Report: Activity number: ESA-2023-04: ESA-Future Earth Joint Program

Expanding EO data usage to address climatic changes in the marine biosphere of the northwest Pacific and Indo-Pacific regional seas (EO-WPI)

Period: 28 October 2022 - 29 December 2023

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Abstract

We started the EO-WPI by distributing questionnaires to identify genuine interests, needs and feedback based on the region. Thirteen finalists were chosen via rather lengthy process of frequent emails, often involving third parties while being mindful of equal opportunity, diversity and inclusive principles. They were from starting graduate students, research staff, and experienced professionals in universities, environmental management, and national agencies. All participants submitted their projects and had them reviewed periodically for their progress by mentors (OCPC members). One participant was ill and replaced by another from the same institute in a later stage. Three 2-hour online sessions, including lectures from OCPC members, were held in May, July, and September for the participants to equip the prerequisite scientific background and state-of-the art handling of EO data and application to understand the ocean color change and its practical purposes. Participants used EO data from Copernicus Marine Service, ESA Sentinel-3 OLCI, NASA Ocean Color, GOCI, NASA Landsat Program and ECMWF. Several participants planned to open their in-situ data in comply with FAIR Guiding Principles for scientific data management and stewardship.

We recorded all online lectures, and multiple views are available from the dedicated webpage. Online lecture sessions built collegial relationships among participants and mentors. Rounds of one-to-one email communications helped launch a project for a participant individually. An in-person workshop was held on 7-9 November 2023 in Bali, Indonesia. All were present except one (unable to travel due to her postnatal care and sent a recorded video report). A three-day workshop was devoted to completing participants' projects, and mentors responded individually to participants' needs. Journal of Sea Research was chosen to deliver products by taking advantage of an open-access journal to stimulate further the use of EO data in Southeast Asia and the Northwest Pacific. The submission started in late December 2023 and will be open until the end of April 2024.

Participants requested additional training opportunities to learn best practices or step-by-step procedures from the field observation and sampling designs, collection, subsequent analysis, and satellite EO data use. Participants thanked ESA-Future Earth for providing this training opportunity and additional support from State Key Laboratory of Estuarine and Coastal Research, East China Normal University, JAMSTEC, and KIOST.

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1. Project information

1.1 Title: Expanding EO data usage to address climatic changes in the marine biosphere of the northwest Pacific and Indo-Pacific regional seas (EO-WPI)

1.2. Duration: 28 October 2022 – 29 December 2023

1.3. Four online and offline workshops and on demand basis training through thirteen one-to-one mentee and mentor pairs.

Participants' projects and mentors

No.	Name	Institution	Project Title	Mentor
1	Martiwi Diah Setiawati	Research Center for Oceanography, National Research and Innovation Agency (Badan Riset dan Inovasi Nasional, BRIN), Indonesia	Estimating the habitat preference of the albacore tuna species in the Southeastern Indian Ocean by daily remote sensing data approach	Young-Je
2	Karlina Triana		The response of physio-chemical parameters to extreme climatic events in Northwestern Pacific Ocean (NWPO)	Eko
3	Edwards Taufiqurrahman		The fate of algal-derived carbon after the harmful algal bloom events in the Jakarta Bay area	Fang Shen
4	Lantun Paradhita Dewanti	Padjadjaran University, Indonesia	Evaluation of the use of vessels multi -aid for small scale fishers in West Java (A case studies in Indramayu and Pangandaran)	Young-Je
5	Noir Primadona Purba		Footprint of Fishing Ground in Indonesia Seas and Oceanographic Condition	Fang Shen
6	Alexander M. A. Khan		Oceanographic drivers of Mobulidae fisheries catch in the southeast Indian Ocean	Yi Xu
7	Riza Yuliratno Setiawan	Universitas Gadjah Mada, Indonesia	The impact of large scale climate oscillation on the onset of phytoplankton bloom in the Indonesian Fisheries Management Areas	Eko
8	Jonson Lumban-Gaol	IPB University, Indonesia	Climate impact on Chlorophyll-a concentration and small pelagic fish in South Java Sea	Yi Xu
9	Madihah Binti Jafar Sidik	Borneo Marine Research Institute, Universiti Malaysia Sabah, Malaysia	Development of ocean colour algorithm in coastal waters	Shaoling
10	Evonne Tan	Universiti Sains Malaysia	Optical properties of coastal waters of the Malacca Strait	Shaoling

11	Alwi Numadi Widyananda	Swinburne University of Technology Sarawak, Malaysia	Applications of Hyperspectral Imaging with Unsupervised Machine Learning for Plastic Detection in Aquatic Environments	Young-Je
12	Jahannah Victoria M. Calpito	University of the Philippines Diliman, The Philippines	Initial insights on the spatial and seasonal variability of phytoplankton functional groups in the Celebes-Sulawesi Sea	Mati
13	Meilun Zhang	Nanyang Technological University, Singapore	Bio-optical relationships in coastal waters of Southeast Asia for application to satellite remote sensing of CDOM and DOC	Mati

2. Activity of online training sessions

	Date & Time (UTC+8)	Lecturer	Title	Duration (minute)
1	May 25 16:00-18:00	Mati Kahru	Creating and analyzing time series of satellite data	30
		Yan Bai	Satellite-based ocean carbon fluxes estimation	30
2	July 26 9:00-11:00	Joji Ishizaka	Red tide and HAB detection by ocean color	30
		Fang Shen	Satellite detection of algal blooms and their species in Eastern China Seas	30
		Yuan Zhang	Marine big data coupling with AI technology for estimating phytoplankton group composition	
		Shaoling Shang	Phytoplankton dynamics from space-a few examples in the China seas	30
3	September 26 16:00-18:00	Young-Je Park	An optimization approach for IOPs and other ocean color products	30
		Bob Brewin	A brief overview of monitoring phytoplankton community structure from space	30
		Yi Xu	Seasonal and interannual variabilities of chlorophyll on the continental shelves	30


IMBeR
Integrated Marine Biosphere Research
Expanding EO data usage to address climatic changes in the marine biosphere of the northwest Pacific and Indo-Pacific regional seas (EO-WPI)
EO-WPI Workshop & Training: Online Session #1
Date & Time : 16:00-17:30 (UTC+8), 25 May 2023
Fang Shen
Mati Kahru
Yan Bai-SIO/MNR
LANTUN PARADHITA DEWANTI
Madihah Jafar Sidik
Jonson Gaol
Indonesia-Alexander Khan
Gi-Hong IMBeR
noir.purba@unpad.ac.id
UGM-Riza Y. Setiawan
Edwards Taufiqurrahman
Jahannah Calpito
Tan Evonne
Fang Zuo
Karlina Triana
Wulan
Scan QR Code
Register to watch the recording
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Expanding EO data usage to address climatic changes in the marine biosphere of the northwest Pacific and Indo-Pacific regional seas (EO-WPI)
EO-WPI Online Training: Session #2
Date & Time : 09:00-11:00 (UTC+8), 26 July 2023
PSDKU
Scan QR Code
Register to watch the recording
esa
futurearth
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Joint Program


IMBeR
Integrated Marine Biosphere Research
Expanding EO data usage to address climatic changes in the marine biosphere of the northwest Pacific and Indo-Pacific regional seas (EO-WPI)
EO-WPI Online Training: Session #3
Date & Time : 06:00-18:00 (UTC+8), 26 September 2023
Alwi Widyananda
Scan QR Code
Register to watch the recording
esa
futurearth
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3. Offline workshop

The in-person workshop was held in Bali, Indonesia on 7-9 November 2023. The 13 participants' projects (Table 1) were reviewed and worked toward their completion for publication. Their abstracts are found in the annex 1.

4. EO datasets and products

4.1 Sentinel-3/OLCI Satellite Detection for Algal Blooms

Algal blooms can cause widespread ecological disasters across the world. The occurrence of algal blooms may lead to coastal hypoxia and toxin accumulation, water quality degradation, fishery and aquaculture activities collapses, even seriously affecting marine ecosystems, human health.

Satellite remote sensing stands out from other approaches since it can provide a synoptic view and continually monitor of algal blooms every day or every hour at a large spatial scale, which has become an effective means.

As a new generation of ocean color sensors, OLCI sensors are installed on two satellites (Sentinel-3A and Sentinel-3B), and can collect data through daily transit in coastal waters, and provide data downloads on the day of transit. Therefore, an automatic platform of the monitoring system for algal blooms in coastal waters of the East China Sea based on Sentinel-3/OLCI observations was developed by the team of Prof. Fang Shen. Monitoring shows that this system also has potential for detecting algal bloom outbreaks in other coastal waters.

Platform and Dataset link: http://www.sklec-oceancolor.cn:8889/home/

Method Reference: Shen F, Tang R, Sun X, et al. Simple methods for satellite identification of algal blooms and species using 10-year time series data from the East China Sea. *Remote Sensing of Environment*, 2019, 235: 111484, doi: 10.1016/j.rse.2019.111484.

4.1.1 Validation for C2RCC atmospheric correction of Sentinel-3/OLCI images in eastern seas of China

The OLCI sensor is one of the payloads on Sentinel-3A (launched on February 16, 2016) and Sentinel-3B (launched on April 25, 2018) satellites of the European Space Agency. The band range of OLCI is 400~1020 nm, including 21 bands. Two satellites operate in the same orbit and pass through at 10 o'clock local solar time. The L1B (zenith radiance received by the OLCI sensor) product includes two spatial resolution products, namely 300 m resolution (Full Resolution, FR) and 1.2 km resolution (Reduce Resolution, RR). This system used L1B data with a resolution of 300 meters (https://scihub.copernicus.eu/dhus).

Due to the atmospheric contribution accounting for over 90% of remote sensing signals, atmospheric correction is crucial for obtaining high-precision ocean color data products. The applicability of three atmospheric correction methods (C2RCC, POLYMER and MUMM) in eastern seas of China was validated and evaluated. Comparison of errors between the atmospherically-corrected remote sensing reflectance and the matchup of in situ data (time window ±3hr) was shown in Table 1. At the OLCI bands of 400 nm, 412.5 nm, 442.5 nm, and 490 nm, the accuracy of the C2RCC is better than the other two algorithms, and the MUMM is the worst. In the other bands, POLYMER has the worst performance compared to the other two atmospheric correction algorithms (RMSE ≥ 0.003 2 sr-1). However, the three atmospheric correction methods tend to underestimate remote sensing reflectance in the red and near-infrared bands, namely 665 nm, 673.75 nm, 681.25 nm, 708.75 nm, 753.75 nm, and 778.75 nm. The MUMM algorithm is prone to overestimation at 400 nm, 412.5 nm, and 445.5 nm, and has a significant difference from the in-situ data (MAPE ≥ 140%). Except for a few data, the remote sensing reflectance at each band after atmospheric correction by POLYMER is lower than the corresponding measured in-situ data, and there are negative values in the 708.75 nm, 753.75 nm, and 778.75 nm bands. In various bands, C2RCC performs well compared to the other two atmospheric correction algorithms (MUMM, POLYMER) (RMSE less than 0.0048 sr^{-1}) and can obtain more effective values. However, there is still a unignored bias between the in-situ data and C2RCC-derived values. It is necessary to continue developing high-precision atmospheric correction algorithms suitable for eastern seas of China.

