Sea Level Trends Around Indonesia From Altimetry and Tide Gauge Data

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Introduction

The Indonesian region consists of thousand of islands and huge population inhabit low lands in coastal areas. Therefore, an understanding of the past and future changes in sea level are of utmost importance in this region.

Sea Level Change in 1993-2009

- Methodology
  - Four tide gauge stations (Benoa, Jakarta, Sibolga and Surabaya) have been selected based on the data availability over 1993-2009. Hourly tide gauge data are from UHSLC (http://ilikai.soest.hawaii.edu/uhslc/rqds.html) and from BAKOSUTANAL, the National Coordinating Agency for Surveys and Mapping in Indonesia. Monthly averages are computed.
  - Multi-mission satellite data have been merged in monthly grids of 0.2 degree spacing (Gaussian weighted method, half-weight of 1 degree and search radius of 150 km). The linear trend has been estimated at each grid point
  - Time-series of tide gauge and of nearest grid point have been compared
- Results
  - The rates of sea level change computed from multi-mission altimeter data are positive and vary spatially from 1 to 16 mm/yr. In the open sea the trends are higher than in the marginal seas (Fig.1)
  - In Sibolga altimetric and in-situ sea level have the highest correlation (0.9) and similar trend (3.7 mm/yr) (Tab.1)
  - Difference in the trends of altimetric and in-situ sea level is generally large (Tab.1)
  - Gaps in tide gauge data are significant, see completeness index CI in Tab.1
  - Jumps in reference level are evident (Fig.3, e.g. at Benoa and Sibolga).
  - Common oceanic signals characterize all time-series (Figs. 2-3)
  - the lower correlation with altimetry can be caused by vertical movements and/or by jumps in the zero reference level of the tide gauge

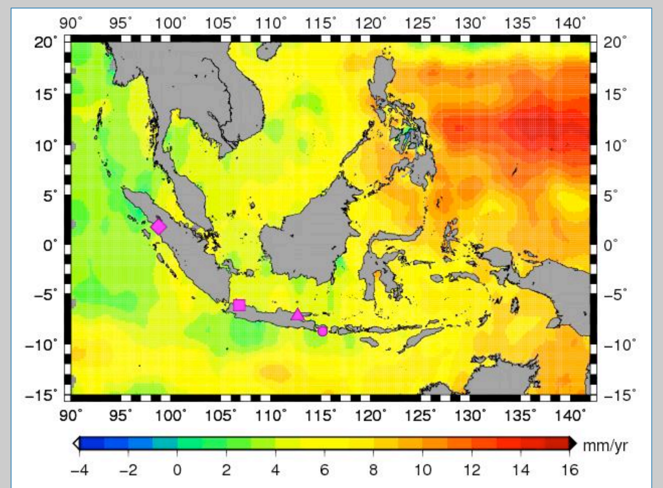

Fig. 1 Linear-term of sea level change from multi mission satellite altimetry in 1993-2009 (mm/yr)

