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Research Article

CHANGES IN THE PHILIPPPINE COASTAL ENVIRONMENT

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ABSTRACT
Global warming is progressing at a faster speed than has been estimated earlier in climate forecasting, and the ocean responds rather quickly to global temperature increase. This study uses remotely sensed data that were accessed from the System for Multidisciplinary Research and Applications (NASA Giovanni) to study environmental change in the Philippines' coast. Monthly averaged sea surface temperature series from around the Philippines indicate that the Philippines follow the global trend in ocean temperature increase and show the increase of about 0.5^0C within two decades. Despite the high variability in temperature, the linear regressions displayed for all seasons show an increase with variations in the range of 0.3^0C to 0.5^0C. Rainfall in the Philippines is connected to the local and remote sea surface temperature, and the monsoon seasons determine to a high degree the rate and volume of precipitation. The data provide evidence that large-scale processes change the level of precipitation, in particular, with respect to the interannual changes and variations that appear to be in the frequency range of El Nino events.
The highest rate in sea surface temperature increase is observed for the June to August season with an estimated value of 0.036^0C y^{-1} and lowest rate is observed for the December to February season at about 0.027^0C y^{-1}. These estimates are based on linear regressions, but the 3rd order polynomial showed variability at decadal time scales and the results provide an estimate of possible future changes. By using estimates for 2020 and 2050 it can be projected that within thirty years, an additional temperature increase of 1.8^0C can be expected in the Philippines' coastal waters.

Keywords: *Marine Environment, Climate Change, Forecasting*

INTRODUCTION

As an island state, the Philippines possesses a large coastal zone relative to its total surface area and, except for a few islands, most have very limited resources that explain also their restricted capacity to mitigating the impact of global change. Like many Small Island States (SIDS), one of the Philippines' concern is environmental degradation in relation to population issues and the anticipated impacts of global change, and in particular, of increasing temperatures and rising sea-level. The Philippines with about 7,600 islands is facing major impacts of climate change that may hinder their aspects of sustainable development because small islands in the Philippines are low-lying and their environmental challenges are similar with respect to resource constraints, population dynamics and exposure to natural disasters and global change. But the magnitude of these changes may differ from island to island according to their geology and geographic locations that determine the vulnerability to extreme natural changes and disasters.

Due to the rapid increase in population and industrialization in the watershed, the water quality deteriorated in the coastal region through excessive urban emissions of nitrogen and phosphorus compounds that led to higher frequencies of harmful microalgae and persistent red tides.

Whereas, the emission of nutrient level can be controlled at the national level through legislation and appropriate land and coastal management, sea level increase and temperature changes are on a global scale, and external driving factors threaten individual countries. The findings by the Intergovernmental Panel on Climate Change (IPCC, 2018) showed with high confidence that human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels, with a likely range of 0.8°C to 1.2°C. Global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate. Although anthropogenic emissions of greenhouse gases may be reduced in the future, elevated CO_2 concentration will still remain in the atmosphere. There is high confidence that for centuries to millennia, greenhouse gases will continue to contribute to changes in the climate system, in particular, to temperature and sea level increase (IPCC, 2018). Because the level and progression of warming varies also with geographic location, this unsettling scenario alerts countries to evaluate their own monitoring strategies in order to set national guidelines for avoidance and mitigation of environmental and socio-economic impact of global change. Accordingly, the Philippines established the Climate Change Commission (CCC), to consolidate climate policy across all levels of government and to guide national programs.

There is now an indication that global warming is progressing at a faster speed than has been estimated earlier in climate forecasting, and the ocean responds rather quickly to global temperature changes. Temperature anomalies are also changing in magnitude, in frequency, as well as in temporal occurrence, and it has been estimated that temperature will rise by 2025 with a 40% chance of being 1.5 °C warmer than the pre-industrial level. Most affected by temperature and sea level increase are smaller islands if linear projections for the next decades are valid. For instance, The Bahamas is already exposed to a critical scenario related to the global warming trend that will surpass the lower limit of global temperature increase as recommended by the Intergovernmental Panel on Climate Change (Szekielda and Watson, 2021). Climate projections for the Philippines show that a temperature increase of about 1.8°–2.2°C increase can be anticipated by 2050 that can lead to wetter wet season, drier dry season and increased incidence of extreme weather and hazardous events. Furthermore, sea levels in the Philippines are rising faster than the global average and estimates for sea level rise by 2100 show an increase of about 0.48-0.65 m that will also increase threats by storm surges and will result in inundation of regions with low topography.

