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Interactive comment on "Sea level trend and variability around the Peninsular Malaysia" *by* Q. H. Luu et al.

Q. H. Luu et al.

tmslqh@nus.edu.sg

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Reviewer: Overall assessment: The research topic in this study is sea level behavior around Peninsular Malaysia on seasonal, interannual, and decadal time scales. The investigation makes use of anomalous sea level time series from tide gauges and satellite altimetry along with vertical land motion trends derived from GPS-station data. The authors relate the sea level behavior to various climate phenomena (i.e., seasonal monsoon, El Nino- Southern Oscillation, Indian Ocean Dipole) by means of a correlation analysis. For context, they compare to sea level trends in adjacent coastal regions as well as rates of global-mean sea level change. A main conclusion seems to be that accounting for vertical land motion is important in sea level studies based on tide-gauge data. I will grant that the research topic is an important one: an understanding

of regional sea level change is of interest to coastal communities; on these grounds, the paper is warranted and sufficiently motivated. However, I have very serious reservations; given the poorness of the analysis, interpretation, and communication (all detailed below), I cannot recommend publication of this paper. I submit that either a very major revision should be undertaken or this paper should be rejected.

Answer: Responses to reviewer's comments are given in details below. We address all questions raised, and have modified the manuscript accordingly. Provided the regional impact of the study, sufficient analysis completed and substantial rewriting made, we believe that the improved manuscript bear an opportunity to be fairly reevaluated.

Reviewer: Major comments: The English usage is very poor. There are confusing word choices, far too many to count, some of which can seriously impede the reader's understanding. [e.g., what is the mechanism meant by "local adjustment to the global warming" on p. 1521 l. 20? How can the (vertical component of the) wind curl, a scalar quantity, blow from the Andaman Sea toward the Malacca Strait (p. 1527 l. 7)? The suggested mechanism on p. 1528 ll. 1-2 ("a combination of signals from atmospheric teleconnection feedback and oceanic lateral fluxes") is so vague and general as to border on tautology. By "quasi-periodic annual cycle" on p. 1527 l. 3 do you mean "semiannual cycle"?] I would recommend the authors consult a native English speaker who would give a very critical and thorough assessment of the paper.

Answer: The manuscript is now intensively reviewed by external researchers in both content and language aspects. The wordings (page 1521 line 20; page 1527 line 3; page 1627 line 7; page 1528 line 1-2) pointed out by the reviewer have been carefully written up.

Reviewer: Interpretations are physically unenlightening. The paper seems to boil down to the authors saying that "the correlation is such-and-such" and "the trend is so-and-so" with not much given by way of physical elucidation. Frequently, the authors "explain" things by appealing to ENSO or IOD, attaching causal verbs, for example "ENSO determines" (p. 1520 l. 8), "ENSO affects" (p. 1520 l. 20), "IOD modulates" (p. 1520 l.21), "ENSO alters" (p. 1523 l. 14), "IOD affects" (p. 1523 l. 16), and so on. Such "explanations" are problematic, not least because, as statistical indices and not physical mechanisms, ENSO and IOD cannot determine or affect or modulate or alter anything! [Alternatively, relational verbs (e.g., correlated with, associated with, linked to, etc.) can be used instead in these cases, as is exemplified on p. 1520 l. 23.]

Answer: Wordings pinned out (page 1520, line 8; page 1520, line 20-23; page 1523, line 14-16) will be refined following the reviewer's suggestion. The physical mechanism associated with ENSO and IOD in Section 1 and Section 3.2 is explained and further elucidated in the revised version.

Reviewer: There are clear methodological mistakes. For example, it is obvious that errors have not been correctly propagated in Table 1. Namely, errors in absolute SLR rate from tide gauge look to have been computed simply by summing the error in relative SLR rate and the error in VLM rate. This is not correct. The absolute errors should be propagated by taking the square root of the sum of squared relative and VLM errors. Conclusions based on these numbers are therefore suspect.

Answer: In line with the reviewer's comment, we recomputed the combined uncertainties. Thanks to the suggestion, the calculated uncertainties are smaller now (i.e., results are better).

