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Ocean Science Discussions

Interactive comment on "Technical Note: Mean sea level variation in the Singapore Strait from long-term tide data" *by* P. Tkalich et al.

P. Tkalich et al.

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Response to Reviewer #1

Firstly, we would like to thank the reviewer for his/her careful review and the critical comments. We know that these comments have helped us to improve the manuscript to a large extent. We have toned down and thoroughly revised the manuscript to meet the journal standard as described below.

Reviewer #1's comment:

The present paper analyses the mean sea level variations in the Singapore Strait (SS) on seasonal to interannual time scales over the period 1994-2007 with tide gauge data. Although the authors claim they are also using wind data from the NCEP reanalysis and

sea level data from the Topex/Poseidon Altimeter, we could not find any use of these datasets throughout the paper. To estimate the SS mean sea level, the authors use a single tide gauge record: the record of the Tanjong Pagar (TP) station. They mention 3 other tide gauge records in the "data and methodology" section but these records are not used to estimate the SS mean sea level. The 3 extra records are compared to the TP record over the year 1998 to check if the TP record is contaminated by vertical movements.

Answer:

The reviewer's commented on the satellite and wind data. In present study, we used the merged global dataset of the 1/3ox1/3o-gridded daily Delay Time products of AVISO (http://www.aviso.oceanobs.com/en/data.html) at the closest grid point to Tanjong Pagar tide gauge in order to verify our analysis. Since the NCEP wind is not implicitly used in this paper, as pointed out by the reviewer, relevant texts in the Data and Methodology section were removed. Moreover, Table 1 in which we have given the details of these datasets was deleted in the revised version. Figure 1a is cleaned, excluding wind and irrelevant labels. In addition, instead of using 1-year data to validate analysis of Tanjong Pagar, long-term datasets of Raffles Lighthouse, Sultan Shoal and Sembawang stations were also included in the analysis of sea level rises/falls as given below.

Reviewer #1's comment:

This paper is dealing with an important issue: the estimation of the sea level variations in the Singapore Strait and more generally in the Indonesian region that links the tropical Pacific Ocean to the tropical Indian Ocean. The topography and bathymetry of this region are complicated and make it difficult to estimate the local mean sea level with in-situ or remote sensing techniques. But this is an important task to do because it provides some information on the ocean dynamics in this region and on the exchanges between the Indian and the Pacific Oceans. For this reason the present article is addressing an interesting problem which is also original because very few studies have

analysed the sea level variations (at least at interannual time scales) in the Singapore Strait before. Unfortunately, the estimation of the SS mean sea level provided here presents two major flaws that make the conclusions of the study questionable and unreliable.

The first major flaw is that the authors used only one tide gauge record (the Tanjong Pagar tide gauge) to estimate the SS mean sea level between 1984 and 2007 while there are many other sources of sea level data in the SS during this period. We have found in the PSMSL, 6 tide gauge stations located in the SS. Some of them, like the "Raffles Light House" or the "Sultan Shoal" have records that cover the whole period 1984-2007 and could help to compute a more consistent SS mean sea level or to validate the TP record. Others like the "West coast" record and the "Jurong" record cover several years among the 1984-2007 period and provide also interesting information to validate the other records or to test the estimation of the SS mean sea level estimation. Some altimetry data is also available in the SS strait: 2 tracks of Envisat and 2 tracks of the series Topex Jason1/2 (track no77 and 242 for Jason 2 for example) are crossing the SS and provide validated sea level data in the SS. All this additional SS strait sea level data should help to construct and validate a reliable SS mean sea level. Instead, the use of a single tide gauge record to estimate the SS mean sea level (like in the present study) casts doubts on the estimation: what if the record is contaminated by shifts due to seismicity or instrumental changes? What about the motion of the ground on which the TP tide gauge is fixed? How can we be sure that the TP record is not representing some local and coastal phenomena that are not representative of the SS mean sea level variations (like wind-forced coastal trapped waves, local flooding events...). The only way to overcome this problem is to compare the TP record to other sources of sea level data over the whole period 1984-2007. This is done in the article only over the year 1998 which is definitely not sufficient. Much more should be done here (at least a comparison at seasonal to interannual time scales over the whole period 1984-2007 with the "Raffle light house" record and the "Sultan Shoal" record which cover the whole period).

