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# Can CGCMs under CMIP5/6 simulate present-day sea level rise in western Maritime Continent?

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**Abstract**. Trends of present-day sea level anomaly (SLA) in western Maritime Continent based on the combination of global thermal expansion and ocean dynamics (steric/dynamic), simulated by Coupled Global Climate Models (CGCMs) under the Climate Model Intercomparison Project phase-5 and 6 (CMIP5/6), are evaluated by using satellite observation. Trends of SLA based on the steric/dynamic component of sea level underestimate the one observed by the satellite for the interior seas of western Maritime Continent. However, satellite observation is also known to overestimate the rate of sea level rise in this shallow basin. Thus, the actual trends of SLA in this area could be approximated based on its steric/dynamic component simulated by CGCMs such as ACCESS1-0 and MIROC-ESM.

## 1. Introduction

The rate of global sea level rise has reached ~3.6 mm/year from 2006-2015 [10]. This rate has been projected to accelerate towards the end of 21st century [19]. The projected sea level has been considered to significantly inundate low-lying areas such as coastal and small islands, and also worsen the impact of several types of natural hazard (e.g., extreme rainfalls, etc.) [17]. For example, towards the end of 21st century, the rate of the projected sea level rise in Singapore Strait (SS) will reached ~7.5 mm/year under the RCP8.5 scenario [4]. This type of scenario has been predicted to increase the frequency of flooding in ~30% of Singapore's land area [20]. Thus, its surrounding regions, known as western Maritime Continent (WMC), are likely suffered similar impact of sea level rise which will lead to socio-economical loss especially in highly vulnerable settlements.

Future sea level in SS is projected by multi-model ensemble for the steric/dynamic components, under various future climate scenarios standardized by the Climate Model Intercomparison Project Phase-5 (CMIP5), combined with the other components of sea level that contribute to the addition of ocean mass (e.g., glaciers, land water, etc.) [4]. Steric/dynamic components dominate the projection of future sea level in SS, as well as globally. Furthermore, the rate of sea level rise based on the steric/dynamic components at the beginning of the future projection was closer to the rate estimated from tide gauges dataset (~3.8 ± 1.3 mm/year) as compared with the other components [4, 21].

Similarity on the rate of sea level rise between data from tide gauges and the simulated steric/dynamic components of sea level indicates a possible reduction in the degree of freedom to describe the long-term sea level in SS and perhaps also in its surrounding area. Such possibility renders the importance to verify the trend of present-day sea level between observational data and the simulated steric/dynamic components of sea level for a larger oceanic settings which is the WMC (Fig. 1). Eventually, as previously mentioned, a similarity between the two datasets in any given location would simplify the effort to estimate its sea level especially in the near future.

Observation of sea level for a large area, such as WMC, can be obtained from satellite altimeter dataset provided by the Copernicus Marine Environment Monitoring System (CMEMS) which started at January 1993 [1] (Fig. 1). This dataset is comparable with CGCMs simulations output under present-day (historical) climate scenario since their time period is overlapped. This satellite dataset, the sea level output from CGCMs, and the methods are detailed in the next section. The third section described the trend of present-day sea level from observation and simulations in WMC and the two focused areas, which are SS and Jakarta Coastal Sea (JCS). Then, we conclude our study in the last section.

## 2. Data and Methods

In this study, we used monthly sea level anomaly (SLA) of the CMEMS satellite altimeter data (0.25° of spatial resolution) which is obtained from data.marine.copernicus.eu (doi.org/10.48670/moi-00148) (Fig. 1). Besides the Copernicus altimeter missions, this dataset is also generated based on Jason-1 to 3 missions which are shown to be well-correlated with data from tide gauges in the region [5]. SLA from this CMEMS dataset is defined as the deviation of sea surface height from its annual mean at 1993-2012. Nurmaulia et al., (2010) showed that the trend of SLA from the older package of CMEMS dataset is well-verified for deep-sea area such as western coast of Sumatra for the period of 1993-2003. But it overestimated the trend of SLA in the shallow-coastal area such as northern coast of Jakarta. This overestimation could also be suffered by some other regions in the interior seas of WMC (e.g., Singapore Strait). Thus, biases suffered by the CMEMS satellite altimeter data for a specific area are also considered in our study.

Verification of the CGCMs simulations for the steric/dynamic components of sea level is based on two physical parameters namely the global thermosteric (steric) and ocean dynamics. In CMIP5/6 database, these parameters are technically labeled as zostoga and zos. Global thermosteric (zostoga) is the change of ocean density in global scale as a respond to the change of global temperature [9]. While ocean dynamics (zos) refer to the variability of the sea surface height above geoid in every location due to smaller scale oceanic processes such as upwelling, boundary currents, etc. [9]. The combination of these two parameters is the definition of the steric/dynamic components of sea level.