Reviewer: Some of the reasoning is invalid (i.e., conclusions do not follow logically from premises). In many places, two sea level trends are compared, and the authors claim that one is greater than or less than the other (see most of section 3.3). However, given the uncertainties, such claims are unwarranted and generally meaningless. As just one example (for others see elsewhere in section 3.3 or section 1), the authors quote a SLR rate in the Malacca Strait of 2.4+/-1.6 mm/yr (page 1528 line 26) and in the Singapore Strait of 3.2+/-1.2 mm/yr (page 1528 line 27); given the overlapping error bars, one cannot say (at least not with any statistical meaningfulness) that the former is

"lower than" the latter, as the authors do. [Relatedly, it is unclear what the error bounds represent or how they are computed. Are they standard errors from a least squares linear fit? Or perhaps 1.96 times the standard error (i.e., the 95% confidence interval)?]

Answer: As described in the footnote of Table 1, all uncertainties within the manuscript are calculated at the 95% confidence level. In comparing the trends, relevant sentences are rewritten more clearly, taken into account the error bound.

Reviewer: Methods and materials are not sufficiently justified or explained. What is meant by "research-quality tide gauge data" (p. 1524 l.10; cf. p. 1524 l. 18)? Do you mean Revised Local Reference (RLR)? If so, say so.

Answer: "Research quality tide gauge data" signify the data that have been passed the quality assessment, including datum evaluation, assessment of level ties to station benchmarks, comparison with nearby stations (http://uhslc.soest.hawaii.edu/thredds/uhslc_quality.html?dataset=uhslc_quality). "Revised Local Reference" term will be added.

Reviewer: Also, is the tide-gauge data corrected for isostatic response to barometric pressure (i.e., inverted barometer)?

Answer: Tide gauge data are used for analysis without applying inverted barometer correction (IBC) due to three following reasons. First, sea level anomaly (SLA) in this region (i.e., southern South China Sea) is mainly driven by changing surface wind blowing from central South China Sea and from east of Andaman Sea (Wyrtki, 1961; Tkalich et al. 2012; Tkalich et al., 2013). It is argued that once the contribution associated with anomalous wind stress is not considered as "noise" to be removed, "correction" of SLA to remove signal associated with atmospheric pressure is not justifiable due to several reasons. Firstly, both atmospheric pressure and surface wind field are two components of the atmospheric system, which is difficult to be separated independently. Secondly, in order to correct for the inverted barometer effect, one needs to extract surface pressure from available dataset or dedicated model, which are not only constrained by spatial resolution and temporal interval, but also imperfect and biased that behave differently in each region (Pascual et al., 2008). Third, we did an analysis applying the IBC for all stations, and found that its contribution to annual sea level is marginal, about 5% of the rate. Thus exclusion of IBC does not remarkably affect our main conclusion.

We will include relevant discussions in the manuscript.

Reference

Pascual, A., M. Marcos, and D. Gomis (2008), Comparing the sea level response to pressure and wind forcing of two barotropic models: Validation with tide gauge and altimetry data, J. Geophys. Res., 113, C07011, doi:10.1029/2007JC004459.

Reviewer: What AVISO product are you using? [AVISO (2013) is not a proper reference.] Are you using alongtrack data or a gridded product? What corrections are applied to the altimetry-based product? How is the altimetry data for Figure 4 chosen? Do you use all along-track data within some radius around the tide-gauge station? Or do you use the grid point nearest the tide gauge site from a gridded product?

Answer: We used Delayed-Time Sea Level Anomalies from mean "all sat merged" gridded product, which employs all missions from four satellites at a given time, and was corrected for sampling and long wavelength errors (http://www.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global/msla.html). The grid point closest to the station is used. We are adding this description in the revised manuscript along with appropriate citation.

Reviewer: Why do you use a somewhat-dated GPS VLM estimate [Simons et al. (2007)]? Much-improved GPS-based VLM estimates have become available in recent years (e.g., Santamaria-Gomez et al. 2012).

Answer: VLM estimates carried out by Santamaria-Gomez et al. (2012) were based on the ITRF2008 dataset (http://itrf.ign.fr). In this dataset, there are 19 stations to measure

land displacements in Malaysia. However, majority of computed data (17/19 stations) are unavailable; while the remaining stations (2/19, namely Bintulu and Kota Bahru) only provided 1-year long data. Using such short and spare data to extrapolate to island-wide locations would lead to unreliable VLM rates. In fact, Santamaria-Gomez et al. (2012) did not take into account GPS stations in Peninsular Malaysia due to poor quality data (Fig 1, page 7; Santamaria-Gomez et al., 2012).