Answer:

The authors would like to thank the reviewer for his/her appreciation of our paper. Matters associated with two major problems addressed by the reviewer have been appropriately resolved in the revised manuscript as described below.

The first issue is the employment of a single dataset at Tanjong Pagar tide station to represent sea level rise in the Singapore Strait without eliminating possible vertical shifts due to natural or artificial impacts, or contributions of local physical phenomena as mentioned by the reviewer. In line with his/her comment, monthly and annual mean sea level datasets at Raffles Lighthouse for the period of 1975–2011, Sultan Shoal and Sembawang for the periods of 1972–2011 are used in the manuscript. The locations of these 4 tide gauge stations are updated in Fig. 1b. In addition, the satellite data from AVISO (as described in the answer above) have also been used to validate the sea level anomaly as shown in the revised Fig. 2.

In a more detail, from all above stations, we found that at annual scale, sea level anomalies in the SS are quasi-periodic in order of $\pm$15 cm, highest during northeast monsoon and lowest during southwest monsoon. At these four stations, regional sea level falls are associated with El Niño events, while rises are associated with La Niña episodes, both variations are in the range of $\pm$9 cm. At the decadal scale, the sea level accelerates since 1993. Moreover, during observation period since 70s, sea levels at those four stations have been rising in SS at a linear trend of 1.6–3.0 mm/year, which are comparable to the global sea level rise (see manuscript for details). To sum up, datasets from these supplemented tide gauge stations provide significant enhancement, and help consolidating our conclusion.

Reviewer #1's comment:

The second major flaw of this paper is the treatment of the TP record for gaps and any type of contamination. The method used to fill in the gaps of the TP record is not clear: how do the authors expect to reconstruct the TP record at interannual time scales with

a method based on tidal harmonics? The method used to correct the TP record for vertical movements is incomplete. The comparison of different tide gauge records over a given year can show the presence of any outlier or contamination from seismicity in this year but what about the other years? Moreover this method based on a comparison over a single year does not allow for the detection of any slow subsidence of the tide gauge station due to natural effects (tectonics or sediment compaction for example) or anthropogenic activity (fluid pumping for example). Consequently the TP record, as it is computed here, could hold signal coming from many sources other than the sea level variations (ground motion signal related to local subsidence for example). It makes all the conclusions unwarranted. A good amount of work is needed here to improve and consolidate the treatment of the tide gauge record.

Answer:

The second problem is associated with analysis of tide gauge data, in particular technique helps filling the gaps and resolving subsidence. In this revision, harmonic constants are no longer used to reconstruct the sea level. Mean sea level was calculated as the average of sea level anomalies available within a certain (monthly, annual) period. In case the gaps with discontinuities longer than a portion, says 1/5, over a considered period (e.g., monthly, annually), these data are not taken into account. For example, the data in 1995 with several discrete gaps are not used in our calculation of mean sea level. Although our treatment is different from what might have been used in PSMSL dataset or others that may leads to losing of certain unknown information, our well consistence with what achieved in PSMSL (Fig. 2d) as well as satellite data (Fig. 2b-c) allow to moving forward with the analysis. Of course, it is difficult with present dataset to separate the sea level subsidence of single tide gauge resulting from natural effects and anthropogenic activity as thoroughly indicated by the reviewers. That is why 4 tide gauge datasets have been used simultaneously as recommended by the reviewer. The consistent rising tendency from 4 tide gauge data and the similarity with global and regional (SCS) trend (as given in the above answer) give a reason-

able standpoint for discussion. In preparing the revision, we have toned writing down, carefully improved the corresponding paragraph. We also removed the old Fig. 2 and redundant texts in the revised manuscript.

Reviewer #1's comment:

Although the subject addressed by this paper is interesting, the 2 major flaws found in the method developed by the authors make me think that the conclusions of this study are not reliable and cannot be published in this form. I think that a pretty big amount of work is still needed to improve and consolidate the method developed by the authors (in particular in terms of comparison with other sea level data and improvement of the treatment of the tide gauge time series). For this reason I would recommend to reject the paper. Nevertheless I think that this work is interesting and is a good start. I encourage the authors to improve their method and to resubmit when it will be mature.