In our study, we used monthly output from one realization (coded as r1i1p1) of the simulation for the historical scenario by 10 models under CMIP5 and 3 models under CMIP6 (Table 1). These are the dataset of the CMIP5/6 model output that are accessible in the World Data Centre for Climate (WDCC; wdc-climate.de) at the beginning of this work. These 13 models have various spatial resolutions with 4 of them considered as low-resolution. We individually verified each model without any conversion on their spatial resolution in order to expose their actual performances [8]. Thus, a fair inter-model comparison is guaranteed since smaller scale signals, produced by models with a higher spatial resolution, are considered.

We applied linear regression to estimate the trend of SLA [14, 21]. Linear regression is applied to the monthly data in order for its standard deviation to be considered in estimating the statistical significance and the range of uncertainty of the trend of SLA. Consequently, the range of uncertainty of this monthly trend is larger than the one from yearly resolution. This monthly trend is then converted and displayed as yearly trend to be comparable with references. On the other hand, the time period for the linear regression follows the overlapping temporal coverage between satellite observation and model simulations. Thus, all calculations start at January 1993 and end at December 2014 for CMIP6 models, and at 2012 (2005) for three (seven) of CMIP5 models (Table 1). These chosen periods allow optimal assessment on the performance of each model with respect to the availability of the satellite observational data. Trends of SLA were estimated for each of the oceanic grid-point in WMC and the focused areas, which are SS and JCS.

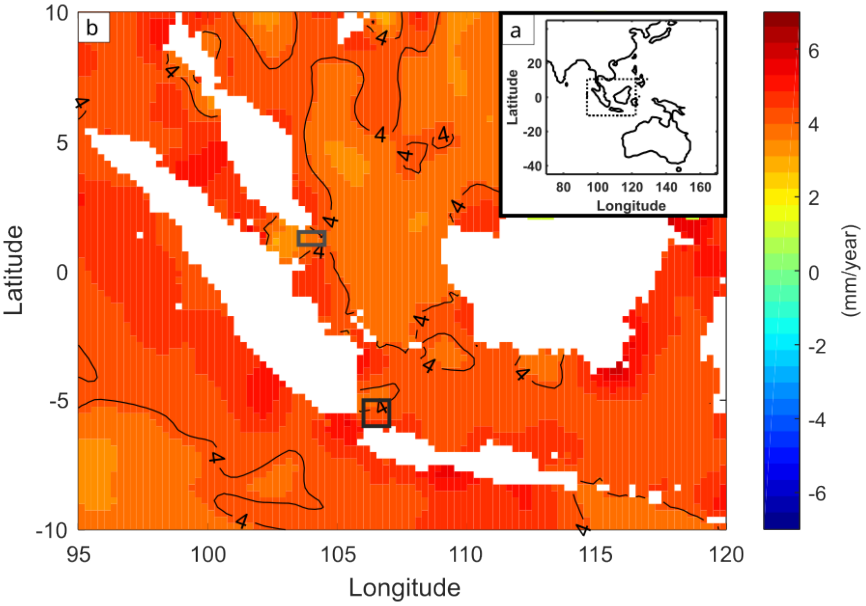

**Figure 1.** (a) Position of the WMC region (dashed rectangle). (b) Trends of sea level anomalies (SLAs) (color shades and contours) based on CMEMS satellite altimeter for the period of January 1993 to May 2022. Trends in all grid points are statistically significant at 95% confidence level based on F-test of the regression coefficient. Solid rectangles are the focused areas, which are SS (light grey) and JCS (dark grey).

SS and JCS are chosen as the focused areas in our study based on two reasons. Firstly, references on the trends of SLA from tide-gauges data for the two areas were available. These references provide rough estimation on the biases suffered by CMEMS satellite altimeter data which can be used to further assess model performances. Secondly, although both areas are located in Sunda Shelf, their geological settings are known to be different, especially in their island's morphogenesis [15]. Such differences might affect the level of resistance of the islands within the two areas in facing the threat of sea level rise. Rocky islands in SS are likely more resistance to the impact of sea level rise as compared to the reef islands in JCS.

**Table 1.** CGCMs of CMIP5/6 which provide output for the steric/dynamic components of sea level under historical scenario and accessible through World Data System (wdc-climate.de) administered by the German Climate Computing Center (DKRZ: Deutsches Klimarechenzentrum GmbH). Horizontal resolution is based on the oceanic component of the CGCM and the lower-resolution models are highlighted in bold. Reference number of each model is stated next to the model name.

