Final Technical Report
CAF2017-RR02-CMY-Siswanto

Developing High Spatiotemporal Resolution Datasets of Low-Trophic Level Aquatic Organism and Land-Use/Land-Cover in the Asia-Pacific Region: Toward an Integrated Framework for Assessing Vulnerability, Adaptation, and Mitigation of the Asia-Pacific Ecosystems to Global Climate Change

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Table of Contents

1.

Project Overview

Project Duration	**:**	3 years
Funding Awarded	**:**	US$ 34,000 for Year 1; US$ 34,000 for Year 2; US$ 24,000 for Year 3
Key organisations involved	**:**	• Japan Agency for Marine-Earth Science and Technology, Japan (Dr. Eko Siswanto) • Burapha University, Thailand (Dr. Anukul Buranapratheprat) • University of Sriwijaya, Indonesia (Dr. Iskhaq Iskandar) • Rajshahi University, Bangladesh (Dr. Latifur R. Sarker) • Bogor Agricultural University, Indonesia (Dr. Jonson L. Gaol) • Nagoya University, Japan (Dr. Joji Ishizaka) • Korea Institute of Ocean Science and Technology, South Korea (Dr. Sinjae Yoo)

Project Summary

Motivated by the fact that Asia's terrestrial and marine ecosystems are highly vulnerable to basin-scale climate changes and the impacts of climate on many parts of the region are understudied, this project is conducted to develop resources and research capacity in the region to tackle the impacts of climate variability. Research resources that have been developed are remote sensing big database of the low-trophic level organisms and the web-based data distributing platform. Based on the aforesaid constructed database, many studies mainly to assess the impacts of climate changes on the low-trophic level organisms and possible driving factors over this APN project target region encompassing the large areas from the eastern Indian Ocean to the western North Pacific Ocean and from the equatorial to Arctic oceans have been carried out. There are many scientific papers produced by this project and published in reputable journals. As contributions to increase regional research capacity, the project also fosters postgraduate students and early-career scientists by involving them in the project research activities and organizing/co-organizing annual scientific workshops to strengthen regional research collaborations. Outputs delivered by this project (scientific evidence, database, web-based data distributing system, human resources, etc.) are valuable to gain more project outcomes in the future.

Keywords: (maximum 5)

Asia-Pacific region, ocean-land interactions, climate change impacts, satellite remote sensing, remote sensing database

Project outputs and outcomes

Project outputs:

- Nineteen peer-reviewed scientific papers have been published in reputable scientific journals
- Ten postgraduate students and early-career scientists have been engaged in the project and four of them are now pursuing a doctoral program in their countries or overseas, two of them are now working as a lecturer and a research scientist
- Remote sensing observation-based low-trophic level organism data distributing website called Low-Trophic Level Organism Map of Asia-Pacific (LowTroMAP)

- Evidence-based information on how climate changes impact, not only the low-trophic but also high-trophic level organisms in the Asia-Pacific regions, which is very valuable for policymakers and stakeholders in tackling climate impacts and adaptation
- Six series of annual remote sensing-related workshops have been organized consecutively

Project outcomes:

- Improved regional research capacity to monitor the impacts of climate changes and to anticipate the climate changes' adverse impacts
- Expanded use of remote sensing technology for both practical and scientific applications in the Southeast Asian region
- Improved community awareness of possible adverse climate impacts on their lives and livelihoods
- Improved regional research networking which leads to new research proposals, data exchanges for the near-future bilateral or international collaborations
- Improved communication between prospective postgraduate students and regional experts that leads to postgraduate research programs or student visiting programs

Key facts/figures

- The Asia-Pacific land and ocean ecosystems from the eastern Indian Ocean to the western North Pacific Ocean are largely affected by basin-scale climate variations of the Indian Ocean Dipole (IOD in the Indian Ocean) and El Nino/Southern Oscillation (ENSO in the Pacific Ocean)

- As shown in Figure 1a-b below, the signs and strengths (indicated by negative/positive and magnitudes of the correlation coefficient) of the IOD and ENSO impacts greatly vary across the zonal and meridional sections. The region impacted most by IOD is the eastern Indian Ocean (Figure 1a), whereas that impacted most by the ENSO is the equatorial western Pacific Ocean (Figure 1b).

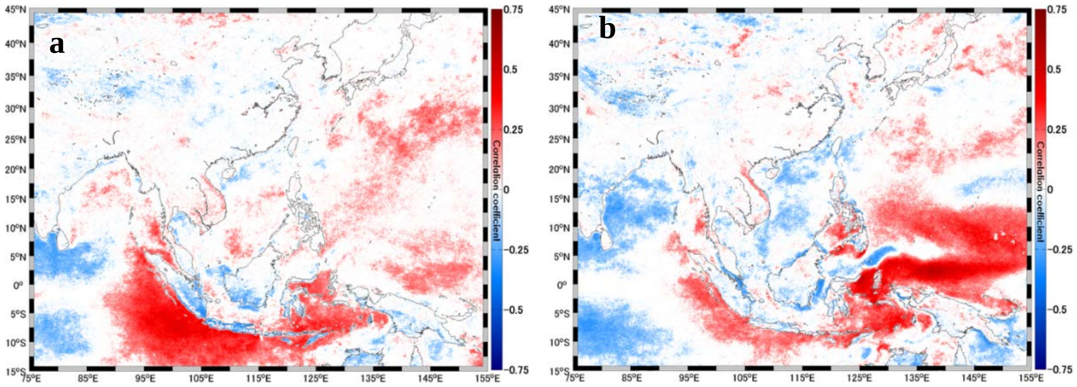

Figure 1. (a) Map of correlation between Dipole Mode Index (DMI) and low-trophic level organism variable. DMI is an index for IOD climate variation. The low-trophic level organism in the ocean and land domains are represented by phytoplankton chlorophyll-a concentration (Chl-a, mg m^{-3}) and normalized difference vegetation index (NDVI), respectively. Red (blue) color indicates that the low-trophic level organism will tend to increase (decrease) during positive Indian Ocean Dipole years. Map (b) is the same as (a) except for the correlation between Nino3.4 and low-trophic level organism variable. Nino3.4 is an index for ENSO climate variation.

- Over the Indonesian lands, both the IOD and ENSO influence the plant biomass (indicated by NDVI) in a similar spatial pattern, i.e., the biomass has tended to be low during the positive phase of IOD and/or positive phase of ENSO (El Nino). This spatial pattern of IOD's or

ENSO's footprint is attributed to severe drought climate during positive phases of IOD or ENSO. During the negative phases of IOD or ENSO, the opposite spatial climate footprint is true.

- High-trophic level organisms and fisheries production in the eastern Indian Ocean benefit from high phytoplankton biomass during positive phases of IOD and ENSO. The fisheries catch of commercial fishes such as Bullet Tuna, Mackerel, Sardine increases during the positive phases of IOD and ENSO.

- Weak correlations in other regions do not necessarily mean that the IOD and ENSO have no impacts on the low-trophic level organisms in those regions, but the footprints of IOD and ENSO and those regions may lag the time of IOD and ENSO peaks. For instance, lagged correlation between phytoplankton biomass in the South China Sea as shown in Figure 2 below.

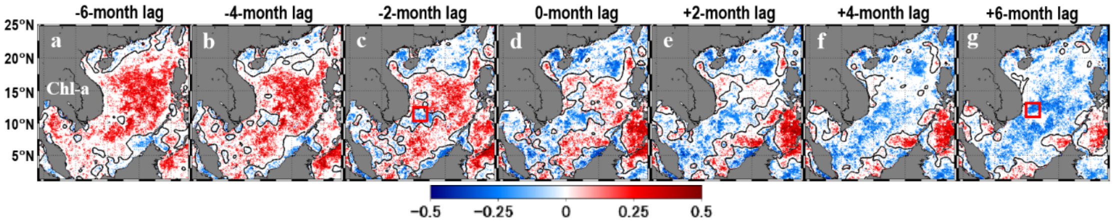

Figure 2. Spatial variations of correlation coefficients (r) derived from regressions of Chl-a against Nino3.4 at –6-month (a), –4-month (b), –2-month (c), 0-month (d), +2-month (e), +4-month (f), and +6-month (g) lags (where negative (–) lag refers to a lead by variables, and positive (+) lag refers to a lead by Nino3.4).

- In the marginal seas of the East and South China Seas, more complex atmosphere-ocean-land interactions (e.g., wind-driven coastal current, river discharge) associated with ENSO drive phytoplankton biomass of primary production variation.

- Following the peak of winter El Nino, Yangtze River discharge is anomalously high, and southerly winds along the Chinese coast are weak. These two conditions allow the surface current from the Yangtze River mouth to strengthen resulting in an unusual southeastward dispersion as shown in Figure 3 below.

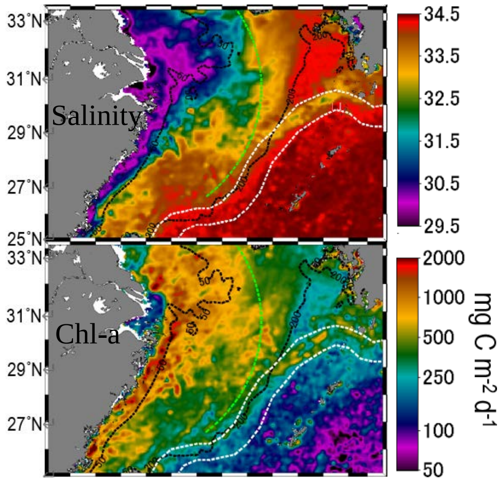

Figure 3. Spatial distributions of surface salinity and phytoplankton primary production during summer 2010 estimated from remote sensing ocean color data. The filament-like patterns of low salinity and high primary production are unusual offshoreward dispersion which is possible because of high rainfall and weak southerly winds associated with El Nino.

- Rather than IOD and ENSO, the western North Pacific Ocean is more influenced by the Pacific Decadal Oscillation (PDO). But, phytoplankton biomass in the subarctic and subtropical western North Pacific Ocean response differently to the PDO because of the difference in the main limiting factors, i.e., light in the subarctic region but nutrients in the subtropical region.

- Apart from the Asia-Pacific regions, climate change, as well as global warming, largely influence phytoplankton Chl-a in the Arctic Ocean and subarctic ocean as can be depicted by long-term trends of phytoplankton CHL and sea surface temperature (SST) (see Figure 2 below).

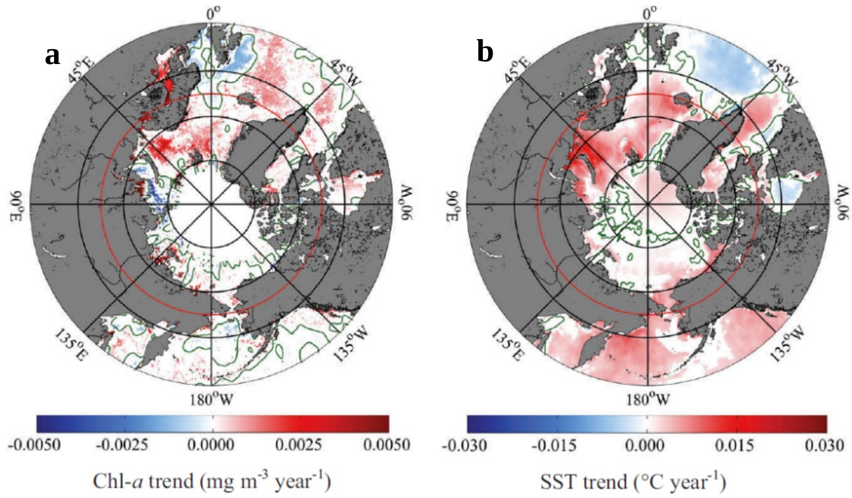

Figure 4. Trends (changes/year) of Chl-a (a) and SST (b) with the past two decades (1997 – 2017) in the Arctic and subarctic oceans. The Red (blue) color indicates an increasing (decreasing) trend.