Answer:

Several works have been done with the revised manuscript. As answered above, we reasonably fulfill the analysis of mean sea level by adding data from 3 more tide gauges instead of a single station and compared it with observations as recommended by the reviewer. It provides a consolidation to our conclusion (as mentioned in the answer above and can be seen in the manuscript). For the second issue, the construction of data from tidal harmonic constants is no longer used. In fact, discrete data are not taken into account. The discontinuous gaps of data are relatively short with respect to the whole period (e.g. at Tanjong Pagar, less than 1 year-data are missing for the period of 28.2 years), thus, do not noticeably alter the mean sea level trend and misinterpret their beneath behaviour (Fig. 2d). From above, we can say it is an intensive revision of majority of sections (Data and Methodology, Results and Discussion, Conclusions and Abstract), as well as all including new figures and improving the earlier figures. This effort is done to make sure that two main problems addressed in the reviewer's comment are carefully resolved. We believe that this revised form merits

reconsideration.

Reviewer #1's comment:

Hereafter I have gathered the detailed comments on the paper. Before getting into these details, I would like to draw the authors' attention to the references. A paper submitted to high standards journals such as Ocean Science should not present such an incomplete reference section. Many references cited in the text are lacking in the reference section (Michael and Andrew 2008, Pavel et al. 2011, Pavel et al. 2012 ...) This is not acceptable.

Answer:

These missing references are corrected in the revised version. The reminder is also achieved for other parts in the revision. We expect no more such bugs available in the revision.

Reviewer #1's comment:

Note that the lines and the pages indicated below refer to the friendly printed version of the article -page 2256 line 22: the assertion that "1.6 mm/yr" over the period 1984-2007 matches the global sea level should be referenced. Moreover I do not agree with this assertion and I would be interested in reading a reference that gives such a value for the period 1984-2007. If we compute the global mean sea level trend over 1984-2007 from the Church et al. 2006, 2011 data for example, we find 2.2mm/yr which is significantly higher than 1.6 mm/yr.

Answer:

Singapore Strait (SS) is situated in the middle of Sunda Shelf, encompassed by South China Sea and Malacca Strait (Fig. 1a). The SS is connected through SCS to the Pacific Ocean on the east, and to the Indian Ocean via the Malacca Strait on the west. In a complicated region like SS, sea level is governed by various scale phenomena, from global to local (global sea level rise, ENSO, monsoon) as described in the Introduction

section. Thus, the difference of mean sea level with respect to the global is understandable. However, we have tone our assertion down as written in the manuscript. In detail, we give a range of trend estimation from these four stations instead of single value. Here, the paper has been revised to include the latest data of Church and White (2011) showing global sea level rise 1.5 mm/year for the period 1884-2009, 2.0 mm/year for 1975-2009, 2.4 mm/year for 1984-2009, and 2.8 mm/year for 1993-2009. During the same periods sea level in SS has been rising at rates 1.0–1.4 mm/year, 1.8–2.3 mm/year and 1.1–4.9 mm/year, respectively.

Reviewer #1's comment:

-page 2256 line 25: Sea level variations are also caused by changes in the temperature of the ocean under-surface and deep layers.

Answer:

This point is updated in the Introduction section.

Reviewer #1's comment:

-page 2257 line 1: which several studies? References are lacking here

Answer:

"Several studies" include works of Le et al. (2002), Rong et al. (2007) which are now updated.

Reviewer #1's comment:

-page 2257 line 8: the reference Michael and Andrew 2008 does not appear in the reference section

Answer:

This citation is corrected to Tsimplis and Shaw (2008) which is available in the bibliography.

Reviewer #1's comment:

-page 2257 line 21: there are much more recent studies that estimate long term sea level trends: Church et al. 2011, Ray and Douglas 2011, Hamlington et al. 2011, Meyssignac et al. 2012...

Answer:

These works have been added in the Introduction section.

Reviewer #1's comment:

-page 2257 line 28-29: I do not agree at all with this assertion. Chambers et al 2002 and Church et al. 2004, 2006 never claim that there are some links between the large inter-annual variability in the Tropical Pacific and Indian Ocean region and the rising trend of the global mean sea level. Chambers et al. 2002 does not even compute the trend of the global mean sea level in his study. This sentence should be clarified or removed.

Answer:

This sentence is removed following the reviewer's suggestion.

Reviewer #1's comment:

-page 2258 line 1: the reference Pavel et al. 2011 does not appear in the reference section. I could not find it on ISI web of science either. It is regrettable because this study is supposed to be the ground basis for the present article.

