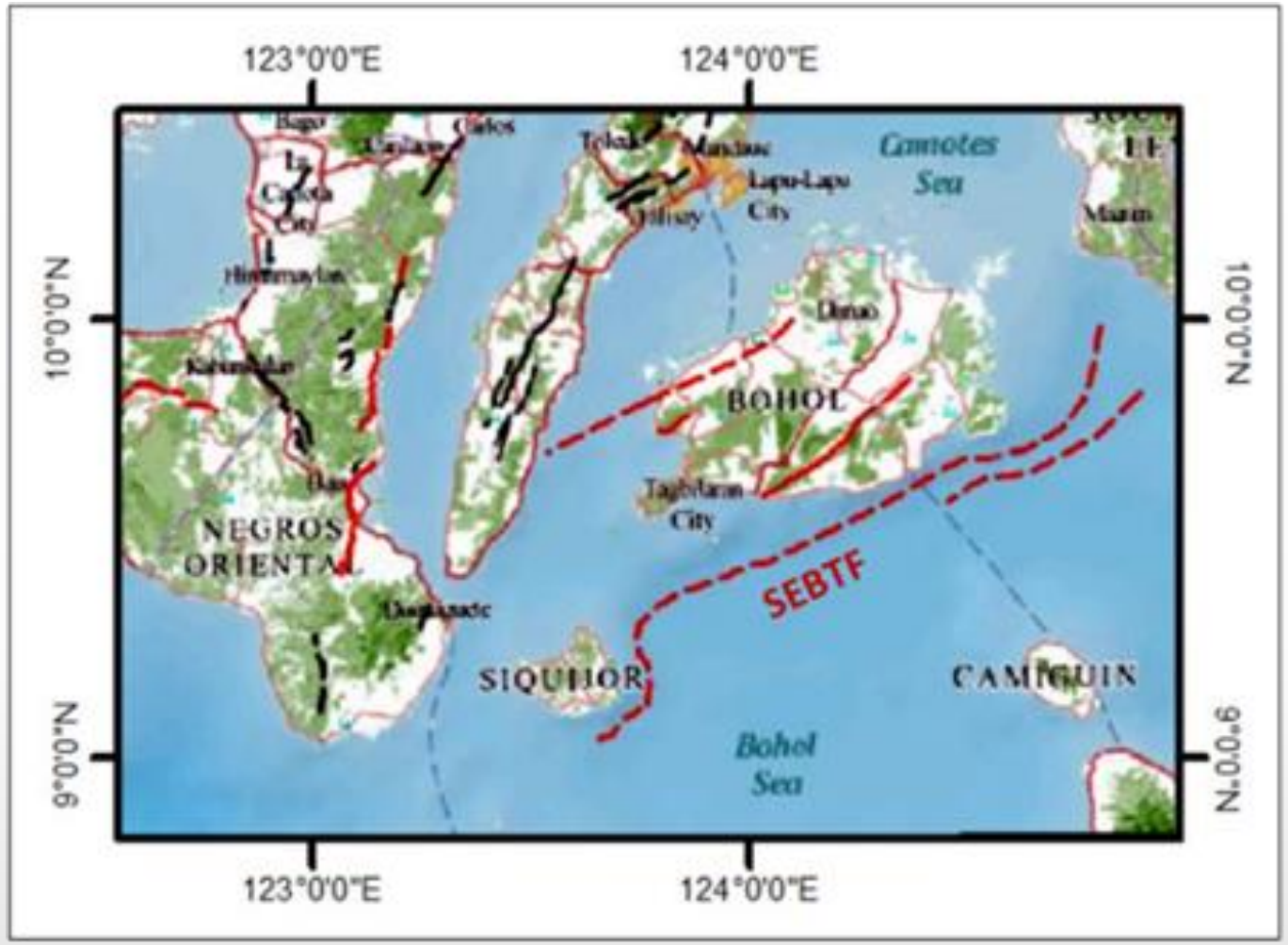
TIDE GAUGE AND SATELLITE ALTIMETRY DATA FOR POSSIBLE VERTICAL LAND MOTION DETECTION IN SOUTH EAST BOHOL TRENCH AND FAULT