- Depend on the regions in the Arctic and subarctic oceans, the ENSO or the Pacific Decadal Oscillation (PDO) is more prominent than in the regions elsewhere in driving the variability of phytoplankton Chl-a. The detailed climate change/global warming impacts in different regions in the Arctic and subarctic oceans will be described in the Results and Discussion Section.
- Over the South Asian land with Bangladesh as a case of study, temperature vegetation dryness index (TDVI, Figure 5) along with the meteorological data (rainfall and temperature) is an important measure for assessing drought and future drought risk.

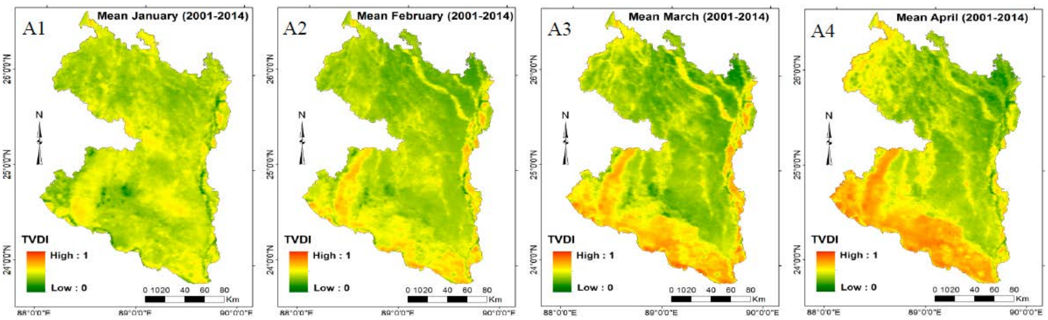

Figure 5. Monthly mean spatial distribution of the Temperature Vegetation Dryness Index (TVDI), for January, February, March, and April over 14 years (2001–2014).

Potential for further work

Regional networking, research collaborations, and research capacity that have been built and improved during the period of this project are very important modal and resources that will lead to further regional research collaborations. This project has mapped the areas in the Asia-Pacific region which are sensitive to and largely impacted by basin-scale climate changes, as well as understand the mechanisms of how climate variations modifying the land-ocean-atmosphere interactions in influencing the ocean and land ecosystems. Understanding the mechanisms and predictive skills on how climate will impact the ecosystems (and hence human life) is very important for climate change adaptation. However, to take more concrete and accurate climate change adaptation actions, rapid distribution of climate change adverse impacts is also essential. Therefore, among the current project collaborators are now proposing a new research project to develop a near-real-time observing system to monitor Asia-Pacific regions. Actions to tackle marine environmental problems such as harmful algal blooms, hypoxia, drink water contamination, human poisoning etc. will benefit from the near-real-time observing systems. Among the collaborators are also planning to prepare a research proposal related to microplastic debris monitoring.

Publications

Peer-Reviewed Publications

Matsumoto, K., Sasai, Y., Sasaoka, K., Siswanto, E., Honda, M.C. (2021), The formation of subtropical phytoplankton blooms is dictated by water column stability during winter and spring in the oligotrophic northwestern North Pacific, Journal of Geophysical Research: Oceans, 126(4), e2020JC016864. https://doi.org/10.1029/2020JC016864

Lumban-Gaol, J., Siswanto, E., Mahapatra, K., Natih, N.M.N., Nurjaya, W., Hartanto, M.T., Maulana, E., Adrianto, L., Rachman, H.A., Osawa, T., Rahman, B.M.K., Permana, A. (2021), Impact of the strong downwelling (upwelling) on small pelagic fish production during the 2016 (2019) negative (positive) Indian Ocean Dipole events in the eastern Indian Ocean off Java, Climate, 9(2), 29. https://doi.org/10.3390/cli9020029

Siswanto, E., Horii, T., Iskandar, I., Gaol, J.L., Setiawan, R.Y., Susanto, D. (2020), Impacts of climate changes on the phytoplankton biomass of the Indonesian Maritime Continent, Journal of Marine System, 212, 103451. https://doi.org/10.1016/j.jmarsys.2020.103451

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Sarker, Md. L.R., Janet, N., Mansor, S.A., Ahmad, B.B., Shahid, S., Chung, E.-S., Reid, J.S., Siswanto, E. (2020), An integrated method for identifying present status and risk of drought in Bangladesh, Remote Sensing, 12(17), 2686. https://doi.org/10.3390/rs12172686

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Siswanto, E., Xu, Y., Ishizaka, J. (2018), A rare dispersion of low-salinity, high-gelbstoff, high-primary production water in the East China Sea during the summer of 2010: Possible influence of the ENSO, Journal of Geophysical Research: Oceans, 123(4), 2757-2767. https://doi.org/10.1002/2017JC013319

Siswanto, E., Ye, H., Yamazaki, D., Tang, D. (2017), Detailed spatiotemporal impacts of El Nino on phytoplankton biomass in the South China Sea, Journal of Geophysical Research: Oceans, 122(4), 2709-2723. https://doi.org/10.1002/2016JC012276

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Siswanto, E., Honda, M.C., Sasai, Y., Sasaoka, K., Saino, T. (2016), Meridional and seasonal footprints of the Pacific Decadal Oscillation on phytoplankton biomass in the northwestern Pacific Ocean, Journal Oceanography, 72, 465-477. https://doi.org/10.1007/s10872-016-0367-z

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Non Peer-Reviewed Publications

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Sari, Q.W., Utari, P.A., Setiabudidaya, D., Yustian, I., Siswanto, E., Iskandar, I. (2018), Variability of surface chlorophyll-a distributions in the northwestern coast of Sumatra revealed by MODIS, Journal of Physics: Conference Series, 1080 012045. https://doi.org/10.1088/1742-6596/1080/1/012045

Awards and honours

Below are awards and honours awarded to early-career scientists who have been engaged in this project.

Awardee: Dr. Qurnia Wulan Sari

- Students travel award for attending 26th IHP (International Hydrological Programme) Training course in Asia and the Pacific Region on coastal vulnerability and Freshwater discharge, November 27th – December 10th, 2016, Nagoya, Japan by UNESCO.
- Fellowships for Sandwich Like Collaboration research with Institute for Space-Earth Environmental (ISEE) Nagoya University, Japan September-December 2018.
- Student travel award for attending the 6th Clim Eco Integrated Marine Biosphere Research (IMBeR) Summer School 2018: August 1st -8th, 2018 in University of Gadjah Mada, Yogyakarta, Indonesia.

- On board partcipant of the Expedition of Widya Nusantara 2017 Cruice chapter: November 25th – December 12nd 2017 in the westrern Sumatra Waters, Indonesia by Lembaga Ilmu Pengetahuan Indonesia (LIPI).
- Graduate with honors (cum laude) Department of Environmental Science, University of Sriwijaya.

Awardee: Ms. Siraporn Tong-u-dom

- Scholarship to pursue a Ph.D. degree at Ehime University, Japan. Her active participation in this project led her to receive a scholarship under the Memorandum of Understanding between Burapha University and Ehime University to carry out further research on "Development of physics-sediment-ecosystem model for Harima-Nada".

Pull quote

- "Climate change largely impacts the biosphere and ultimately humans. Climate changes, especially global warming, however, are the result of rapidly increasing human intervention to nature. Humans are now facing the so-called Anthropocene, the new geological era when global environmental changes are mainly driven by human activities. So, humans are now harvesting what they have done to nature for decades. As part of responsibilities to be taken, humans urgently have to take actions to tackle climate change-driven adverse impacts. Research-based evidence, i.e., climate change impacts on the land-ocean ecosystems, demonstrated by this project may be partly from the human intervention. This project has raised awareness of climate changes and their possible ecological and societal impacts in the Asia-Pacific region, especially in developing countries.
  Dr. Eko Siswanto (Principal Investigator)
  Deputy Senior Scientist
  Japan Agency for Marine-Earth Science and Technology

- "This APN project builds on the understanding of global climate change for regional marine ecosystems through research collaborations in Asia. This cooperation allows our institutions to get an advantage from the transfer and exchange of knowledge among the member researchers. It also helps in empowering graduate students to gain knowledge and work experience as research assistants. The benefits resulting from this cooperation to people and the nation are information for adapting to future environmental changes in the region".
  Dr. Prasarn Intacharoen
  Head, Department of Aquatic Science, Faculty of Science, Burapha University

- "This collaborative research helps us understand the mechanisms of regional marine ecosystem impacts from climate change. This is essential to humanity's adaptation to the world's climate change problem we are facing now. The valuable experience researchers obtained can also be transferred to students and the public through teaching and lectures on various occasions. Thank you to APN for the financial support and Dr. Eko Siswanto, the project leader, and staff at JAMSTEC for research facilitation and coordination".
  Dr. Anukul Buranapratheprat (Co-Principal Investigator)
  Associate Professor
  Department of Aquatic Science, Faculty of Science, Burapha University

- "This APN collaborative project provides me research opportunity with many specialists in the field of remote sensing, numerical modeling and marine biology from both national and international organizations. Climate change research capability in our institution is then significantly enhanced. This also help me to the get better understanding of the mechanisms of physical and biogeochemical processes in the ocean. The opportunity to deliver presentations of our research outcomes to international scientific workshops is also provided. I am very grateful to APN for the financial support and project leaders in Japan and Thailand for providing this opportunity".

Ms. Siraporn Tong-u-dom
Graduated student, Research assistant
Department of Aquatic Science, Faculty of Science, Burapha University

- "This is the challenging research project for Indonesia as a large coastal nation. I am very happy to be part of this research project as it was one of the best learning and working experiences of my career. I did gain a lot of experience of working with people from many different countries, especially in the field of ocean remote sensing. Working with the world's leading ocean color remote sensing experts allowed me to learn new skills that will be incredibly valuable to my research. This opportunity also allowed me to connect with many other scientists working in this field. In addition, this project also allowed me to gain an invaluable network of peers from Asia-Pacific region who bring their own expertise and experience that further enriching my experience. Thank you APN for sponsoring this incredible project!".
  Dr. Iskhaq Iskandar (Co-Principal Investigator)
  Professor
  Faculty of Mathematics and Natural Sciences, Sriwijaya University

- "My enthusiasm for ocean color remote sensing study was initially fostered when our lecture has shown us the satellite image for surface chlorophyll-a in the Indonesian sea. I realized that Indonesia has great marine and coastal resources. However, Indonesia still faces many problems related to this subject, such as resource depletion, degradation of the coastal ecosystem, and lack of human resources to manage those potential marine and coastal resources. Through this research project, I gained a lot of knowledge and experience working with satellite oceanography. In addition, I also learned how to work as a team, developing a research plan, and working with various people especially in the field of ocean color remote sensing. I am now at my new institution, Department of Marine Science, Padjadjaran University, Bandung, Indonesia. I will transfer my knowledge and experience gained from this research project to undergraduate and post-graduate students. With this greater knowledge background and experience, I will be able to help them better than I can now. It is very important to educate the young students about the importance of the ocean for our future life".
  Dr. Qurnia Wulan Sari
  Lecturer
  Faculty of Fisheries and Marine Sciences, Padjadjaran University

Acknowledgments

This project will not be able to be completed without strong commitment and collaborations from the collaborators mentioned above and supports from their institutes. We would like to thank postgraduate students and early-career scientists from collaborating institutes who hardly worked and provided contributions to this project. We also would like to thank all anonymous reviewers for their valuable advice, instructions, and suggestions when reviewing our scientific papers. Our works can be done also because of free satellite and re-analyzed data provided by the Ocean Biology Processing Group (OBPG) at the NASA Goddard Space Flight Center, the NASA EOSDIS Physical Oceanography Distributed Active Archive Center (PO.DAAC), the National Center for Atmospheric Research, Copernicus Marine Environment Service (CMEMS), the Asia-Pacific Data Research Center (APDRC), and the NOAA Climate Prediction Center.