Table 1 Accuracy evaluation of three atmospheric correction algorithms

波长/nm	RMSE/(10^{-3} sr^{-1})			MAE/(10^{-3} sr^{-1})			MAPE/%		
	C2RCC	POLYMER	MUMM	C2RCC	POLYMER	MUMM	C2RCC	POLYMER	MUMM
400	4.13	4.41	10.79	3.21	3.67	9.83	41	44	213
412.5	3.99	4.36	7.68	3.01	3.53	6.69	36	41	141
442.5	4.10	4.64	6.81	3.21	3.68	6.02	36	39	140
490	4.79	4.97	4.90	3.74	3.82	4.43	40	37	89
510	4.72	5.28	4.21	3.65	4.12	3.74	40	41	70
560	4.34	5.31	3.53	3.31	4.03	3.04	33	43	56
620	3.22	4.21	3.05	2.24	3.21	2.44	49	66	81
665	3.21	3.75	2.71	2.21	2.82	2.05	61	72	84
673.75	3.23	3.64	2.62	2.29	2.72	1.98	63	71	80
681.25	3.21	3.64	2.60	2.29	2.75	1.91	64	73	83
708.75	3.12	4.45	3.21	2.21	3.62	1.93	70	116	69
753.75	3.21	3.24	2.38	2.30	2.40	1.49	88	94	81
778.75	3.04	3.23	2.40	2.18	2.40	1.44	86	99	90

4.1.2 Demonstration for algal bloom detection

The three-band model and defined an index for the detection of "red tide" algal blooms (RDI) was expressed by (Shen et al. 2019)[1]:

$$\mathrm{RDI} = \left(\frac{1}{R_{\mathrm{rs}}(\lambda_1)} - \frac{1}{R_{\mathrm{rs}}(\lambda_2)}\right) \times R_{\mathrm{rs}}(\lambda_3) \quad (1)$$

As recommended for turbid waters, the λ_1, λ_2, and λ_3 values for Eq. (1) were set using the OLCI bands of 665, 560, and 753 nm. the RDI calculation with the difference and ratio of remote sensing reflectance may suppress the bias caused by atmospheric correction to some extent.

The RDI index and the chlorophyll *a* are positively correlated as assumed, the index indicates the detection of an algal bloom when the chlorophyll *a* has reached a higher magnitude. The term "detection" denotes that an algal bloom is more likely to occur, but this does not mean that it definitely occurs. The reason is that the chlorophyll *a* may not be a proxy for algal cell abundance, due to the diversity in algal cell structure and size.

Research indicated that a specific threshold for the chlorophyll *a* that can indicate an algal bloom outbreak is difficult to determine when there is various concentration of suspended particulate matter. Estimating RDI values from the satellite data is effective. Investigation shows that the probability of the occurrence of algal blooms is very high if the RDI calculated by OLCI data is more than 0.14.

4.2 Macro-algal (*Sargassum*) bloom monitoring using geostationary ocean color data from GOCI-II

Floating *Sargassum* patches in the East China Sea (ECS) and adjacent waters serve as important habitats for diverse marine organisms including commercially valuable fish species (Safran and Omory, 1990)[2]. However, the proliferation of this brown macroalgae often become problematic when it washes ahore in large masses (Hwang et al. 2016)[3]. Since 2015, these Sargassum landing has caused significant economic losses to local aquaculture, tourism and the fishing industries in Jeju island and the southwest coastal region of the Korean peninsula. According to the Korean government, annual landing of *Sargassum* patches on Jeju Island range from 200 to 12,000 metric tons varying across different years. Since local area landing masses are connected to spatio-temporal variability of the floating algae in surrounding waters, the ECS and Yellow Sea (YS), a good understanding of the recent distribution of floating Sargassum is important. To investigate this, we utilize the data from the Geostationary Ocean Color Imager (GOCI)-II, a satellite sensor observing the seas around Korea including the ECS and YS, ten times a day with a spatial resolution of 300 meters. The sensor has 12 spectral bands in the 380~865 nm wavelength range. In particular, it has the red chlorophyll absorption band at 660 nm and three near infra bands at 709, 745, 865 nm which are useful to detect the presence of floating algae. In addition, the green band at 555 nm is useful

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[1] Shen, F., Tang, R., Sun, X., & Liu, D. (2019). Simple methods for satellite identification of algal blooms and species using 10-year time series data from the East China Sea. Remote Sensing of Environment, 235, 111484.

[2] Safran, P., & Omori, M. (1990). Some ecological observations on fishes associated with drifting seaweed off Tohoku coast, Japan. Marine Biology, 105, 395-402.

[3] Hwang, E. K., Lee, S. J., Ha, D. S., & Park, C. S. (2016). Sargassum golden tides in the Shinan-gun and Jeju Island, Korea. Korean Journal of Fisheries and Aquatic Sciences, 49(5), 689-693.

for discriminating brown algae from green algae, although it is not specifically discussed in this study. For further details on GOCI-II and data download, refer to the National Ocean Satellite Center's webpage (https://nosc.go.kr/eng/main.do).

In this study, GOCI-II data from January to June for 2021-2023 were utilized and manually selected images, filtering out those covered by clouds (Fig.1). Floating vegetation exhibits distinct reflectance characteristics, characterized by low reflectance in red absorption peak and high reflectance in the near-infrared bands. The difference in the reflectance between near-infrared and red bands serves as a sensitive metric for detecting floating algae. However, this reflectance difference is influenced by water turbidity. To remove this, we employed the spatial anomaly of the reflectance difference, derived by subtracting the local mean of the reflectance difference. The reflectance difference anomaly is approximately proportional to the floating algae-covered ratio referred to as FAR (Floating Algae-covered Ratio). FAR values range between 0 and 1, where 0 indicates no floating algae presence within a pixel, while 1 indicates completely coverage by floating algae. Individual GOCI-II image yields a FAR image, and a spatial averaging process is applied to enhance visibility. Subsequently, by averaging all FAR images within a month, a composite FAR image for each month is generated. The methodology aligns with a previous study by Park (2020)[4], which described a floating algal bloom event in 2015.

[4] Park, Y. J. (2020). An Analysis on the Distribution of Floating Seaweed in the East China Sea and Southern Yellow Sea in 2015–the Case of Sargassum observed by the Geostationary Ocean Color Imager. KMI International Journal of Maritime Affairs and Fisheries, 12(2), 21-35.

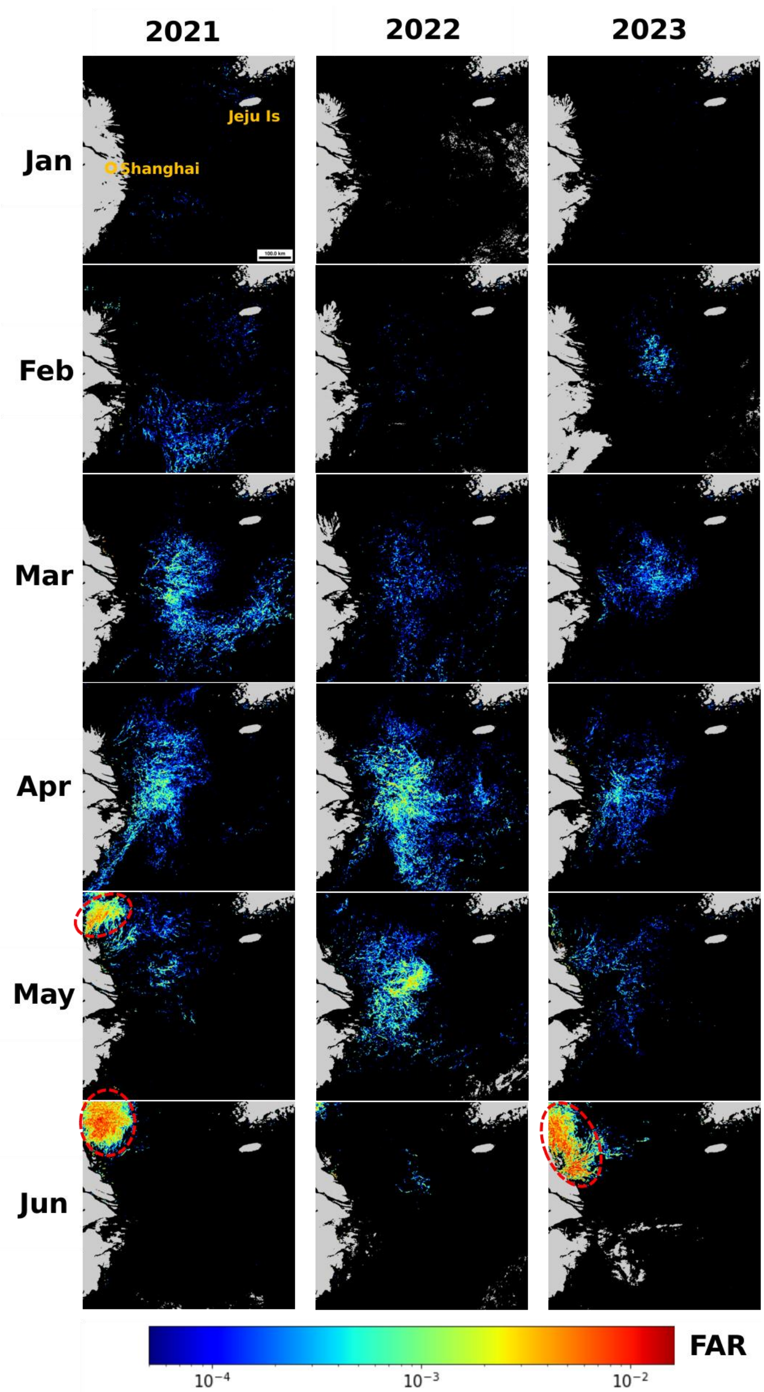

Fig. 1. Monthly composite FAR image from January to June for the years 2021-2023. Refer to the main text for the FAR definition. Gray color represents land or clouds. Note that intense blooms in May and June as indicated red dotted line in the Subei Shoal and the north area are attributed to Ulva prolifera (green algae) blooms.

4.3 CDOM algorithms validation using in situ data

With support of ESA Activity ESA-2023-04 we started a study "Bio-optical relationships in coastal waters of Southeast Asia for application to satellite remote sensing of CDOM and DOC" conducted by graduate student Meilun Zhang of Nanyang Technological University (Singapore) and Dr. Mati Kahru of the University of California, San Diego (USA). We performed match-up analysis between in situ measurements of the colored dissolved organic matter (CDOM) and estimates by various satellite products. Considering various complicating factors (e.g. errors in atmospheric correction in the coastal zone, space and time discrepancies between in situ and satellite observations), we obtained reasonable agreement with satellite observations using GIOP algorithm applied to level-2 data from MODIS-Aqua and VIIRS-SNPP (Fig. 2). Preliminary analysis using corresponding data from MODIS-Terra and VIIRS-JPSS1 showed discrepancies and were not used in time series. Time series of CDOM concentration (adg443, m^{-1}) were constructed as means of adg443 of MODIS-Aqua and VIIRS-SNPP measurements and showed reasonable dynamics (Fig. 3) with maxima in the rainy summer months.

