizontal positions and from 7 to 25 cm in vertical positions.

## In port calibration of the GPS antenna / water :

The boat roof GPS antenna elevation above sea-level has been estimated using a secundary GPS antenna directly above water and laser ranges.
We removed the oceanic tidal signal by an hourly prediction using FES2002 modeling (LeProvost et al., 2002).




Hroof/water = LR + ΔhGPS + d
Results :
2 calibrations sessions have been successfully done in Luganville port (Santo island):
Day 76 : Hroof/water = 8.515 (+/-0.008) - 0.5092 (+/-0.0679) - 0.035= 7.9708 +/- 0.068 m
Day 79 : Hroof/water = 8.4487 (+/-0.005) - 0.4281 (+/-0.049) - 0.035= 7.9856 +/- 0.05 m

We take the average of the two results :
=> Hroof/water = 7.978 +/- 0.06 m

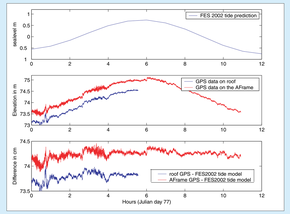



Figure 6 : Comparison between the two shipboard GPS observations (roof and A-frame) and FES2002 ocean tide prediction

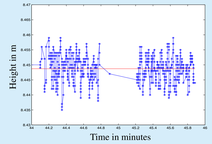



Figure 7 : Example of laser range data from the A-frame down to the water. The altitude difference between the laser ranging device and the A-frame GPS antenna phase center is estimated to 0.035m

## Ellipsoidal elevation of the seafloor at Wusi, by a combination of pressure measurements and GPS data :

The ellipsoidal elevation of the seafloor is obtained from an adjustment of pressure measurements and shipboard GPS data over the submerged gauge.
Adjustment and residual are shown figure 8.

Results :
Mean water depth at Wusi site : 11.592 m (averaged depth since October 2000, when a seismic event occured on Santo and induced a 3.7cm vertical movement at Wusi site, see Figure 2)
Ellipsoidal altitude of the seafloor at Wusi : 50.57 m

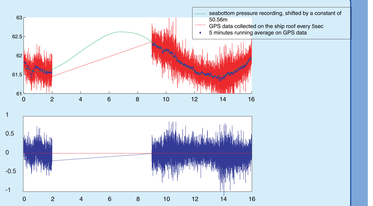



Figure 8 : Comparison between sealevel estimated from seabottom pressure and from shipboard GPS data. 19/03/2003

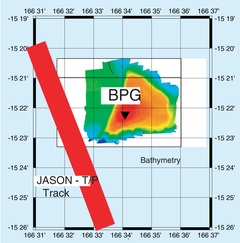



Figure 9 : Wusi site configuration showing the distance between the BPG and the satellite track.

## Ellipsoidal altitude of sealevel from Topex data and from BPG recording tied by GPS : preliminary analysis

Topex-Poseidon data processing :
Wet and dry tropospheric corrections
Sea State Bias correction
Solid Earth tide correction
Polar tide correction
Due to the strong topography in the area, the geoid slope is important and cannot be neglected if one uses altimetry data that are not perfectly collocated. For that reason, Topex data have been extracted at 10 Hz and then recomputed at 1 Hz by averaging the consequent 10 values around a central location chosen to be along the track exactly at the Wusi BPG latitude.

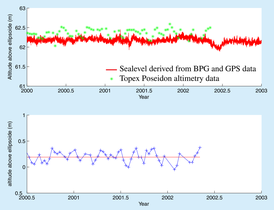



Figure 10 : Comparison between sealevel estimated from seabottom pressure and GPS data and from Topex-Poseidon altimetry data.

## Conclusion and perspectives :

We were able to compare sealevel absolute elevation using two sets of independant measurements.
The work is still in progress and we hope to reduce the 20 cm difference by taking into account the local geoid gradient and thus better estimate the impact of the distance between the satellite measurements and the BPG site. The slope of the local geoid is huge, due to the presence of the subduction zone (Figure 11). GPS data collected on the ship may help us in determining the geoid difference between the two data location points.
We will also work on reducing the RMS on the geoid altitude determined by satellite altimetry, by refining geophysical corrections applied on the data, especially Sea State Bias (height for big waves are underestimated) and radiometer corrections which have not yet been checked (may be biased by the presence of land nearby).
We will also cross-check our final comparison results with the new Jason satellite data.

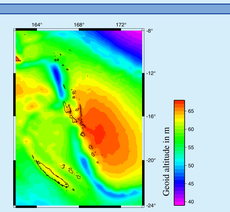



Figure 11 : Geiod variations from Topex Poseidon data (UCSD database).

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