1. Introduction

The Earth is now under the so-called ‘Anthropocene’ the new geological era when the changes on Earth's surface are more influenced by human activities. Global warming due to increasing greenhouse gasses in the atmosphere is a concrete footprint of human-induced Earth’s change. Scientists suggest that global warming also influences the basin-scale climate variations such as the El Nino/Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) (Karamperidou et al., 2020).

Specifically, the Asia-Pacific land and ocean ecosystems are vulnerable to both basin-scale climate changes and human activities. This is because the Asia-Pacific region is located between the Indian Ocean and the Pacific Ocean where the IOD and ENSO occur, respectively, and surrounded by densely populated countries. Currently, about 40% of Asia’s population lives within 100 km of the coast and about 60% within 400 km of the coast. The concentration of human settlements in the coastal zone is caused by the economic benefits that can be gained from coastal industries/activities such as marine aquaculture, tourism, and recreation. However, population density and economic growth in the coastal zone increase the pressures on the marine coastal ecosystems.

Among the most important pressures in the lands are land use/cover change, habitat conversion, and biodiversity losses, whereas in the marine environments are increasing rate of organic and inorganic material loads that lead to coastal water pollution, eutrophication, red tide outbreaks, hypoxia, which eventually cause coastal industrial damages, ecosystem destructions, huge livelihood/economic losses, and adverse societal impacts (e.g., severe illness and fatalities to humans).

Furthermore, by varying precipitation, river discharge, wind-driven upwelling/downwelling, and atmospheric aerosol deposition, climate change (including global warming) can accelerate the aforesaid environmental problems (Palani et al., 2007; Villanoy et al., 2011; Siswanto, 2015; Xiao et al., 2019; Yñiguez, et al., 2020). To plan concrete and accurate actions to tackle the adverse impacts of climate change, identifying the regions which are vulnerable to climate change as well as understanding the responsible mechanisms are very important prerequisites in the integrated measures and policies of climate change adaptation.

To identify the detailed spatial fingerprint of climate changes over the Asia-Pacific region, big datasets covering the large area over a long-term period consisting of couples of climatic oscillations are needed. Thus, this project is designed to understand the impacts of basin-scale climate variability on the Asia-Pacific region ecosystem, especially on its low-trophic level organisms, by constructing the low-trophic level organism database over the Asia-Pacific region.

2. Methodology

2.1. Study Areas

Researches which have been carried out during this project mainly focus on the Asia-Pacific region and the Arctic-subarctic region (see Figure 6). While the Asia-Pacific region, due to its location between the Indian Ocean and the Pacific Ocean, is vulnerable to IOD and ENSO (e.g., Saji et al., 1999; Wilson and Adamec, 2001), the Arctic-subarctic region is sensitive to global warming (e.g., Agusti et al., 2010).

This document will only report the key studies focusing on the main areas such as Bangladesh, Bay of Bengal, eastern Indian Ocean, Maritime Continent, the subtropical marginal seas, western North Pacific Ocean, and the Arctic-subarctic region. Detailed reasons for these study region selections can be read in their full papers as listed in the Publications section above.

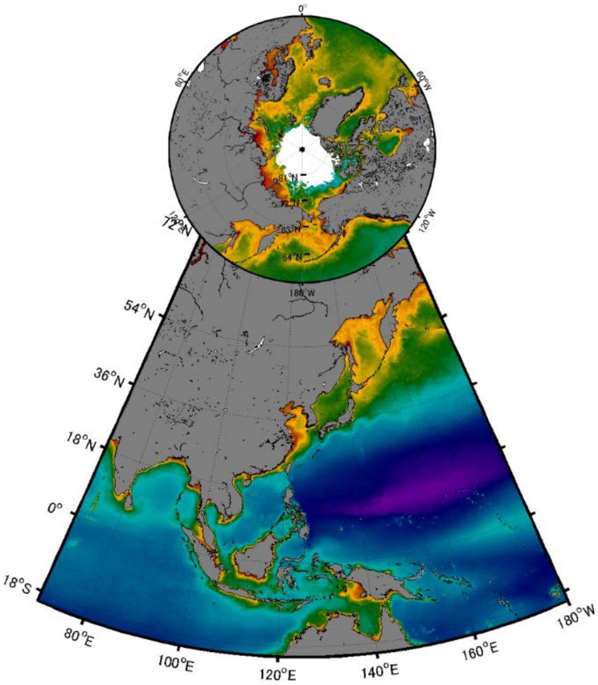

Figure 6. Map of study regions focused during this project encompassing the vast area from the eastern Indian Ocean to the western North Pacific Ocean as well as the Artic-subarctic region.

2.2. Satellite and Reanalyzed Data

The studies conducted in this project mainly used satellite remote sensing data constructed by this project and modeled/reanalyzed data acquired from their sources. Depending on the environmental variables, the data sources are different. For phytoplankton chlorophyll-a (Chl-a) data were acquired from the Ocean Colour-Climate Change Initiative (OC-CCI) Project (https://esa-oceancolour-cci.org/), the GloColour Project (http://www.globcolour.info/), and the NASA Ocean Biology Processing Group (OBPG, http://www.globcolour.info/).

Land vegetation index data were acquired from the NASA-OBPG and the Land Processes Distributed Active Archive Center (LP DAAC, https://lpdaac.usgs.gov/). Sea surface temperature (SST) data were downloaded from the Copernicus Marine Environment Monitoring Service (CMEMS, http://marine.copernicus.eu/) and Physical Oceanography Distributed Active Archive Center (http://podaac.jpl.nasa.gov/AVHRR-Pathfinder), whereas for land surface temperature (LST) data were from LP DAAC. Wind speed and direction data were acquired from the Cross-Calibrated Multi-Platform (CCMP) Project (http://podaac.jpl.nasa.gov/), satellite sea surface height anomaly (SSHA) data were from CMEMS and AVISO+ (https://www.aviso.altimetry.fr/), and reanalyzed ocean mixed layer depth (MLD) were from the CMEMS. As a proxy of nutrient load from the land, the project used modeled river discharge data from the JAXA (https://www.eorc.jaxa. jp/water/) and rainfall data from the Climate Prediction Center Merged Analysis of Precipitation (CP-CMAP, (https://www.esrl.noaa.gov/psd/data/gridded/data.cmap.html). Besides modeled discharge, in situ river discharge data from Datong hydrological gauge (http://www.hydroinfo.gov.cn) were also used.

As measures of climate variability, the project used common indices of climate change, i.e., the Nino3.4 an index for ENSO (http://www.cpc.ncep.noaa.gov/data/indices/sstoi.indices), dipole mode index (DMI) for IOD (http://www.jamstec.go.jp/aplinfo/sintexf/iod/dipole_mode_index.html), and Pacific Decadal Oscillation Index (PDOI) for PDO (http://jisao.washington.edu/pdo). The project also used in situ temperature and salinity data measured by Argo floats. The Argo float data were acquired from the Japan Agency for Marine-Earth Science and Technology (JAMSTEC, http://www.ja mstec.go.jp/ARGO/argo_web/argo/?page_id=100&lang=en) and Argo float data portal (http://www. argodatamgt.org/Access-to-data/Argo-data-selection).

2.3. Data Analysis

Spatiotemporal data analysis was mainly conducted in four approaches, i.e., 1) composite analysis to average the data during normal years separately from data during extreme climatic events and compare their difference, 2) general linear regression analysis to directly correlate a measure of climate variation (climatic index) to an environmental variable of interest to identify the spatial variation of sensitivity to climate changes, 3) multiple linear regression analysis to relate variable of interest to probable environmental variables and assess the main forcing factors that play an important role behind the climate changes, and 4) empirical orthogonal function (EOF) analysis to find the main modes of spatiotemporal variations of the variable of interest and then relate the main modes to climate index. Linear regression and EOF analysis require spatiotemporally filled data, so spatiotemporal interpolation was conducted to reconstruct missing data.

Missing data are commonly found in satellite Chl-a and SST data due to cloud coverage and rain belts. Therefore, spatiotemporal interpolation was applied to Chl-a and SST datasets using the EOF-based data interpolation (e.g., Alvera-Azcárate et al., 2005). All spatiotemporal analysis was carried out using these constructed no-gap datasets.

3. Results & Discussion

This section reports the main results from the main articles selected among those listed in the publication section above. The reason for this selection is the articles directly mention climate change impacts. The results will be followed by discussion and organized into four main subsections based on study areas' geographic position, i.e., maritime continent, marginal seas, Artic-subarctic regions, and south Asia-Bay of Bengal. Full results and discussion of what will be reported here can always be seen from their original articles listed in the publication section.

3.1. Maritime Continent

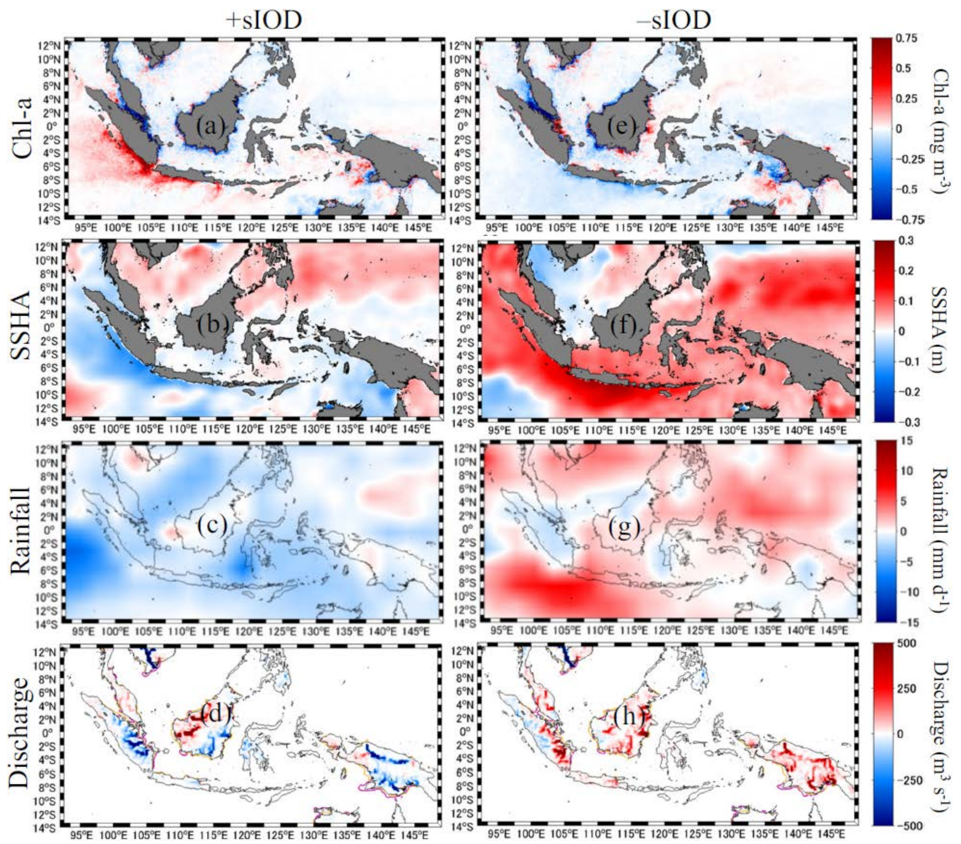

Figure 7. (a) Map of mean Chl-a during +sIOD event averaged from September to December. The Chl-a was determined by subtracting the mean Chl-a during neutral condition (2001, 2003, and 2013) from the mean Chl-a during +sIOD event (2012 and 2019). Panels (b), (c), and (d) are the same as panel (a), but they are maps of SSHA, rainfall, and river discharge, respectively. Panels (e–h) are the same as panels (a–d), but they correspond to a -sIOD event.