For appropriate planning with respect to sustainable development, it is essential to have access to a database that would allow, for instance, to mitigate the potential impact of climate change on various resource areas, health and infrastructure in the Philippines (USAID, 2017).

The present global temperature increase is a threat to sustainable development as can be observed in the changes in the ecosystem that have already been documented on a global scale. There are indications that the global marine ecosystem is equally undergoing substantial changes (Behrenfeld *et al.*, 2006), and locally, large changes appear in chlorophyll concentration and temperature distribution (Szekielda 2020a,b,c). As global oceanic primary production is in decline, it raises the question of how far regional and local biological systems are affected by global change. For instance, large ecosystems like the upwelling in the NW Indian Ocean have already shown significant modifications (Szekielda, 2021a). The trend, based on studies conducted in time series, show the link of major environmental management changes and effects of nutrient flow and changes in eutrophication of coastal regions especially in the vicinity of river discharge that indicates significant reduction in biomass concentrations and temperature increase (Szekielda, 2021b).

The Philippines weather and climate are mainly dominated by the southwest monsoon that lasts approximately from May to October, and the northeast monsoon from November to April with a temperature range of about 21°C to 32°C. Based on temperature and rainfall data, the climate of the country can be divided into the major seasons, namely the rainy season, that last approximately from June to November; and the dry season that covers normally the time from December to May. However, rainfall distribution throughout the Philippines varies from one region to another, depending upon the direction of the moisture-bearing winds and location of the mountain systems.

The above-described scenario, although not complete, indicates a complicated picture with respect to the anticipated future changes and uncertainties in forecasting the socio-economic impact of global climate change at local and regional levels. Consequently, there is a need to further elaborate on the environmental conditions that can be expected to change in response to global warming. It is therefore the aim of the following study to identify changes of environmental conditions in the coastal region of the Philippines based on long-time observations of temperature and precipitation, and use the observations to estimate potential changes for the next decades to come with respect to local warming trends.

The study takes into account that the West Philippine Sea has a very fragile marine environment that is under threat through global change:

1. The coastal sea in the West Philippine Sea contains higher biomass concentrations compared to the eastern coast in the Pacific, and water exchange through several straits already indicate signals that result from global warming;
2. Preliminary observations with inter-annual time series of chlorophyll show highest values during the NE monsoon, December to February, and lowest for March to May, but significant changes were observed over decades that are most probably linked to climate change;
3. Sea surface temperatures increased around the Philippine coast during the last decades, and it is important to identify the scale and trend of temperature changes in the coastal zone in order to act appropriately in mitigating the impact of climate change;
4. Rainfall in the Philippines is connected to the local and remote sea surface temperature, and the monsoon seasons determine to a high degree the rate and volume of precipitation.

MATERIALS AND METHODS

This study uses remotely sensed data that were accessed from the System for Multidisciplinary Research and Applications (NASA Giovanni). The system allows the analysis of Earth remote sensing data on weather, climate, atmospheric composition and dynamics, oceanography and hydrological processes, and it can be accessed through https://giovanni.gsfc.nasa.gov/. The data sets in this study cover a time frame of almost two decades. Sea surface temperature is based on daytime measurements through the atmospheric window at 11μm and is expressed in centigrade. Remotely sensed temperature estimates and rainfall data were analyzed as monthly averaged mean and were then subdivided by seasons. Rainfall data were reported for the land surfaces of the Philippines and sea surface temperature was analyzed for the surrounding waters of the Philippines covering the region that is shown in Figure 1 and is defined by the coordinates at site 117^0E, 5^0N, 128^0E, 20^0N.