| Project | Model name (Ocean component) [References] | Country | Horizontal resolution | Period |
|---|---|---|---|---|
| CMIP5 | ACCESS1-0 (ACCESS-OM) [12] | Australia | 360x300 | 1850-2005 |
| | **CSIRO-Mk3-6-0 (GFDL-MOM2) [6]** | Australia | 192x189 | 1850-2005 |
| | **IPSL-CM5A-LR (OPA) [13]** | France | 182x149 | 1850-2005 |
| | MRI-ESM1 (MRI-COM3) [2] | Japan | 360x368 | 1850-2005 |
| | NorESM1-ME (MICOM) [3] | Norwegia | 320x384 | 1850-2005 |
| | CCSM4 (POP2) [7] | USA | 320x384 | 1850-2005 |
| | **MIROC-ESM (COCO) [23]** | Japan | 256x192 | 1850-2005 |
| | **MIROC5 (COCO4.5) [22]** | Japan | 256x192 | 1850-2012 |
| | BCC-CSM1-1 (MOM4-L40) [24] | China | 360x232 | 1850-2012 |
| | BCC-CSM1-1-M (MOM4-L40-1) [24] | China | 360x232 | 1850-2012 |
| CMIP6 | CanESM5 (CanOE) [18] | Canada | 360x291 | 1850-2014 |
| | CMCC-ESM2 (NEMO3.6) [11] | Italy | 362x292 | 1850-2014 |
| | CMCC-CM2-SR5 (NEMO3.6) [11] | Italy | 362x292 | 1850-2014 |

The spatial distribution of the SLA trends in WMC, as well as for the two focused areas, for each model is compared with the one calculated based on the CMEMS satellite observation data (Fig. 2-4). In addition, we provide depictions of the temporal coherency between each model and satellite observation for the two focused areas (Fig. 3 & 4). Furthermore, we also provide the individual trend of the two SLA components from each model for the two focused areas (Tabel 2). The results should fairly demonstrate the performance of each model in simulating present-day trend of SLA with a quick look on its variability.

## 3. Model-Data comparison for the present-day trends of SLA in WMC

Trends of SLA from CMEMS satellite altimeter data for all three time periods are homogeneously positive (Fig. 2. a, i, m). Trends for longer periods are generally larger (smaller) and more (equally) significant than the shorter period especially in the interior seas (west-coast) of WMC. Nevertheless, these results showcased the spatial variability of the rate of sea level rise in present-day WMC. Consequently, these features are the main targets to be verified by model simulations.

Spatial distributions of the trends of SLA in WMC from all 13 models are plotted on their own spatial resolutions (Fig. 2. b-h, j-l, n-p). The spatial resolution of CMIP6 models is relatively higher than CMIP5 to which allows them to better represent the land-sea distribution of WMC. However, Figure 1 shows that there is no correlation between spatial resolution and model performance in simulating the trends of SLA. IPSL-CM5A-LR and MIROC-ESM are the two (out of four) low-resolution models which, in general, out-performed the other models. These two models are the only models with positive trends of SLA throughout WMC, thus, their simulations are the most consistent with CMEMS satellite data as compared to the other models. Models beside IPSL-CM5A-LR and MIROC-ESM, including CMIP6's, simulate negative trends of SLA in exterior southwest of WMC (Fig. 2, d-h, j-l, n-p). On the other hand, the worst performed models are CSIRO-Mk3-6-0 and MIROC5 since they simulate negative trends of SLA throughout WMC (Fig. 2. d, j).

In the interior seas of WMC, models beside CSIRO-Mk3-6-0 and MIROC5 simulate positive trends of SLA, but those with statistical significances are only from five models (IPSL-CM5A-LR, MIROC-ESM, ACCESS1-0, BCC-CSM1-1 and BCC-CSM1-1-M) (Fig. 2. b, c, h, k, l). Thus, despite the underestimation of the trends by these five models, they can be considered as the best performed models in our study. However, these five models might actually perform better since CMEMS satellite data is known to overestimate SLA in the shallow seas [14]. Thus, we further evaluate the performance of each model in simulating trends of SLA in SS and JCS since biases suffered by CMEMS satellite data from the two areas are quantifiable.

