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Climate Change Impacts on Sea Level Rise in Selingan Island in the East Coast of Sabah, Malaysia

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ABSTRACT

Sea level change is of considerable concern due to its major climate change-related impacts in coastal ecosystems. Within the Coral Triangle, the islands and their surrounding in the East Coast of Sabah are known as the most biologically diverse and ecologically rich regions on earth. The considerably low-lying area of the coastal setting makes it vulnerable to the impact of sea level change. Thus, it is an indication of urgency to investigate the impacts of climate change and sea level change on coastal inundation and the ecosystem at the coastal areas. By the end of century, based on the worst-case scenario of RCP 8.5, almost 2.5 acres of coastal land in Selingan Island will be lost due to 879 mm of sea level rise. Most of the sandy beaches at the southern part of the island is vulnerable to sea level rise. The high vulnerability of the ecologically sensitive island ecosystem and potentially high risk of coastal inundation may warrant specific adaptation strategies to ensure sustainability of the island ecosystem.

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INTRODUCTION

Changes in sea level occur over a broad range of temporal and spatial scale with many contributing factors, thus making it an integral measure of climate change. The rise of sea level around the world is not uniform where the rate in some regions is several times higher than the global mean rise, while in other regions the rate is lower and this shows a substantial difference from the global change (Levitus *et al*., 2005). Most of the Malaysian coastal areas are considered low-lying areas. This makes the coastal areas vulnerable to coastal erosion, land loss and inundation from sea level rise and some areas are already experiencing the impacts from the sea level rise. Sabah has a long history of setting aside important natural areas for conservation of its unique and rich flora and fauna which form a crucial part of the nature conservation in Sabah.

Thus there is a need to identify the risk of climate impacts and its vulnerability to the ecosystem. Eventually could lead to the implementation of adaptation and mitigation. Selingan Island (Figure 1) is located at 6°10'25.8"N 118°03'37.5"E, 40 km north of Sandakan in the East Coast of Sabah. The island is well known for the nesting of two endangered species of sea turtles, the green and hawksbill turtles (State of the Coral Triangle, 2014). The focus of this study is to assess the impact of climate change on sea level rise and identification of high vulnerability area in Selingan Island under different RCP scenarios.

Methodology:

Using statistical downscaling, large-scale forcing fields are connected to local sea-level variations by means of statistical transfer functions, translating the trends from the large scale to regional and local scale (Hünicke and Zorita, 2006; Hünicke, 2010). The strategy of projecting future sea level change in this study is the application of simple statistical regression models with coarse resolution Global Climate Models (GCMs) in which 19 years of tidal data (1994 - 2013) as the predictand and climate drivers such as mean sea level pressure (MSLP), sea surface temperature (SST), zonal wind (U) and meridional wind (V) as the predictors. The data of predictors were obtained from ERA-Interim database. The first part of the study was set out to investigate the influence of possible climate forcing on sea level variations. All the predictors were standardized and anomaly of the predictors and predictand were calculated. The predictors were then correlated with the predictand. The highest positive and negative correlations between predictors and predictand would be obtained.

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Fig. 1: Selingan Island in Sandakan waters (Source: Google Earth, 2015).

Principal Component Analysis (PCA) was performed on the predictors to transform the variables into its principal components. The number of principal components (PCs) usually varied between 1 to 4 and in our case, the first and second accounts for as much of the variability in the data as possible. Regression analysis was conducted using time series of the PCs to check the coefficient value between the tide and the PCs. First PC of variables MSLP, U, V and second PC of SST together with anomaly of tide were selected based on the coefficient value to prepare for regression analysis to form a regression model that represent the reconstructed sea level change (Eq. 1).