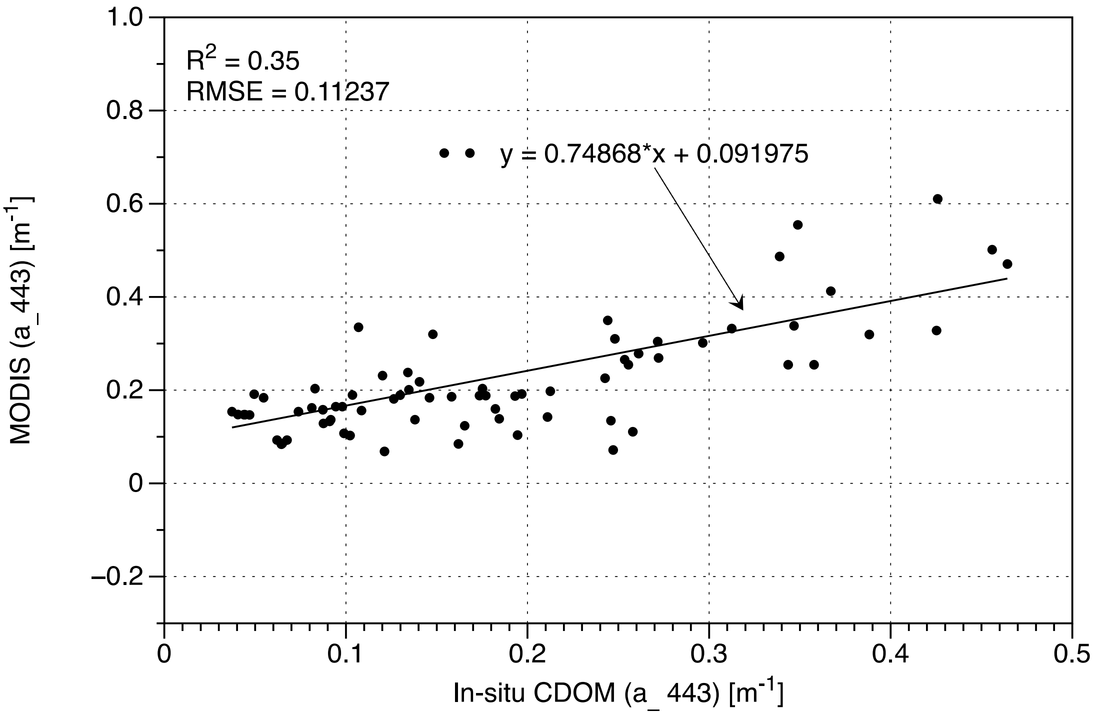

Fig. 2. Satellite match-ups of CDOM using GIOP algorithm applied to level-2 data from MODIS-Aqua off Singapore

We then used OLCI-A and OLCI-B level-2 full resolution (300 m) data that have a standard dataset ADG443_NN. Due to their higher spatial resolution (300 m versus 1000 m) OLCI data looked superior. However, preliminary time series for 2022 looked quite different from similar analysis of MODIS-Aqua and VIIRS-SNPP data (Fig. 2). The absolute level was about 2x higher and the annual cycles did not follow those of the other sensors and were different even between OLCI-A and OLCI-B themselves. In discussion with Dr. Ewa Kwiatkowska of EUMETSAT we learned that OLCI IOP data will be reprocessed in 2024. After January 10, 2024 we will be given a newly reprocessed OLCI-A and OLCI-B dataset by Juan Ignacio Gossn (EUMETSAT) corresponding to our extensive list of in situ samples in the Singapore area. We will then continue our analysis using the reprocessed OLCI data.

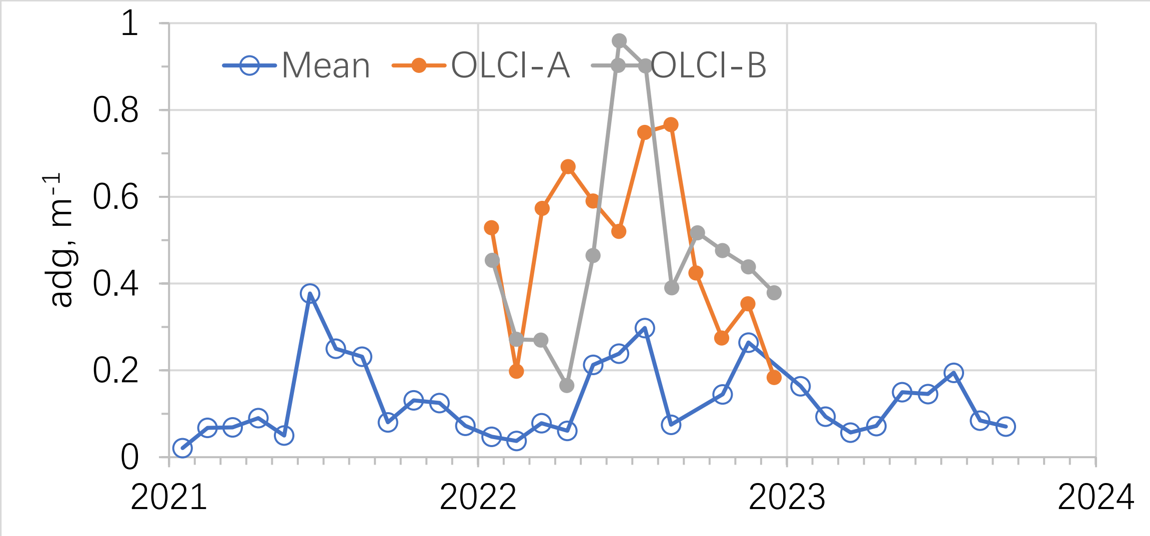

Fig. 3. Time series of CDOM (adg443) from the merged NASA processing (Mean. blue line) and from OLCI-A and OLCI-B (brown and green lines) around the St. Johns and Raffles stations off Singapore.

As you can see, there are significant differences not just between NASA and ESA processing but also beteen OLCI-A and OLCi-B.

4.4 Monthly 4-km Dataset of Global Phytoplankton Functional Type (1997–2020)

Accurate monitoring of the spatial-temporal distribution and variability of phytoplankton type composition is of vital importance in better understanding of marine ecosystem dynamics and biogeochemical cycles. While existing bio-optical algorithms provide valuable information, relying solely on satellite ocean color data remains insufficient to obtain high-precision retrieval of phytoplankton types due to the intricate nature of the bio-optical signal and phytoplankton type composition itself. An interdisciplinary approach combining advancements in machine learning with marine big data from ocean observations and simulations offers a promising avenue for more accurate quantification of phytoplankton type composition.

An ensemble learning approach, called the spatial-temporal-ecological ensemble (STEE) model, was developed to construct a robust prediction model for phytoplankton functional types. The model introduces multiple data simultaneously: ocean color, physical oceanographic, biogeochemical, and spatial and temporal information.

A dataset of global phytoplankton functional type including eight distinct types (i.e., Diatoms, Dinoflagellates, Haptophytes, Pelagophytes, Cryptophytes, Green Algae, Prokaryotes, and Prochlorococcus) by the STEE model was generated, and derived from the merged SeaWiFS, MERIS, MODIS-Aqua, and VIIRS data of the Ocean-Color Climate Change Initiative (OC-CCI, version 5.0) from the European Space Agency with the spatial resolution of 4 km. At present, the monthly average data of global phytoplankton type composition from 1997 to 2020 can be provided. The seamless global daily time series data is expected to be available in the next year.

Dataset link: https://1drv.ms/f/s!AgOcOG0HOHXIgX4OliC_dozAA5R-?e=lNuiBC

Method Reference: Zhang Y, Shen F, Sun X, et al. Marine big data-driven ensemble learning for estimating global phytoplankton group composition over two decades (1997–2020). *Remote Sensing of Environment*, 2023, 294: 113596, doi: 10.1016/j.rse.2023.113596.

4.4.1 Satellite data and marine big data sources

Multiple environmental data were collected as input predictors (Table 2). The data inputs include spectral remote sensing reflectance (R_{rs}), Chlorophyll-a concentration (Chla), particulate backscattering coefficient (b_{bp}), phytoplankton absorption coefficient (a_{ph}), diffuse attenuation coefficient at 490 nm (K_d490), and water class (water class memberships of each pixel to 14 optical water classes). Photosynthetically Available Radiation (PAR) data were obtained from the Copernicus Marine Environment Monitoring Service (CMEMS) GlobColour data archive. Several reanalysis products as ancillary predictors, including biogeochemical hindcasts, physical reanalysis and meteorological data are utilized.

Table 2 Predictors and corresponding data products.

Predictors and corresponding data products.

Dataset	Abbreviation	Definition	Resolution	Reference/DOI
Bio-optical data	$R_{412\text{–}670}$	Remote sensing reflectance at 412, 443, 490, 510,555 and 670 nm	4 km, Daily, 1997.9–2020.5	Sathyendranath et al. (2019)
	$a_{412\text{–}670}$	QAA absorption due to phytoplankton at 412, 443, 490, 510,555 and 670 nm		
	$b_{412\text{–}670}$	QAA backscatter due to particulate matter at 412, 443, 490, 510,555 and 670 nm		
	K_d490	diffuse attenuation coefficient at 490 nm		
	Chla	Chlorophyll-a concentration		
	WC	memberships of each pixel to 14 optical water classes		
	PAR	Photosynthetically Available Radiation		Team et al. (2017)
Biogeochemistry data	NC	Nitrate concentration	1/4°, Daily, 1997.9–2020.5	https://doi.org/10.48670/moi-00019
	PC	Phosphate concentration		
	SC	Silicate concentration		
	DO	Dissolved oxygen		
Ocean Physical data	SST	sea surface temperature	1/20°, Daily, 1997.9–2020.5	Merchant et al. (2019)
	SSS	sea surface salinity	1/12°, Daily, 1997.9–2020.5	https://doi.org/10.48670/moi-00021
	UML	Upper Mixed Layer depth		
	EOV	Eastward ocean current velocity		
	NOV	Northward ocean current velocity		
Meteorological data	WS	sea surface wind speed	1/4°, Daily, 1997.9–2020.5	https://doi.org/10.48670/moi-00185
	EW	West to East component of wind-to vector		
	NW	North component of the wind-to vector		
Spatio-temporal information	sLat	Sine of latitude	–	–
	sLon	Sine of longitude		
	D2C	Haversine distance to coast		
	Year	Year		
	*C*mon	months of the year, converted using cosine		
	*N*mon	Number of months since September 1997		

4.4.2 Spatial-temporal-ecological ensemble (STEE) model

We construct a multi-source data-driven PG retrieval model. Specifically, the spatial distribution of PG is modelled as a nonlinear mapping f_x of multiple environmental predictors (i.e., bio-optical, biogeochemistry, physical, meteorological, and distributed spatially and temporally), expressed as follows:

$$PG = f_x(\text{input predictors}) = f_x(p_{\text{Bio-optical}}, p_{\text{Biogeochemistry}}, p_{\text{Physical}}, p_{\text{Meteorological}}, p_{\text{Spatio-temporal}}) \quad (2)$$

The STEE model is implemented by integrating three powerful machine-learning regression techniques: Gradient Boosting Machine (GBM), One-dimensional Convolutional Neural Network (1d-CNN), and Attentive Interpretable Tabular Learning neural network (TabNet). Each sub-model obtains the input data and generates an independent prediction output. Finally, ridge regression was introduced as a combinatorial approach to form ensemble predictions.

4.5. Monthly 1-km Dataset of Satellite-Derived pCO2 and Air–Sea CO2 Flux

4.5.1. South China Sea (2003-2019)

We developed a retrieval algorithm for sea surface partial pressure of CO2 (pCO_2) by a combination of our previously established mechanistic semianalytical method (MeSAA) and machine learning (ML) method, named MeSAA-ML-SCS, built upon a large dataset of sea surface pCO_2 collected from in situ measurements during 44 cruises /legs to the South China Sea in the last two decades. The South China Sea (SCS) is one of the largest marginal seas in the world with several sub-regional characteristics. It includes a river-dominated, highly productive continental shelf in the north (Pearl and Red rivers), an oligotrophic deep ocean basin in the center, a continental shelf with the Mekong River and islands in the south.

We set several semianalytical parameters, including pCO_{2_therm} represented the combined effect of thermodynamics and the atmospheric CO_2 forcing on seawater pCO_2; upwelling index (UISST) and mixing layer depth (MLD) to characterize the mixing processes; and chlorophyll-a concentration (Chl-a) with remote sensing reflectance at 443 and 555 nm [Rrs(443) and Rrs(555)], which were proxies of biological effects and other characteristics for distinguishing shelf, basin, and subregions. We set the difference between seawater pCO_2 and atmospheric pCO_2 ($\Delta pCO_2^{Sea\text{-}Air}$) as the output, and the seawater pCO_2 was finally obtained by summing atmospheric pCO_2 and $\Delta pCO_2^{Sea\text{-}Air}$.