Results and discussion in this part are cited from Siswanto et al. (2020) and Lumban-Gaol et al. (2021). The maritime continent due to its location which is between the Indian and Pacific Oceans is expected to be sensitive to climate variations of the IOD and ENSO. The left column of Figure 7 shows anomalies of Chl-a, SSHA, rainfall, and river discharge during a single positive IOD (+sIOD), deviations from the same variables during neutral years. In general, during +sIOD Chl-a from the eastern Indian Ocean to the eastern Indonesian archipelagic seas is high (Figure 7a). High Chl-a is attributed to increased nutrients from the deep layer lifted by upwelling as indicated by low SSHA (Figure 7b). In contrast in the coastal regions, Chl-a tends to decline probably due to the decrease of nutrient supply from the land as rainfall (hence river discharge) tends to decrease during +sIOD (Figure 7c, d).

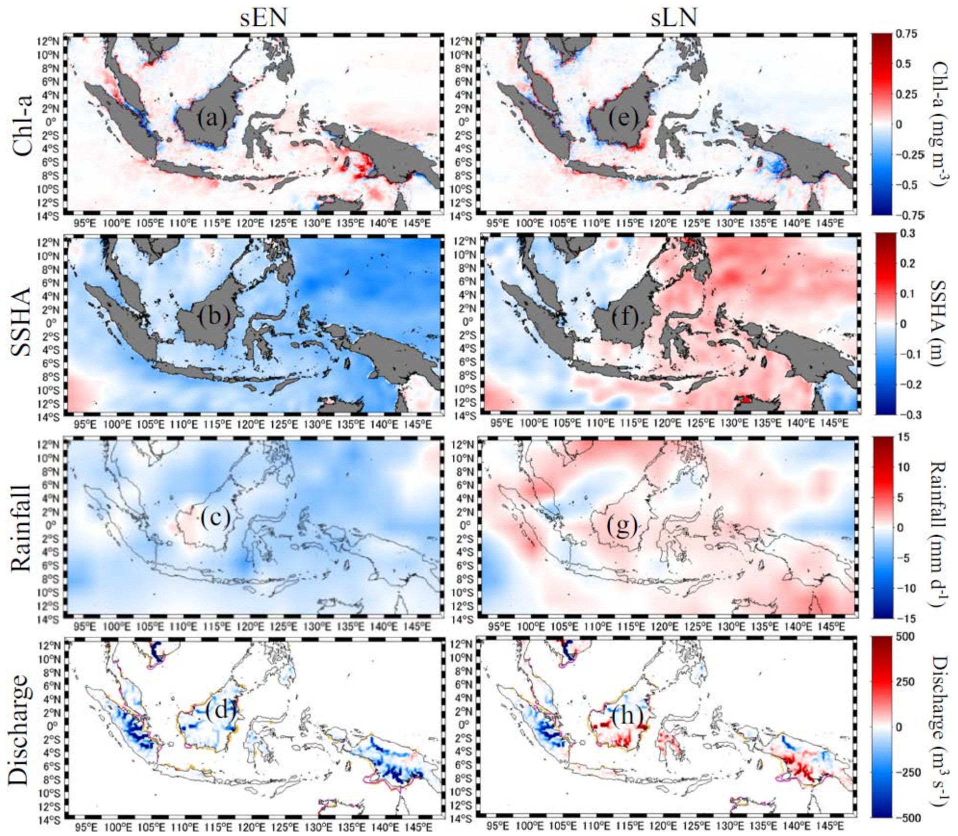

Figure 8. (a) Map of mean Chl-a during sEN event averaged from September to December. The Chl-a was calculated by subtracting the mean Chl-a during neutral condition (2001, 2003, and 2013) from the mean Chl-a during sEN event (2002, 2004, and 2009). Panels (b), (c), and (d) are the same as panel (a), but they are maps of SSHA, rainfall, and river discharge, respectively. Panels (e–h) are the same as panels (a–d), but they correspond to sLN events (1999 and 2000).

During -sIOD (right column of Figure 7), Chl-a from the eastern Indian Ocean to the eastern Indonesian archipelagic seas tends to decline (Figure 7e) which is attributed to the reduction of surface layer nutrient caused by downwelling as depicted by high SSHA (Figure 7f). In many coastal regions, Chl-a tends to increase mainly due to increased nutrient supply from the land associated with high rainfall (hence river discharge) (Figure 7g, h).

Similar to Figure 7, Figure 8 also shows anomalous Chl-a, SSHA, rainfall, and river discharge, but during the single El Nino (left column) and single La Nina (right column) event. Chl-a from the eastern Indian Ocean to the eastern archipelagic seas during El Nino (Figure 8a) tends to be high, but not as high as that during +sIOD (Figure 7a). Relatively high Chl-a during El Nino is also attributed to upwelling (Figure 8b). Rainfall (hence discharge) (Figure 8c, d) tends to be low the factor that causes low Chl-a in many coastal regions. In general, Chl-a also tends to be high during La Nina (Figure 8e).

The contrasting pattern between high Chl-a during +sIOD and low Chl-a during -sIOD (Figure 7a, e) is much more remarkable than that between El Nino and La Nina (Figure 8a, e). The more pronounced Chl-a contrasting pattern during IOD than during ENSO is caused by the fact that the contrasting patterns of other geophysical variables (SSHA, rainfall, and discharge) also tend to be more pronounced during IOD than during ENSO. This can be an indication that the IOD event influences biogeophysical variabilities stronger than the ENSO.

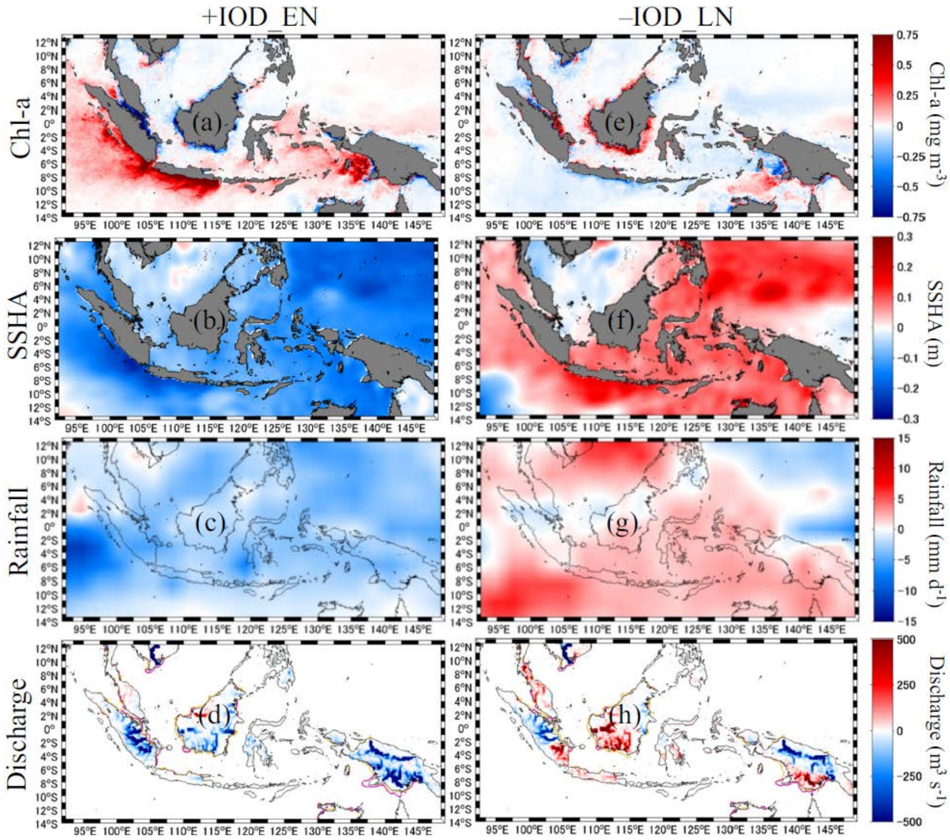

Figure 9. (a) Map of mean Chl-a during +IOD_EN event averaged from September to December. The Chl-a was calculated by subtracting the mean Chl-a during neutral condition (2001, 2003, and 2013) from the mean Chl-a during +IOD_EN event (1997, 2006, and 2015). Panels (b), (c), and (d) are the same as panel (a), but they are maps of SSHA, rainfall, and river discharge, respectively. Panels (e–h) are the same as panels (a–d), but they correspond to -IOD_LN events (1998 and 2010).

Figure 9 that shows anomalies of Chl-a, SSHA, rainfall, and river discharge during concurrent +sIOD and El Nino event (hereafter +IOD_EN, left column) and anomalies of the same biogeophysical variables during concurrent -sIOD and La Nina (hereafter -IOD_LN, right column). It is clear that the contrasting pattern of biogeophysical variables between +IOD_EN and -IOD_LN is much more similar to that between +IOD and -IOD that than between El Nino and La Nina. This fact confirms the more dominant impact of IOD than that of ENSO in the maritime continent.

The contrasting pattern of low and Chl-a can be specifically seen during 2016 -sIOD and 2019 +sIOD (Figure 10). Chl-a within the period from July to October 2016 (-sIOD, left column of Figure 10) is much lower than that in the same period 2019 (+sIOD, right column of Figure 10). The highest Chl-a increase during 2019 +sIOD is observed in the Pelabuhanratu Bay reaching a concentration of > 10 mg m^{-3}.

Interestingly, the commercial fish (e.g., Bullet Tuna, Mackerel, Indian Scad, Sardine, Moonfish, small shrimp, etc.) landing in the Pelabuhanratu fish landing port during +sIOD is much higher than that during -sIOD (Figure 11). Clearly, the high fisheries production is attributed to high phytoplankton primary production as surrogated by high phytoplankton Chl-a. Note that the aforesaid tendency of high fisheries production which is accompanied by high Chl-a is observed not only in the Pelabuhanratu Bay but also in the other coastal regions extending from the west coast of Sumatra to the south coast of Java including the Bali Strait of Indonesia. These results are consistent with Sartimbul et al.'s (2010) study showing high Sardinella Lamuru fish catch in the Bali Strait during 2007 +sIOD. Therefore, climate changes largely influence not only low-trophic (phytoplankton Chl-a), but also high-trophic level organisms (fishes).

It is thus can be expected that not only in the Pelabuhanratu Bay and Bali Strait, other regions showing high Chl-a during +sIOD (e.g., along the coast from west Sumatra to south Java and eastern Indonesian archipelagic seas) may also have high fisheries landing and/or landing. Unfortunately, unlike satellite Chl-a data, fisheries production and landing data are not available publicly, so how the climate changes impact fisheries production in other regions in the maritime continent are still understudied. Collaborations to record and share the fish catch and landing dat are thus needed not only among the research/academic institutes but also including fisheries companies to address this issue in the new platform of research collaboration in the future.

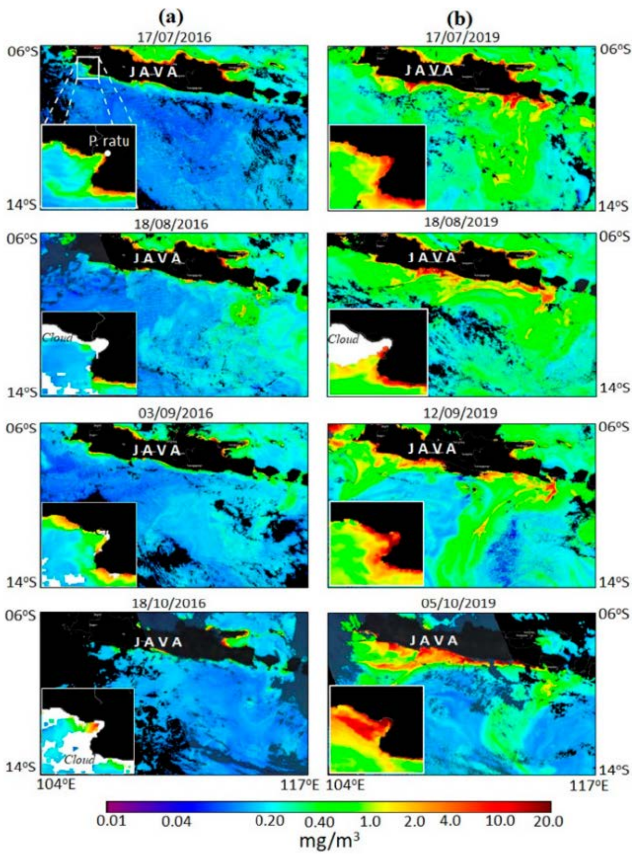

Figure 10. Distributions of chlorophyll-a concentration (July–October) in the Eastern Indian Ocean off Java and the Palabuhanratu Bay during: (a) the 2016 Indian Ocean Dipole negative phase; and (b) the 2019 Indian Ocean Dipole positive phase. The chlorophyll images of each month (July–October) are shown using the daily image of the cloud-free days available during the respective months.