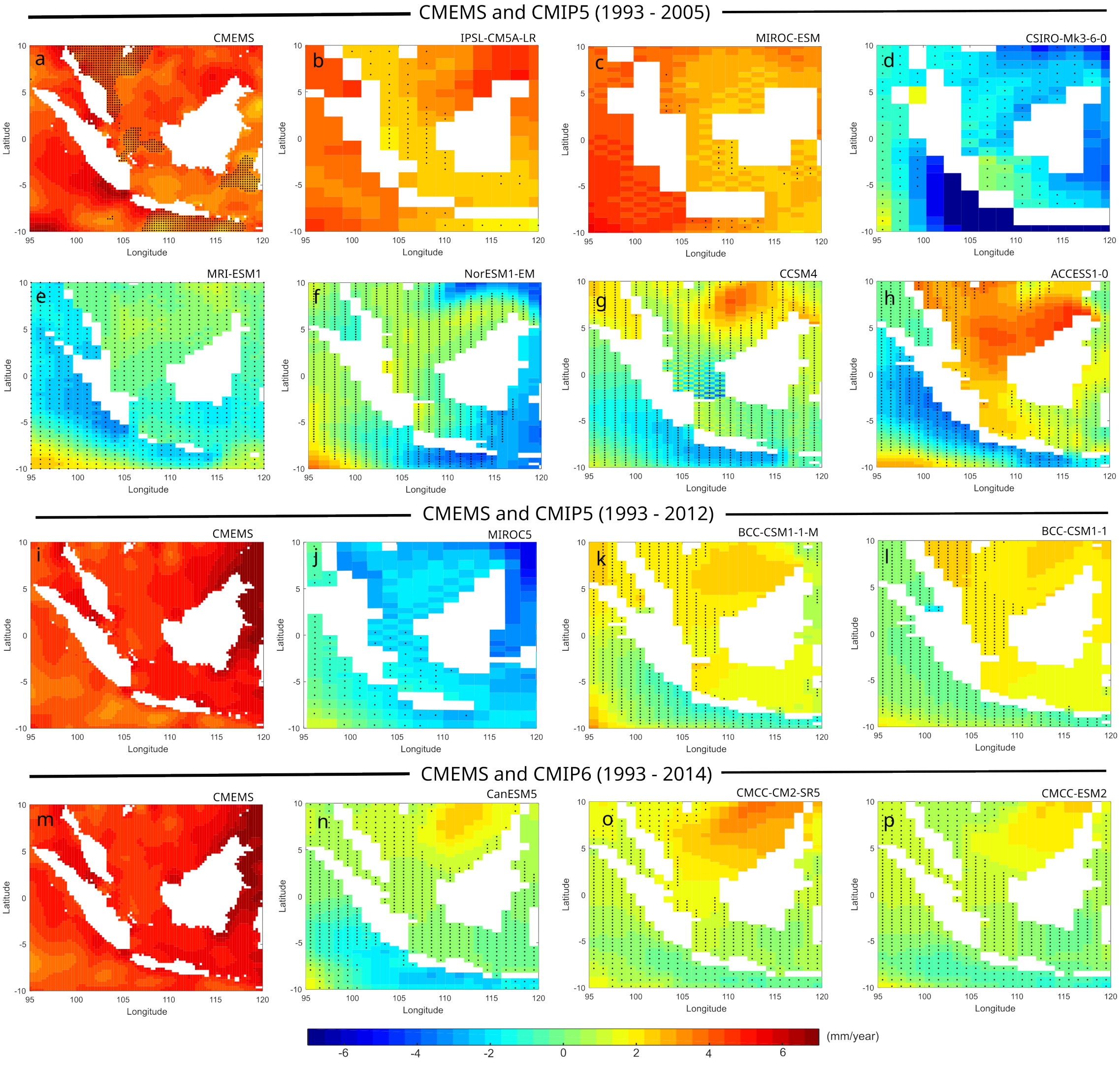

**Figure 2.** (a, i, m) Trends of sea level anomalies (SLAs) (color shades) based on CMEMS satellite altimeter, steric/dynamic component from CMIP5 models for the period of (b-h) 1993-2005, (j-l) 1993-2012, and (n-p) CMIP6 models for the period of 1993-2014. Dotted areas are SLA trends without statistical significance at 95% confidence level based on F-test of the regression coefficient.

### *3.1. Singapore Strait*

SS is a narrow passage between southern coast of Singapore territory and northern coast of Batam and Bintan islands. The area of this small strait can be estimated within 1.0N-1.5N and 103.5E-104.5E, which is a minor part of the intersection zone between Malaka and Karimata Straits. The rate of the in-situ sea level rise in SS was ~3.8 ± 1.3 mm/year for the period of 1993-2009 [21]. This rate is overestimated by CMEMS satellite data by ~0.6 mm/year which is still within the range of uncertainties of the trends from both time series (Fig. 3). This bias might compensate the performance of CMIP5/6 models when their trends of SLA in SS underestimate the one from CMEMS satellite data.