R. Reyes
D. Noveloso
A. Rediang
B. M. Passaro
C. D. Bringas
D. M. Nagai

INTRODUCTION

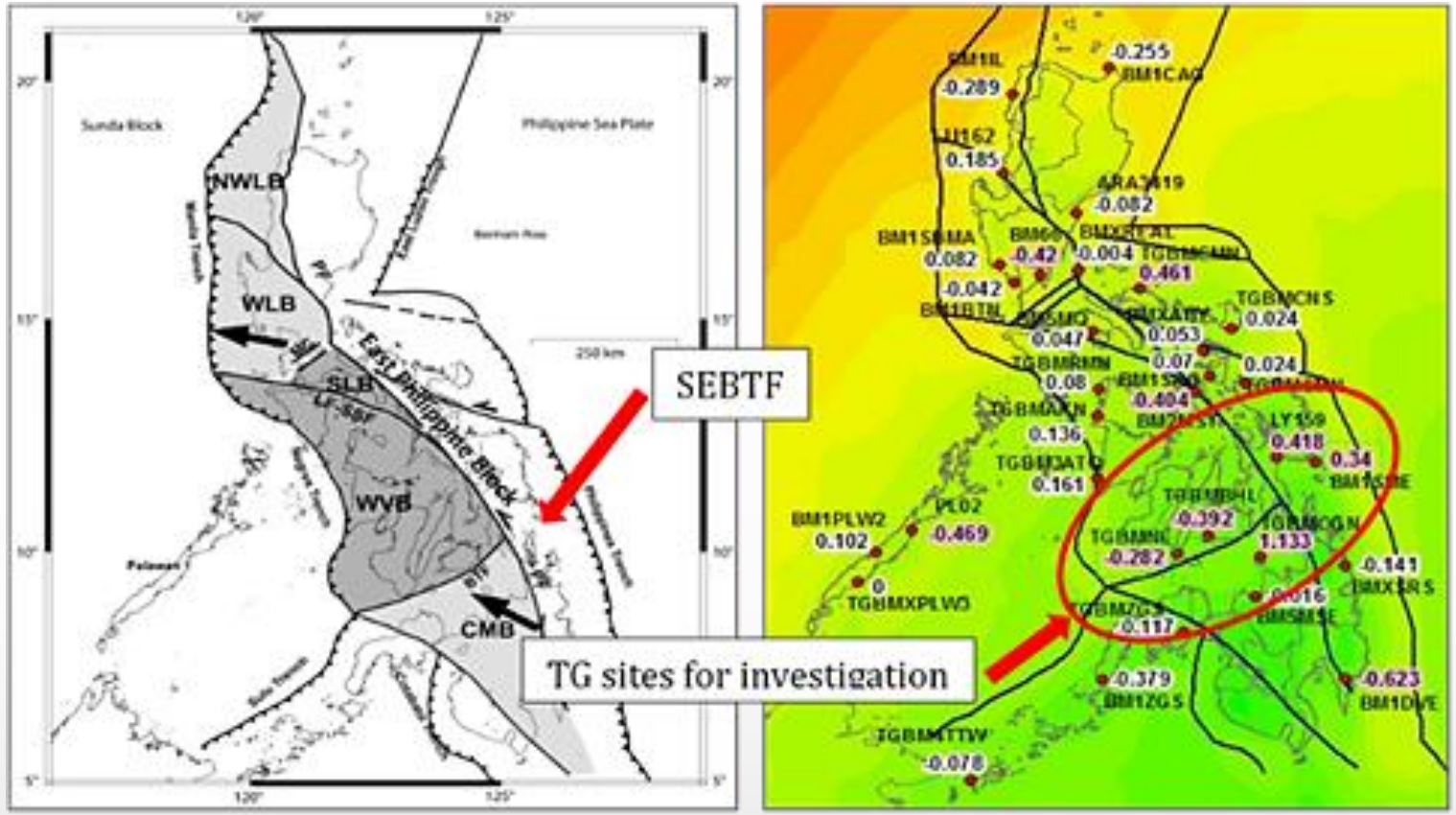
- Global mean sea level (GMSL) rate is 3.2 mm/year computed from satellite altimetry data over 1993 to 2012
- Regional MSL rates vary from the GMSL due to influencing factors such as vertical land motion, tide influence, storms, climatic variability, etc.
- In the open ocean, satellite altimetry is very reliable but in the coastal areas the signal is degraded
- Until recently, due to the development of new processing algorithms called retracking, altimeter data near the coasts can now be used
- The potential of satellite altimetry, tide gauge and GNSS data for VLM determination were demonstrated in several studies *(Fenoglio-Marc et al. 2004, 2011, 2012; Avsar, et al. 2017; Kleinherenbrink et al. 2018; Wöppelmann and Marcos 2015; Ray et al. 2010; Nerem and Mitchum 2002; Kuo et al. 2008; Zulkifli et al. 2018; Yildiz et al. 2013)* with encouraging results.