We compared several ML models, and the XGBoost model was confirmed as the best. Independent cruise-based datasets that are not involved in the model training were used to validate the satellite products, with low root-mean-square error (RMSE = 11.69 μatm) and mean absolute percentage deviation (APD = 1.59%). On this model, we produced a 1km monthly mean pCO_2 and air–sea CO_2 flux dataset for the South China Sea from 2003 to 2019. This shared long time series, high-accuracy dataset (1 km) can be helpful to further improve our understanding of the air–sea CO_2 exchange dynamics in the SCS.

Dataset link: https://zenodo.org/records/7743187.

Method Reference: Song Z, Yu S, Bai Y, et al. Construction of a high spatiotemporal resolution dataset of satellite-derived pCO_2 and air-sea CO_2 flux in the South China Sea (2003-2019) [J]. IEEE Transactions on Geoscience and Remote Sensing, 2023. https://doi.org/10.1109/TGRS.2023.3306389.

4.5.2. East China Sea (2003-2019)

Based on in situ seawater pCO_2 data collected on 51 cruises/legs over the past two decades, a satellite retrieval algorithm for seawater $pCO_2$was developed by combining the semi-mechanistic algorithm and machine learning method (MeSAA-ML-ECS) for the Bohai Sea (BS), Yellow Sea (YS), and East China Sea (ECS), which forms one of the largest marginal sea systems in the world, including semi-enclosed ocean margins and a wide continental shelf influenced by the Changjiang River and the strong western boundary current (Kuroshio).

MeSAA-ML-ECS introduced semi-analytical parameters, including the temperature-dependent seawater pCO_2 ($pCO_{2,\ therm}$) and upwelling index (UISST), to characterise the combined effect of atmospheric CO_2 forcing, thermodynamic effects, and multiple mixing processes on seawater pCO_2. The best-selected machine learning algorithm is XGBoost. The satellite-derived pCO_2 achieved excellent performance in this complicated marginal sea, with low root mean square error (RMSE = 20 μatm) and mean absolute percentage deviation (APD = 4.12 %) for independent *in situ* validation dataset. On this basis, we produced 1-km monthly average pCO_2 and Air-Sea CO_2 flux remote sensing data products for the East China Sea from 2003 to 2019. These datasets will benefit further research on carbon fixation and its potential capacity.

Dataset link: https://zenodo.org/records/7701112.

Method Reference: Yu S, Song Z, Bai Y, et al. Satellite-estimated air-sea CO2 fluxes in the Bohai Sea, Yellow Sea, and East China Sea: Patterns and variations during 2003–2019[J]. Science of The Total Environment, 2023, 904: 166804. doi: https://doi.org/10.1016/j.scitotenv.2023.166804.

5. Synergistic datasets to combine geostationary and polar-orbiting satellite data

5.1 Synergetic Dataset (GOCI II and MSI) for floating macroalgae

As described earlier, GOCI-II images are highly valuable for monitoring wide areas such as ECS and YS for floating algal blooms. GOCI-II shows high sensitivity, capable of detecting algal surface as small as ~0.2% of a pixel. However, its low spatial resolution limits the detection of small-size patches. The early period blooms in the YS and ECS start with low-density, small patches. The floating algae patches can be accumulated along the shores of Jeju island and the southwest coastal area of the Korean peninsula when northwest monsoon is strong, and may result in significant economic damage.

Recently, new generation high resolution satellite data are available suitable for coastal area monitoring. These include Multi-Spectral Imager (MSI) aboard Sentinel-2A and 2B, as well as Ocean and Land Imager (OLI) aboard Landsat-8/9. For monitoring macroalgal blooms, we can use MSI data with 10m and 20m spatial resolutions which are much finer - 15 or 30 times smaller- than GOCI-II. This means MSI can detect much smaller, sparser algal patches compared to GOCI-II. The 10m data are available for four wavebands centered at 490,560,665 and 842nm. MSI data are available on the Copernicus Data Space Ecosystem.

However, MSI data alone are not sufficient for timely detection since it provides one image every five days. Table 3 provides quick comparisons of key specifications.

Table 3. GOCI-II and MSI key specifications

	GOCI-II	MSI
Satellite platform	GK-2B	Sentinel-2A/B
Spatial resolution	250 m at nadir	10m, 20m, 60m
Spectral bands	12 bands (380, 412, 443, 490, 510, 555, 620, 660, 680, 709, 745, 865 nm)	10m- 4 bands (490, 560, 665, 842 nm) 20m - 5 bands (705, 740, 783, 1610, 2190 nm) 60m - 4 bands (443, 865, 945, 1375 nm)
Area coverage	local area (2500 km x 2500 km around Korea)	global coverage
Revisit frequency	10 times per day	once per 5 days

We performed a comparison between GOCI-II and MSI (10m) for detection of floating algae (*Sargassum honeri*) along the northern coast of Jeju Island on January 27, 2021 as depicted in Fig. 4. GOCI-II image reveals only a few isolated patches off the coast, all of which has corresponded detection in the MSI image as marked green dashed lines. However, the MSI image shows finer details, revealing wide spread streaks near and off the coast. A significant portion deted by MSI remained entirely undetected in the GOCI-II image. Although this example represents initial stage of algal blooming, it underscores the importance of utilizing high-resolution images for better monitoring of floating algae blooms.

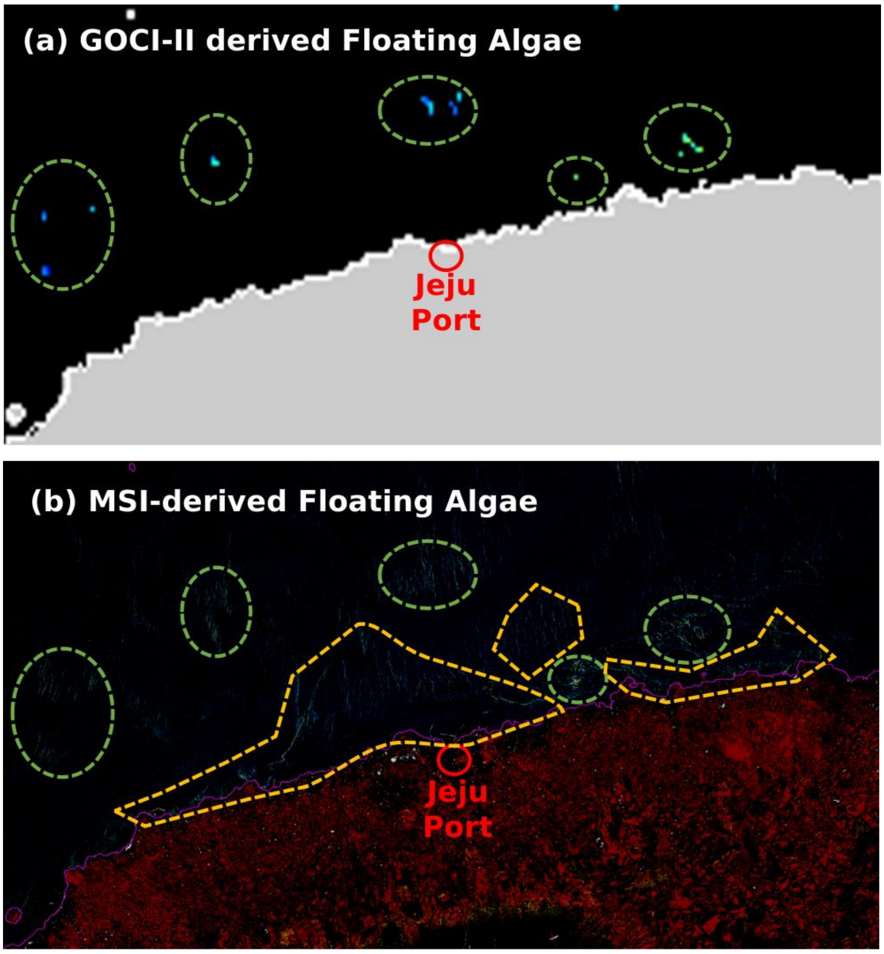

Fig. 4. Floating algae distribution near the northern coast of Jeju Island on January 27, 2021 based on (a) GOCI-II image and (b) MSI image. The green color represents corresponding floating algae patches while orange color represents those completely missed by GOCI-II detection.

We suggest a strategy incorporating both low and high resolution imagery for monitoring floating algae blooms. Low resolution images such as those from GOCI-II and MODIS cover large regions and offer frequent updates, enabling timely identification of bloom areas. Frequent GOCI-II images are useful to observe temporal changes such as movement and blooming area. This data helps in understanding bloom dynamics and seasonal variations. On the contrary, high resolution satellite images (e.g., Sentinel-2/MSI, Landsat/OLI) are useful to confirm and analyze bloom areas identified with low resolution images. High resolution images provide finer details, enabling a closer examination of bloom extension in the vicinity of coast or islands.

5.2 Synergetic Dataset of Monthly 250-m Phytoplankton POC and Organic Detritus POC in eastern seas of China (2022)

Particulate Organic Carbon (POC) is rich in the continental shelf marginal seas, and the eastern seas of China boasts one of the world's widest continental shelves. In this region, different types of particles play distinct roles and contribute differently to the carbon cycle. Therefore, clarifying the particle composition in the estuarine-nearshore-shelf areas is crucial for accurately assessing the contributions to the marine carbon reservoir and carbon cycling. Currently, remote sensing estimates of POC often use proxy parameters such as total particle concentration, total particulate backscattering, or attenuation coefficients. However, in the turbid and optically complex waters of estuarine-coastal-shelf environments, there are issues of unstable relationships or low correlations. The main bottleneck in this work is related to the complex and variable characteristics of natural marine particle compositions. The key to addressing this issue is first distinguishing the types of particles, specifically, differentiating inorganic particles, organic detritus, and living algae. Based on this premise, the correlation between different types of particles and POC needs to be explored.

To address this gap, Prof. Shen's team established a particle classification model for the eastern seas of China based on in situ spectral data. This allowed for the estimation phytoplankton POC, organic detritus POC, and total POC, achieving innovation and breakthroughs in POC remote sensing estimation by disentangling particle composition. Applying disentangling particle composition method can enhance the understanding of the roles of different particle composition in coastal carbon cycling affected by strong land-sea exchange.

The method then was applied to the synergetic dataset, merged from geostationary satellite GOCI-II data and polar-orbiting Sentinel-3/OLCI. This allowed for the estimation of monthly average concentrations of phytoplankton POC, organic detritus POC, and total POC. The spatial resolution is 250 m, and the temporal resolution is monthly average. This dataset can be utilized for research on coastal carbon cycling, carbon storage, and related studies.

Dataset link: https://1drv.ms/f/s!AgOcOG0HOHXIggMSPe1TW0icHS4g?e=mn01Sp

Method Reference: Li M, Shen F, Organelli E, et al. Disentangling Particle Composition to Improve Space-Based Quantification of POC in Optically-Complex Estuarine and Coastal Waters, *IEEE Transactions on Geoscience and Remote Sensing*, 2023, Early Access. doi: 10.1109/TGRS.2023.3341462.

5.2.1 Synergetic dataset from multi-mission satellite data

The concept of synergy in the field of remote sensing, as described by Cracknell (1998)[5], is the processing of two or more data sources to provide more environmental information than any individual data source. This clearly extends the meaning of traditional remote sensing image fusion, and is also in line with the rapid development of contemporary earth observation technology, which integrates data and information generated by multiple types of satellite observations, in situ measurements, and numerical models.

