

MONITORING OF MARINE DYNAMICS AND MARINE ENVIRONMENT DISASTERS WITH MULTIPLE SATELLITES DATA

DRAGON 6 2025 Symposium

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[PROJECT ID. 95549]





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**PROJECT TITLE: MONITORING OF MARINE DYNAMICS AND MARINE ENVIRONMENT DISASTERS WITH
MULTIPLE SATELLITES DATA**

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SENTCHEV, ALEXEI; HAUSER, DANIELE**

PRESENTED BY: XU, YING; SCHMITT, FRANÇOIS G.



Project's context

- The marine environment is highly variable in time and in space.
- It is a complex system and extreme events may lead to environmental disasters, to blooms, to high winds and high waves.
- Remote sensing can help to detect and characterize such events, and monitor them.
- Adequate algorithms and methods must be developed for this



Project's objectives

Use multiple satellites to jointly monitor marine environmental disasters and better understand relevant dynamics of marine environmental disasters.

- To perform consistency verification on the wind and wave fields provided by multiple satellite missions
- To combine multiple satellite data to monitor and track the development trend of marine environmental disasters
- To characterize marine dynamics and better understand their potential mechanisms related to marine environmental disasters

Project's objectives of Dragon 6-95549



International team

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Wenming LIN (Nanking University of Information Science and Technology)

Xiuzhong LI (Nanking University of Information Science and Technology)

François G SCHMITT (CNRS) PI, France

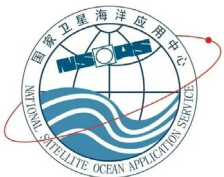
Elena ALEKSEENKO (University of Littoral)

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Daniele HAUSER (CNRS)

Laboratories: **LOG**, Wimereux

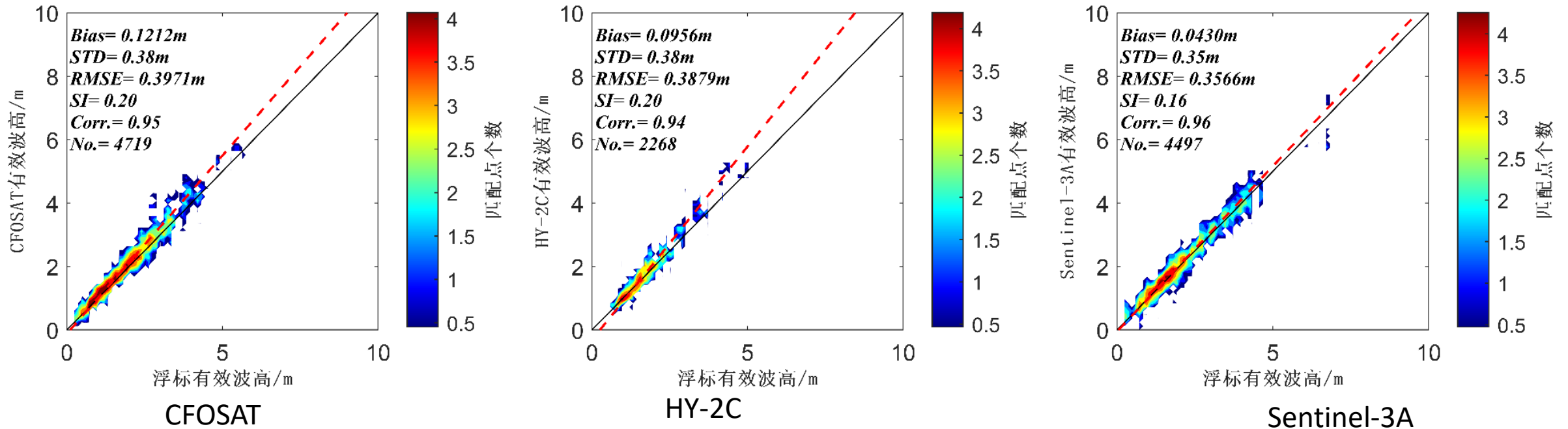
and **LATMOS**, Paris



Consistency verification on the wave fields



Uncertainty analysis was performed for 9 in-orbit SWH observation satellites data.