STUDY AREA



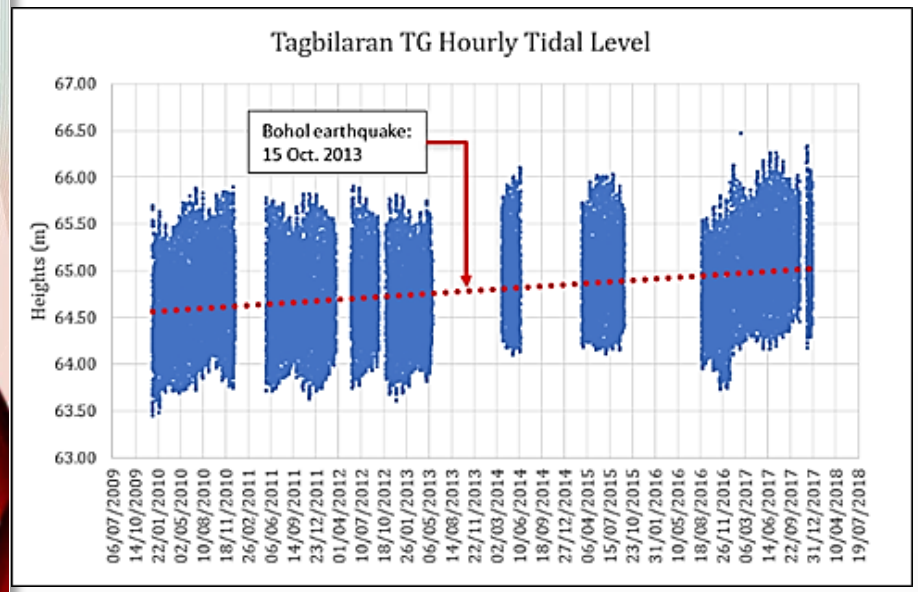
- This study explores the possibility of using satellite altimeter data near the coasts of the Islands of Bohol, Camiguin and Negros where the SEBTF is located
- Reports of land emerging from the bottom of the sea after the earthquake in October 15, 2013 were reported