Answer:

This citation is corrected to Tkalich et al. (2012) which has been published as Tkalich, P., P. Vethamony, M. T. Babu , and Malanotte-Rizzoli, P.: Storm surges in the Singapore Strait due to winds in the South China Sea, Nat. Hazards, doi:10.1007/s11069-012-0211-8, 2012.

Reviewer #1's comment:

-page 2258 line 26: a reference is lacking here

Answer:

Citations including Fang et al. (1999) and Ko et al. (2008) have been referred to.

Reviewer #1's comment:

-page 2259 line 2: the authors indicate that there is 8 tide gauge stations in the SS but then they use only a single one to compute the SS mean sea level. Why? At least the records should be cross-checked on the longest period possible to find any outliers, shifts or contamination in the data and to estimate the shared variability.

Answer:

This question is relevant to what has been answered above with simultaneous use of four tide gauge data.

Reviewer #1's comment:

-page 2259 line 5-7: Why does the TP record provided here ends in 2007? On the PSMSL website the TP record goes until 2011 and presents an interesting interannual variability between 2007 and 2011. The authors should justify why they use a short record which ends in 2007.

Answer:

In line with the reviewer's comment, we extended the estimation of mean sea level at the Tanjong Pagar tide gauge station to its longest available period of 1984–March 2012 by using raw hourly data from University of Hawaii Sea Level Center and Maritime and Port Authority of Singapore, instead of the periods provided by PSMSL (1989–2011) as well as previously used in the submitted manuscript (i.e., 1984–2007). Please note that the data before 1984 is only available in chart. The additional 4.2-year data

alter the gained tendency, and contributed to better estimation of long-term trend along with data from 3 supplemented stations as shown in the revised version.

Reviewer #1's comment:

-page 2259 line 7: the authors say they fill in the gaps of the TP record using tidal harmonics. Looking at the TP record on the PSMSL website it appears that in 1995 some data are lacking for at least 6 month. How do the authors expect to reconstruct the sea level signal at seasonal to interannual timescales with tidal harmonics? They should clarify their method and explain it in details because it seems a priori impossible. I recommend as well that the authors show a plot with the raw data (monthly time series for example) to enable the reader to make his own opinion on the gaps and the variability contained in the raw record.

Answer:

Again this is a relevant comment which has been mainly answered above. It is noted again that the missing data is no longer reconstructed. We skipped the period containing long gaps in the revised analysis. However, the obtained results agree well with the observation and other analysis. Detailed validation of sea level with altimeter data and comparison of its mean with PSMSL data are shown in Fig. 2.

Reviewer #1's comment:

-page 2259 line 10: Why introducing the NCEP data and the Topex data since it is not used in this study? Additionally, when introducing datasets, the sources should be mentioned: which NCEP reanalysis do you want to use? Where does the Topex data come from, AVISO?

Answer:

This is a relevant comment which has been explained earlier. Here, no NCEP wind data are directly used in this revision. The altimeter data are obtained from AVISO.

Reviewer #1's comment:

-page 2259 line 12: Why performing a harmonic analysis? Table 2 is never commented in the text or compared to other results. It does not lead to any conclusion.

Answer:

In line with the reviewer's comment, this table is removed from our paper.

Reviewer #1's comment:

-page2259 line 14: the tide gauge data could be contaminated by vertical movements which come from other sources than the one mentioned here: seismicity, tectonics, instrumental changes (the TP tide gauge has been changed in 1997), ground water pumping, sediment compaction etc...

Answer:

This is a relevant comment. We understand the reviewer's suggestion in considering contaminant to vertical movements while using single tide gauge data for short period. That is why four more stations instead of only one Tanjong Pagar, and longer periods upto 40 years are used. This point has been highlighted above.

Reviewer #1's comment:

-page 2259 line 20: the fact that there is no abnormal value in the 4 tide gauge record during the year 1998 does not mean that it could be the case for the other years. The comparison should be done for the whole period. Moreover this comparison technique only allows for the detection of shifts in the records. It cannot detect spurious trends that come from ground subsidence for example. This point should be investigated.

Answer:

This paper is no longer use of such 1-year comparison technique.

Reviewer #1's comment:

-page 2259 line 24: the reference Pavel et al. 2011 does not appear in the reference section

Answer:

The citation is corrected to Tkalich et al. (2012).