$$Y_{rsl} = C_1 P_1 + C_2 P_2 + \dots + C_m P_n \quad \dots \text{ Eq. 1}$$

Where,

Y_{rsl} = Reconstructed sea level in mm

C_m = Coefficient value of each the predictors

P_n = Principal Component of each of the predictors

The establishment of the statistical relationship between the sea level and the climatic data sets in the observation record allows an estimation of regional climate change by statistical means through the application of regression models to the corresponding output of different future RCP scenarios and GCM simulations. Representative Concentration Pathways (RCP) are scenarios of different rates and magnitudes of climate change use for accessing the plausible projection of different aspects of the future that are constricted to investigate the potential risks impacts of climate change (Moss *et al*., 2008). GCMs climate data of MSLP, SST, U and V from 2006 to 2100 were obtained from CMIP5 database and interpolated with reanalysis climate data. Anomaly of GCMs was calculated and the time series was extracted. GCMs time series from year of 2006 to 2100 were then introduced into the Y_t in Eq. 2 to form a new sea level projection for Selingan Island.

$$SL_f = R_1 Y_2 + R_2 Y_2 + \dots + R_c Y_t \quad \dots \text{ Eq. 2}$$

SL_f = Future sea level in mm

R_c = Coefficient value of each predictor in reconstructed sea level

Y_t = Time series value of GCMs

RESULTS AND DISCUSSIONS

The sea level of Sandakan waters was computed from monthly data tidal records. The monthly sea level data is calculated and presented as yearly changes. The anomaly of Sandakan's sea level displayed a positive change at the rate of 5.38 mm/year from 1994 to 2013 (Figure 2). Decreased in sea level was recorded in 1997/1998, which may due to the effect of *El Nino*. According to Widlansky *et al*. (2014), due to strong *El Nino* event, the sea level can drop and remain below normal for up to a year in tropical western Pacific.

The correlation between the Sandakan sea level anomaly and the climate drivers is shown in Figure 3. The red-coloured region indicates the sea level anomaly that is positively correlated to the climate drivers whereas the blue-coloured region indicates the negative correlation.

Generally, the sea level responses to the pressure change through an inverted barometer effect where the sea level changes by 1 cm if the sea level pressure changes by 1 mbar (Stammer and Huttemann, 2008). Based on the results shown in Figure 3, the mean sea level pressure is negatively correlated with the sea level anomaly where the sea level anomaly decreases when the mean sea level pressure increases. The trend of sea level anomaly is also showing a positive correlation with the sea surface temperature in the East Coast region of Sabah. In particular, the variations in sea level change manifest itself not only as variations in SST and MSLP but also as surface winds (U and V). The surface winds, particularly the trade wind are characterized by converging the pressure and temperature over the Indo-Pacific region. Generally, the easterly winds blow west across the tropical Pacific and pile up the warm surface water in western Pacific including the Indo-Pacific region. Thus, the higher sea surface temperature in this region has increased the sea level. During *El Nino* event, the easterly prevailing winds stall causing the warm water begins to spread eastward and high-pressure system starts to develop where there is low pressure over the Borneo region (Linden, 2006). In addition, the sea surface temperature decreases and lowers the sea level.

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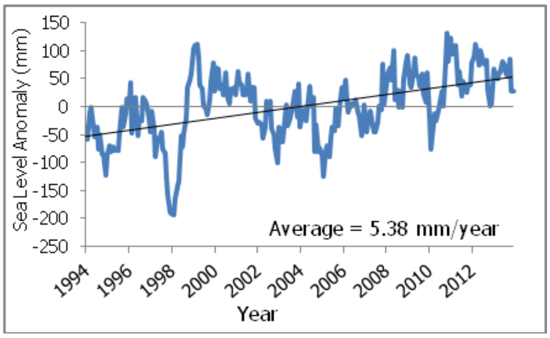

Fig. 2: Sea level anomaly of Sandakan waters from 1994 to 2013.