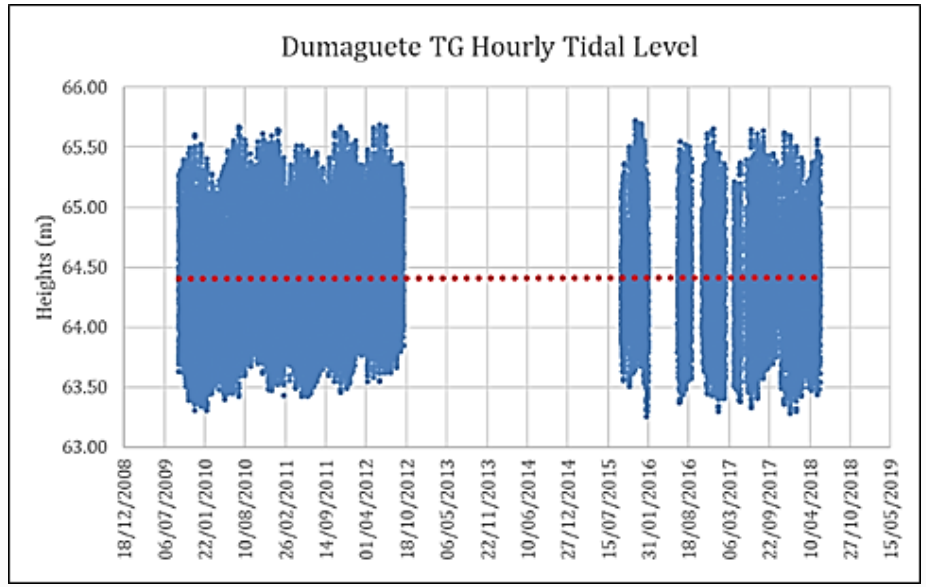
STUDY AREA

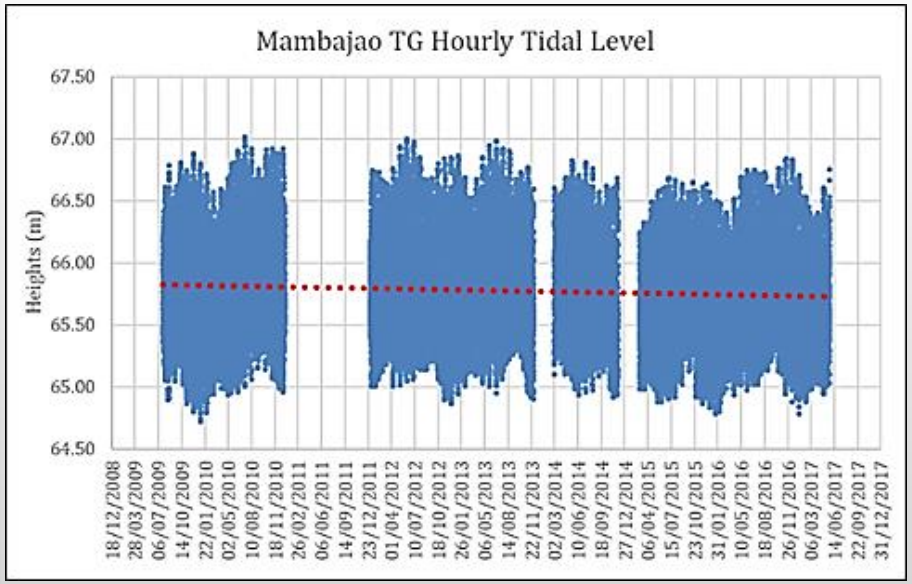


- Previous study of Reyes and Forsberg (2017) showed clustering of large offsets of the MSLs from the Philippine Geoid Model (PGM) of 2014 in the vicinity of the SEBTF as shown.

TIDE GAUGE SEA LEVEL

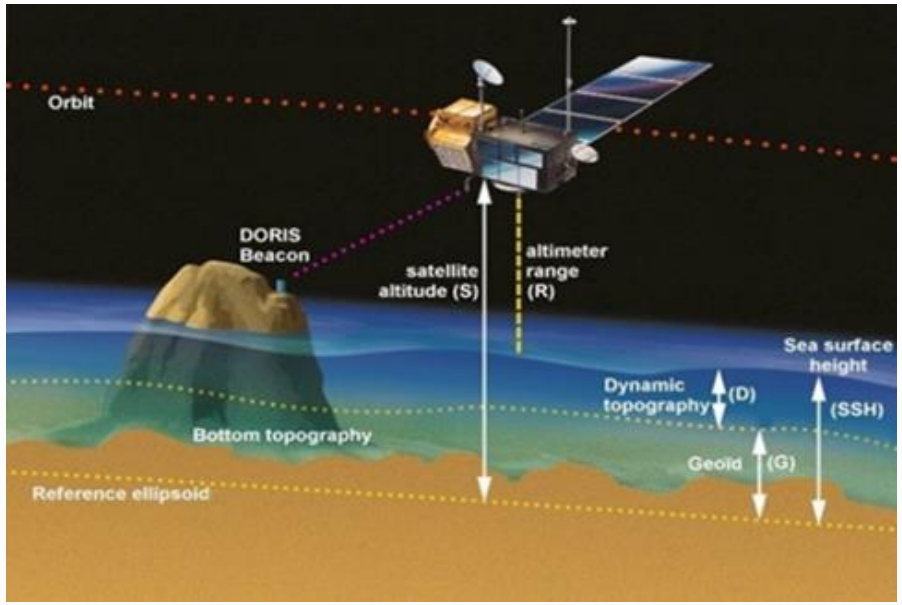


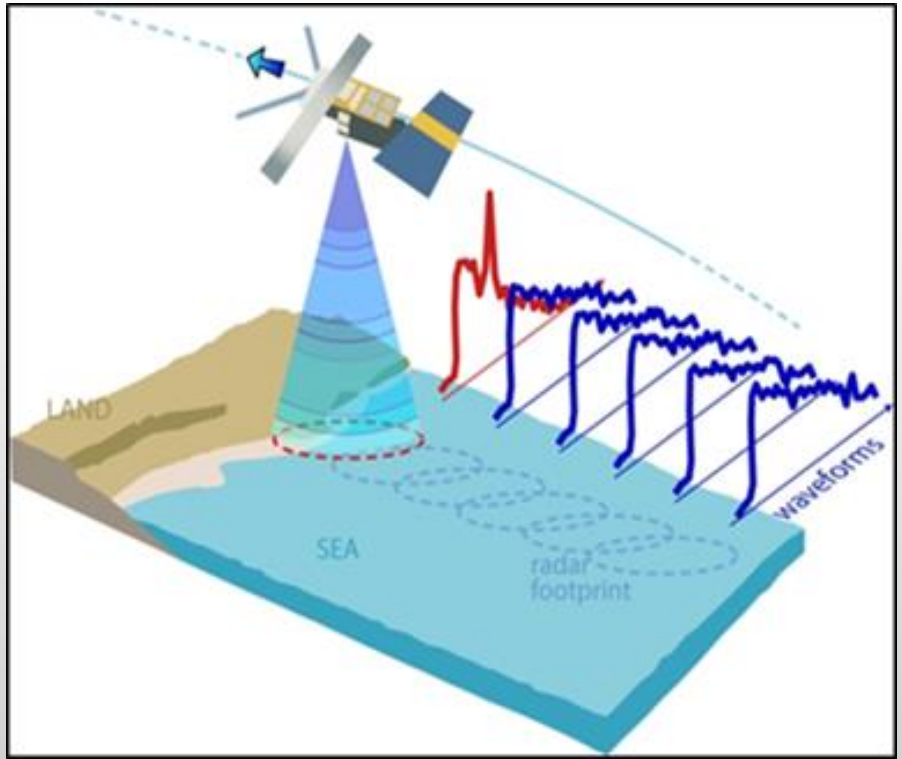




- Tagbilaran, Bohol TG sea level exhibit an increasing trend
- Dumaguete, Negros Oriental TG sea level is increasing but very minimal
- Mambajao, Camiguin TG sea level shows a downtrend