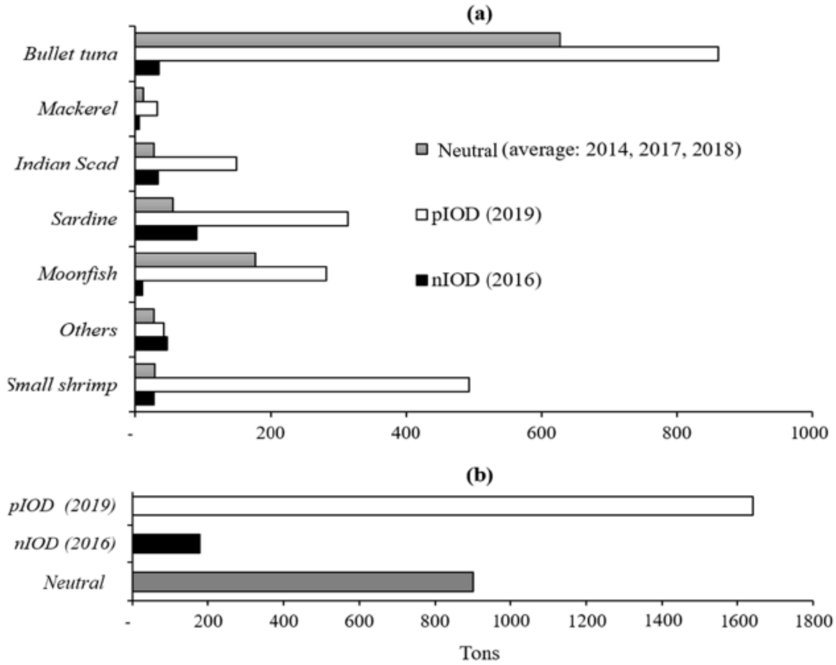

Figure 11. Variation in the catches of small pelagic fish (a) by species, and (b) total catch in the Palabuhanratu Fishing Port during the neutral conditions (average of 2014, 2017, and 2018), -sIOD (2016) and +sIOD (2019).

3.2. Marginal Seas

The South China Sea is the largest marginal sea in the Asia-Pacific region. In this study, the project used lagged-correlation analysis (linear correlation between geophysical variables and climate index) to understand the detailed spatiotemporal response of biogeophysical variables to the ENSO. Figure 12 shows the maps of correlations between variables Chl-a (1st line), SST (2nd line), meridional wind speed (VW, 3rd line), and zonal wind speed (UW, 4th line) and Nino3.4 (index of ENSO) with different time lags, from 6 months (-6-month lag) before to 6 months (+6-month lag) after the peak of winter ENSO. Positive (red areas) correlation means Chl-a tends to be high (or higher than a normal year) during the El Nino year, whereas the negative correlation (blue areas) means that Chl-a tends to be low (or lower than a normal year) during the El Nino.

However, the spatial response of Chl-a to El Nino depends on the time relative to the winter peak of El Nino (0-month lag) (Figure 12a-g). Chl-a tends to be high 6 months before the peak of ENSO and tends to decline thereafter to reach the lowest Chl-a level 6 months after the ENSO peak. Interestingly, the opposite correlation is observed between the SST and Nino.3.4 (Figure 12h-n), i.e., low SST (high SST) in 6 months before (after) the peak of El Nino. High (low) phytoplankton Chl-a accompanied by low (high) SST explains the general nutrient (from deep layer) limitation in the South China Sea. High Six months before the El Nino peak, high Chl-a is attributed to increased input of nutrients from the deep layer driven by upwelling as indicated by SST cooling. The opposite mechanism due to downwelling is true for low Chl-a and high SST in 6 months after the El Nino peak.

Tan and Shi (2009) and Zhao and Tang (2007) showed similar results but only over the small and limited area west of the Vietnamese coast (see small red box in Figure 12c, 12g). Therefore, the importance of this project result is the response of biogeophysical variables to ENSO can be observed over a much larger area (entire South China Sea basin) than that previously shown by previous works. The impact of ENSO on the low-trophic level organism in the South China Sea has been known from this project. But how the high-trophic level organisms (fisheries resources) will be impacted by Chl-a changes related to ENSO variation is still unclear. As already discussed, in the maritime continent high

Chl-a due to +sIOD increases fisheries catch/landing. So, in the future, it is worth investigating how the ENSO will impact the fisheries catch/landing in the South China Sea.

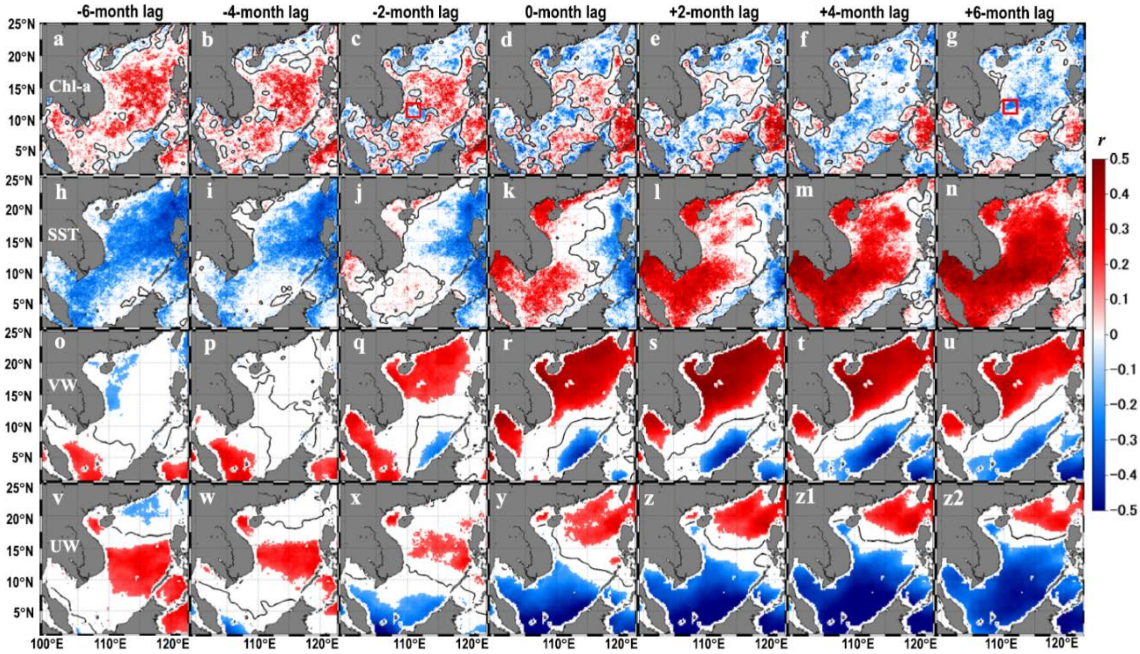

Figure 12. Spatial variations of correlation coefficients (r) derived from regressions of Chl-a against Nino3.4 at (a) 26 month, (b) 24 month, (c) 22 month, (d) 0 month, (e) 12 month, (f) 14 month, and (g) 16 month lags (where negative (–) lag refers to a lead by variables, and positive (1) lag refers to a lead by Nino3.4). (h–n, o–u, v–z2) The same as Figures 6a–6g, except that values of r were derived from regressions of Nino3.4 against SST, VW, and UW, respectively. White areas and black lines indicate insignificant r (p>0.05) and r50, respectively. The red box in Figures 6c and 6d aligns with Box S defined in Zhao and Tang [2007] and Tan and Shi [2009].

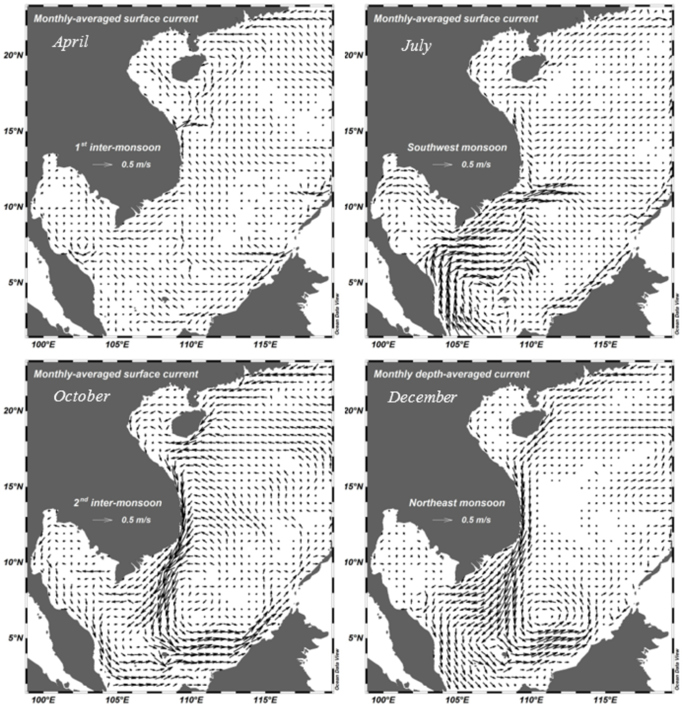

Figure 13. Simulated monthly surface currents in the South China Sea in April (1st inter-monsoon), July (southwest monsoon), October (2nd inter-monsoon) and December (northeast monsoon).

The impacts of ENSO on the South China Sea likely propagate into the Gulf of Thailand as can be depicted by Nino3.4-SST and Nino3.4-Chl-a correlations (see Figure 12a-n) which are in the same phase as observed in the South China Sea. This can be expected because the water column of the Gulf of Thailand is largely influenced by the South China Sea water column and Mekong River discharge (Figure 13, and see Buranapratheprat et al., 2016) that both of which are also largely influenced by the ENSO variability.

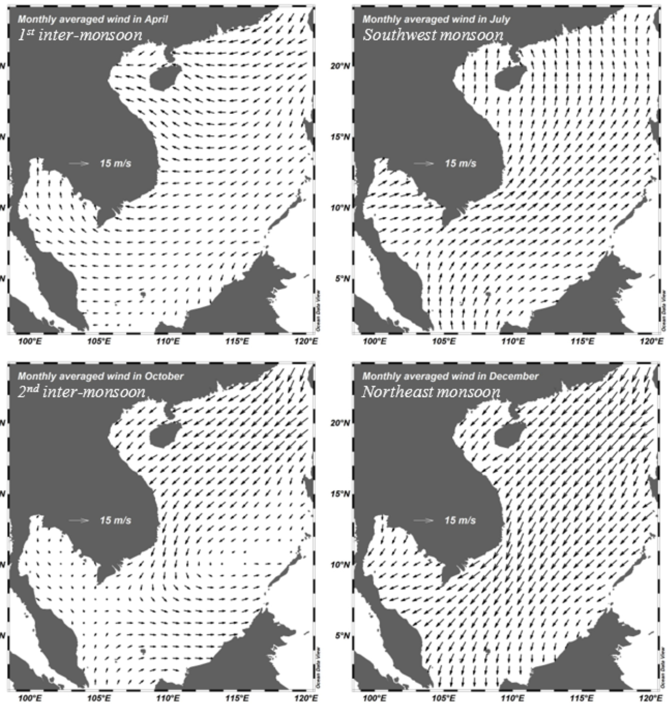

Figure 14 Monthly surface wind in the South China Sea in April (1st inter-monsoon), July (southwest monsoon), October (2nd inter-monsoon) and December (northeast monsoon). Data source from QuickScat (http://www.remss.com/).