[5] Cracknell, A. P. (1998). Review article Synergy in remote sensing-what's in a pixel?. International journal of remote sensing, 19(11), 2025-2047.

In land remote sensing, satellite images with different spatial and temporal resolutions obtained by different sensors are often fused, so that satellite images can maintain multi spectrum and improve spatial and temporal resolution, thus obtaining more information. This idea has been widely used in land target recognition, ground object classification, change detection and other fields. There are many fusion methods, mostly achieved through complex mathematical transformations or interpolation, but the data fidelity is not high.

The practice of ocean color remote sensing mostly involves the collaboration of satellite data or products from multi-mission ocean color sensors, which can compensate for the limitations in the life cycle of in orbit satellites, deficiencies in sensor signal attenuation, insufficient observation frequency affected by cloud cover. It also helps to improve the global satellite data spatiotemporal coverage and increase the opportunity for satellite ground synchronization verification.

Even if polar-orbiting ocean color satellites transit once a day for observation, the impact of cloud cover in coastal oceans may lead to a decrease in observation frequency (Fig. 5-1), resulting in gaps in the time series of ocean color data products. Comparatively speaking, geostationary satellite (e.g. GOCI) can transit hourly, greatly increasing earth observation frequency (Fig. 5-1), especially for nearshore and coastal waters affected by tides and waves. High frequency observation helps to accurately estimate and analyze ocean color products related to environment and climate change. Therefore, generating the synergetic dataset of Sentinel-3/OLCI data and GOCI data can improve the accuracy and precision of time series ocean color data products.

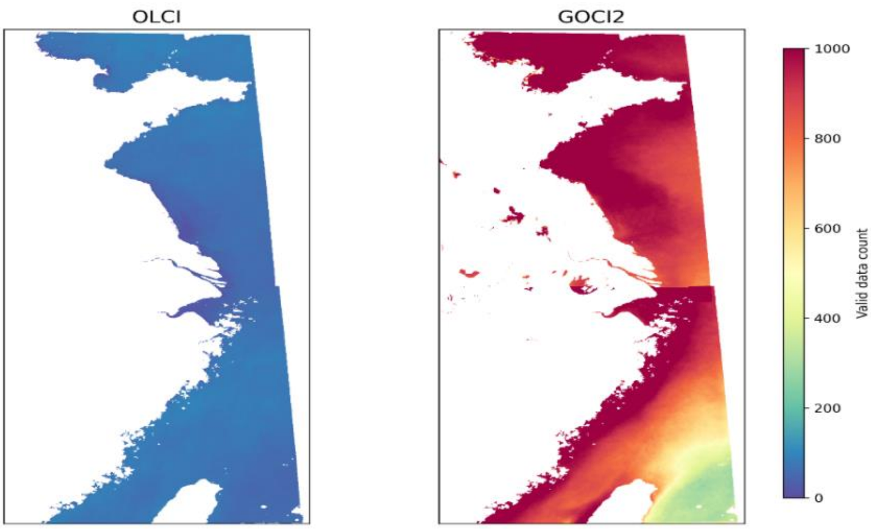

Fig. 5-1 Comparison of valid satellite data counts between Sentienl-3/OLCI and GOCI-II in the eastern seas of China in 2022

Synergy methods are mostly simple and easy to operate, with high data and product fidelity, and can even reduce product errors. For instance, the method of weighted average and target analysis techniques was applied to integrate multi-sensor ocean color products (Pottier et al. 2006)[6]; inter-

[6] Pottier, C., Garçon, V., Larnicol, G., Sudre, J., Schaeffer, P., & Le Traon, P. Y. (2006). Merging SeaWiFS and MODIS/Aqua ocean color data in North and Equatorial Atlantic using weighted averaging and objective analysis. IEEE transactions on geoscience and remote sensing, 44(11), 3436-3451.

mission bias correction method was utilized to generate multi-mission merged ocean color products (Sathyendranath et al. 2019)[7]. The prerequisite for generating synergetic datasets from multi-mission data products is the consistency of atmospherically-corrected remote sensing reflectance data from various satellite missions, as well as the validation with in situ data.

5.2.2 Validation and consistency for GOCI-II and Sentinel-3/OLCI atmospherically-corrected data products

Sentinel-3/OLCI data can be obtained via https://dataspace.copernicus.eu/. Remote sensing reflectance (R_{rs}) of OLCI can be obtained through the module of the Case 2 Regional Coast Colour (C2RCC) for atmospheric correction that was imbedded into ESA's Sentinel toolbox SNAP. GOCI-II radiance data can be downloaded from https://nosc.go.kr/opendap/, then the R_{rs} was obtained with the neural network atmospheric correction algorithm designed for GOCI-II, trained by the simulation dataset generated with a coupled ocean-atmosphere model. The coupled ocean-atmosphere model integrates a semi-analytical bio-optical model (Lee et al., 2002)[8] and a semi-empirical radiative transfer model (Shen et al., 2010)[9] and the AHMAD2010 aerosol model (Ahmad et al., 2010)[10].

The in-situ measured R_{rs} data from a fixed platform in Dong'ou (27.675°N, 121.355°E) shared by the China National Satellite Ocean Application Service (NSOAS) was used to verify the accuracy of GOCI-II R_{rs} results (Fig. 5-2). To ensure matching pixel selection, a time window of no more than 30 minutes was imposed between the image acquisition and in situ sampling times. Moreover, a 3×3 window was employed for averaging pixel values in matched instances. The accuracy assessment encompassed a total of 21 matched data. The determine coefficient (R^2), mean absolute percentage error (MAPE), and root mean square error (RMSE) were 0.97, 34.37%, and 1.71×10^{-3} sr^{-1}, respectively. The results indicated that the atmospheric correction method performed well in atmospheric correction for GOCI-II.

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[7] Sathyendranath, S., Brewin, R. J., Brockmann, C., Brotas, V., Calton, B., Chuprin, A., ... & Platt, T. (2019). An ocean-colour time series for use in climate studies: the experience of the ocean-colour climate change initiative (OC-CCI). Sensors, 19(19), 4285 https://doi.org/10.3390/s19194285.

[8] Lee, Z., Carder, K. L., & Arnone, R. A. (2002). Deriving inherent optical properties from water color: a multiband quasi-analytical algorithm for optically deep waters. Applied optics, 41(27), 5755-5772.

[9] Shen, F., Verhoef, W., Zhou, Y., Salama, M. S., & Liu, X. (2010). Satellite estimates of wide-range suspended sediment concentrations in Changjiang (Yangtze) estuary using MERIS data. Estuaries and Coasts, 33, 1420-1429.

[10] Ahmad, Z., Franz, B. A., McClain, C. R., Kwiatkowska, E. J., Werdell, J., Shettle, E. P., & Holben, B. N. (2010). New aerosol models for the retrieval of aerosol optical thickness and normalized water-leaving radiances from the SeaWiFS and MODIS sensors over coastal regions and open oceans. Applied optics, 49(29), 5545-5560.

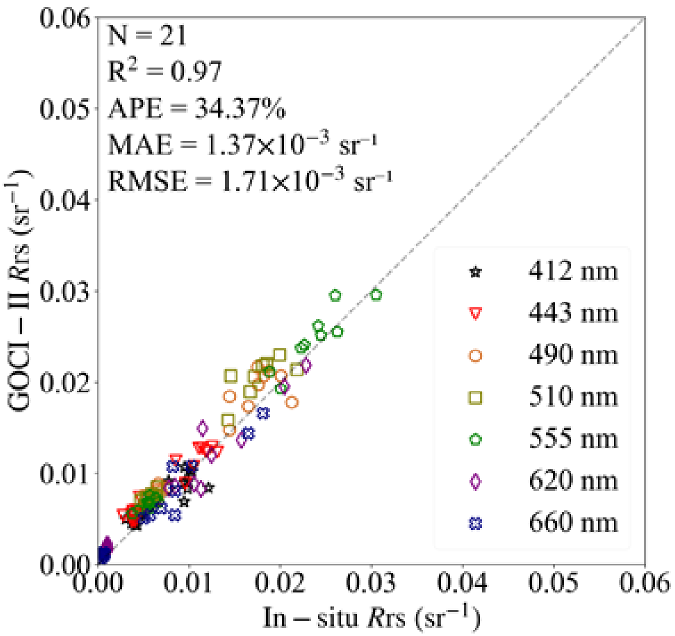

Fig. 5-2 Comparison between in situ R_{rs} in fixed platform and GOCI-II atmospheric corrected R_{rs}

For the cross-comparison of R_{rs} results between GOCI-II and Sentinel-3/OLCI, we chosen images of October 1st, 2021, encompassed coastal turbid waters, algal bloom waters, and clean waters. The comparison results were presented in Fig. 5-3. The correlation coefficients in the 412, 443, 709 and 865 nm were lower than other bands, R^2 of these bands were less than 0.4. R^2 gradually increased from 412 nm to 560 nm bands, decreased from 560 nm 865 nm band, and the highest correlation appeared in 560 nm. The results indicated that the atmospheric correction results of GOCI-II and Sentinel-3/OLCI are in good correlation from 490 nm to 680 nm.

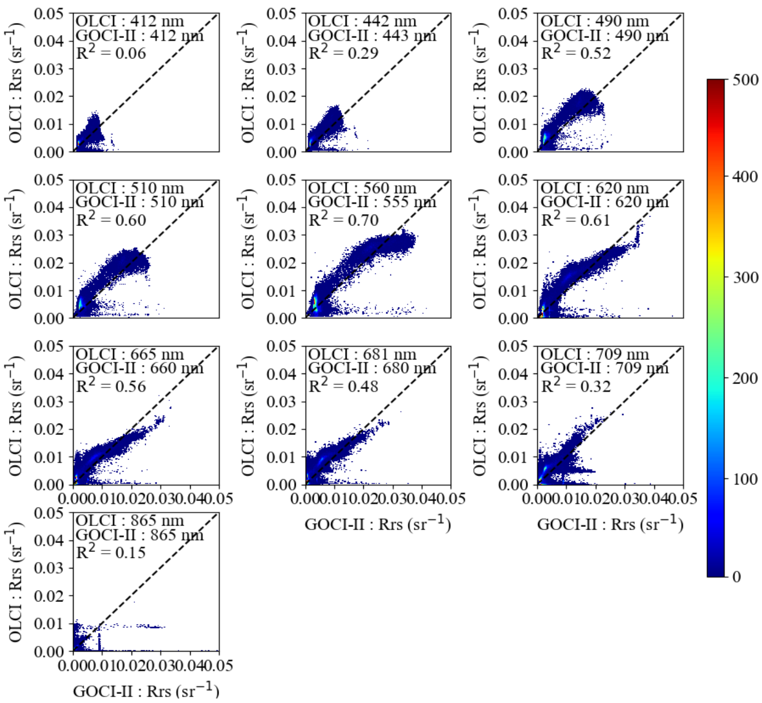

Fig. 5-3 Comparison between Sentinel-3/OLCI C2RCC R_{rs} and atmospheric corrected R_{rs} of GOCI-II

5.3 Merged Dataset of Global Ocean Chlorophyll-a Concentration (1998–2019)

Chlorophyll-a concentration (Chla) is recognized as an essential climate variable and is one of the primary parameters of ocean-color satellite products. Ocean-color missions have accumulated continuous Chla data for over two decades since the launch of SeaWiFS (Sea-viewing Wide Field-of-view Sensor) in 1997. However, the on-orbit life of a single mission is about five to ten years. To build a dataset with a time span long enough to serve climate change related studies, it is necessary to merge the Chla data from multiple sensors. The European Space Agency has developed two sets of merged Chla products, namely GlobColour and OC-CCI (Ocean Colour Climate Change Initiative), which have been widely used. Nonetheless, issues remain in the long-term trend analysis of these two datasets because the inter-mission differences in Chla have not been completely corrected.