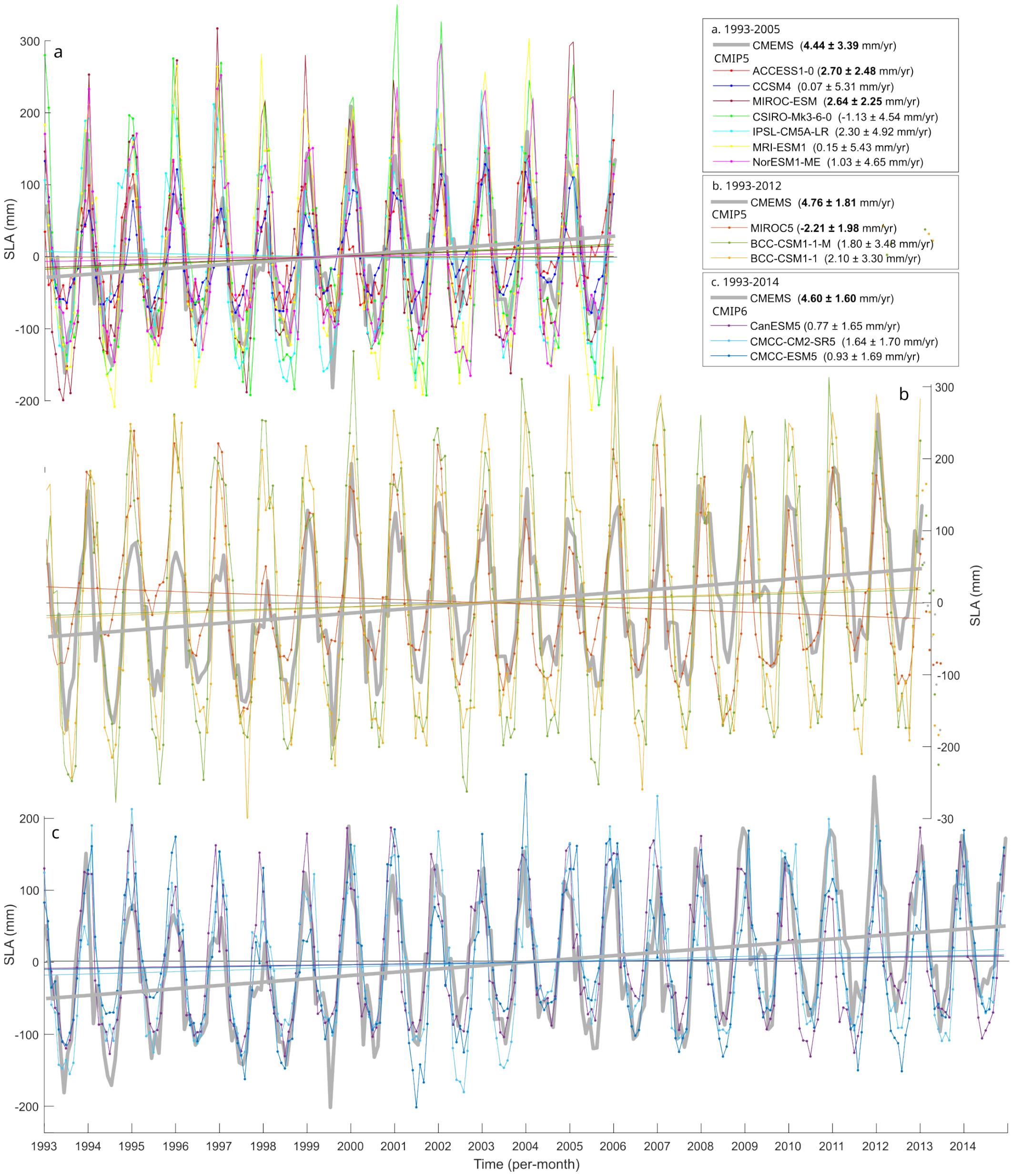

**Figure 3.** Spatially averaged SLAs and their trends from CMEMS satellite altimeter and steric/dynamic component from CMIP5/6 models for Singapore Strait (1.0N-1.5N and 103.5E-104.5E for the high resolution model, 1.0N-1.5N and 103.5E-106.0E for the low resolution). The periods are for (a) 1993-2005 and (b) 1993-2012 for CMIP5, and (c) 1993-2014 for CMIP6. The SLA trend for each curve is shown inside the bracket. And bolded numbers are significant trends at 95% confidence level based on F-test of the regression coefficient.

Unlike CMIP6, CMIP5 models mostly lack of several smaller-scales straits in WMC, including SS. Thus, we approximated the area of SS by the nearest grid-points in the west side of Karimata Strait (see Fig. 3 caption for detail). Consequently, we defined area of SS in low-resolution models by 1.5 degrees wider to the east than the high-resolution models. Such difference is also meant to appreciate the spatial precision resolved by the high-resolution models. The spatially averaged time series of SLA from models and satellite data were re-centered and plotted together for each time period (Fig. 3 & 4).

These time series were fully displayed in order to get a general outlook on the model performances in simulating SLA variability. These plots are also overlaid by lines that represent the trend of each model. Such representation of these time series is meant to fairly assessed model performances in simulating SLA in SS.

Monthly SLA in SS from CMEMS satellite data is clearly dominated by annual variability (Fig. 3). On the other hand, the SLA in SS does not seems to respond to the inter-annual variability since there is no large deviation during strong El Nino events as compared to the other years (e.g., 1997/98). These features are well simulated by all models despite its various magnitudes. These results put some confidence in the performance of CMIP5/6 models in simulating the variability of SLA in SS since they are generally only suffered from a systematic bias in the magnitude of SLA.

All 13 models underestimated the trends of SLA in SS, as compared to the one from the CMEMS satellite data, and only two of them show positives and statistically significant trends (ACCESS1-0 and MIROC-ESM) (Fig. 3). The two CMIP5 models underestimated the trends of SLA in SS by ~1.7 mm/year for the period of 1993-2005 with respect to to the trend from CMEMS satellite data (Fig. 3.a). Thus, the two models might underestimated the actual trend of SLA in SS by ~1.1 mm/year if we consider the bias of the CMEMS satellite data as previously mentioned. Despite the underestimations of the trends of SLA in SS by the two models, the upper bound of its uncertainties remain overlapped with both satellite and tide-gauges data. On a closer inspection, the trends of SLA in SS by the two models are dominated by the global thermosteric component rather than the local ocean dynamics since the trends for the latter component are not statistically significant (Table 2).