Like in the South China Sea, the wind field in the Gulf of Thailand is also greatly influenced by the Asian monsoon (Figure 14). Therefore, the ENSO fingerprint in the Gulf of Thailand resembles that in the South China Sea.

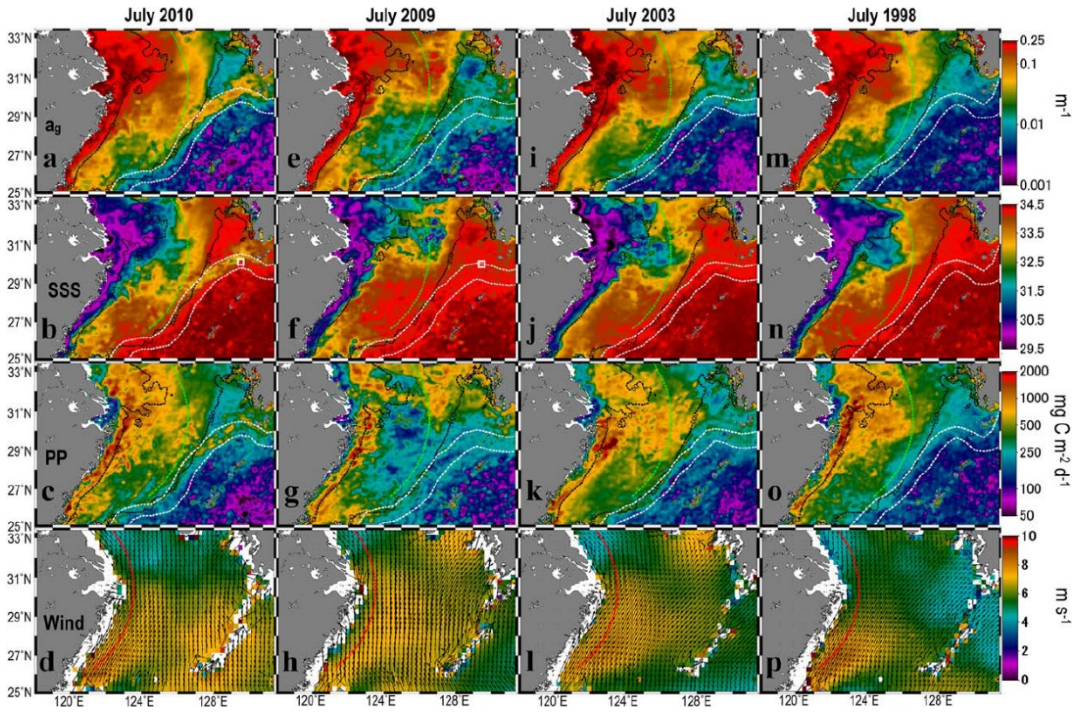

Figure 15. Spatial variability of (a) ag, (b) SSS, (c) PP, and (d) wind field in July 2010. Plots (e–h), (i–l), and (m–p) are the same as plots (a–d), but show data from July 2009, July 2003, and July 1998, respectively. White and green dashed lines (in the ag, SSS, and PP maps) indicate, respectively, the approximate edges of the Kuroshio Current axis and the arc corresponding to the ag, SSS, and PP time series data in Figures 4a–4c. Black dashed lines indicate the 50 and 200 m isobaths. White small squares in Figures 3b and 3f indicate the positions of Argo floats in July 2010 and July 2009, respectively, the salinity profiles of which are shown in Figure 5. Red dashed lines (in wind field maps) indicate the arc line corresponding to the wind field time series data in Figures 4d and 4e.

Another marginal sea investigated in this project is the East China Sea. The East China Sea receives a huge amount of freshwater (and hence organic and inorganic materials) from one of the World's largest rivers, the Yangtze River. Figure 15 presents the spatial distribution of dissolved organic matter (ag, 1st line), surface salinity (SSS, 2nd line), phytoplankton primary production (PP, 3rd line), and wind field (4th line) during July 2010, 2009, 2003, and 1998.

Terrigenous materials supplied from the lands can be depicted by high ag (due to high organic carbon), low SSS (due to freshwater discharge), and high PP (due to high input of inorganic nutrients) over the coastal region. Especially in July 2010 (Figure 15a, b, c), high ag, low SSS, and high PP waters formed elongated filament-like patterns extending from the center of the East China Sea to the area south of Kyushu, Japan. Such an unusual surface water dispersion is attributed to weak southerly winds and high Yangtze River discharge which are associated with the ENSO.

3.3. Western North Pacific Ocean and Arctic-subarctic Region

The project also tried to identify the impacts of both the ENSO and the PDO on the low-trophic level organism (represented by Chl-a) in the western North Pacific Ocean. Observing spatial patterns of correlations between Chl-a and climate indices (Nino3.4 for ENSO and PDOI for PDO). Spatial variation of correlation between Chl-a and Nino3.4 and between Chl-a and PDOI is very similar. This is because the ENSO is the high frequency of PDO so that the high-frequency oscillation of PDO is the ENSO oscillation itself.

The left panels of Figure 16 show the maps of correlation derived by linearly regressing PDOI against Chl-a (a), MLD (b), SST (c), and PAR (d). In the Chl-a-PDOI correlation map, in general, a negative (positive) correlation is observed over the area north (south) of 42°N. The 42°N latitude can thus be considered as the border separating subarctic (north) from subtropical (south) areas of the Pacific Ocean sector. This means that during the positive phase of PDO, Chl-a in the subarctic (subtropical) area tends to be low (high). This is attributed to the tendency of deepened MLD during a positive phase of PDO as depicted by the positive correlation between MLD and PDOI (Figure 16b) and different phytoplankton limiting factors i.e., light and/or temperature (nutrients) in the subarctic (subtropical) area. Deepened MLD in the subarctic area leads to transport phytoplankton into a dim-light deep layer thus phytoplankton are exposed to a low light environment and hence reduces phytoplankton growth. In the subtropical area, a deepened MLD leads to increase surface nutrients and hence stimulates phytoplankton growth.

The importance of light and/or temperature in the subarctic area can also be confirmed by the positive values of partial regression coefficients for PAR (βPAR) and SST (βSST) (see Figure 16g, h) resulted from the multiple linear regression analysis. The importance of nutrients in the subtropical area can also be depicted by negative values of partial regression coefficients for SST (βSST).

Integrating all subarctic regions from both Pacific and Atlantic sectors, the annual mean of Chl-a over the entire subarctic region has tended to increase within the period from 1997 to 2012 but tended to decline thereafter (Figure 17b). Similar Chl-a temporal trends are also observed in the Arctic Ocean (Figure 16a). Attributed to anthropogenic global warming, SST in the Arctic and subarctic oceans has tended to increase within the past two decades (Figure 17a, b). As one of the results, the sea ice concentration (SIC) in the Arctic Ocean has tended to decline within the past two decades (Figure 17a).

Linearly regressing Chl-a from 1997 to 2017, an increasing Chl-a trend is observed almost over the entire Arctic-subarctic ocean (Figure 18a). In the Arctic Ocean, increasing SST and reducing SIC (Figure 18b, e) play the main factors for Chl-a increasing trend. However, the temporal variation of aggregate Chl-a shows a declining trend since 2012. The aggregate Chl-a declining trend since 2012 is caused by declining Chl-a in many parts of the Arctic-subarctic oceans which are attributed to many factors such as climate variations (PDO, ENSO, Atlantic Meridional Overturning Circulation), river discharge, water column stratification, etc. Thus, declining Chl-a since 2012 is not related to global warming, because both SST and SIC still show increasing trends till 2017.

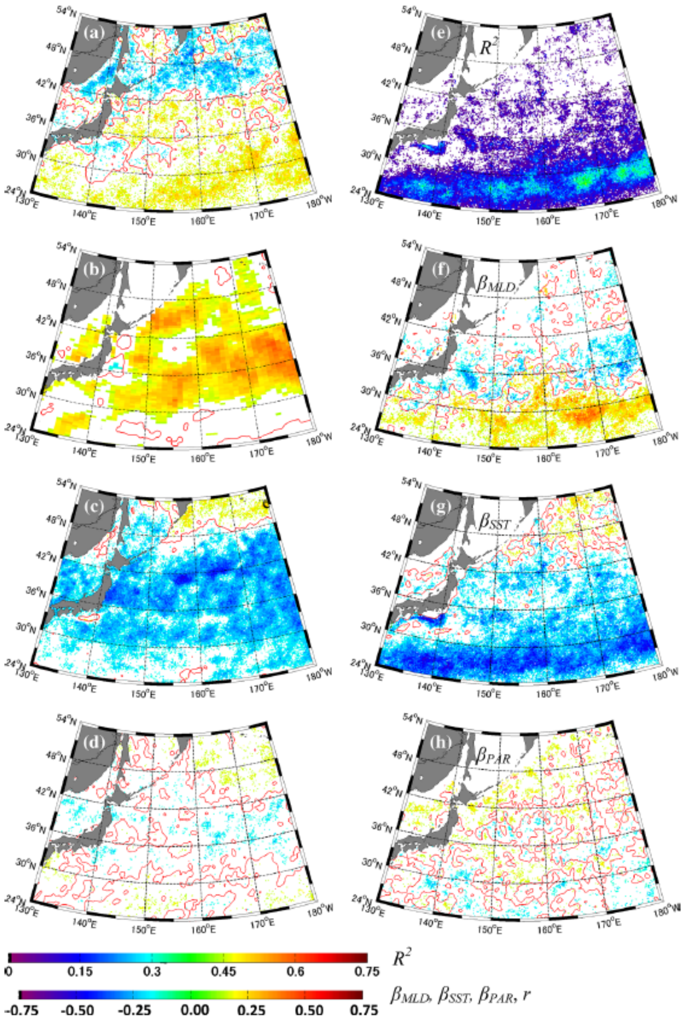

Figure 16. Left panels: spatial variations of significant correlation coefficients derived from regressions of Chl (a), MLD (b), SST (c), and PAR (d) against PDOI based on 16-year monthly anomaly data (all seasons) from September 1997 to June 2013. Areas with insignificant correlation values are masked out (white areas). The anomaly data were derived by removing variable seasonal cycles and long-term trends. Red contours indicate zero correlation values. Right panels: spatial variations of significant coefficients of determination, standardized partial regression weights for MLD (βMLD) (f), SST (βSST) (g), and PAR (βPAR) (h) derived from multiple linear regressions of the standardized Chl anomaly on standardized SST, MLD, and PAR anomalies (Chl = I + βMLD MLD + βSST SST + βPAR PAR, where I is the intercept) using all monthly data (all seasons) from September 1997 to June 2013. The areas with insignificant coefficients, βSST, βMLD, and βPAR are masked out (white areas). Red contours indicate zero contours for βSST, βMLD, and βPAR.

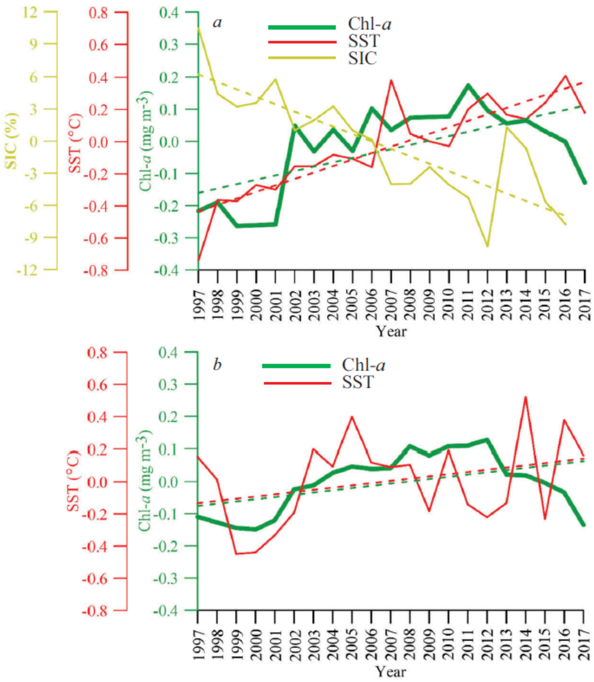

Figure 17. Temporal variations of SIC (yellow line), SST (red line), and Chl-a (green line) annual means in (a) the entire Arctic Ocean and (b) the entire subarctic region (excluding SIC) from 1997 to 2017. Annual mean values are the average of data collected from April to September. Dashed lines were fitted by linear regression to data of the corresponding colour.