RESULTS

Figures 2A and 2B show the periodicity in precipitation due to the monsoonal changes, and its interpretation has to take into account regional differences that impact the averaged data. The progression from the summer raining season to the winter dry season is not continuous, rather, complexity is introduced because the data contain measurements from different geographical locations that have varying climate and local forcing factors such as typhoons and changes in sea surface temperature. For instance, during the northeast monsoon coastal upwelling, changes in sea surface temperature relate to wind stress (Martin and Villanoy, 2007), and the intensity of El Niño and La Niña episodes have an impact on coastal weather conditions. In addition, the eastern

coast of Luzon is impacted by the Kuroshio Current that sheds aperiodically eddies through the Luzon Strait into the western part of Luzon and further into the South China Sea that elevates occasionally the sea surface temperature (Jia and Chassignet, 2011, Szekielda, 2020c).
The data provide evidence that large-scale processes change the level of precipitation, in particular, with respect to the interannual changes and variations that appear to be in the frequency range of El Nino events as indicated by the 3rd order polynomial fit of the data in Figure 2B. The same figure also shows the linear regression with a trendline that indicates a slight decrease of precipitation.

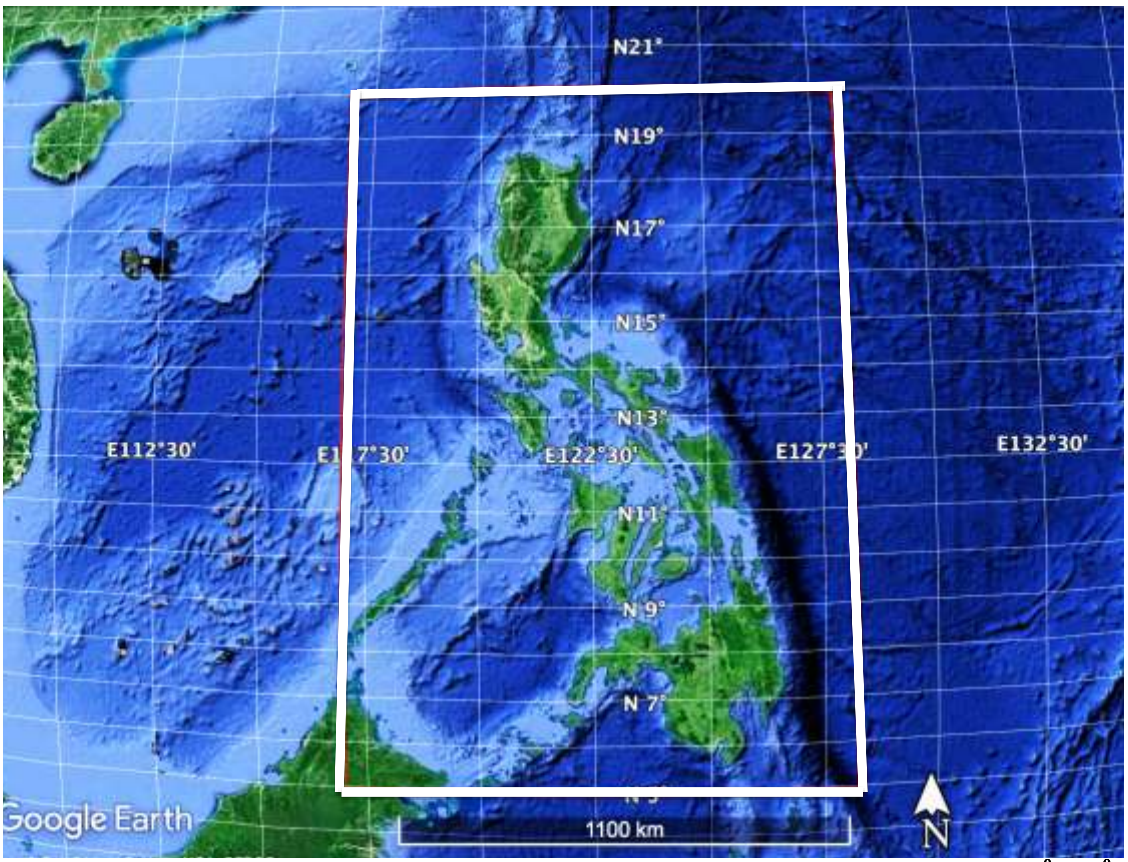

Figure 1: Location of sea surface temperature observations that covers the area 117^{0}E, 5^{0}N, 128^{0}E, 20^{0}N. Rainfall data were analyzed over the land cover of the Philippines only.