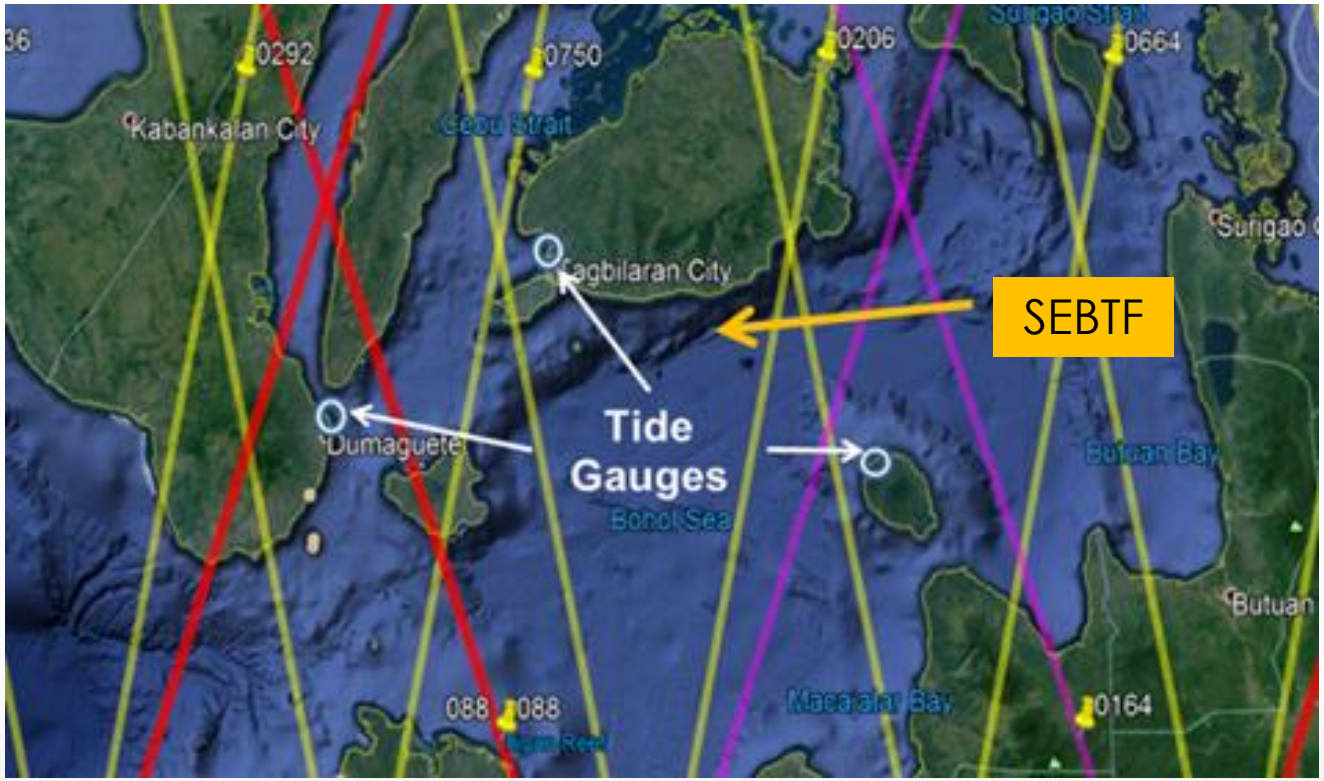
SATELLITE ALTIMETRY





- Satellite altimeter is like a tide gauge in the sky
- Unlike tide gauge stations, satellites are not affected by land subsidence or any ground movements since they are in space
- A large portion of the data from satellite altimetry is not suitable for coastal applications due to contamination with land and calm water interferences
- New retrackers dedicated for coastal observations were developed such as ALES, OCOG, COASTALT, X-TRACK, etc., produced promising results on sea level observations on coastal areas.