The long-term trend of geophysical variables depends largely on the period of the data used. The trends can also be driven by the dominant climates that occur within the investigation period. Therefore, updating the global trends of geophysical variables every five years is worth investigating to understand the most recent trends and valuable for predicting climate impacts and mitigation scenarios in the future.

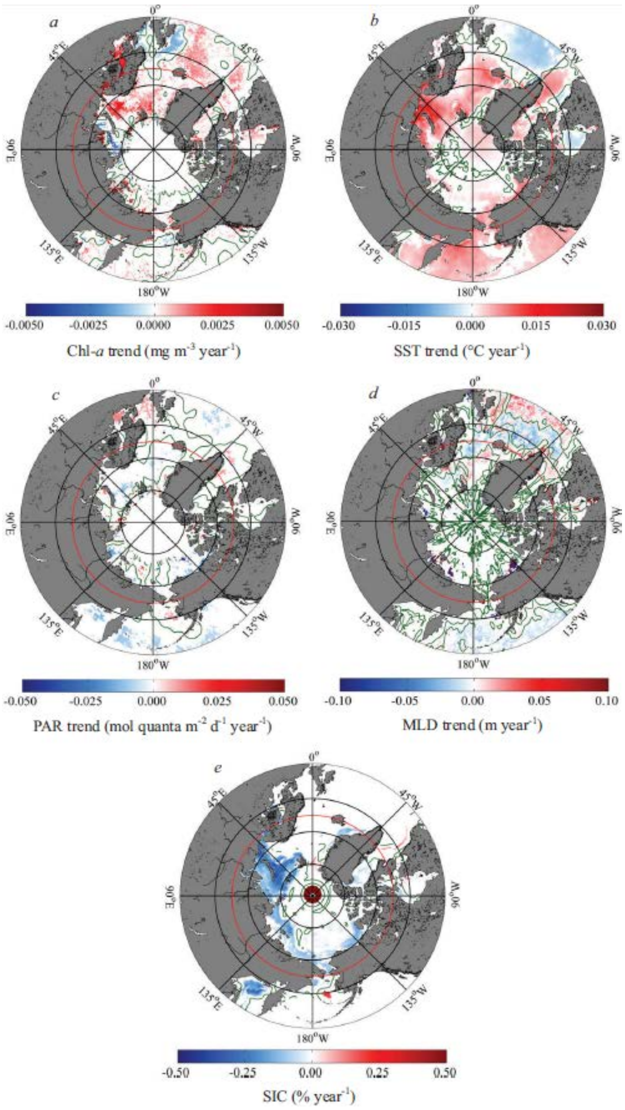

Figure 18. Spatial variation of overall trends of (a) Chl-a, (b) SST, (c) PAR, (d) MLD, and (e) SIC in the ASAO, calculated by a robust regression analysis of datasets covering 1997–2017. Areas where the trend was insignificant at the 95% confidence level (Mann-Kendall trend test) are masked (white areas). The green line denotes a trend value of zero. The solid-red circle denotes the Arctic circle (65°N).

3.4. South Asia and the Bay of Bengal

Besides in the southeast Asian and east Asian regions, the changes in the land-ocean-atmosphere interactions driven climate changes also occur in the south Asian region. On the main land-ocean-atmosphere interactions is the deposition of terrestrial aerosols into the Bay of Bengal driven by Asian monsoons. As can be seen from Figure 19, aerosols (and hence deposition into the Bay of Bengal) seasonally increase from March, peaking in July, and then decreases thereafter. Over the eastern Indian Ocean west of Sumatra, Indonesia, high aerosols can be observed around fall (September to November) (Figure 19, 4th rows). Such a high aerosol concentration is attributed to seasonal biomass burning which can be caused by human activities and climatic anomalies.

Siswanto (2015) has shown that besides seasonal variation, high aerosols in the eastern Indian Ocean in fall is also interannually caused by severe drought condition triggered by +IOD climate variation. As can be seen from Figure 20, besides intense upwelling as indicated by low SSHA (Figure 20a) and low SST (Figure 20b) aerosol concentration is very high during 1997 +IOD (Figure 20c). Anomalously high southeasterly winds prevailing during +IOD cause upwelling and severe drought in the southeast Asia which triggers massive biommas burning or wildfires. The aerosol plumes are then transported westward by anomalously easterly winds and fertilize the eastern Indian Ocean. Such an atmospheric deposition triggers phytoplankton growth resulting in high phytoplankton Chl-a in the eastern Indian Ocean (Figure 20d). Siswanto (2015) also estimated that although high Chl-a in the eastern Indian Ocean during +IOD is largely attributed to nutrient supply from the deep ocean layer due to upwelling, the contribution of nutrients from the atmospheric aerosol deposition is also non-trivial.

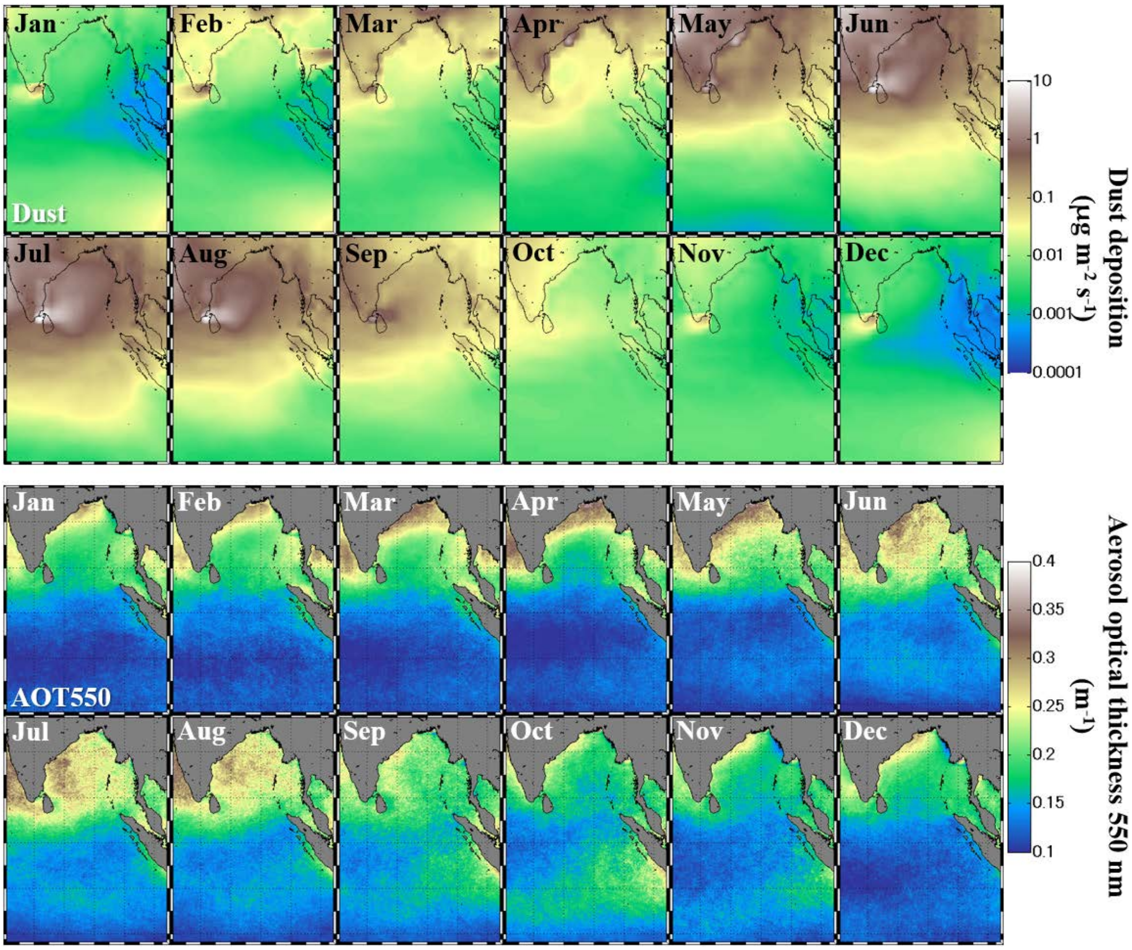

Figure 19. Monthly climatology of dust deposition (1st and 2nd rows) and aerosol optical thickness (3rd and 4th rows) in south Asia and the Bay of Bengal. Monthly climatological values were derived by averaging long-term data records from 1997 to 2017.

The atmospheric deposition also plays an important role for phytoplankton in the Bay of Bengal the fact being confirmed by positive partial linear regression for dust deposition (βDD, Figure 21c) derived from multiple linear regression analysis. In the western Bay of Bengal, nutrients from the deep layer seem to be more important for phytoplankton as indicated by the negative partial linear regression for SST (βSST, Figure 21a) and negative partial linear regression for SSHA (βSSHA, Figure 21b).

Regression of phytoplankton Chl-a against Nino3.4 (index for ENSO) and DMI (index for IOD) yields negative partial linear regression for Nino3.4 (βNINO, Figure 22a) over the western bay and positive partial linear regression for DMI (βDMI, Figure 22b) over the center or eastern bay. The areas showing negative βNINO (Figure 22a) are almost in the same areas showing negative βSST and βSSHA (see dashed boxes in Figures 21a, b, c, 22a, b). These results imply that during El Nino (positive Nino3.4), Chl-a in the western Bay of Bengal tends to below. Such a declined Chl-a is caused by a reduction of nutrient supply from the deep layer which can be explained by negative βSST and βSSHA.

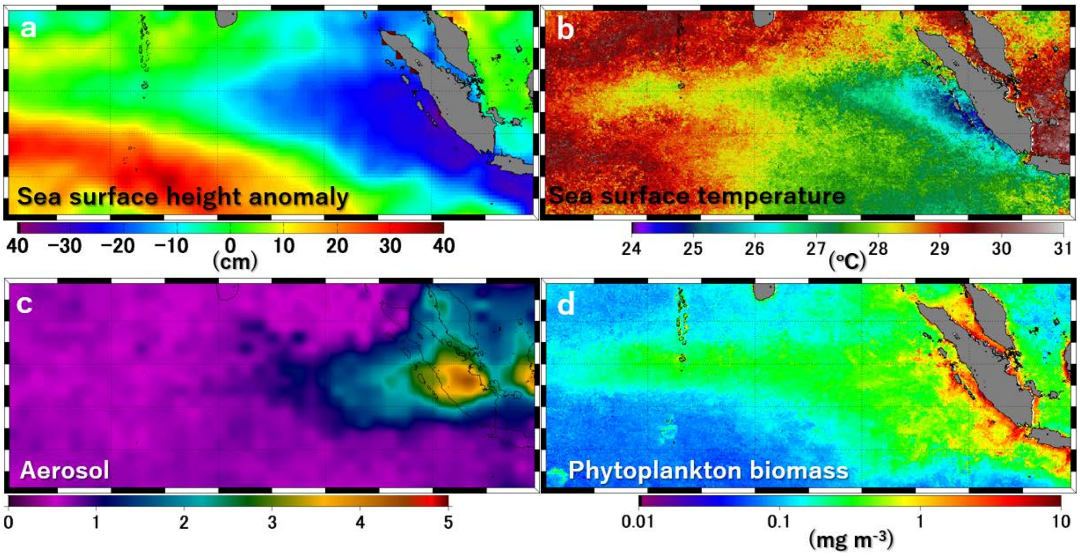

Figure 20. Spatial variations of SSHA (a), SST (b), aerosols (c), and phytoplankton Chl-a (d) in the eastern Indian Ocean during the extreme 1997 +IOD.