### *3.2. Jakarta Coastal Sea*

JCS is an offshore region within ~100 km from the north of Jakarta's coast [16]. This small part of Java sea is within 6.0S-5.0S and 106.0E-107.0E, which also contains a chain of islands known as Seribu islands. Nurmaulia et al. (2010) estimated the trends of sea level from tide-gauge in the coast of Jakarta for the period of 1993-2003 and from its nearest grid-point of the satellite altimeter data to the be 1.2 ± 2.5 mm/year and 5.3 ± 2.2 mm/year respectively. These two trends were comparable since the tide-gauge data was claimed to be free of any vertical land movement during that period. Thus, the positive bias of the satellite altimeter data for that period was ~4.1 mm/year. This bias could possibly lower the trend of SLA in JCS from CMEMS satellite altimeter data for the period of 1993-2005 to ~0.2 mm/year (Fig. 4. a). Despite the possibility of having a small and perhaps insignificant trend, the uncorrected trend of SLA in JCS from CMEMS satellite altimeter data remains statistically significant (Fig. 4. a). Thus, comparison between the trend of SLA in JCS from CMEMS satellite altimeter data and the output of CMIP5/6 models remains possible.

Principle of fairness in showcasing the performance of CMIP5/6 models, such as the one in SS, is also applied in JCS. JCS area is represented in all 13 models with a one degree shift to the north and west sides of the original area for the low-resolution models (see Fig. 4 caption for details). The area shift was due to a larger size of Java island in the low-resolution models that considerably shift its northern coastlines towards offshore (Fig. 2). On the other hand, SLA in JCS underwent similar treatment with the one in SS for their temporal plots (Fig. 4). Thus, performances of the CMIP5/6 models in simulating the trend and variability of SLA in JCS was assessed similarly with the one in SS.

Unlike in SS, there is no discernible coherency between SLA variability in JCS by the CMIP5/6 models with the one from CMEMS satellite data (Fig. 4). Low-resolution models clearly unable to simulate the inter-annual variability shown by the satellite data since they maintained the domination of annual variability such as shown in SS (Fig. 4. a, b). High-resolution models of CMIP6 discerned a slightly better coherency with the observation as compared to the other models (Fig. 4. c). Thus, the low performance of almost all CMIP5/6 models in simulating the variability of SLA in JCS might be related to the under-representation of the land-sea distribution and perhaps the shape of coastlines around Java sea. However, the trends of SLA in JCS from all models may still be accounted since they might be dominated by the larger-to-global scales components rather than locals.