SATELLITE AND TIDE GAUGE DATA



- Altimeter data were from Topex Poseidon, EnviSat, Jason 1, Jason 2, Saral/Altika, GFO and RA2 satellites provided by AVISO+, CTOH, PODAAC, OpenADB and Dr. Passaro
- Hourly TG data were provided by Oceanography Division, Hydrography Branch of NAMRIA.
- TG data were interpolated to match the time of acquisition of the satellites

DATA COMPARISON

- Criteria for determining if the sea level observed by the satellite altimeter and the tide gauge is valid for comparison.
  1) the standard deviation of the differences between altimetry and tide gauge data should not exceed 30 cm; and
  2) the difference between altimetry and tide gauge data should not exceed the 12 cm threshold (Valladeau and Ablain 2011).
- Also, satellite altimeter should have a minimum of 2 years observations.
- Passing these criteria means that the 2 datasets are correlated and therefore in agreement
- **Diff = SSH – TGSL**

Where: SSH is the Sea Surface Height from altimetry

TGSL is the Tide Gauge Sea level

METHODS

1. Programming
2. Tide gauge data processing
3. Satellite altimetry data processing
4. Time colocation
5. Differencing and filtering

RESULTS

Product	Satellite	From	Freq	TG Location	RMSD	Ave Sat Alt SSH	Ave TGSL	Diff
ALES	Jason-1	OpenADB	1Hz	Tagbilaran	0.5672	64.1236	64.6003	0.4768
				Mambajao	1.9952	63.8747	65.7659	1.8912
				Dumaguete	0.3429	64.1036	64.3324	0.2288
ALES	Jason-2	DGFI-TUM	20Hz	Tagbilaran	0.7313	64.1802	64.7721	0.5918
				Mambajao	No data			
				Dumaguete	0.4731	64.1366	64.3589	0.2223
ALES	EnviSat	PODAAC	18Hz	Tagbilaran	3.1258	61.8007	64.9073	3.1065
				Mambajao	4.2121	61.8214	65.9537	4.1323
				Dumaguete	2.9999	61.6374	64.6086	2.9712
PISTACH	Jason-2	AVISO	20Hz	Tagbilaran	0.5751	64.3677	64.7726	0.4049
				Mambajao	No data			
				Dumaguete	0.4227	64.2888	64.3762	0.0874
PEACHI	Jason-2	AVISO	20Hz	Tagbilaran	0.6252	64.2970	64.7639	0.4668
				Mambajao	No data			
				Dumaguete	0.4359	64.2445	64.3667	0.1222
PEACHI	SARAL /AltiKa	AVISO	40Hz	Tagbilaran	0.9350	63.8678	64.7960	0.9283
				Mambajao	2.4239	63.5642	65.9079	2.3438
				Dumaguete	No data			
X-TRACK	GFO RA-2 Jason 1	AVISO/ CTOH	1Hz	Tagbilaran	0.6138	64.3986	64.8589	0.4603
				Mambajao	1.8230	64.0889	65.8294	1.7405
				Dumaguete	0.5264	64.1228	64.4261	0.3033

- In general, TGSLs are higher than the SSHs determined by satellite altimeter
- Data from EnviSat is giving large differences from TG data