To obtain more accurate Chla trends in the global and various oceans, we produced a new dataset by merging Chla records from the SeaWiFS, MODIS (Medium-spectral Resolution Imaging Spectrometer), MERIS (Moderate Resolution Imaging Spectroradiometer), VIIRS (Visible Infrared Imaging Radiometer Suite), and OLCI (Ocean and Land Colour Instrument) with inter-mission differences corrected in this work. This remote sensing merged dataset has a spatial resolution of 4km and a temporal resolution of monthly average, covering the global maritime area.

The fitness of the dataset on long-term Chla trend study was validated by using in situ Chla and comparing the trend estimates to the multi-annual variability of different satellite Chla records. The results suggest that our dataset can be used for long-term series analysis and trend detection.

Dataset link: https://zenodo.org/records/7092220

Method Reference: Yu S, Bai Y, He X, et al. A new merged dataset of global ocean chlorophyll-a concentration for better trend detection[J]. Frontiers in Marine Science, 2023, 10: 1051619. doi: https://doi.org/10.3389/fmars.2023.1051619.

5.4 Reconstruction of 3-D Ocean Chlorophyll a Dataset in the Northern Indian Ocean (2000–2019)

We present a novel method using satellite and biogeochemical Argo (BGC-Argo) data to retrieve the 3-D structure of chlorophyll a (Chla) in the northern Indian Ocean (NIO). The random forest (RF)-based method infers the vertical distribution of Chla using the near-surface and vertical features. The input variables can be divided into three categories: 1) near-surface features acquired by satellite products (Rrs, SST, Kd490, PAR, SLA and Wind); 2) vertical physical properties obtained from temperature and salinity profiles collected by BGC-Argo floats; and 3) the temporal and spatial features, i.e., day of the year, longitude, and latitude. The RF-model is trained and evaluated using a large database including 9738 profiles of Chla and temperature-salinity properties measured by BGC-Argo floats from 2011 to 2021, with synchronous satellite-derived products. The retrieved Chla values and the validation dataset (including 1948 Chla profiles) agree fairly well, with R2=0.962, root-mean-square error (RMSE) = 0.012, and mean absolute percent difference (MAPD) = 11.31%.

Based on this model, we produced a monthly average 3-D Chla profile product of 0-200m (32 vertical levels) in the northern Indian Ocean from 2000 to 2019. This will help to quantify phytoplankton productivity and carbon fluxes in the NIO more accurately. We expect that RF-model can be used to develop long-time series products to understand the variability of 3-D Chla in future climate change scenarios.

Dataset link: https://zenodo.org/records/10452898.

Method Reference: Hu Q, Chen X, Bai Y, et al. Reconstruction of 3-D Ocean Chlorophyll a Structure in the Northern Indian Ocean Using Satellite and BGC-Argo Data[J]. IEEE Transactions on Geoscience and Remote Sensing, 2022, 61: 1-13. doi: https://doi.org/10.1109/TGRS.2022.3233385.

6. Expanding optical characteristics database of the Indo-Pacific regional seas and demonstrating their response to climate changes.

Participants shared monthly IOP data (backscattering, CDOM, Chl-a, and POC) collected from the Singapore Strait over 2017-2023, light absorption of CDOM in relation to the El-Nino and tropical depression variations in the Malacca Strait, Chlorophyll a and CDM sampling of Celebes-Sulawesi Sea has started recently for the first time. Low-cost instruments, ASD Fieldspec® HandHeld 2 spectroradiometer and PlanktoScope (Pollina et al., 2022)[11] for field phytoplankton identification, for the underfunded and remote sites were also introduced to calibrate and validate the space observed data at the workshop. Participants also noted that small-scale fishers would be greatly benefit from the EO data products to locate fishing grounds to save fuel expenses.

7. Strengthening collaborative networks between Ocean Color professionals and early career researchers (ECRs) in the northwest Pacific and Indo-Pacific regions.

Several participants who had no prior learning expressed gratitude to mentor to enlarge their scientific border to satellite remote sensing such as how to access, download, validate satellite data and perform sensor-in-situ comparison, match-ups. Participants wanted to organize series of talks, meet regularly and working together to validate satellite data with in-situ data as the CIP region covers approximately 6000 km (E-W) x 4000 km (N-S) and is populated with so many islands with considerable distance, with different water masses and different terrestrial material inputs. They also wanted to start collaborative publications, laboratory experiments, and awareness campaign of the marine bio-optical EO data. One participant proposed to use Forel-Ule[12] color scale to observe ocean color of the Case 2 Waters throughout the region as a part of citizen-science activities.

Participants viewed that Ocean Color is a key essential fishery resources indicator, and climate variable identified by the Global Climate Observing System (GCOS). Participants understood that fishing activities can be significantly benefited by ocean color information. Ocean color needs to be measured accurately and continuously over time to serve as a means to monitor and assess change to the ocean and to other Earth systems, including the atmosphere, terrestrial biosphere, and land. Temporal frequency and spatial resolution, and then match these requirements to the capabilities of existing instruments (from shipboard and moorings to satellites). Satellite-*in situ* matchups for developing region-specific algorithms may provide a practical way forward for generating global

[11] Pollina, T., Larson, A. G., Lombard, F., Li, H., Le Guen, D., Colin, S., ... & Prakash, M. (2022). PlanktoScope: affordable modular quantitative imaging platform for citizen oceanography. Frontiers in Marine Science, 9, 949428. https://doi.org/10.3389/fmars.2022.949428.

[12] Nie, Y., Guo, J., Sun, B., & Lv, X. (2020). An evaluation of apparent color of seawater based on the in-situ and satellite-derived Forel-Ule color scale. Estuarine, Coastal and Shelf Science, 246, 107032. https://doi.org/10.1016/j.ecss.2020.107032.

POC products (Evers-King et al., 2017)[13]. Total suspended matter concentration (g m-3) would be a good start as well as HPLC chlorophyll measurements. (Valente et al., 2022)[14].

All participants requested additional training opportunities to learn best practices or step-by-step procedures from the field observation and sampling designs, collection, subsequent analysis, and satellite EO data use.

8. EO data to provide administrative tools to help decision makers

Participants viewed that EO data are essential for the decision makers to manage, conserve the marine environment, and utilize the marine resources of CIPR, particularly fisheries resources, terrestrial peat carbon behavior (CDOM) leaching into the sea, and harmful algal blooms. Participants also viewed that scientists need to provide easy-to-use platforms for various stakeholders, such as https://incois.gov.in/MarineFisheries/PfzWebGis http://118.97.27.101/peta-daerah-penangkapan-ikan-nasional, and PDPI Map (fishing area forecast map) to save vessel fuel for fisheries management. While satellites observed EO data are readily available free of charge for most cases, in situ calibration and validation are still challenges in some areas Awareness of the availability of EO data among decision-makers will help to seed funds to carry out in situ calibration and validation research activity.

The Central Indo-Pacific region (CIPR) is lies under the jurisdiction of three countries, The Philippines (US$ 0.4 Trillion in 2022) is a large archipelago of over 7000 islands with 114 million residents with an increase of 1.58% a year, its coastlines are populated by coral reefs, seagrass meadows, and mangrove forests. The islands have narrow coastal plains, and active volcanoes, are soaked with tropical cyclones, and rainstorms often. Maritime industries grew by 21.1% in 2022 and accounted for about 3.9% of the national GDP as a gross value of PHP857.74 billion (x 0.018 = USD 15.4 Billion), and employ 2.23 million people (4.7% of total national employment). Among the maritime industries, ocean fishing, the manufacture of ocean-based products, sea-based transportation and storage, and ocean-based power generation/transmission/distribution account for 31.5%. 21.6%, 14.6%, and 11.3%, respectively. Ocean fishing employs 1.1 million people. Coastal accommodation/food/beverage services, coastal recreation, and offshore and coastal mining and quarrying grew as much as 248, 162, and 56%, respectively[15]. Offshore magnetite sand (volcanic minerals and lava fragments) mining projects using a siphon dredging system with a 30 MMT production rate a year started in 2021to extract from about 50 km^2 off Cagayan for the next 25 years[16] and Lingayen Gulf to extract 25 million metric tons (MMT) per year is scheduled soon[17].

Malaysia (34 million populations, US$ 0.4 Trillion in 2022) consist of Peninsular Malaysia and East

[13] Evers-King, H., Martinez-Vicente, V., Brewin, R. J., Dall'Olmo, G., Hickman, A. E., Jackson, T., ... & Sathyendranath, S. (2017). Validation and intercomparison of ocean color algorithms for estimating particulate organic carbon in the oceans. Frontiers in Marine Science, 4, 251. https://doi.org/10.3389/fmars.2017.00251.

[14] Valente, A., Sathyendranath, S., Brotas, V., Groom, S., Grant, M., Jackson, T., ... & Zibordi, G. (2022). A compilation of global bio-optical in situ data for ocean colour satellite applications–version three. Earth System Science Data, 14(12), 5737-5770. https://doi.org/10.5194/essd-14-5737-2022.

[15] The Philippine Statistics Authority (PSA), 24 October 2023.

[16] Proposed increase in extraction volume of the Cagayan Offshore magnetite mining project EIA report.

[17] Stakeholders alarmed on proposed offshore mining in Lingayen Gulf, 27 September 2021.

Malaysia (Sabah and Sarawak, northern part of the Borneo), has maritime Exclusive Economic Zones and continental shelves in the South China Sea and Sulu Sea, and partly controls the Strait of Malacca and the Strait of Johor. The fishing industry accounts for about 12% of the national GDP. Since 1974, Malaysia has produced 9 billion barrels of oil and 50 trillion cubic feet of gas. Currently, Malaysia produces 660,000 barrels of liquids and approximately 7.0 billion cubic feet of gas per day. The country's remaining commercial reserves are estimated at over 17 billion barrels of oil equivalent from more than 400 fields, with gas making up three-fourths of the mix.[18] The majority of Malaysia's oil comes from offshore fields, off the coast of states of the Terengganu (East of the peninsular), and Sabah and Sarawak. The crude oil and condensate sector contributes 4.3 % of national GDP[19]. - the maritime industry contributes about 40% of the national GDP from ports and shipping, and marine tourism.

Indonesia, with more than 17,500 islands with US$ 1.3 trillion in 2022, 276 million populations)[20]. – fishery sector supports US$27 billion (2%) and 7 million jobs, providing >50% of the country's animal-based protein needs. The tourism industry generates US$27 billion a year. Marine debris costs US$0.45 billion a year. Forest conversion moratorium to all mangrove ecosystems.[21] Oil and gas platforms offshore of Sumatra, Java, Kalimantan, and Natuna Sea.[22] Oil spill damages often occurred[23], including transboundary pollution from neighboring States. In 2009, the Montara oil well, 250 km off the coast of Western Australia exploded to spew more than 2,500 barrels of oil a day into the Timor Sea for 74 days in 2009. The resulting oil slick killed seaweed crops and destroyed fishing grounds, and polluted waters over 90, 000 km^2. Over a hundred thousand seaweed farmers have claimed it destroyed their livelihoods, not been compensated and resolved yet until 2022[24]. Such transboundary spread of oil slick requires satellite monitoring over the wide sea surface. The Central Indo-Pacific region (CIPR) is located where the surface water moves from the Pacific to the Indian Ocean (the warm route, about 8.5 Sv)[25] while deep water moves from the Indian Ocean to the Atlantic starting from the Drake Passage and the south of Tasmania (the cold routes)[26]. The climatological significance of the CIPR is great as the global thermohaline circulation (THC) or "conveyor belt (about 20 Sv, starting from the North Atlantic)" is responsible for a large portion of the heat transport from the tropics to higher latitudes. The terrestrial Philippines, Sundaland, and Wallacea are important biodiversity hotspots in the world[27] while their marine biosphere exhibits

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18 Production | Malaysia Petroleum Management (MPM) (petronas.com)

19 Malaysia: share of crude oil sector to the GDP 2022 | Statista

20 GDP (current US$) | Data (worldbank.org)

21 World Bank. (2021). Oceans for Prosperity: Reforms for a Blue Economy in Indonesia. The World Bank, Washington, D.C. 41p.