Reviewer #1's comment:

-page 2260 line1-7: I understand that the wind dataset has been used in the previous study (Pavel et al. 2011). But what has been done here with this dataset?

Answer:

This is a relevant comment. The wind dataset is no longer used in the manuscript. Thus, its corresponding context is removed or modified in the updated manuscript, including (but not limited to) Fig.1a, Table 1 as well as associated paragraphs describing in the sections (Introduction, Data and Methodology).

Reviewer #1's comment:

-page 2260 line 15: the reference Pavel et al. 2012 does not appear in the reference section

Answer:

The citation is corrected to Tkalich et al. (2012).

Reviewer #1's comment:

-page 2260 line 24: what do you mean with "oceanic features". Please describe and justify

Answer:

This text is redundant and has been removed.

Reviewer #1's comment:

-page 2261 line 1: I understand that Figure 3 is based on the TP record only. Some work is needed to justify that TP gives a reliable estimate of the SS mean sea level (see the beginning of this review)

Answer:

This is a relevant comment. Not only analysis of Tanjong Pagar tide gauge data verified with satellite observation and PSMSL database, but also three more datasets are used simultaneously in the new version.

Reviewer #1's comment:

-page 2261 line 11: to justify the impact of El Niño, you could compare the TP record with a Niño index

Answer:

This paper incorporates the Multivariate ENSO Index (MEI, http://www.esrl.noaa.gov/psd/enso/mei/) to justify the impact of El Niño. MEI consists of six main variables (sea-level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky) which have been observed over the tropical Pacific for many years (Wolter and Timlin, 1993, 1998). Large positive value of MEI implies the El Niño tendency, while negative one indicates the La Niña episode. Analysis is showed in Fig 4 and sub-sections 4.2, 4.3.

Reviewer #1's comment:

-page 2261 line 17-18: this sentence is inconsistent

Answer:

It is redundant and has been removed.

Reviewer #1's comment:

-page 2261 line 21: You should justify with a computation or a reference that the 1.6 mm/yr matches with the global sea level rise. I do not agree with this assertion. If you compute the global sea level rise over 1984-2007 with Church et al.2006, 2011 data (available on the web) you will find 2.2 mm/yr which is significantly higher than 1.6 mm/yr.

Answer:

This is a relevant comment and explained elsewhere in this response.

Reviewer #1's comment:

-page 2262 line1-3: I do not understand this sentence

Answer:

We mean that the Singapore Strait is connected through SCS to the Pacific Ocean on the east, and to the Indian Ocean via the Malacca Strait on the west. As a result, sea level rise in the Singapore Strait is influenced by nearby connected regions, including those from global sea level rise, El Nino events and regional monsoon. Anyway, this sentence is rewritten as in the Introduction section.

Reviewer #1's comment:

-page 2262 line 26: the use of a single tide gauge record does not allow to estimate the time-evolution of the MSL variability of the SS. You should use more data to compute your estimation or validate it.

Answer:

This is a relevant comment and indicated earlier.

As described above, we have revised the manuscript following the reviewer's comments. We appreciate the reviewer's valuable suggestions for revision of this manuscript, which is added in Acknowledgement in the revised paper.

Interactive comment on Ocean Sci. Discuss., 9, 2255, 2012.

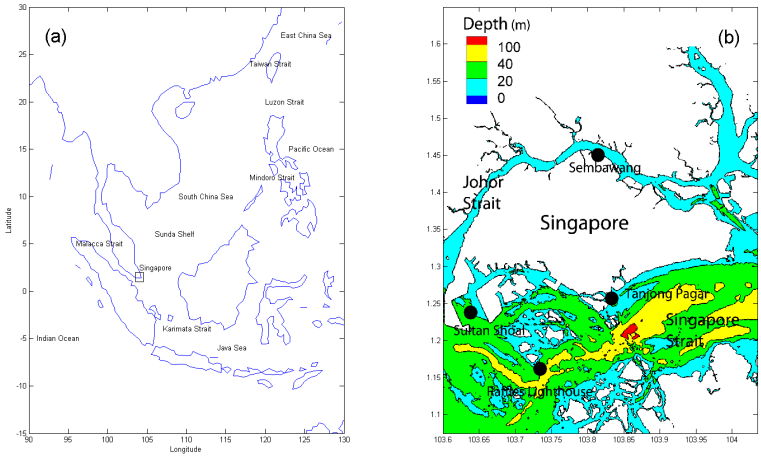

Fig. 1. (a) Study area. (b) The Singapore Strait and its vicinity.