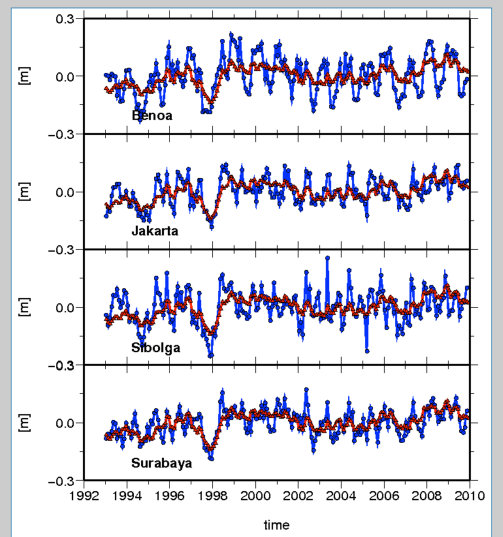

Fig. 2 Altimetric time-series co-located to tide gauges

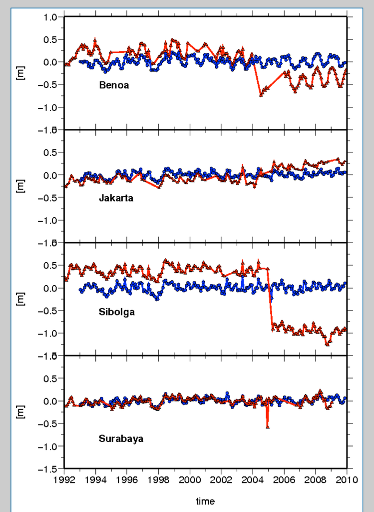

Fig. 3 Sea level from tide gauge and altimeter.

Station	Altimetry (mm/yr)	Tide Gauge (mm/yr)	AL-TG (mm/yr)	Distance (km)	Correlation Correlation	RMS (mm)	CI percent
Benoa	3.4 ± 3.0	-11.3 ± 4.3	14.7 ± 1.8	6.7	0.87	75	74
Jakarta	5.1 ± 2.0	0.3 ± 2.4	4.8 ± 1.6	14.4	0.73	55	73
Sibolga	3.7 ± 2.6	3.7 ± 3.0	0.0 ± 1.2	25.2	0.92	41	90
Surabaya	4.5 ± 2.0	9.0± 2.3	-4.5 ± 2.3	8.9	0.78	51	83

Tab 1: Linear trends in 1993-2003 of monthly time-series at tide gauge and corresponding nearest altimeter point grid, correlation, root mean square differences (RMS) and completeness index CI

Sea level from GITEWS tide gauge stations

The tide gauge stations installed by the Coordinating Agency for Surveys and Mapping (BAKOSURTANAL) (80) as well as by IOC and USA (10) are for monitoring and realtime transmission of sea level data only (Fig.4).

Within the German Indonesian Tsunami Early Warning System (GITEWS) project and as a contribution to the Indonesian Tsunami Early Warning System (InaTEWS), Germany has provided 10 GPS-controlled tide gauges, installed on sites at the islands of Sumatra, Java, Sumba, and Rote facing the Indian Ocean. Fig. 5 shows the seven GITEWS cGPS@TG sites used here.

The GPS-controlled stations allow both a continuous monitoring of sea level (with automated alert in case of rapid sea level change) and of the movements of the tide gauge station. The longest GPS record starts in 2007 (Sadeng station, SADE), tide gauge data are available since end of 2007 (Seblat, SEBL). Most stations have several sensors: radar (RA), pressure sensor (PR), encoder measuring sea level in a stilling well (ENC).

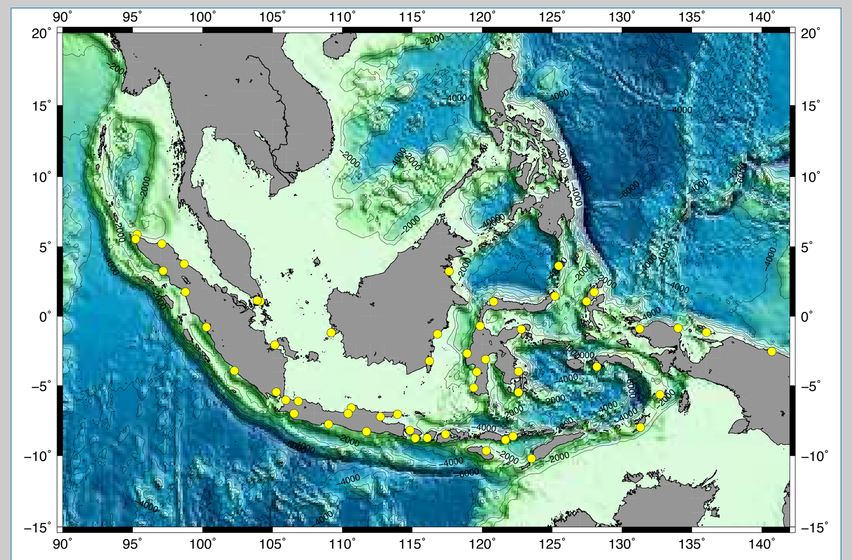

Fig. 4 Tide gauge stations of BAKOSURTANAL

Fig. 5 Stations of the GITEWS cGPS@TG sites in Indonesia

The different sensors usually show some differences in the recorded sea level. Comparison with sea level from satellite altimetry helps to identify the most reliable sensor. Fig. 4 and 5 show sea level from different sensors and from altimetry at two stations.