22 Indonesia Oil & Gas Concessions and Major Infrastructure Map, April 2018.

23 Syakti, A. D. (2018). Marine bioremediation in indonesia: die before blossom. Omni-Akuatika, 14(3), 117-127. http://dx.doi.org/10.20884/1.oa.2018.14.3.584.

24 Doherty, B. (2022). Very Hard Life Now: 12 Years after the Montara Oil Spill, Indonesians are Still Fighting to Be Heard. The Guardian, 15.

25 Gordon, A. L. (1986). Interocean exchange of thermocline water. Journal of Geophysical Research: Oceans, 91(C4), 5037-5046. https://doi.org/10.1029/JC091iC04p05037.

26 Speich, S., Blanke, B., de Vries, P., Drijfhout, S., Döös, K., Ganachaud, A., & Marsh, R. (2002). Tasman leakage: A new route in the global ocean conveyor belt. Geophysical Research Letters, 29(10), 55-1.https://doi.org/10.1029/2001GL014586.

27 Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. Nature, 403(6772), 853-858. https://doi.org/10.1038/35002501.

maximum biodiversity in CIPR and the seas adjacent to the northern part of Australia (i.e., Indo-Australian Archipelago, IAA) owing to the convergence of Eurasia, Australia, and the Pacific/Philippine Sea plates with a complex mosaic of oceanic, arc, and microcontinental fragments[28].

Volcanic ash fallouts are a salient feature of the Central Indo-Pacifc (CIP) region as it is located in the active plate boundaries. Annually about 13 ±5 volcanoes spew vast amounts of volcanic ash into the atmosphere and on the ocean surface. Volcanic ashes deposited on the watersheds drain also into the coastal ocean. Fresh volcanic ash contains Fe (0.09%) and P (0.01%) (e.g., Indonesian volcanos) and dissolves immediately (<24 h) after being in contact with water.[29] The specific gravity of dry volcanic ash varies from 0.4~0.7 g cm^{-3},[30] thus it is lighter than seawater, thus it falls on the surface will stay sufficient time in the surface layer to leach out nutrients contained. Therefore, volcanic ash falls increase the primary productivity in the adjacent seas and oceans. Post- Bali workshop dialogue between regional participants and Fang Shen explored the impact of volcanic ash falls on the carbon dynamics and fishing grounds using satellite and *in situ* biogeochemical Argo floats (BGC-Argo, https://biogeochemical-argo.org/data-access.php) observed chl a.

CIP region as a whole hosts 37,251 km^2 of mangrove forests, which accounts for over 25% of the world total.[31] CIP islands are mostly of volcanic origin, therefore, poros rock and soil discharge a great amount of freshwater to the coastal region through submarine groundwater discharge paths. Seagrass beds covers 3,065 km^2.[32] No significant salt marsh develops in the CIPR[33].

Therefore, EO data are essential to monitoring water movement in the atmosphere and ocean, marine primary productivity, fishing ground, volcanic eruptions, and the spread of volcanic ash plumes over the ocean, and understanding the natural phenomena associated with these oceanographical and volcanic/tectonic plate dynamcs.

9. Summary

An international study group for the ocean color-based plant species identification and carbon flux in the Indo-Pacific oceans, https://imber.ecnu.edu.cn/OCPC/list.htm, has recognized the enormous potential to aid sustainable development in the Central Indo-Pacific (CIP), where rapidly developing

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economies require marine resources ever more and the residents become equipped with a high-speed internet that enables to download bulky satellite observed data products and other earth observed (EO) data from the global EO data providers. The group felt that the experience of EO data processing centered around the Northwest Pacific can be directly applied to the CIP region.

The pool of CIP regional scientists is relatively small and scattered over a thousand kilometers or more in the separated islands. They are relatively poor in their research resources, although they expand them rather quickly. Consequently, their exposure to the international community is far less sufficient to produce socially meaningful scientific products utilizing EO data. Using EO data has been expanded to the much wider scientific community than before, such as fisheries, marine protected area management, nonliving marine resource exploitations, and maritime hazards preparedness sectors. To meet such a demand, the group published "Ocean Color Sensors and Their Data Access: A Brief Overview" to guide non-satellite data processing professionals and beginners in 2022.

At the end of 2022, ESA and Future Earth graciously provided a training opportunity for the group. By distributing questionnaires to the potential participants, the group selected thirteen participants from Indonesia, Malaysia, the Philippines and Singapore. The participants are diverse in their scientific interests and data processing capacities. All participants submitted their projects and had them reviewed by mentors to complete. Three 2-hour online sessions, including lectures from OCPC members, were held in May, July, and September for the participants to equip the prerequisite scientific background and state-of-the-art handling of EO data. An in-person workshop convened on 7-9 November 2023 in Bali, Indonesia. A three-day workshop was devoted to completing individual projects, and mentors responded individually to the needs of the participants. A special issue of an international academic journal was chosen to host project reports and to stimulate further use of EO data in the CIP and the Northwest Pacific region.

Participants requested additional training opportunities to learn best practices or step-by-step procedures from the field observation and sampling designs, collection, subsequent analysis, and satellite EO data use. As the CIP region is populated with active volcanoes and subject to large-scale atmospheric and oceanic change, and global climate changes, the region demands more usage of EO data to aid its sustainable development and mitigate climate change in the coming years.

News published

News in English

Venturing abroad: An ECNU Workshop Empowering the Indo-Pacific Marine Biosphere with the Expanding Application of Remote Sensing to Deal with Climate Change

EO-WPI Online Training: Session #1 Held on 25 May

EO-WPI Online Training: Session #2 Held on 26 July

EO-WPI Online Training: Session #3 Held on 26 September

News in Chinese

华东师大赋能印太海洋生物圈应对气候变化

拓展遥感数据应用，华东师大工作坊“走出去” 赋能印太海洋生物圈应对气候变化

Acknowledgements

ESA and FE jointly funded an in-person workshop held in Bali with additional support from State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Japan Agency for Marine-Earth Science and Technology, and Korea Institute of Ocean Science and Technology.

Annex 1. The progress reports of participants (abstracts).

Improving Predictive Fishing Zone Selection for Small-Scale Fishers in the Java Sea: A Case Study in Indramayu with Multi-Aid Vessel Support

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Abstract

The utilization of Vessel Multi-Aid (VMA) devices by small-scale fishers plays a crucial role in estimating fishing areas. The VMA offers a comprehensive range of features, including location tracking, weather forecasting, navigation capabilities, an electronic logbook, and a map for predicting fishing areas. However, the conventional use of these devices often falls short in predicting fishing zone potential within the proximity of the fishers' operational areas. The predominant focus of existing predictions on open sea areas has left small-scale fishermen in need of more accurate predictions for coastal regions. This study aims to assess the suitability of VMA predictions for fishing areas by incorporating temperature and chlorophyll-a data. By integrating chlorophyll-a and sea surface temperature data into the VMA system, this study seeks to create a comprehensive database of fishing areas. This database is intended to provide small-scale fishermen with valuable information to enhance their fishing operations. The research was conducted in Indramayu (Part of FMA 712, Java Sea), a region characterized by a significant number of small-scale fishers. The study focuses on purse seine fishers, who target anchovies, a small pelagic fish commodity, as the main catch. By integrating chlorophyll-a and sea surface temperature data into the VMA system, this study seeks to create a comprehensive database of fishing areas. This database is intended to provide small-scale fishermen with valuable information to enhance their fishing operations. The accessibility of this data can enhance the utilization of Vessel Monitoring Systems (VMA) among small-scale fishermen, promoting the adaptation of technology to support quota-based fisheries policies in Indonesia.

Relationship between oceanographic characteristics and *manta sp* caught by the small-scale gillnet fisheries in the southeast Indian Ocean

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Abstract

Indonesian coastal waters include important marine megafauna biodiversity hotspots. However, there are increasing concerns over the rapid decline of ecologically and socio-economically important species, such as sharks and rays due to unsustainable human activities, primarily fisheries catch. The majority of Indonesian fishers are engaged in small-scale fisheries (SSF), which provide important sources of income and protein for coastal communities. However, SSF are currently exempt from fisheries management measures and are largely unregulated despite contributing a significant proportion of catch. Generalised Additive Models (GAM) were used to investigate the effect of oceanographic parameters on Mobulidae (Mobula spp.) fisheries catch based on landings data from Cilacap, Central Java, Indonesia over ten years (2009 – 2018). Monthly Mobulidae catch was generally higher June to November, corresponding with relatively high salinity (sal), chlorophyll (chl), nitrate (nit), current velocity (vel) and kinetic energy (kin) levels, and relatively low sea surface temperature (sst), oxygen (oxy) and sea surface height (ssh) levels. GAM results showed that Mobulidae catches were strongly related to sst, nit, oxy, chl and sal. Positive associations were observed between landings and sst (<28 0C); ssh (<0.9 m); chl (ranges from 0.32-0.45 mg/m3); sal (>34.1‰); nit (>0.0045 mg/m3); phy (<0.001 mg/m3); vel (>0.29 m/s); oxy (<0.182 mg/m3); and kin (>0.04 m/s). Understanding drivers of species distribution within fishing grounds can aid development of effective management and conservation actions. The assessment would be improved by onboard vessel recorded spatial and temporal fishing effort and species-specific catch. The results help inform much needed management measures including habitat protection and bycatch reduction to improve the conservation status of Mobulidae species in the southeast Indian Ocean.

Climate impact on Chlorophyll-a concentration and small pelagic fish in South Java Sea

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Abstract

The Southeast Monsoon (SEM) triggers upwelling along the south coast of Java and the Bali Islands of Indonesia, and the upwelling intensity increases during El Niño and Indian Ocean Dipole (IOD). To understand the impacts of the monsoon wind system, El Niño and the IOD on the variability of Chlorophyll-a (Chl-a) concentration and its impact on sardine (Sardinella lemuru) production in the Bali Strait, we analyzed the monthly fish landing (production) data and catch per unit of effort (CPUE) from 1992 to 2019 and satellite Chl-a data from September 1997 to December 2019. The wavelet analysis provided the annual and interannual variability of Chl-a concentration and sardine production in the Bali Strait. Our results indicate a robust relationship between sardine production and the El Nino and IOD index. Chl-a concentration significantly increases under the influence of IOD (+) and El Nino due to intense upwelling. The high magnitude of Chl-a concentration, followed by higher sardine production, was also more distinctly noticed in the IOD (+) years than in the El Niño years. There is a time lag of 3 months for the sardine production to respond to increased Chl-a concentration. Given the ability of ocean color data to explain the variability of sardine production, it could be developed as a tool for sustainable management of the sardine fishery in the Bali Strait.