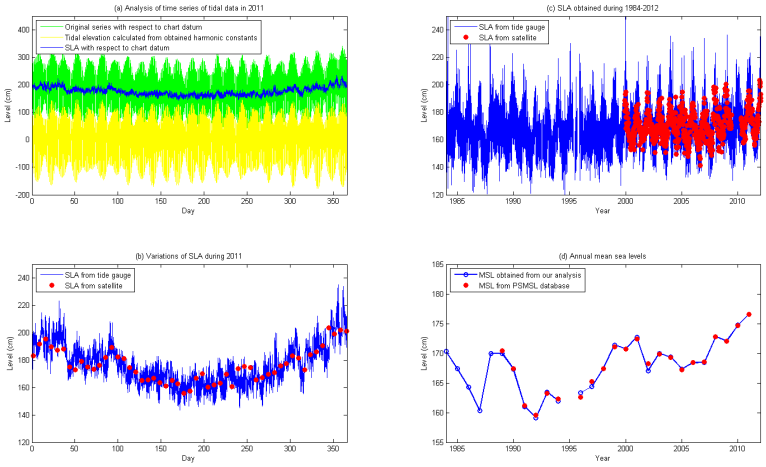

Fig. 2. (a) Typical one year analysis. Comparison of SLA from gauge (blue) and AVISO (red) during (b) one year and (c) 1984–2012. (d) Annual MSL (blue lines) in accordance with PSMSL (red symbols).

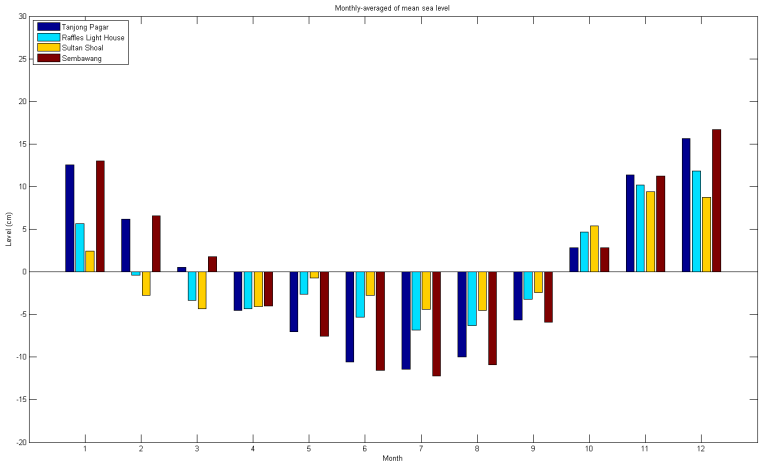

Fig. 3. Monsoonal and seasonal influence on sea level variations (monthly sea level).

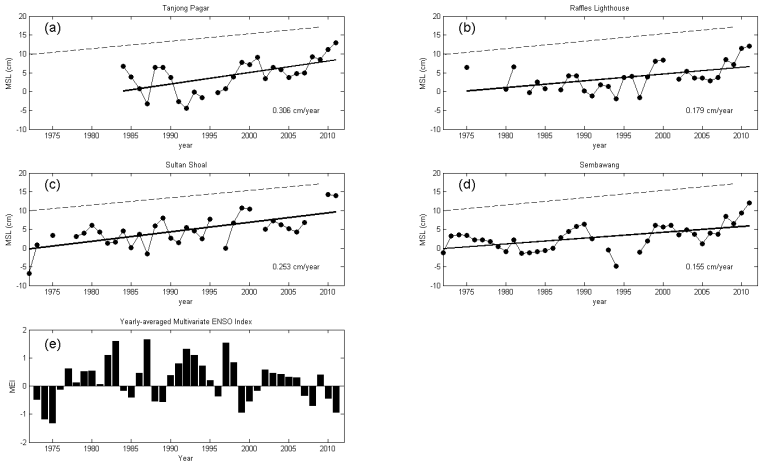

Fig. 4. Trends of annual MSL at (a) TP, (b) RL, (c) SH and (d) SE, in correspondence with (e) ENSO index. Thick lines represent tendency from local MSL; dash lines indicate global trend during 1972–2009.