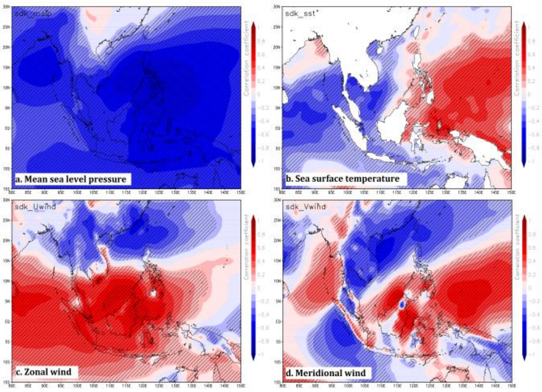

Fig. 3: Correlations of predictand (sea level anomaly) and the predictors (climate forcing).

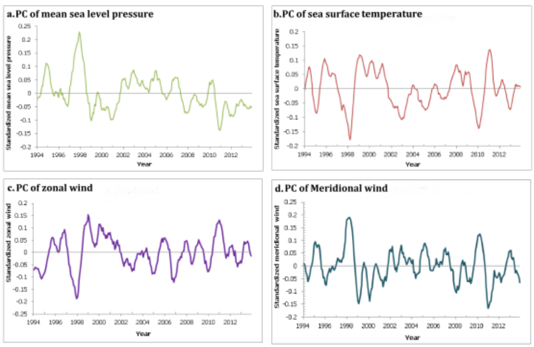

Fig. 4: PCs of the predictors (a) MSLP, (b) SST, (c) U and (d) V.

The principal components (PCs) of every climate forcing for Sandakan waters are also shown in Figure 4 (a–d). The PCs with highest EOF variance percentage varied between number 1 and 2. The time series associated with the leading principal components was determined and the reconstruction of sea level was based on the statistical model. The sea level reconstruction using mean sea level pressure, sea surface temperature, zonal wind and meridional wind as predictors and the sea level as predictand are shown in Figure 5, where the correlation between the observed and reconstructed sea level is 0.84 (all predictors). Initially, the sea level reconstructed using only mean sea level pressure as predictor (Figure 5-a) showed that both curves are slightly fitting. The correlation, r between the observed and reconstructed sea level is 0.73. This indicated that the information contained in the mean sea level pressure is able to reconstruct much of the sea level variations. However, there seems to be a non-negligible amount of sea level variability that cannot be explained mean sea level pressure linearly. In order to improve the performance of the reconstructed sea level, the statistical model in Eq. 1 was augmented to include the sea surface temperature, zonal wind and finally meridional wind. The reconstruction (Figure 5-b) showed some improvements with the addition of the other three predictors and the correlation had increased compared to the former reconstruction. Though, there are some factors remains responsible for the underestimation and overestimation of the reconstructed sea level. These deviations were resulted from regional ocean temperature differences corresponding to global thermal expansion or long term and large scale change in ocean with atmospheric circulation that affect the regional sea level changes (Church *et al*., 2008; Albrecht and Weisse, 2012).

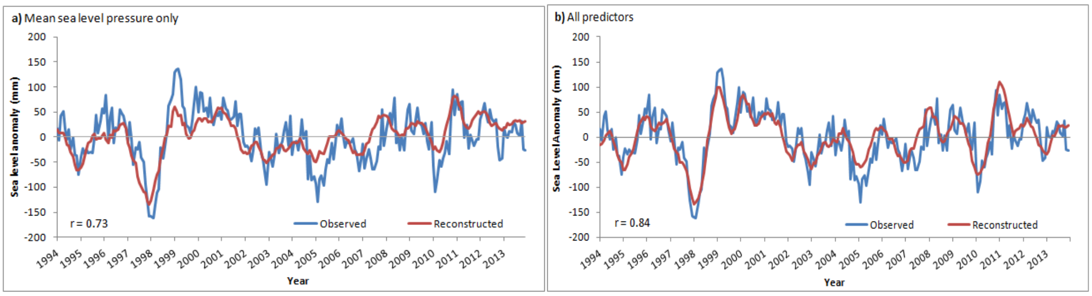

Fig. 5: Comparison of observed and reconstructed sea levels with (a) one predictors of mean sea level pressure (mslp) only and (b) all predictors.