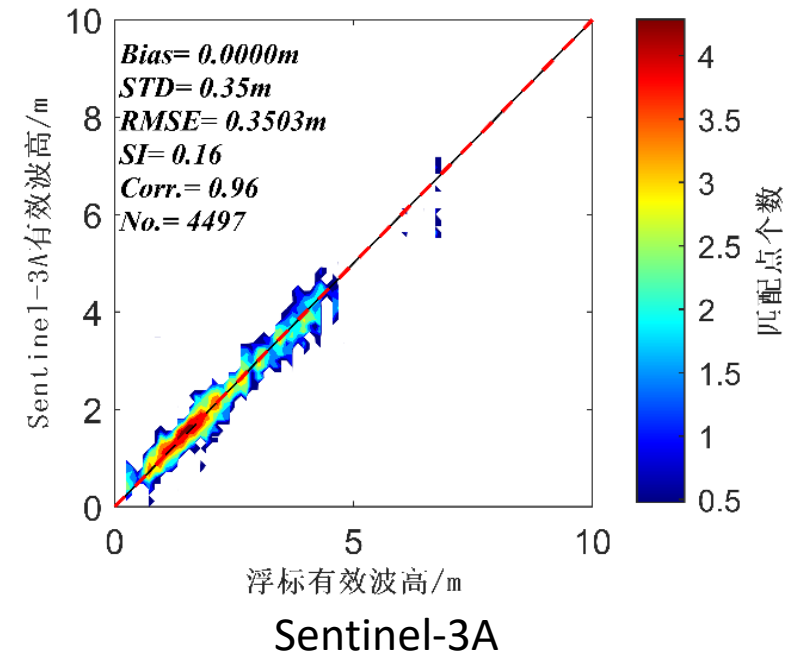
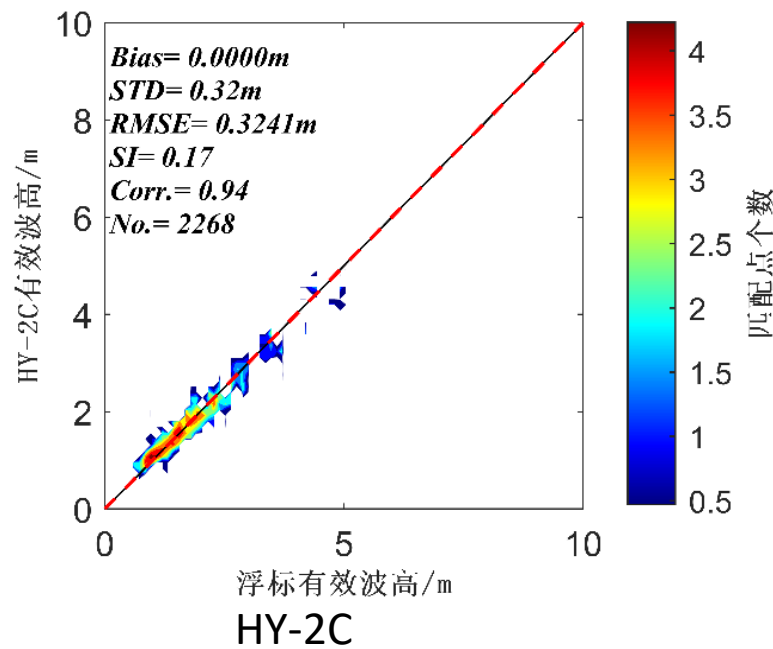
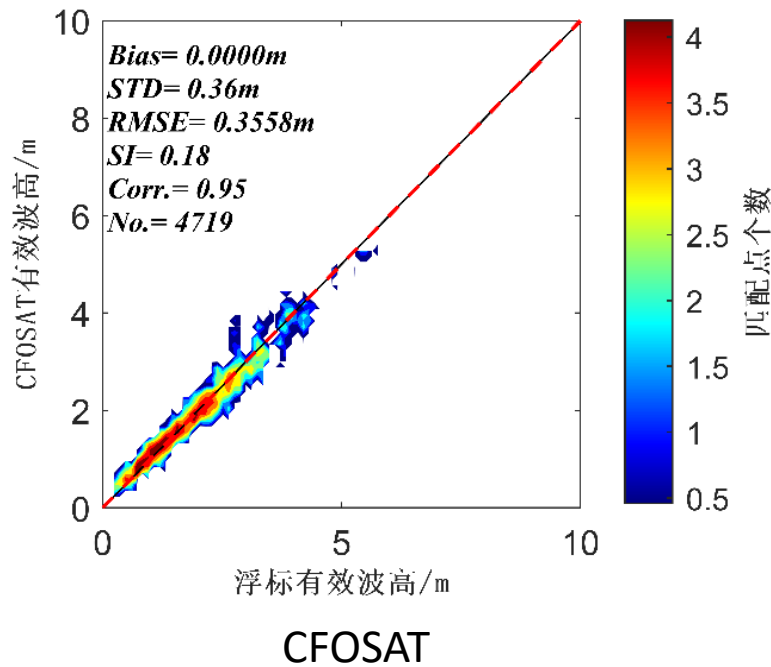