Although the changes in precipitation and sea surface temperature seem to be small, the analysis demonstrates a change in precipitation over a time span of twenty years that may be related to environmental degradation that have already affected the Philippines' agriculture, water, infrastructure, and coastal ecosystems (USAID, 2017).
A monthly averaged sea surface temperature series from regions around the Philippines as shown in Figure 3A indicates that the Philippines follow the global trend in ocean temperature increase and shows the increase of about 0.5C within two decades. Furthermore, the typical annual fluctuations due to the monsoon seasons are recognized, but interannual changes are detected. The difference in temperature between night and day in Figure 3B seems to be constant, at a level of around 0.7C lower at night compared to the day temperature although a small variation was observed around 2014.

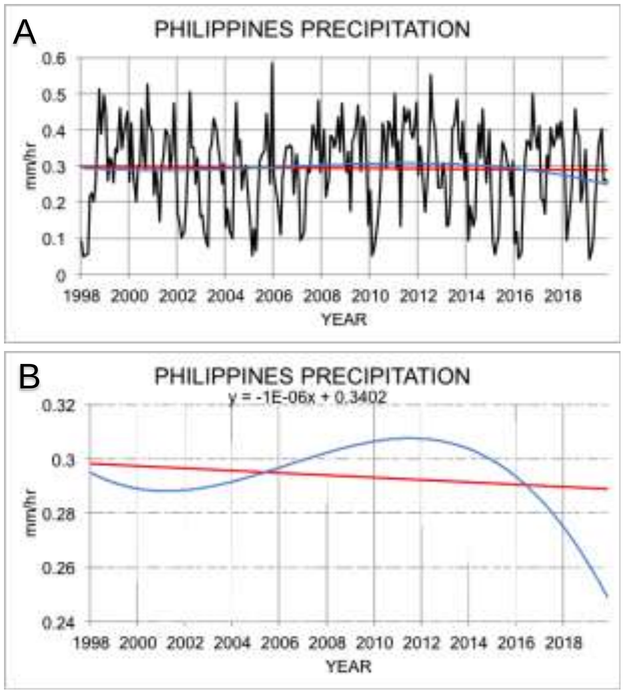

Figure 2: A. Time series of precipitation over Philippine land surfaces. The linear regression lines are shown in red and the 3rd order polynomial fit in blue. The regressions are shown in Figure 2B with an expanded vertical scale.

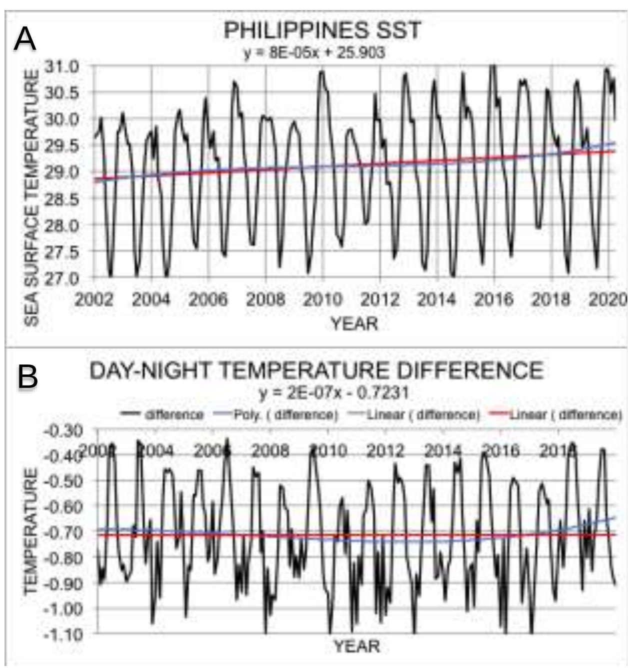

Figure 3: A. Sea surface temperature series for the Philippine site at 117^{0}E, 5^{0}N, 128^{0}E, 20^{0}N as shown in Figure 1. The linear regression lines are shown in red and the 3rd order polynomial fit in blue. B. Difference day-night temperature changes.