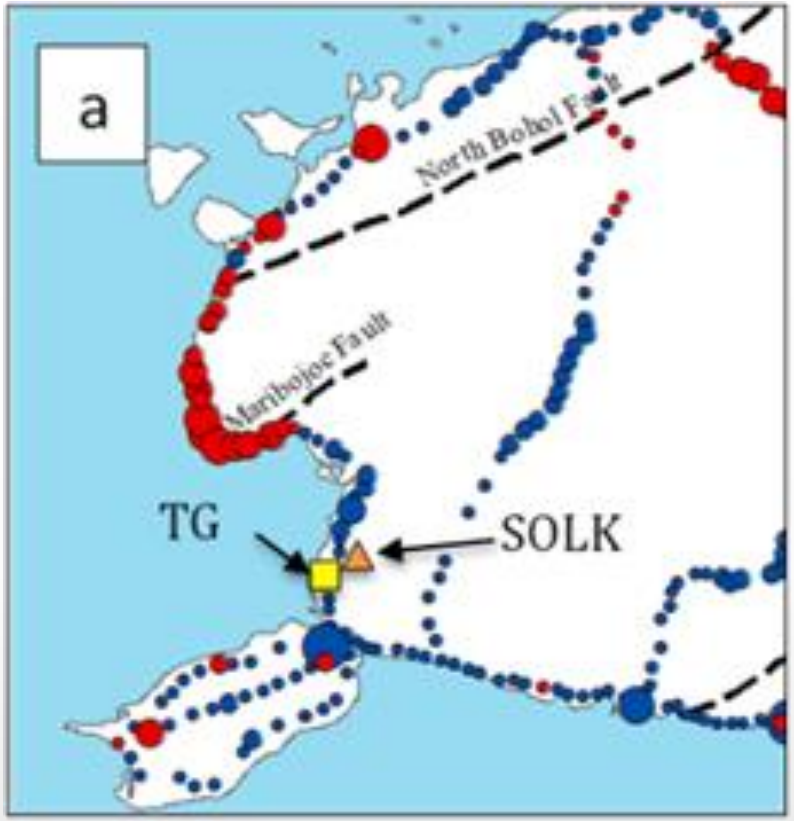
RESULTS

- The difference between the averages of SSH-TGSL at Mambajao TG (excepting ALES-EnviSat result) of around 1.99 m conforms with the more than 1 m difference of TGSL from the PGM 2014 (Reyes, Forsberg, 2017).
- In Dumaguete, the SSH-TGSL difference in average is -16.52 cm which is just 4 cm more than the 12 cm criteria (excepting ALES-EnviSat and X-TRACK).
- There is an average difference of -45.22 cm in Tagbilaran that is way above the 12 cm allowable. The RMSD average is 59.53 cm, which also exceeded the 30 cm standard deviation allowed. Therefore, the SSH and TGSL are not correlated.

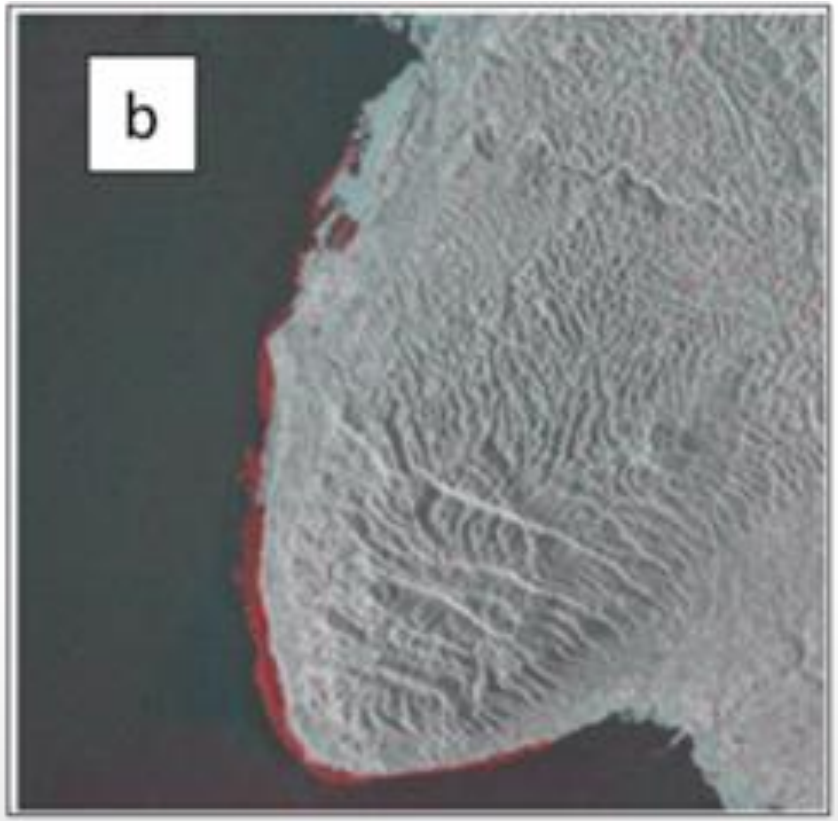
VERTICAL LAND MOTION

- The TGSL in Mambajao, Camiguin is exhibiting a downward trend at a rate of 9.4 mm/year that could mean land uplifting. This needs further investigation as it is unusual, as global SL trend is on the rise.
- In Dumaguete area the difference in average of SSH-TGSL as previously mentioned is -16.62 cm. The computed downward VLM rate is around 1.8 mm/year.
- The VLM rate computed for Tagbilaran is around 5 mm/year from 2009 to 2017. The big SSH-TGSL difference may suggest that land subsidence is occurring.

