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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.

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Reviewer: This is a short paper based on a straightforward analysis of some Malaysian MSL records downloaded from the PSMSL, climate indices obtained, regressions and correlations performed, and results presented. It is not very profound but I am sure the work has been done well technically, and the paper will do no harm in showing the value of sea level data in a national context. The main problem with the paper itself is that the English of the text is poor, even though I suspect it has been looked over already by the OSD editors. It is understandable but the frequent odd wording detracts from the pleasure of reading it. I suggest that the text is revised by someone else.

Answer: In line with the reviewer's comment, the manuscript has been revised intensively and improved in language used by appropriate experts. Below are our detailed

responses to reviewer's comments.

Reviewer: Some other comments below: 1520, line 5 - 'is assumed' → 'is shown can be assumed'?

Answer: Corrected to "is presumed".

Reviewer: 'At annual' → 'At seasonal timescale' presumably

Answer: Corrected.

Reviewer: Section 1 - this reads like a literature search. You could refer to a couple of other papers, for example Tsimplis and Woodworth (JGR, 1994) showed that the seasonal cycle is often different for countries with two coastlines such as Malaysia - India, Thailand, Korea are other examples. Also there have been several papers recently by Merrifield and colleagues which discuss the role of changing wind fields on secular sea level changes.

Answer: We have revised the manuscript and added following studies (which included of papers suggested by the reviewer) into the introduction and discussion. Pattern of seasonal cycle in various countries, role of atmospheric forcing in secular change and contribution of vertical land motion to estimated trend were reviewed.

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. Fenoglio-Marc, L., C. Braitenberg, and L. Tunini (2012): Sea level variability and trends in the Adriatic Sea in 1993–2008 from tide gauges and satellite altimetry, Phys. Chem. Earth, 40-41, 47–58. 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. GarcÄś′a-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.

Gómez-Enri, J., A. Aboitiz, B. Tejedor and P. Villares (2012) Seasonal and interannual variability in the Gulf of Cadiz: Validation of gridded altimeter products, Estuar., Coast. Shelf Sci. 96, 114-121.

Merrifield, M. A., P. R. Thompson, and M. Lander (2012), Multidecadal sea level anomalies and trends in the western tropical Pacific, Geophys. Res. Lett., 39, L13602.

Merrifield, M. A., and M. E. Maltrud (2011), Regional sea level trends due to a Pacific trade wind intensification, Geophys. Res. Lett., 38, L21605.

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.

Srinivas, K. and Dinesh Kumar, P.K. (2006): Atmospheric forcing on the seasonal variability of sea level at Cochin, southwest coast of India, Cont. Shelf Res., 26, 1113–1133.

Torres, R. R., and M. N. Tsimplis (2012), Seasonal sea level cycle in the Caribbean Sea, J. Geophys. Res., 117, C07011.

Tsimplis, M. N., and P. L. Woodworth (1994), The global distribution of the seasonal sea level cycle calculated from coastal tide gauge data, J. Geophys. Res., 99(C8), 16031–16039.

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.

Reviewer: 1525, line 1 and elsewhere - I think most sea level people now agree that

the word 'absolute' is not a good one. There is not much 'absolute' about them. What you are referring to is tide gauge data to which VLM rates from GPS have been added, so you obtain a 'geocentric' rate just like for altimetry. These yield 'ellipsoidal heights'.

Answer: In line with the reviewer's comment, the term “absolute” has been replaced by “geocentric” in the manuscript.

Reviewer: 1526, 10-16 - I don't see a consistency between these numbers and those in Table 1. I can't see where the -0.2 comes from, and the others are similar to but not the same as Table 1. Maybe some of the small differences come from using the original values versus the gap-filled ones? But that filling is a very marginal one, as Figure 4 shows.

Answer: The negative regional rate is caused by the gappy data. To derive the average rate for each region, we computed a single regional value for certain year using data from all considered stations (given with respect to the Revised Local Reference in PSMSL database). A linear trend was then extracted from these consecutive values to represent regional rate.

To understand how the gappy data could lead to a weird rate, please consider the following example. Initially, when there is no gappy data, the regionally-average sea level ($\bar{\eta}^N$) for a certain year (y) is given by the mean of individual sea level (η_i) at N considered stations by the formula

$$\bar{\eta}^N(y) := \frac{1}{N}\sum_{i=1}^{N}\eta_i(y) \tag{1}$$

The average of individual trends is basically the same with the trend derived from regionally-mean values. However, while there are gappy data (here denoted by

$\eta_{(M+1)}, \eta_{(M+2)}, ..., \eta_N$), the regionally average sea level (containing the missing) is

$$\bar{\eta}^M(y) = \frac{1}{M}\sum_{i=1}^{M}\eta_i(y) = \frac{N}{M}\left[\bar{\eta}^N(y) - \frac{1}{N}\sum_{i=M+1}^{N}\eta_i(y)\right] \quad (2)$$

The error due to the missing data ϵ is determined by

$$\epsilon(y) = \bar{\eta}^M(y) - \bar{\eta}^N(y) = \frac{1}{M}\sum_{i=M+1}^{N}\left[\bar{\eta}^N(y) - \eta_i(y)\right] \quad (3)$$