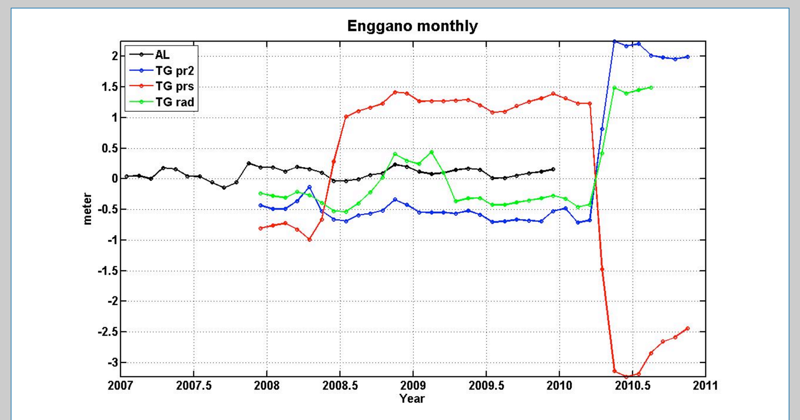

Fig. 6 GANO: sea level from altimetry and tide gauge sensors

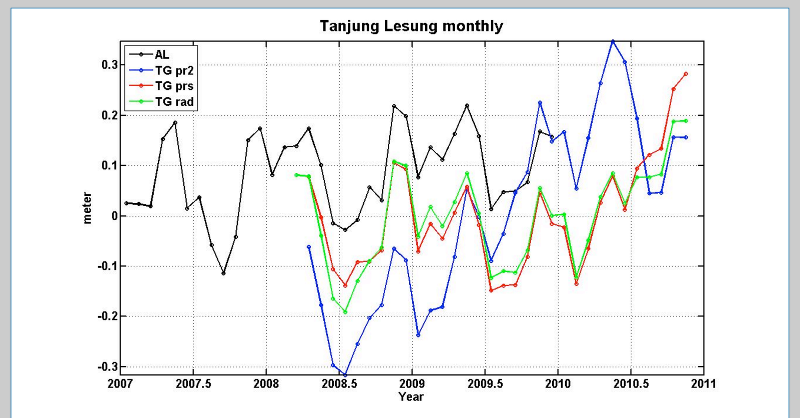

Fig. 7 TJLS: sea level from altimetry and tide gauge sensors

In GANO one of the pressure gauges agrees well with the altimetric sea level in 2008-2009. Several jumps are present in the records of the other sensors, a jump in march 2010 is common to all sensors. In TJLS both the radar sensor and one pressure sensor agreee with altimetric sea level, the other pressure sensor has spurious trends.

GANO and TJLS are located near to a descending Envisat track, SEBLAT under a descending Topex track.