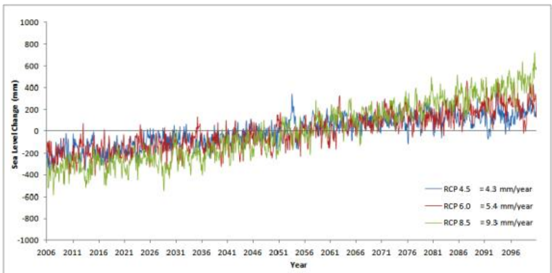

Fig. 6: Future sea level projection based on three different RCP scenarios.

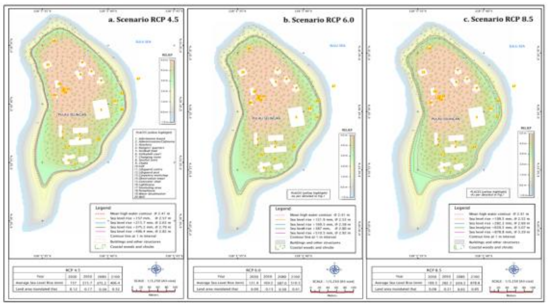

Fig. 6: Projected inundated area of Selingan Island by the end of century based on different future scenarios.

The future projection of sea level change for Selingan Island was investigated based on RCP 4.5, RCP 6.0 and RCP 8.5 scenarios. By the end of this century, the rates of sea level change in Selingan Island water are 4.3 mm/year (RCP4.5), 5.4 mm/year (RCP 6.0) and 9.3 mm/year (RCP8.5) (Figure 6). The rate of sea level change based on the scenarios determined the magnitude of the impacts to the ecosystem. Figure 7 displayed the inundated area of Selingan Island in the future based on three different RCP scenarios. Under RCP 4.5 scenario, with the projected sea level rise of 406.4 mm, the area to be inundated is about 0.8 acre of land area (mostly sandy beach). A small part of sandy beach and vegetated areas at the northern and northwestern parts of the island would be potentially inundated. Under RCP 6.0 scenario, a sea level rise of about 510.5 mm would potentially inundate a slightly larger area of about 1.0 acre of coastal land. Under the worst case scenario of RCP 8.5, about 2.5 acre of land would be loss due to inundation, with the projection of 879 mm of sea level rise. The sand beaches at the southern part of the island would be considered the most vulnerable due to sea level rise. Changes of coastline landscape and disappearance of sandy beaches could potentially affect the nesting ground of the turtles, which come ashore to lay eggs throughout the year. How significant is this impact on these turtles, is yet to ascertain, but certainly warrant a strategic adaptation policy to encounter plausible effect due to climate change. Other possible risk would be associated with the health of the coral reefs due to the disruption of sunlight and changes on sea surface temperature. According to

Field *et al*. (2011), the growth of coral and reef accretion are not fast enough to keep pace with 2 – 4 mm/year of estimated sea level rise and its effects.

Conclusions:

This study was based on statistical downscaling where the influences of climate forcing on sea level changes were statistically analyzed and discussed. The projection of future sea level in Sandakan waters particularly in Selingan Island under different RCP scenarios were found to increase by 406.6 mm (RCP 4.5), 510.5 mm (RCP6.0) and 878.8 mm (RCP8.5) at the end of the century. Under these scenarios, the potential areas to be lost due to inundation would be 0.8 to 2.5 acres of mostly sandy beaches at the south eastern part of the island. Other potential risks that are associated with this change are the loss of nesting ground of the endangered turtles, coral health and coastal erosion. All these plausible impacts due to climate change on sensitive ecosystem such as the Selingan Island, warrant for a strategic adaptation policy and action plan to ensure the sustainability of islands and the surrounding ecosystems.

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