We consider the simplest case where there is only one datum (η_N) missing. The error due to this missing at the year y is

$$\epsilon(y) = \frac{1}{M}\left[\bar{\eta}^N(y) - \eta_i(y)\right] \quad (4)$$

For example, mean sea level of 6 stations in the Malacca Strait (namely, Langkawi, Pinang, Lumut, Kelang, Keling and Kakup) for the year 2010 are, respectively, 714.1, 703.5, 708.1, 705.0, 810.1 and 714.5 (in cm, with respect to PSMSL's Revised Local Reference level). Assume the data at Keling is missing, then the error is estimated as

$$\epsilon(2010) = \frac{1}{5}\left[\frac{1}{6}(714.1 + 703.5 + 708.1 + 705.0 + 810.1 + 714.5) - 810.1\right] = -16.8 \quad (5)$$

Take into account the interannual variability of each station of the order $\pm$5 cm, such large error (-16.8 cm) certainly significantly modifies the regression rate, particularly while missing data are at both ends of regression segment.

The above example illustrates how the gappy data may attribute to wrong estimate of trend slope. As the gaps present at records of most tide stations in Malacca Strait, the

computed rate can be negative as mentioned in the manuscript. In case we directly derive the regionally-average rate from the mean of individual rates, the missing data problem is not resolved. Therefore, gap-filling technique is required. In fact, in the revised manuscript, we have used a method suggested by another reviewer to fill the gap, which gave better estimates over the ones in the first version.

Reviewer: There is a problem with all the rates quoted in this paper though, in that they come from very short records. Also they have a lot of interannual signals, discussed elsewhere in the paper, which implies serial correlation of the annual means. So, have the standard errors on the rates been calculated by ordinary least-squares, and if so how much do you think the errors may have been underestimated?

Answer: Indeed, the longer the records, the better, but unfortunately longer data are not available for the region. The standard errors have been calculated using least-square regression analysis. Besides, the calculated rate is based on the assumption that there is no noise in the measurement, which leads to the underestimation of trend coefficient. In the absence of noise levels, this problem is ignored.

Reviewer: Line 22 - by all means refer to fig. 3c in the text, but also then you should refer to 3a and b.

Answer: Section 3.1 (Interannual sea level variability) has 3 paragraphs, each of them describes variability in different regions. The first paragraph deals with the pattern in the eastern coast of Peninsular Malaysia, which is demonstrated in Fig. 3c. That is why only Fig. 3c (Monthly climatology of SLA in the eastern Malaysia Peninsular) is mentioned in Line 22. Contents associated with Fig. 3a and 3b are described in the two remaining paragraphs.

Reviewer: The correlations with ENSO and IOD are interesting. But a sentence on how they are themselves correlated would be useful, and also the fact that there have been only two major IOD events I think in recent years.

Answer: The correlations among sea level at all stations are very high within each side of the Peninsular Malaysia, in the range of 0.89-0.98; while their consecutive stations exhibit stronger relationship, in between 0.93-0.98 (as shown in Table R1 below). This discussion was added into the revised manuscript.

Reviewer: p1529, 17 - this isn't true. By 'on the GIA' you mean 'on the use of GIA models' but (a) such models are not perfect even in formerly-glaciated areas (what you mean by 'polar areas'), (b) you could argue the models are more consistent in the far field in fact, such as Malaysia, and (c) the real issue is that there are always many geological processes operating at any one location. You could perhaps refer to several papers by Guy Woppelmann.

Last sentence of section 3 - this is an important recommendation, to have more GPS at tide gauges. What are you going to do about it? Who is the recommendation aimed at? A Malaysian ministry or academics or the international community? You could for example refer to the latest GLOSS Implementation Plan available from the PSMSL web site which emphasies why such GPS measurements are needed.

Answer: In line with the comment, last paragraph in page 1529 is rewritten 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

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."

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Woodworth, P.L. (2006): Some important issues to do with long-term sea level change, Phil. Trans. R. Soc. A, 364, 787–803.

Wöppelmann, G., C. Letetrel, A. Santamaria, M.-N. Bouin, X. Collilieux, Z. Altamimi, S.

D. P. Williams, and B. Martin Miguez (2009), Rates of sea-level change over the past century in a geocentric reference frame, Geophys. Res. Lett., 36, L12607.

Reviewer: 1535 - I don't like the SLR acronym which can mean 'sea level rise' or 'satellite laser ranging' and anyway what you mean is 'change' and not 'rise' as a positive change is not a given always.

Answer: The acronym SLR is no longer used in the manuscript.

Reviewer: Also, how did you average the individual rates into regional average ones?

Answer: We computed a mean sea level (with respect to Revised Local Reference) from all stations within considered region for each year. A linear trend was then extracted from time-series of these mean sea levels using the regression analysis. Note that the gappy data are filled. As the spatial distribution of these stations are reasonably equitable along each coast (Fig 6), the averaged rate may be representative for each region.