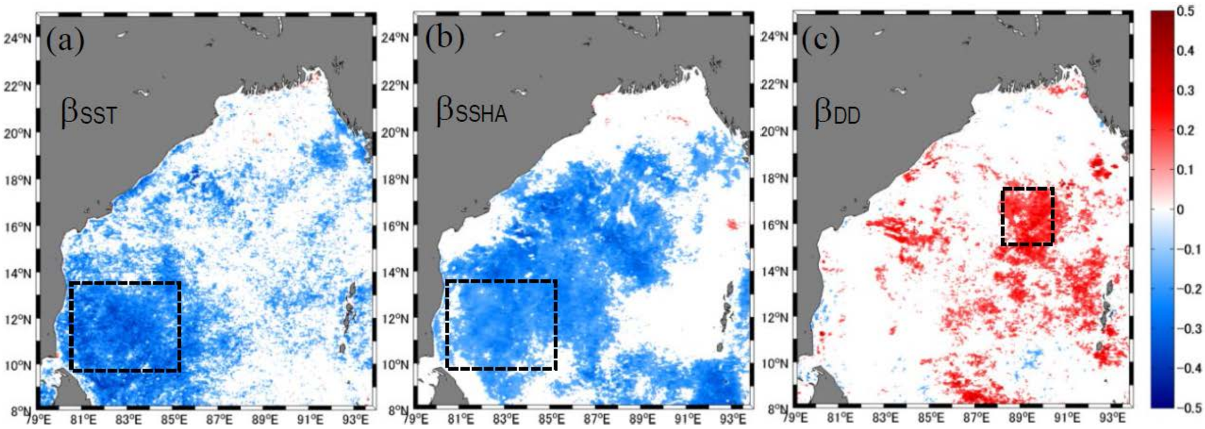

Figure 21. Spatial variations of (a) β_{SST}, (b) β_{DD}, and (c) β_{SSHA} resulted from a multiple linear regression analysis. Areas where β values were insignificant at the 95% confidence level are masked (white areas). Red (blue) areas in panel indicate significant positive (negative) associations between CHL and the variables.

This means that during El Nino, water column stratification in the western bay tends to strengthen and warm the SST (hence reduce nutrient availability). Reduction of nutrient supply is then manifested as a Chl-a decline during El Nino. In contrast, in the eastern bay, Chl-a tends to increase during +IOD as indicated by positive βDMI. The increase of Chl-a during +IOD seems to be attributed to an increase in dust deposition as depicted by positive βDD (Figure 22b).

Unlike in the ocean, impacts of climate changes on the terrestrial low-trophic level organisms or land vegetation are obscured by human activities. In this project, we found that the severe drought in South Asia (Bangladesh as a case study) cannot be explained by climate change alone. Human interventions such as irrigation, reservoir construction, etc. also play an important role in determining drought conditions. Therefore, developing any predictive skill to predict climate change impacts on land vegetation and drought conditions should include human interventions.

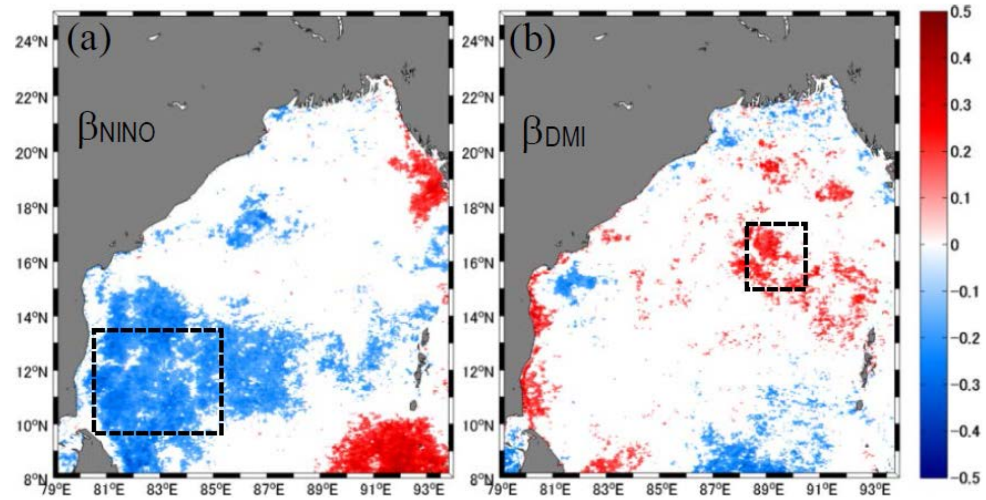

Figure 22. Spatial variations of (a) β_{NINO} and (b) β_{DMI} resulted from a multiple linear regression analysis. Areas where β values were insignificant at the 95% confidence level are masked (white areas). Red (blue) areas in panel indicate significant positive (negative) associations between CHL and climate indices.

This project (see Sarker et al., 2020) thus proposes a practical approach to assess drought and risk in the future by combining a remote sensing-based drought index, the temperature vegetation dryness index (TVDI), climate data (i.e., rainfall and temperature), and field observations. Figure 23 shows monthly climatological means of TDVI (in stretched and classified values) for January, February, March, and April. Applying this approach, the project found five insights: (i) the TVDI successfully indicates the drought conditions and agrees with field observations, (ii) the integrated use of TVDI and climate data provides the best understanding of the difference between meteorological drought and droughts resulting from surface moisture conditions, (iii) the TVDI results agree with rainfall data in March and April in a part of the study area where irrigation is not available, (iv) the TVDI can be used along with climate data to predict the potential risk of drought, and (v) while meteorological drought exists due to low rainfall and high temperature in this study region in the pre-monsoon season, because of widespread irrigation practices, meteorological drought is unable to trigger agricultural drought over most parts of the study area.

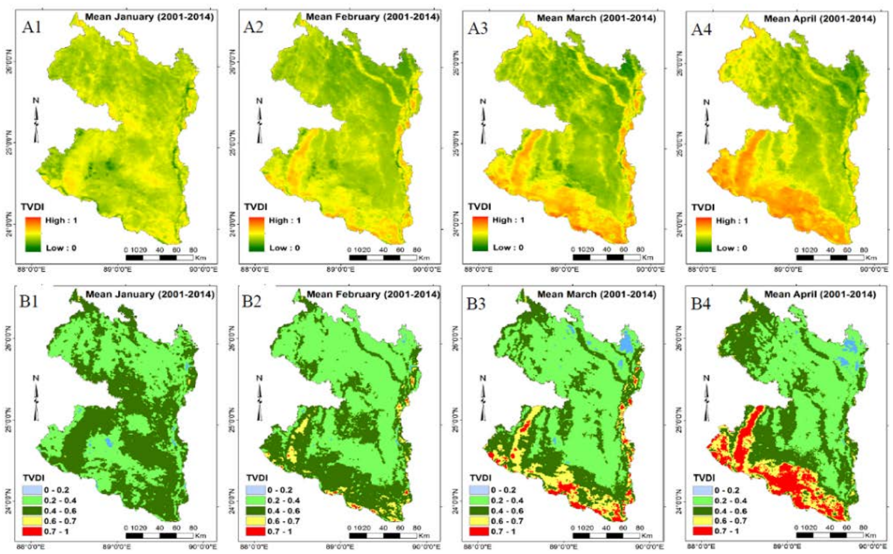

Figure 23. Monthly mean spatial distribution of the Temperature Vegetation Dryness Index (TVDI), for January, February, March, and April over 14 years (2001–2014) (23A): stretched and (23B): classified.

4. Conclusions

Understanding the spatiotemporal fingerprints of climate changes on the low-trophic level organisms in the Asia-Pacific region by employing the constructed long-term big satellite remote sensing data is one of the main objectives of this project. The followings are the main conclusions combined from all that we have learned during executing this project. Depending on the geographic position of the region of study one basin-scale climate influence more than other climates (e.g., IOD in the maritime continent, ENSO in the marginal seas, and PDO in the western NorthPacific Ocean). The wind-driven Ekman pumping and atmospheric aerosol deposition are the main mechanisms through which the climates influence the low-trophic level organisms (surrogated by phytoplankton) in the open oceans. Whereas in the coastal waters, climates influence the low-trophic organisms by modifying rainfall, river discharge, and hence the supply of nutrients from the coastal lands. Unlike in the ocean environments, the impacts of climate change on the terrestrial ecosystems are largely obscured by human interventions (e.g., irrigations, dam construction, etc.). Considering human activities is thus necessary to develop any predictive skills in assessing the impacts of climates on terrestrial ecosystems (e.g., drought, future drought risk, land vegetations). Depending on the prevailing climate modes, both low- and high-trophic level organisms benefit from the climate-driven land-ocean-atmosphere interactions. Due to limited high-trophic level organism data, there are still many areas in the Asia-Pacific region where the impacts of climate change on high-trophic level organisms have not been investigated.

5. Future Directions

Understanding the mechanisms and predictive skills on how climate will impact the ecosystems (and hence human life) is very important for climate change adaptation. However, to take more concrete and accurate climate change adaptation actions, rapid distribution of climate change adverse impact information is also essential. Therefore, among the current project collaborators are now proposing a new research project to develop a near-real-time observing system to monitor Asia-Pacific regions. Actions to tackle marine environmental problems such as harmful algal blooms, hypoxia, drink water contamination, human poisoning etc. will benefit from the near-real-time observing systems. Among the collaborators are also planning to prepare a research proposal related to microplastic debris monitoring. One proposal has been submitted last March to get a research fund to develop a near-real-time observing system to anticipate climate adverse impacts in Asian waters under the e-ASIA Joint Research Project. We also plan to write a proposal on the same topic above to be submitted again to Asia-Pacific Network for Global Change Research (APN) to get APN research funds mainly for organizing workshops and traveling for attending international scientific forums. Another opportunity for collaboration is the research activities related to monitoring marine micro-plastic debris. We are under discussion for preparing a proposal to get funds under the Science and Technology Research Partnership for Sustainable Development (SATREPS).

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7. Appendix

Conferences/Symposia/Workshops

Documents of workshops that have been organized by this project are separately attached. The document of each workshop is a booklet containing the agenda and all abstracts presented during the workshop.

List of Young Scientists

Ms. Siraporn Tong-u-dom
Graduated student, Research assistant
Department of Aquatic Science, Faculty of Science, Burapha University
Aommy_se7en@hotmail.com
Role: modeling and studying the surface water circulations connecting the South China Sea and the Gulf of Thailand
Message: This APN collaborative project provides me research opportunities with many regional experts in the various research field of Earth observation. This also helps me to get a better understanding of the mechanisms of physical and biogeochemical processes in the ocean. The opportunity to deliver presentations of our research outcomes to international scientific workshops is also provided. I am very grateful to APN for the financial support and project leaders in Japan and Thailand for providing this opportunity.

Dr. Qurnia Wulan Sari
Lecturer
Faculty of Fisheries and Marine Sciences, Padjadjaran University
qurnia.wulansari@gmail.com
Role: Processing satellite data to understand the impacts of Indian Ocean Dipole on phytoplankton in the specific areas in the maritime continent
Message: Through this research project, I gained a lot of knowledge and experience working with satellite oceanography. In addition, I also learned how to work as a team, developing a research plan, and working with various people especially in the field of remote sensing. I am now at my new institution, Department of Marine Science, Padjadjaran University, Bandung, Indonesia. I will transfer my knowledge and experience gained from this research project to undergraduate and post-graduate students. With this greater knowledge background and experience, I will be able to help them better than I can now. It is very important to educate the young students about the importance of the ocean for our future life.