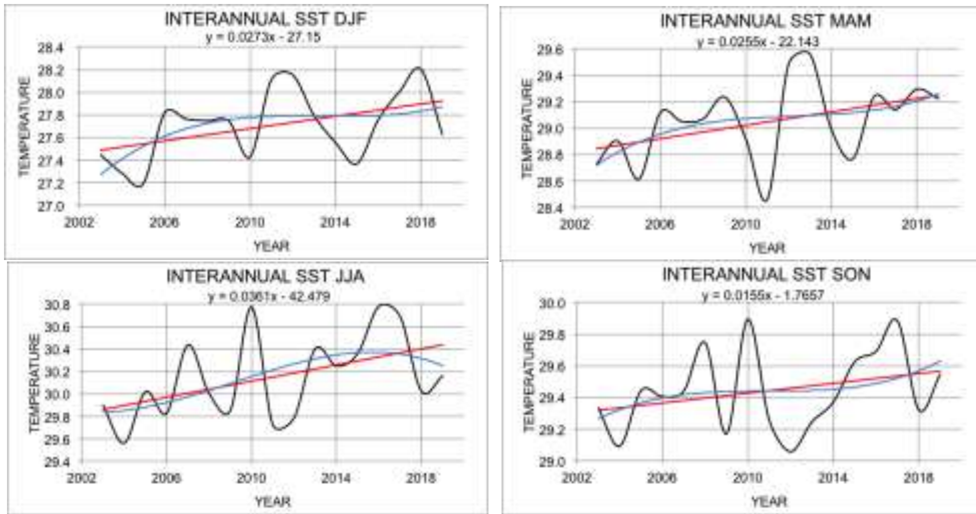

Figure 4: Seasonal sea surface temperature changes for Philippine site at 117⁰E, 5⁰N, 128⁰E, 20⁰N, as shown in Figure 1. The linear regression lines are shown in red and the 3rd order polynomial fit in blue.

Precipitation in the Philippines is controlled by atmospheric circulation and sea surface temperature that influence either locally or remotely the rainfall. However the yearly averaged data suppress fluctuations that are based on seasonal changes especially those that appear during the summer and winter seasons. In order to isolate details of interannual changes, sea surface temperature and precipitation data were subdivided according to seasons. Figure 4 shows the analysis of sea surface temperature with the corresponding linear regressions and 3rd order polynomial fits.

Relation between sea surface temperature and precipitation over land are complicated as shown in Figure 5 in conjunction with scatter diagrams comparing precipitation and sea surface temperature changes.