Reviewer: Figure 4 - I think the caption should explain, in brief, how you pinned the red lines to the black ones - same means over some common period? Also make clear to the reader that the black ones are relative sea level and the red are geocentric - this can be either in the text or caption.

Answer: The caption in Fig. 4 is revised as "Annual sea level at tidal gauges around the Peninsular Malaysian: (a) Malacca Strait, (b) eastern Peninsular Malaysia. Filled circles show relative data from PSMSL; while open circles indicate restored missing data. Red lines represent annual geocentric satellite altimetry data, which were adjusted to the mean level of tide gauge data for period 1993-2011".

Reviewer: Figure 5b is missing?

Answer: Fig. 5b is originally submitted with the manuscript (but is missing in the publication due to unknown reason). We will check it with the OS technical team.

Reviewer: Figure 6 - say clearly in the caption that the yellow band in (a) is magnified in (b), although obvious to you. And that distance is measured clockwise along the coast somehow.

Answer: The caption in Fig. 6 is corrected as "Correlations of interannual sea level with MEI (blue lines) and DMI (red lines) at tide gauges (a) along the Peninsular Malaysia, and (b) in the Singapore Strait (magnified from the yellow shade in Fig. 6a). The correlation coefficients are computed using de-trended annual sea level from PSMSL (before reconstruction). The green band shows the transitional region where spatial gradient of correlation associated with DMI is the highest. Distance is measured counterclockwise along the coast."

Reviewer: In conclusion, I would be happy to see the paper progress from OSD to OS as long as the points above can be attended to and if the text can be cleaned up.

Answer: Authors would like to thank the reviewer for his/her constructive comments and suggestions that improve the manuscript significantly.

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

Stations	Langkawi	Pinang	Lumut	Kelang	Keling	Kakup	Sultan Sho	Raffles Lig	Tanjong P	Sembawa	Johor	Sedili	Tioman	Gelang	Cendering	Geting
Langkawi	1.00	0.97	0.98	0.96	0.98	0.89	0.92	0.90	0.67	0.74	0.70	0.74	0.74	0.81	0.75	0.61
Pinang		1.00	0.97	0.95	0.98	0.95	0.93	0.94	0.72	0.76	0.76	0.80	0.81	0.86	0.79	0.67
Lumut			1.00	0.95	0.98	0.93	0.81	0.88	0.69	0.64	0.78	0.80	0.77	0.78	0.74	0.72
Kelang				1.00	0.96	0.90	0.80	0.81	0.67	0.56	0.63	0.70	0.73	0.74	0.75	0.59
Keling					1.00	0.97	0.86	0.90	0.72	0.73	0.79	0.83	0.82	0.82	0.76	0.71
Kakup						1.00	0.94	0.95	0.76	0.83	0.88	0.87	0.89	0.92	0.87	0.77
Sultan Shoal							1.00	0.94	0.81	0.74	0.87	0.87	0.90	0.89	0.87	0.75
Raffles Lighthouse								1.00	0.85	0.83	0.92	0.90	0.91	0.94	0.91	0.79
Tanjong Pagar									1.00	0.88	0.82	0.83	0.90	0.88	0.88	0.71
Sembawang										1.00	0.80	0.86	0.84	0.81	0.80	0.68
Johor											1.00	0.97	0.96	0.98	0.97	0.90
Sedili												1.00	0.95	0.96	0.96	0.92
Tioman													1.00	0.98	0.97	0.89
Gelang														1.00	0.98	0.94
Cendering															1.00	0.93
Geting																1.00

Fig. 1. Correlation coefficients between sea levels at stations around the Peninsular Malaysia for the period 1984-2011.

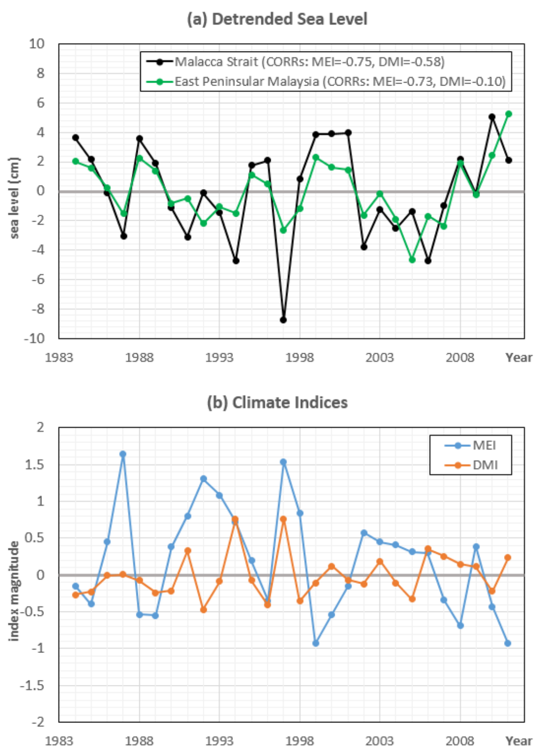

Fig. 2. (a) Detrended annual sea levels around the Peninsular Malaysia; and (b) annual MEI and DMI indices.