VERTICAL LAND MOTION

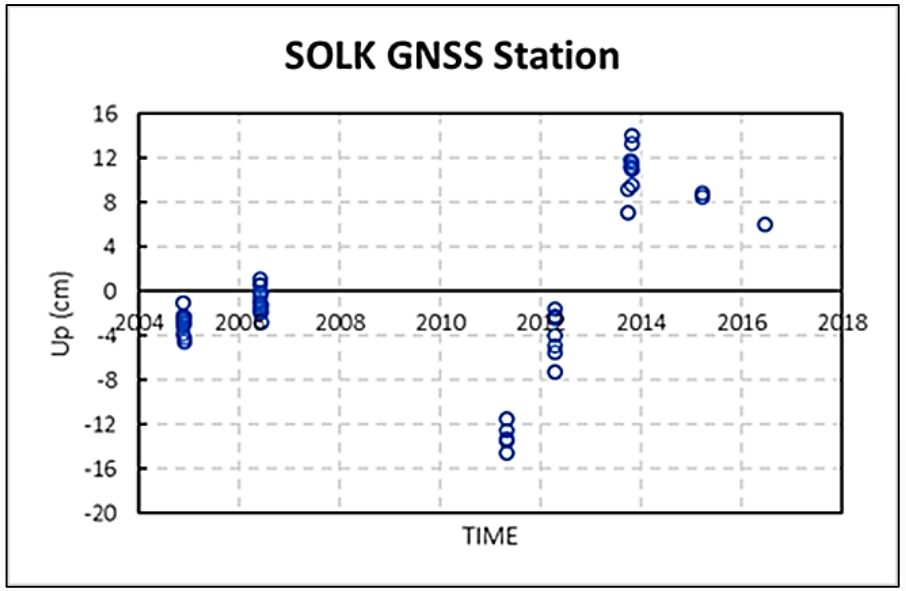


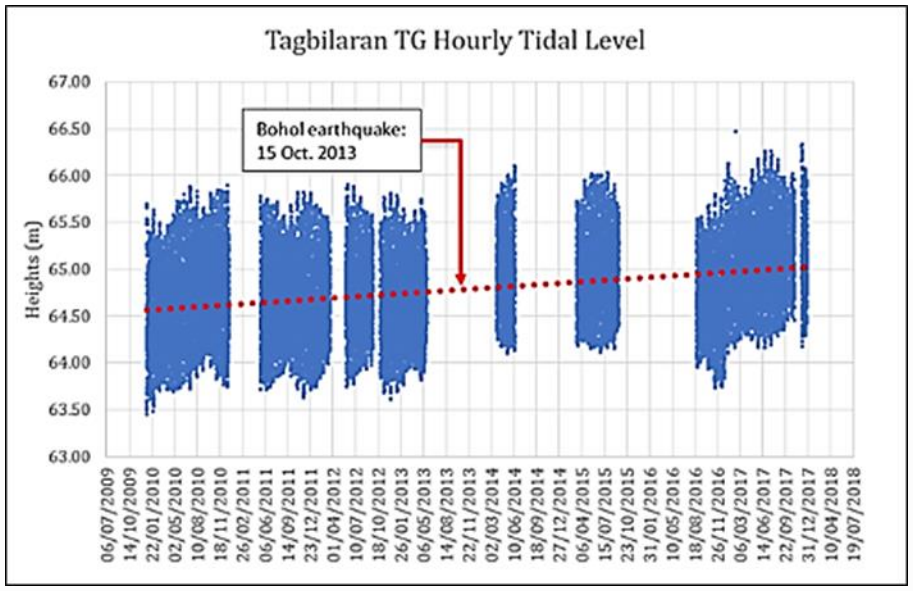
(a) Land uplift (red) and land subsidence (blue) from geodetic levelling (Flores, Madjus and Reyes, 2017)



(b) Land uplift (red) and land subsidence (cyan) from RADARSAT SAR interferometry (Kobayashi, 2014)

VERTICAL LAND MOTION





- The GNSS survey campaign conducted by PHIVOLCS showed land subsiding from 2006 to 2011
- After the October 2013 earthquake the data showed a sudden vertical increase.
- This increase was also recorded by the TG as the SL moved up after observation was resumed in early 2014.
- The GNSS measurements trend starts to go down at 27 mm/year after the October 2013 observation.
- The rate of SSH-TGSL difference after the earthquake is 17 mm/year.
- The difference between these rates is probably due to the distance between the sensors. This downtrend corresponds to an increase in the TGSL for the same period as shown in the Figure.
- Thus, the findings from GNSS survey and geodetic levelling validate also the result of this study.

CONCLUSIONS

- Based on the TG data in Mambajao, Camiguin the rate of SL decrease that could correspond to land uplift is around 9.38 mm/year. In the case of Mambajao the TG and TGBM levels should be checked as coastal altimetry and geoid differences from TGSL both showed large discrepancies.
- The Dumaguete, Negros Oriental data showed minimal difference between the average of SSH-TGSL. The rate is around 1.8 mm/year (<GMSL rate of 3.2mm/yr)
- The VLM rate computed for Tagbilaran is around 5 mm/year from 2009 to 2017. The big SSH-TGSL difference suggests that land subsidence is occurring.
- The finding in Tagbilaran is supported by the GNSS measurements from survey campaigns of PHIVOLCS, the geodetic levelling conducted by NAMRIA and the RADARSAT Interferometry by Kobayashi (2014).

ACKNOWLEDGMENT

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