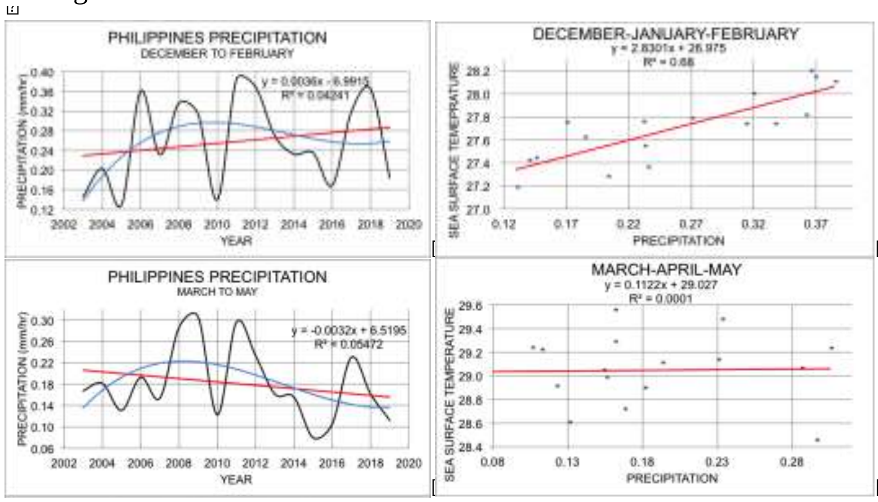

Figure 5: Interannual precipitaion changes and relationship between sea surface temperature and precipitation in the Philippines grouped by seasons. The left column shows monthly-averaged precipitation expressed in mm hr^{-1}, and the right column shows the temperature-precipitation relationship. The linear regression lines are shown in red and the 3rd order polynomial fit in blue.

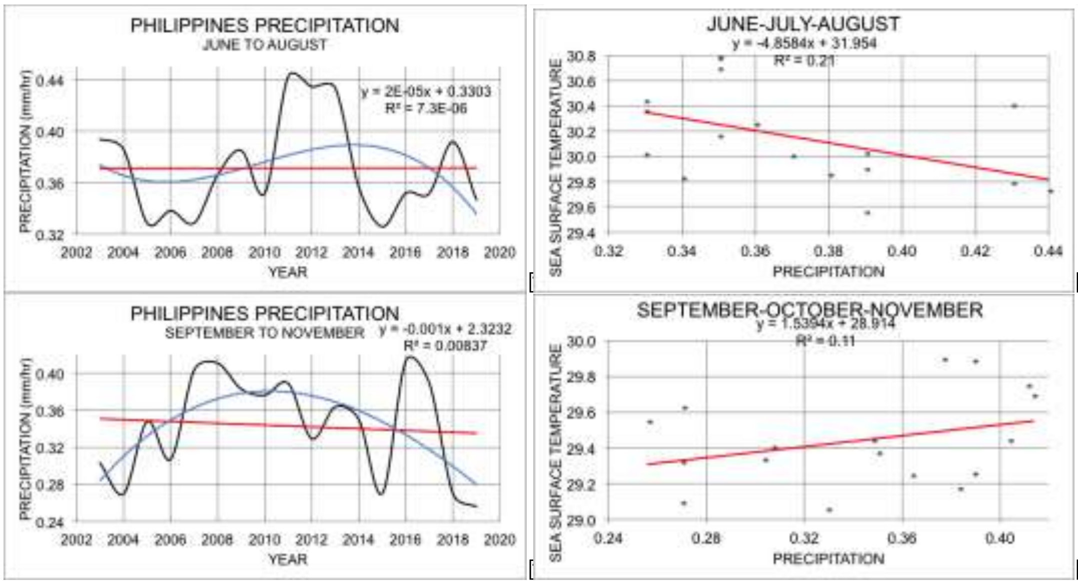

Figure 5 continued: Interannual precipitaion changes and relationship between sea surface temperature and precipitation in the Philippines grouped by seasons.

The interannual presentation of precipitation rate and the relationship to sea surface temperature shows that in addition to seasonal differences in precipitation, considerable variance is observed and shows that intensity and duration are not uniform from year to year. The data for the summer season June to August show a negative relationship between sea surface temperature and precipitation. Normally, precipitation coincides with warmer sea surface temperatures, however, a negative correlation was earlier observed during the summer monsoon as well (Trenberth and Shea, 2005). Stronger heat transfer from the ocean to the atmosphere and increased turbulence in the upper water column due to elevated wind speed explain the cooling. Thus, the negative correlation between rainfall and sea surface temperature during the SW monsoon is not necessarily the cause for increasing rainfall as the relation may reveal. This is in agreement with observations under similar conditions during the SW monsoon, particularly during moderate and relatively stronger monsoon regimes, when a warmer local sea surface temperature is generally related to a more intense rainfall over the western Philippines (Takahashi and Dado, 2018).

DISCUSSION

The analysis presented in Figure 4 is used to estimate the rate of sea surface temperature changes and the results are listed in Table 1 for the seasons in 2020, 2035 and 2050. The highest rate is observed for the June to August season with an estimated value of about $0.036^{0}C\ y^{-1}$ and lowest rate is observed for the December to February season at $0.027^{0}C\ y^{-1}$. These estimates are based on linear regressions, but the 3rd order polynomial showed variability at decadal time scales and the results provide hindsight to the dimension of possible future changes.