Sea surface dynamics of mackerels (*Rastrelliger* sp.) potential fishing grounds in the southern Makassar Strait

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Abstract

Mackerel (*Rastrelliger* sp.) is a species of pelagic fish that is abundant and of great economic importance to Indonesia. The growing demand for mackerel has increased mackerel fishing effort. Using remote sensing technology, the potential fishing zone for mackerel can be determined. The major goal of this study was to determine the characteristics of the sea surface of the mackerel potential fishing grounds in the southern Makassar Strait by analyzing satellite data of chlorophyll-a concentration, sea surface temperature (SST), and wind speed from 2003 to 2019. The 2015-2019 mackerel catch data was also analyzed in this study. The results indicated that the highest number of mackerel was caught during the months of March to May and September to October. During March-May, the mackerel fishing grounds demonstrate chlorophyll-a concentration of 1 mg m^{-3}, SST of 29-30°C, and wind speed of 1 m s^{-1}. During September-October, the mackerel fishing grounds exhibit chlorophyll-a concentration of <0.5 mg m^{-3}, SST of 28-29°C, and wind speed of 5-7 m s^{-1}. Interestingly, no mackerel fishing grounds were found in the upwelling region of the southern Makassar Strait. It seems that mackerels disfavor waters with chlorophyll-a concentration >1 mg m^{-3}, SST <28°C, and wind speed >7 m s^{-1}.

Footprint of Fishing Ground Based on In-situ Tracking and Oceanographic Characteristics in Indonesian Seas

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Abstract

The Indonesian seas are characterized by a complex interplay of ocean dynamics, which, in turn, influence the formation of productive fishing grounds in the region. The aim of this research was to analyze data from in-situ ship tracking and oceanographic conditions. Fishing data were acquired from Global Fishing Watch (GFW) from 2014 to 2018, classified and filtered on small pelagic fishes and mainly purse seine fishing gear on geartype. The oceanographic characteristics including sea surface temperature (SST), sea surface salinity (SSS) and chlorophyll-a (Chlor-a). The results show that Sea Surface Temperature (SST) ranges from 24°C to 31°C, and Chlorophyll-a (Chlor-a) concentrations range from 0.025 mg/l to 10 mg/l. The fishing grounds are primarily located within Fishery Management Areas (FMAs), except for FMA 714. This study aids fishermen in identifying suitable fishing locations and assists the government in managing maritime resources on the continent.

The habitat preference of commercial tuna species based on a daily environmental database approach in the tropical region of Eastern Indian Ocean Off Java-Bali Waters

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Abstract

This article investigates the habitat characteristics of commercial tuna species in the Eastern Indian Ocean off the coasts of Java and Bali using daily oceanographic measurements. Furthermore, this is the first time anyone has studied the habitat features of large pelagic fish, including tuna species, using the daily geographic distribution of oceanographic data. We used five main daily oceanography parameters in this study: sea surface temperature (SST), sea surface chlorophyll (CHL-a), sea surface height (SSH), dissolved oxygen at 100m (DO100), temperature at 100m (temp100), and a combination of yellowfin, albacore, and bigeye tuna catches using long lines. We used Generalized Additive Models (GAMs) from univariate variables to combine all variables to investigate the link between the environmental database and tuna catch. With P-values less than 0.001, the results indicated that all variables influence the existence of all tuna species. The most important predictor variable for all tuna species is temperature, followed by DO100 for bigeye and yellowfin tuna and SSH for albacore tuna. Bigeye and yellowfin tuna prefer a lower temperature of 100, while albacore tuna prefer a higher temperature of 100. They all, however, avoid SSTs of more than 29 °C. To properly account for the consequences of global warming on the oceans, more study of the long-term SST trend specific to tuna species is required.

The fate of algal-derived carbon after the harmful algal bloom events in the Jakarta Bay area

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Abstract

The algal bloom phenomenon in Jakarta Bay is thought to have increased over the past few decades, with eutrophication being one of the main factors contributing to the events. Aside from the evident ecological impacts such as fish kills, the presence of flourishing algae can also contribute to the escalation in the concentration of organic carbon, which, for example, may lead to an elevation in the levels of methane gas from the decomposition process of carbon. The primary objective of this research is to conduct a spatial and temporal analysis of the algal bloom phenomenon by utilizing satellite data in conjunction with field observation data. Subsequently, the investigation seeks to estimate the potential for the formation of organic carbon within each of these algal bloom occurrences. We used the observational data obtained from Jakarta's Department of Environment, and NASA's Ocean Color satellite data. It is anticipated that the findings of this study will yield a more profound understanding of the likelihood and consequences of algal blooms, as well as the carbon that results from these blooms.

The variability of sea surface height and temperature in the Northwest Pacific Ocean (NWPO) during ENSO events in 2021-2023

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Abstract

Recently, 2021–2022 has been identified as a La Niña year, and the ongoing 2023 is considered a moderate to strong El Niño year. The Northwestern Pacific Ocean (NWPO) is evidenced significant effects on regional and global ocean-atmospheric coupling variability in recent decades, and it is suspected that it will be greatly affected by the current ENSO events. This study aims to investigate the variability of sea surface height and temperature in the NWPO during ENSO events in 2021–2023. This study was performed based on the reprocessed satellite models of sea surface height (SSH) and sea surface temperature (SST) from December 2020 – November 2023. The climate index of the Southern Oscillation Index (SOI) and Pacific Decadal Oscillation (PDO) represent the extreme climatic events in this study. The satellite models are displayed in charts and graphs and quantitatively analyzed with statistical methods of Pearson Correlation and linear regression. The results show that the recent ENSO events have a strong influence on SSH by 66.6% in the tropical zone of the NWPO. Conversely, SSH in the subtropical and temperate zones does not appear to be affected by climate events, but they exhibit stronger seasonal variability and are more sensitive to SST changes.

Variation of Fish landing in Kota Kinabalu, Sabah Malaysia: is there any response to ENSO activities?

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Abstract

The area off Kota Kinabalu is an important fishing ground of Malaysia. It is not clear if there Is any changes of the abundance and diversity of fishes in this fishing ground under global warming. Here in this study a 20-years dataset of fish landing (2000-2019) obtained from the Fisheries Department of Sabah were analyzed. In particular changes of fish landing during a few strong ENSO events were examined. Satellite sea surface temperature and chlorophyll data in the same temporal range as well as local meteorological data were used to help understand the changes observed. The results will provide more insights for the understanding of regional eco-responses to global change.

Applications of hyperspectral imaging with unsupervised machine learning for plastic detection in aquatic environments

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Abstract

Remote sensing has shown potential in detecting floating plastic targets with the advantage of periodic observations and wide area coverage. Plastic accumulation has been reported in global regions, however, there is insufficient knowledge on faster methods of detecting floating plastics through hyperspectral imaging systems. This work aims to develop an algorithm based on hyperspectral imaging using the Analytical Spectral Devices (ASD) HandHeld 2 spectroradiometer, in conjunction with the HydraSpectra (HS) sensor from the Commonwealth Scientific and Industrial Research Organization (CISRO). The devices acquired spectral data in the range of 450 to 1050 nm for further use with unsupervised machine learning. Spectral samples of the water surface from the Sibu River were collected by the spectroradiometer and the data was compared with those collected from a fixed HS sensor. The focus site was at a jetty at Kampung Telaga Air, Kuching, Malaysia. Further spectral samples were taken of water surfaces from three water bodies, including a river near a tourist spot, a small lake and a swimming pool. Plastic detection was based on spectral readings of a floating plastic bottle. The results show a spectral range corresponding to the turbidity of the water as well as sky conditions, indicating several factors that alter spectral readings. In addition, the ASD spectroradiometer was able to discern the plastic bottle on all water surfaces.

CDOM Distribution in the Malacca Strait in an inter-monsoon season

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Abstract

Anthropogenic activities are influential in elevating dissolved organic matter (DOM) concentration in aquatic bodies. Chromophoric dissolved organic matter (CDOM) is a fraction of DOM that contains chromophores and absorbs surrounding lights. Increasing CDOM presence in water reduces photosynthesis available radiation (PAR) of sunlight that will affect primary productivity. Understanding the source, distribution, and transformation of CDOM is vital to delineating its fate and influence on water bodies. Situated along the west coast of Peninsular Malaysia, the Malacca Strait is heavily industrialized, with nearby waters subjected to intense human activities. Our knowledge of biogeochemical properties such as CDOM and the application of remote sensing in scientific work in this region remains relatively sparse. Thus, our work is a preliminary study that focuses on understanding the biogeochemical variables that influence CDOM presence in this region while using remote sensing to understand its spatial distribution. Water samples and hydrological parameters were collected in April 2023 along the northern Malacca Strait to analyze biogeochemical variables (e.g., dissolved organic carbon (DOC), CDOM) and establish their underlying relationship. This study hypothesizes that the source, characteristic and distribution of CDOM is influenced by the surrounding environmental factors and other biogeochemical components. By using in-situ measurements and satellite data collected from Ocean Colour-CCI (OC-CCI) and Moderate Resolution Imaging Spectroradiometer (MODIS), it is expected that both datasets demonstrate consistency and the inter-annual variability of CDOM distribution from 2013 to 2023 will show comparable and significant differences. This study is important to understand the production and removal process of CDOM and further pave the way towards developing remote sensing data in this region.

Bio-optical relationships in coastal waters of Southeast Asia for application to satellite remote sensing of CDOM and DOC

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Abstract

Southeast Asia's (SEA's) carbon-rich peatlands are recognized as a major source of fluvial dissolved organic carbon (DOC) fluxes to coastal waters, contributing to more than ~10% of the annual global land-ocean terrestrial DOC flux. Colored Dissolved Organic Matter (CDOM) as the optically active component of DOC, affects phytoplankton communities and primary productivity of coastal waters. We examined the bio-optical relationship between CDOM and DOC in Southeast Asian waters through a hybrid approach of combining in-situ measurements with satellite remote sensing. We first investigated the relationship between DOC concentration and CDOM absorption at 443 nm (a_433) with 192 in-situ measurements at 4 sampling sites at the Singapore Strait, for the period 2017-2023 with monthly resolution. The Pearson correlation shows that DOC and CDOM a_443 correlates the most during the Southwest Monsoon period (Jun - Sep) with a R^2 = 0.91, while the correlation is low during the Northeast Monsoon period (Dec – Mar) with R^2 = 0.31. To test whether this relationship is consistent with satellite data, we utilized the absorption of detrital and dissolved matters at 443 nm (adg_443) from MODIS Aqua L2 IOP data and perform a model-insitu comparison with field CDOM a_443 measurements. The comparison shows a relatively low R^2 value of 0.16, indicating poor satellite detection of adg_443 at coastal Singapore. Interestingly, we found a better match between in-situ CDOM a_443 and satellite a_443 (total absorption at 443nm) with R^2 = 0.35, indicating that the separation of phytoplankton absorption (aph) and adg is difficult and error prone. Future work includes generating time-series map of CDOM from satellite data to examine its temporal variability and relationship with DOC. Our current findings highlight the necessity to develop more advanced algorithm to improve satellite performance and possibly semi-analytical model to monitor biogeochemical changes in Southeast Asia coastal waters.

Initial insights on the spatial and temporal variability of phytoplankton functional groups in Celebes-Sulawesi Sea

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Abstract

Celebes-Sulawesi Sea is bounded by the Mindanao Island in the north, the Sulu ridge and Borneo in the west, and Sulawesi in the southeast. It has been described as generally oligotrophic although published and accessible in-situ data is severely lacking. In this regard, satellite remote sensing may be able to shed some light on phytoplankton variability trends in this understudied region. Using satellite data spanning 10 years, monthly means revealed a significant increasing trend in chlorophyll and sea surface temperature. In terms of phytoplankton size classes, mean microphytoplankton also has a significant increasing trend while nano- and picophytoplankton showed the opposite. Interestingly, in terms of phytoplankton functional types, dinoflagellates did not have any significant trend while other groups displayed either a significant negative or positive trend. Results of multivariate linear regression and EOF patterns will also be discussed. As initial findings are limited by datasets used, more work needs to be done to incorporate other ecologically-informative variables such as physicochemical datasets and extend the temporal coverage for a more thorough analysis.