Although VLM data published by Simons et al. (2007) is limited, their availability and coverage provided us a good baseline to improve the estimate for sea level rise, as there are 9 stations around the Peninsular Malaysia, each of which spans 10 years (1994-2004). To our knowledge, it is the best public VLM information in Malaysia available at this time.

Reference

Santamaria-Gomez, A., M. Gravelle, X. Collilieux, M. Guichard, B. Martin Miguez, P. Tiphaneau, G. Wöppelmann (2012): Mitigating the effects of vertical land motion in tide gauge records using a state-of-the-art GPS velocity field. Global and Planetary Change, Vol. 98-99, pp. 6-17.

Simons, W. J. F., Socquet, A., Vigny, C., Ambrosius, B. A. C., Haji Abu, S., Promthong, C., 15 Subarya, C., Sarsito, D. A., Matheussen, S., Morgan, P., and Spakman, W.: A decade of GPS in Southeast Asia: resolving Sundaland motion and boundaries, J. Geophys. Res., 112, B06420.

Reviewer: Other comments: The comparison between sea level from radar altimetry and tide gauges is too cursory and needs to be discussed more. Namely, there are clear interannual differences between the respective red and black curves in Figure 4. Why is this? Is it likely that these differences reflect errors in the altimetric retrievals close to land? Or could it be that the tide gauge data reflect highly localized small-scale processes (e.g., coastal currents, eddies, response to river runoff) that are smoothed out by the footprint of the altimeters? See, for example, Vinogradov and Ponte (2010,

2011) for discussion of some of the issues that need to be kept in mind when comparing time series from altimeters and tide gauges.

Answer: The discrepancies between interannual variability of tide gauge records versus from satellite altimetry are due to the following reasons. Firstly, spatial resolution of AVISO gridded data is 1/4 degree x 1/4 degree; while tide gauge sites are highly local, and its data are much affected by smaller-scale features (e.g., riverine discharges, coastal dynamics) as pointed out by the reviewer. In fact, oceanic characteristics (currents, eddies, wave propagation, etc.) in the Malacca Strait are not well understood. Secondly, annual mean of sea level from tide gauge is mainly deduced from hourly records; while that from satellite is derived from smoothed data having a temporal interval of 7 days. An illustration for “noisy” tide gauge data in compared with smoothed satellite data can be seen in Fig 2b (Tkalich et al., 2013). Third, there are lots of uncertainties and biases retained in the data, due to the fact that data (measured from two differences sources) are handled using different post-processing tools, models and parameterization. As a result, one should not expect the identical results in interannual variations observed from tide gauge and satellite (see, e.g., comparision of interannual variabilities between Figure 13.3c and Figure 13.3d, page 1147, IPCC, 2013). The above discussions and data limitations will be discussed in the revised version.

Reference

IPCC (2013): Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Reviewer: More references need to be given with respect to vertical land motion. To the point, it is simply false to claim that "present in situ estimate (sic) of global SLR rates mostly rely on the GIA : : : (Church and White 2006,2011)" (p. 1529 ll. 16-17).

See, for instance, Woeppelmann et al. (2007,2009) and the dozens of more recent papers that have cited these works.

References Vinogradov, S. V., and R. M. Ponte (2010), Annual cycle in coastal sea level from tide gauges and altimetry, J. Geophys. Res., 115, C04021, doi:10.1029/2009JC005767. Vinogradov, S. V., and R. M. Ponte (2011), Low-frequency variability in coastal sea level from tide gauges and altimetry, J. Geophys. Res., 116, C07006, doi:10.1029/2011JC007034. Santamaria-Gomez, A., et al. (2012), Mitigating the effects of vertical land motion in tide gauge records using a state-of-the-art GPS velocity field, Global Planet. Change, 98-99, 6-17. Wöppelman, G., et al. (2007), Geocentric sea-level trend estimates from GPS analyses at relevant tide gauges worldwide, Global Planet. Change, 57, 396-406. Wöppelmann, G., et al. (2009), Rates of sea-level change over the past century in a geocentric reference frame, Geophys. Res. Lett., 36, L12607, doi:10.1029/2009GL038720.