Using estimates between 2020 and 2050 it can be projected that within thirty years a temperature increase of $1.8^{0}C$ can be expected. Taking into account the estimates for temperature increase made by the IPCC (2021b) showing that global surface temperature was about $1.09^{0}C$ higher in 2011–2020 compared to 1850–1900 with an increase in the ocean of about $0.88^{0}C$, we would have a total increase in temperature of about $3^{0}C$ over a time span of 100 years that would correspond to a warming trend of about $0.003^{0}C\ y^{-1}$.

Table 1: Estimated sea surface temperature changes for the Philippine coast. The last column gives the approximated temperature increase ($^0C\ y^{-1}$) for the time span 2020 to 2050.

SEASON	EQUATION	^{0}C 2020	^{0}C 2035	^{0}C 2050	$^0C\ y^{-1}$
DEC -FEB	y = 0.0273x - 27.15	28.00	28.41	28.82	0.027
MAR-MAY	y = 0.0255x - 22.143	29.37	29.75	30.13	0.025
JUN-AUG	y = 0.0361x - 42.479	30.44	30.99	31.53	0.036
SEP-NOV	y = 0.0155x - 1.7657	29.54	29.78	30.01	0.008

Temperature forecasting for all seasons shows that the land surface of the Philippines is exposed to increasing mean temperatures by 1.8^{0}C to 2.2^{0}C in 2050 relative to the baseline established for 1971-2000 (PAGASA, no year). Estimates show for the period 1951 to 2010 an increase of about 0.65^{0}C that corresponds to an average increase of about 0.011$^0C\ y^{-1}$. In comparison, the average rate for the surrounding ocean area of the Philippines based on the present study gives an average increase of sea surface temperature of about 0.024$^0C\ y^{-1}$. Under the assumption that the different data sets are comparable, the ocean temperature seems to increase at a higher rate than the land surfaces of the Philippines. In addition, the temperature increase in the ocean is not evenly distributed and linear regression analysis shows that the slope of increase differs from region to region. This is an important factor in mitigating the effect of global warming with sustainable development strategies especially for small islands. For instance, a comparison of observations from the Philippines with those obtained in The Bahamas in Table 2, provides evidence that the change in sea surface temperature ($^0C\ y^{-1}$) varies to a high degree between the two regions by almost a factor of two.

Table 2: Estimates of temperature increase ($^oCy^{-1}$) based on linear regression for seasons, ($^{1)}$ this manuscript, $^{2)}$ Szekielda and Watson, 2021).

SEASONS	PHILIPPINES$^{1)}$	BAHAMAS $^{2)}$
DEC -FEB	0.027	0.064
MAR-MAY	0.025	0.048
JUN-AUG	0.036	0.040
SEP-NOV	0.008	0.068

The described analysis of selected environmental conditions of the Philippines has to be viewed against the outcome of the Intergovernmental Panel on Climate Change (IPCC, 2018) that assessed scientific, technical and socio-economic literature relevant to global warming of 1.5°C above pre-industrial levels. The Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2021) reiterated that climate changes are widespread, rapid, and intensifying. “Unless there are immediate, rapid, and large-scale reductions in greenhouse gas emissions, limiting warming to 1.5°C will be beyond reach”. The forecasting showed a global warming that is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate. Extreme ocean temperature increase have already documented for large ocean regions (Roxy et al., 2019, Szekielda, 2020b). The surface temperature of the oceans to a depth of about 700 meters has been warmed at a rate by 0.11°C, 0.07°C and 0.05°C per decade for the Indian, Atlantic and Pacific Oceans, respectively (Hoegh-Guldberg et al., 2018). However, deviations from the global annual average increase of temperature can be higher, and the Philippines are not an exemption from this trend. The problem of global sea surface temperature increase is that anthropogenic emissions of greenhouse gases will persist for centuries to millennia especially in the atmosphere, and will continue to be the risks for human survival.

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