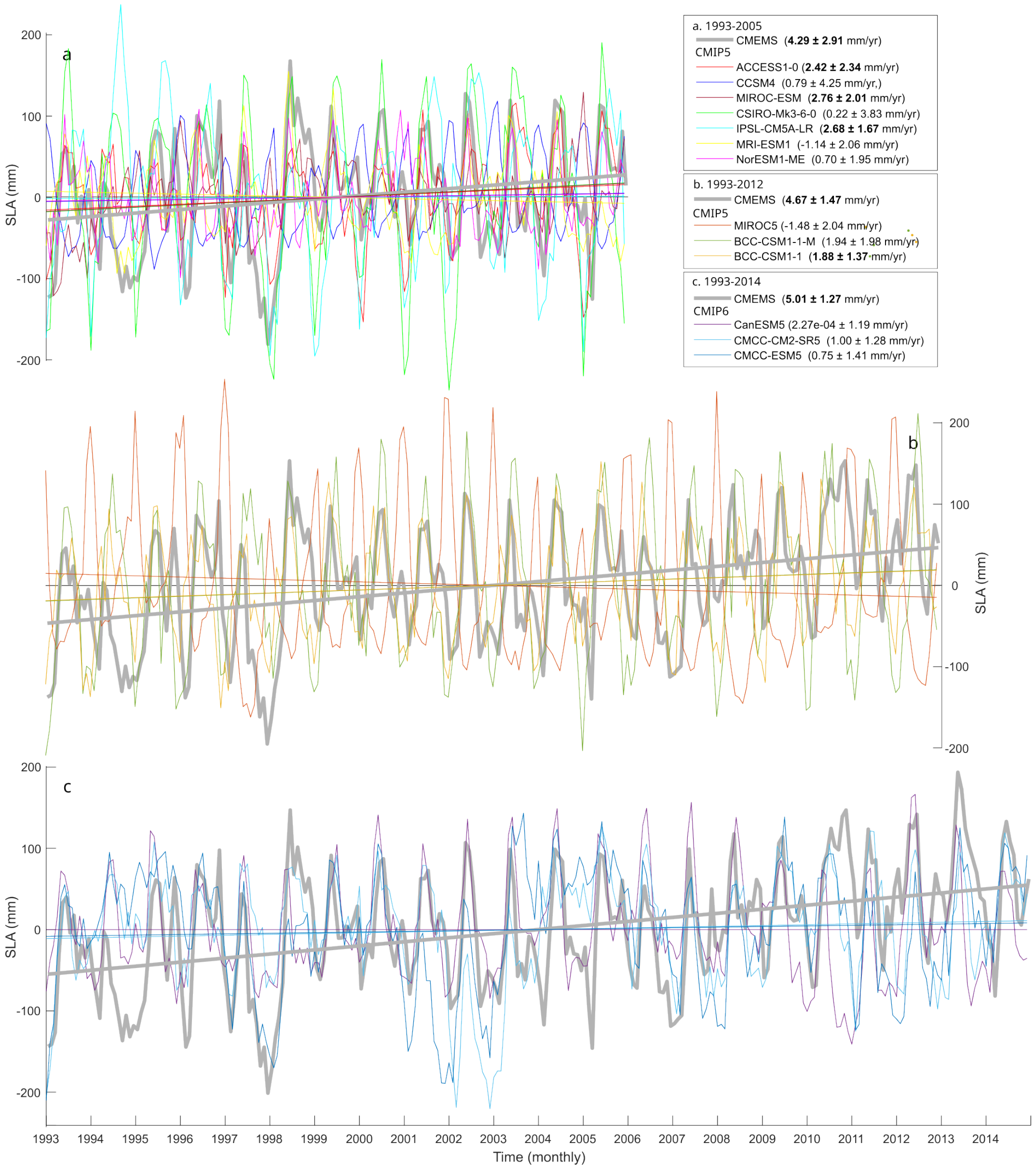

**Figure 4.** Spatially averaged SLAs and their trends based on CMEMS satellite altimeter and steric/dynamic component from CMIP5/6 models for Jakarta Coastal Sea (6.0S-5.0S and 106.0E-107.0E for the high resolution model, 6.0S-4.0S and 105.0E-107.0E for the low resolution). The periods are for (a) 1993-2005 and (b) 1993-2012 for CMIP5, and (c) 1993-2014 for CMIP6. The SLA trend for each curve is shown inside the bracket. And bolded numbers are significant trends at 95% confidence level based on F-test of the regression coefficient.

All 13 models exhibit weaker trends of SLA in JCS as compared to the CMEMS satellite data, and only four of them show positives and statistically significant trends (ACCESS1-0, MIROC-ESM, IPSL-CM5A-LR, and BCC-CSM1-1) (Fig. 4). Despite the overestimation of the trends of SLA in JCS by these four models, the lower-bound of the uncertainties from these models overlapped with the uncertainties of the satellite data. On a closer inspection, the trends of SLA in JCS by three out of these four models (MIROC-ESM, IPSL-CM5A-LR, and BCC-CSM1-1) were dominated by the ocean dynamics rather than global thermosteric component (Table 2).

**Table 2.** Trends and standard deviations of the global thermal expansion (zostoga) and the spatially averaged dynamic sea level (zos) for Singapore Strait (1.0N-1.5N and 103.5E-104.5E for the high resolution model, 1.0N-1.5N and 103.5E-106.0E for the low resolution) and Jakarta Coastal Sea (6.0S-5.0S and 106.0E-107.0E for the high resolution model, 6.0S-4.0S and 105.0E-107.0E for the low resolution) from CMIP5/6 models. Bold numbers are significant trends at 95% confidence level based on F-test of the regression coefficient.

| Project (period) | Model | SLA trend in global thermosteric (zostoga) | | SLA trend in ocean dynamics (zos) | | | |
|---|---|---|---|---|---|---|---|
| | | | | Singapore Strait | | Jakarta Coastal Sea | |
| | | Trend (mm/year) | St. Dev. (mm) | Trend (mm/year) | St. Dev. (mm) | Trend (mm/year) | St. Dev. (mm) |
| CMIP5 (1993-2005) | ACCESS1-0 | **1.51 ± 0.12** | 0.03 | 1.19 ± 2.49 | 0.59 | 0.91 ± 2.37 | 0.56 |
| | CSIRO-Mk3-6-0 | **1.35 ± 0.10** | 0.02 | -1.13 ± 4.53 | 1.07 | 0.22 ± 3.83 | 0.91 |
| | IPSL-CM5A-LR | **1.61 ± 0.10** | 0.02 | 2.30 ± 4.92 | 1.17 | **2.68 ± 1.67** | 0.40 |
| | MRI-ESM1 | **0.93 ± 0.13** | 0.03 | -0.78 ± 5.41 | 1.28 | **-2.07 ± 2.04** | 0.48 |
| | NorESM1-ME | **1.90 ± 0.10** | 0.02 | -0.87 ± 4.63 | 1.09 | -1.20 ± 1.94 | 0.46 |
| | CCSM4 | **1.99 ± 0.13** | 0.03 | 0.07 ± 5.30 | 1.26 | 0.79 ± 4.25 | 1.01 |
| | MIROC-ESM | **2.32 ± 0.11** | 0.03 | 2.64 ± 2.25 | 0.53 | **2.76 ± 2.01** | 0.48 |
| | | | | | | | |
| CMIP5 (1993-2012) | MIROC5 | **1.43 ± 0.08** | 0.04 | -2.21 ± 1.98 | 0.90 | -1.48 ± 2.04 | 0.93 |
| | BCC-CSM1-1 | **1.50 ± 0.06** | 0.03 | 2.10 ± 3.30 | 1.50 | **1.88 ± 1.37** | 0.62 |
| | BCC-CSM1-1-M | **1.92 ± 0.06** | 0.03 | 1.80 ± 3.48 | 1.58 | 1.94 ± 1.98 | 0.90 |
| | | | | | | | |
| CMIP6 (1993-2014) | CanESM5 | **1.92 ± 0.05** | 0.03 | 0.77 ± 1.65 | 0.87 | 2.28E-04 ± 1.19 | 0.63 |
| | CMCC-ESM2 | **1.83 ± 0.06** | 0.03 | 0.93 ± 1.69 | 0.89 | 0.75 ± 1.41 | 0.74 |
| | CMCC-CM2-SR5 | **1.96 ± 0.05** | 0.03 | 1.64 ± 1.70 | 0.89 | 1.00 ± 1.29 | 0.67 |