SWH comparison

Consistency verification on the wave fields



The least squares regression analysis method was adopted to calibrate the satellite SWH data using buoy data.



Calibration with buoys

Consistency verification on the wave fields

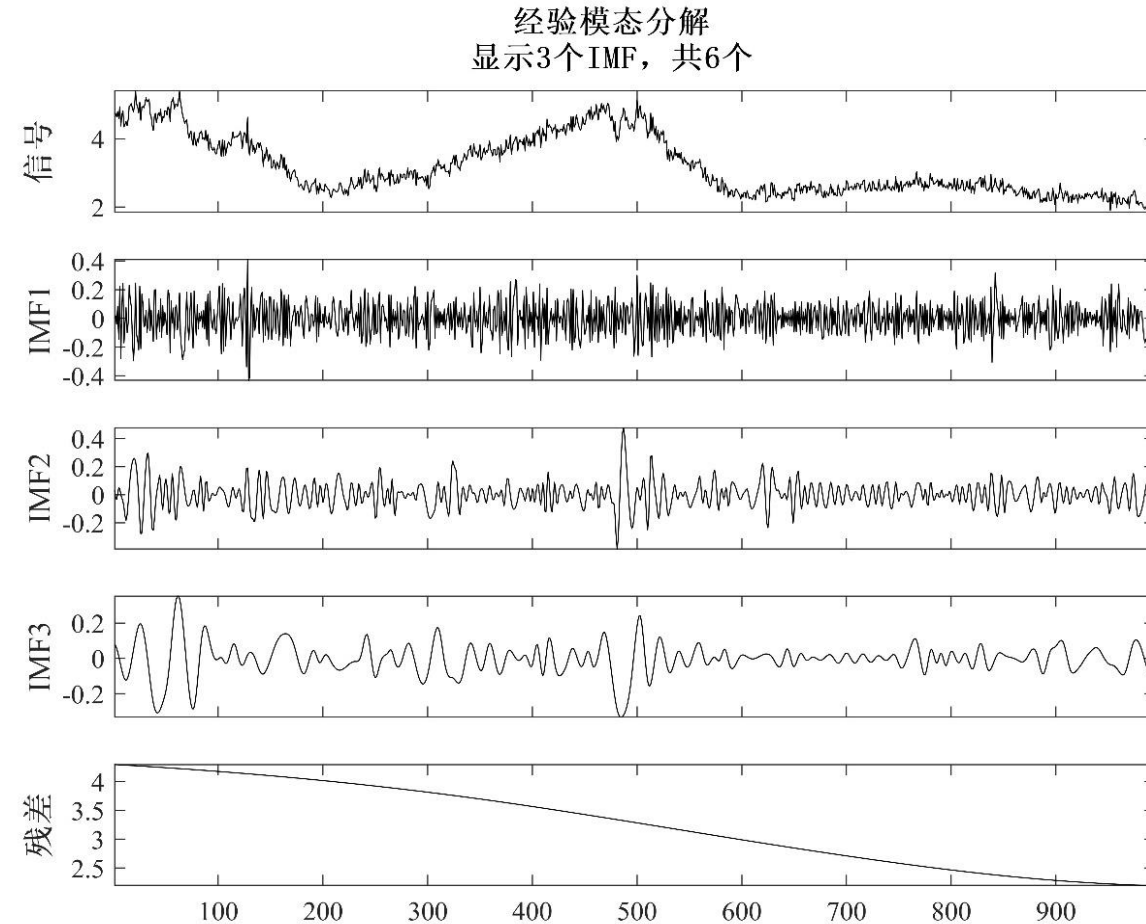


9 satellites SWH data was calibrated.