Answer: The mentioned paragraph (lines 16-25, page 1529) is re-written up as follow:

“At global scale, estimate of sea level rise rate using tide gauge data is mainly based on two different methods to correct for vertical displacement: GIA modelling and geodetic observation. The first approach (e.g., Church and White, 2006; 2011) discounts vertical motion using prediction from GIA models to acquire viscoelastic adjustment due to on-going rebound of ice sheets from the past. It is limited not only due to the parameterization (and hence accuracy) in each GIA model, but also due to the fact that other local sources of VLM (due to active tectonic movement, anthropogenic impact of underground water, sediment compaction), having the same magnitude in many areas, have not been taken into account in these GIA models (Santamaría-Gómez et al., 2014). The geodetic approach becomes more promising, as it measures all land displacement referred directly from GPS stations, and occasionally from DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) system or absolute gravity station (Wöppelman et al. 2007, 2009, 2014; Santamaria-Gomez et al. 2012, 2014). Considering that sea level measured from tide station is more accurate in coastal regions than the one from satellite altimetry in terms of temporal and spatial resolution, continuous observations of VLM are as important. Enhanced by the VLM, this study showed that the corrected SLR rate is about 30% higher than the relative speed measured directly at tide gauges around the Peninsular Malaysia.

However, present network of GPS stations is sparse and recent. For instance, only 10 year VLM data are available for the Malaysia region. For this reason, our study underlines the fact that more efforts should be put forward in the future to measure and analyze the VLM along with the tide gauge records, in order to get better in situ estimates of SLR phenomena. It requires not only the exertion from international bodies such as International Earth Rotation and Reference Systems Service to improve the International Terrestrial Reference Frame (ITRF, http://itrf.ensg.ign.fr) or Intergovernmental Oceanographic Commission to implement update on Global Sea-level Observing System (GLOSS), but also contribution from concerned governments to deploy and incessantly maintain instruments to well understand risks associated with sea level rise in the changing climate."

Along with papers suggested by the reviewer, the revised manuscript further discuss the VLM in following references.

Ballu, V., M.N. Bouin, P. Siméonid, W. C. Crawford, S. Calmant, J.M. Boré, T. Kanas, and B Pelletiera, Comparing the role of absolute sea-level rise and vertical tectonic motions in coastal flooding, Torres Islands (Vanuatu), P.N.A.S., 108(32), 13019–13022. Fu, L.L and B.J. Haines (2013): The challenges in long-term altimetry calibration for addressing the problem of global sea level change, Adv. Space Res., 51(8), 1284–1300. GarcÄśa-Lafuente, J., J. Del RÄśo, E. Alvarez Fanjul, D. Gomis, and J. Delgado (2004), Some aspects of the seasonal sea level variations around Spain, J. Geophys. Res., 109, C09008. Palanisamya, H., A. Cazenave, B. Meyssignac, L. Soudarin, G. Wöppelmann and M. Becker (2014): Regional sea level variability, total relative sea level rise and its impacts on islands and coastal zones of Indian Ocean over the last sixty years, Glob. Planet. Change, 116, 54–67. Santamaría-Gómez, A., Gravellem M.

and G. Wöppelmann (2014), Long-term vertical land motion from double-differenced tide gauge & satellite altimetry data, J. Geod., 88, 207–222. Yildiz, H., Andersen,O.B., Simav, M., Aktug, B. and Ozdemir, S. (2013): Estimates of vertical land motion along the southwestern coasts of Turkey from coastal altimetry and tide gauge data, Adv. Space Res., 51(8), 1572–1580. Vinogradov, S. V., and R. M. Ponte (2010), Annual cycle in coastal sea level from tide gauges and altimetry, J. Geophys. Res., 115, C04021. Woppelmann, G., Marcos, M., Santamaria-Gomez, A., B. Martín-Míguez, M.N. Bouin, and M. Gravelle (2014), Evidence for a differential sea level rise between hemispheres over the twentieth century. Geophys. Res. Lett., 41, 1639-1643.

We thank the reviewer for his detailed and useful comments which improve the manuscript.

Interactive comment on Ocean Sci. Discuss., 11, 1519, 2014.