## 4. Conclusions

Estimating future sea level in WMC under a warming world is an urgent matter due to the pressing demand to mitigate the impact of sea level rise especially for the coastal community. However, long-term sea level is known to be governed by various components to which its precision become a great challenge to be achieved. Thus, the trend of SLA is commonly used as the main physical quantity to be estimated, comprehended, and modeled. CGCMs under CMIP5 are known to project the dominant components of the global SLA, which are the global thermosteric and the ocean dynamics [4]. The domination of these two components also occurs in SS which is a narrow strait at the northwestern of the interior seas of WMC. Furthermore, the trends of SLA in SS from tide-gauges appear similar to its future projection especially in the early years. Thus, we assessed the possibility of estimating the trend of present-day SLA by its steric/dynamic components simulated by the CGCMs under CMIP5/6.

We assessed the performances of CGCMs under CMIP5/6 in simulating present-day trends of SLA by mean of comparison with CMEMS satellite altimeter data and its estimated biases [14, 21]. We assessed the spatial variability of the trends of SLA in WMC as well as its temporal variability for the two focused areas (SS and JCS). In general, all 13 models underestimated, if not wrongly simulated, the trends of SLA in WMC (Fig. 2). Furthermore, IPSL-CM5A-LR and MIROC-ESM from CMIP5 are the only models with spatial homogeneity of sea level rise in WMC which is similar to the satellite data. Apart from these two models, only ACCESS1-0 and two BCC models show significant trend of SLA in the interior seas of WMC. The coarse grid resolutions of IPSL-CM5A-LR and MIROC-ESM suggest that the trends of SLA in WMC are generally independent of model spatial resolution. However, spatial dependency in model performances is shown between SS and JCS areas, mainly for the aspect of temporal variability and the domination among the two SLA components in constructing the trend.

SLA in SS has a clearer and rather dominant annual variability than in JCS, but without a discernible respond to ENSO events (Fig. 3). Conversely, SLA in JCS has a strong inter-annual variability on top of its annual signal (Fig. 4). Consequently, the variability of SLA in SS is better simulated than the one in JCS (Fig. 3 & 4). Furthermore, low-resolution models simulate variability of SLA in JCS similar to the one in SS. On the other hand, models such as ACCESS1-0 and MIROC-ESM underestimated the trends of SLA in SS while they overestimated the one in JCS (Fig. 3 & 4).

These differences could possibly related to the differences in the contribution between of the global thermosteric and ocean dynamics components in constructing the trend. In general, trends of SLA in SS were mainly contributed by the global thermosteric component, while the one in JCS is mainly contributed by the ocean dynamics (Table 2). However, these excursions from the actual trends of SLA remains within their range of uncertainties. Thus, it is valuable to further explore the possibility to approximate the trends of present-day SLA in SS and JCS by their steric/dynamic components simulated by the CMIP5/6 models. Furthermore, the mechanisms behind the long-term change of SLA can also be investigated by conducting a model diagnostic on the physical composition of the steric/dynamic components of the SLA [10].

Spatial distribution of the biases in the present-day trends of SLA from satellite observation in WMC could be further estimated by using dataset from a larger network of tide-gauges in the region. These estimates would allow a comprehensive assessment of the model performances in simulating the trends of present-day SLA in WMC. Such assessment would be useful for model selection in order for their future projection of SLA to be considered. On the other hand, contribution of the other components of sea level (e.g., glaciers, land water, etc.) are going to be eminent towards the end of 21st century [4]. Thus, proper projections of all components of sea level are likely becoming more important especially for the far future.

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## Authors contributions

Y S Djamil proposed the main idea, developed the methods, conducted the analyses, discussed the results, and wrote the manuscript. Thus, Y S Djamil acts as the main contributor. Author member: A Maharani acquired and inventorised all datasets and performed some test on the methods. T Solihuddin and M D Setiawati contributed to the discussions of the main idea and its background motivation, as well as correction on the manuscript. A M Muslim, T Eguchi, and U Chatterjee provided information about the context of this research, discussions, and correction on the manuscript. L O Alifatri contributed to the data management and discussions.

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