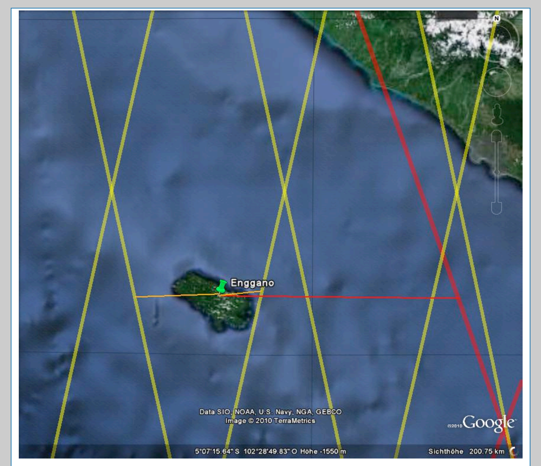

Fig. 8 GANO: altimetric tracks

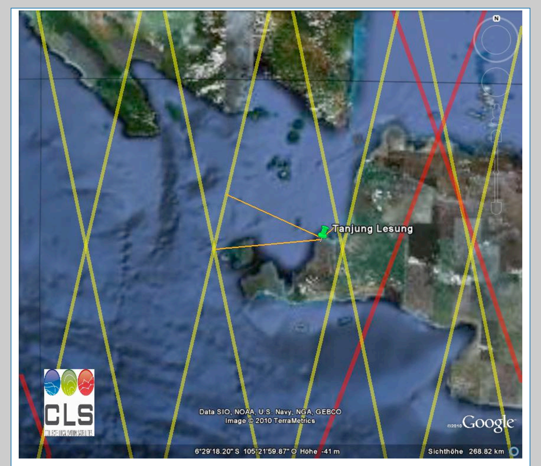

Fig. 9 TJLS: altimetry tracks

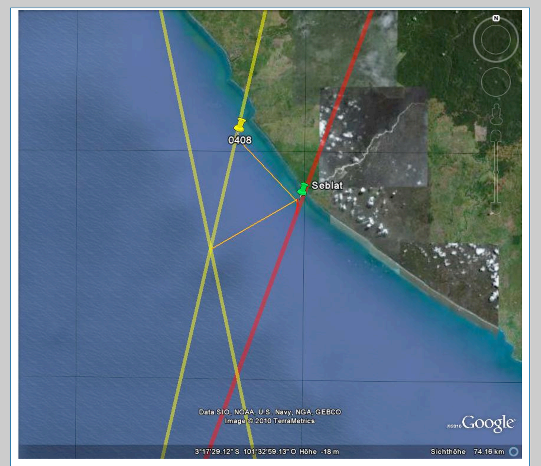

Fig. 10 SEBLAT: altimetry tracks

GPS-controlled tide gauges in Indonesia

- Results
  - Preliminary rates have been computed accounting for the gaps due to the Earthquakes. Levelling at stations GANO and TDAL between GPS-Antenna and the tide gauge is necessary as they are far apart.

    Fig. 5 shows the displacement in the ITRF2005 reference system for the period 2008 to 2010, computed at the seven GITEWS cGPS@TG sites. Velocities are dominated by post-seismic displacements (Schoene et al., 2011).

    The proper modelling of the vertical movements is the key to sea level change studies.

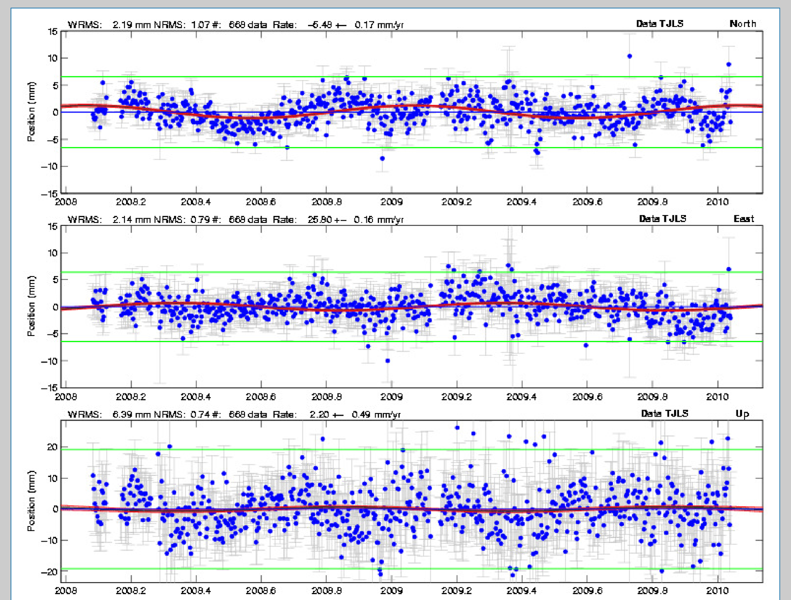

Fig. 11 CGPS at TG (North, East, Up) at Tanjung Lesung (TJLS).

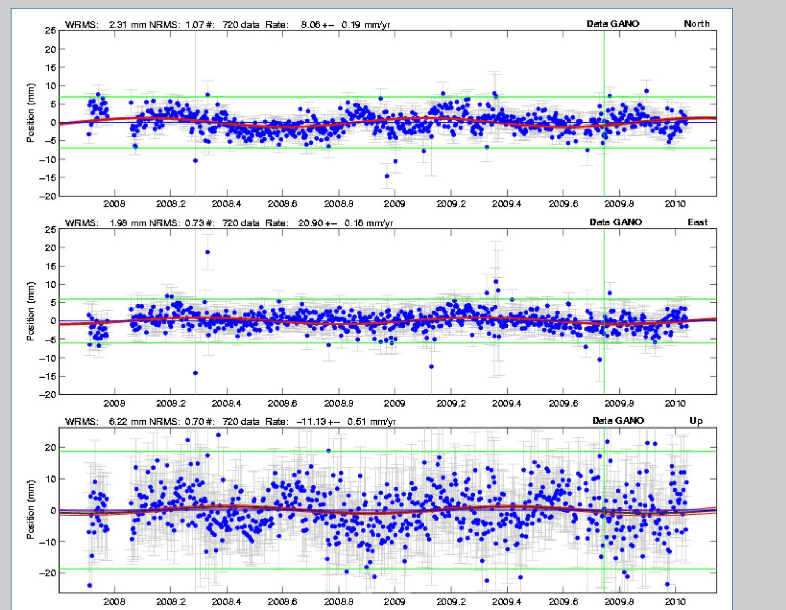

Fig. 12 CGPS at TG (North, East, Up) at Engano (GANO).

Looking at sea level changes, we are mainly interested in vertical movements of the Earth crust. The vertical movements at stations located on Java (e.g. 2.2 ± 0.49 mm/yr at TJLS (Fig. 11)) are smaller than for stations located on Sumatra (e.g. 10.9 ± 0.44 mm/yr at TDAL and -11.13 ± 0.5 mm/yr at GANO (Fig.12)).

Station	North	East	Up
MEUL	-34.5 ± 1.35	-15.51 ± 1.46	13.94 ± 4.06
GANO	8.06 ± 0.19	20.9 ± 0.16	-11.13 ± 0.51
SADE	-7.56 ± 0.21	28.92 ± 0.17	3.6 ± 0.61
SEBL	-34.34 ± 0.85	-20.48 ± 0.81	19.20 ± 1.76
TDAL	1.46 ± 0.19	5.19 ± 0.2	10.09 ± 0.44
TJLS	-5.48 ± 0.17	25.8 ± 0.16	2.2 ± 0.49
WAIK	16.72 ± 0.23	31.07 ± 0.19	-2.85 ± 0.56

Tab 2: GPS rates (mm/yr) at the cGPS@TG stations

Conclusions

- In 1993-2009 satellite altimetry shows a positive sea level trend in the Indonesian region
- Local geodynamic activity affects changes in the reference level of tide gauge data at many stations making the use of tide gauge stations for sea level change studies difficult
- the GPS-colocated stations allow a parallel monitoring of sea level and vertical land motion. The longest GPS record starts in 2007 (Sadeng station, SADE), tide gauge data are available since end 2007.

References

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[2] T. Schoene, J. Illigner, P. Manurung, C. Subarya, J. Khafid, C. Zech, and R. Galas. GPS-Controlled tide gauges in Indonesia - a German contribution to Indonesia's Tsunami Early Warning System . *Nat. Hazards Earth Syst. Sci.*, 11:731–740, 2011.

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