卫星	校正公式
Jason-3	$SWH_{J3_{cal}} = 1.0069SWH_{raw} - 0.0403$
Saral	$SWH_{AL_{cal}} = 1.0090SWH_{raw} - 0.0379$
Cryosat-2	$SWH_{C2_{cal}} = 0.9685SWH_{raw} + 0.0252$
CFOSAT	$SWH_{CFO_{cal}} = 0.8897SWH_{raw} + 0.1057$
HY-2B	$SWH_{H2B_{cal}} = 1.0493SWH_{raw} - 0.1704$
HY-2C	$SWH_{H2C_{cal}} = 0.8191SWH_{raw} + 0.2586$
Sentinel-3A	$SWH_{S3A_{cal}} = 0.9595SWH_{raw} + 0.0459$
Sentinel-3B	$SWH_{S3B_{cal}} = 0.9618SWH_{raw} + 0.0049$
Sentinel-6A	$SWH_{S6A_{cal}} = 0.9434SWH_{raw} + 0.0971$

SWH calibration with buoy data

Filtering based on Empirical Mode Decomposition (EMD)

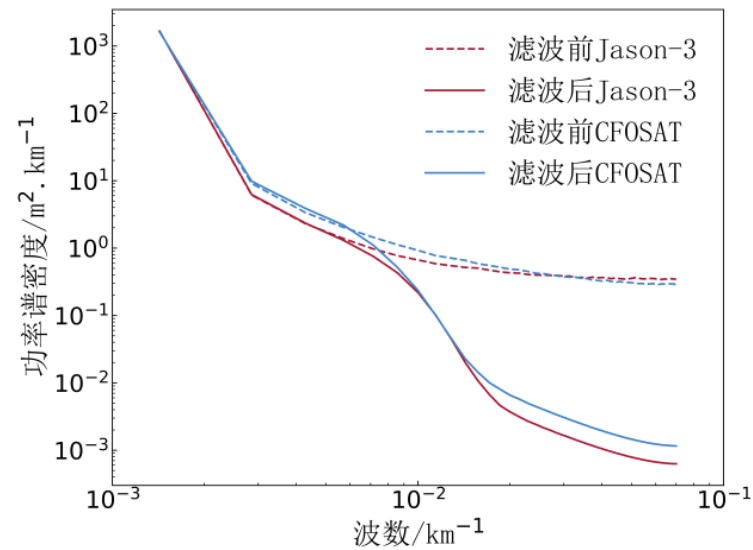


EMD filtering of SWH data

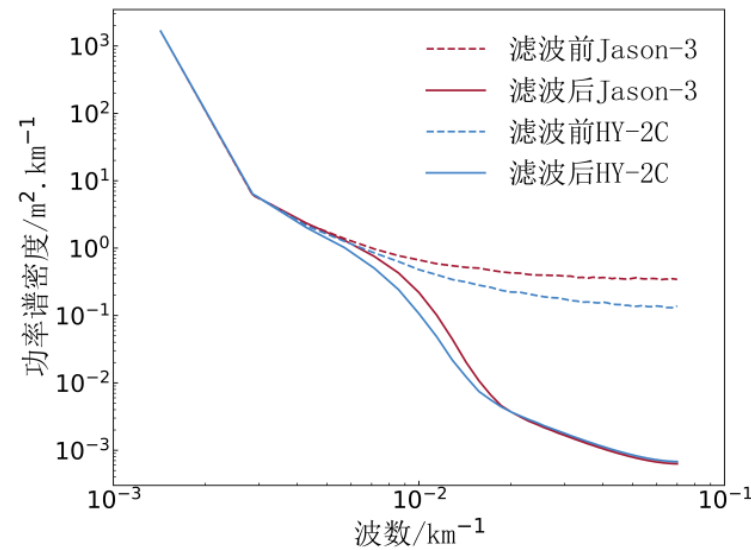
Consistency verification on the wave fields



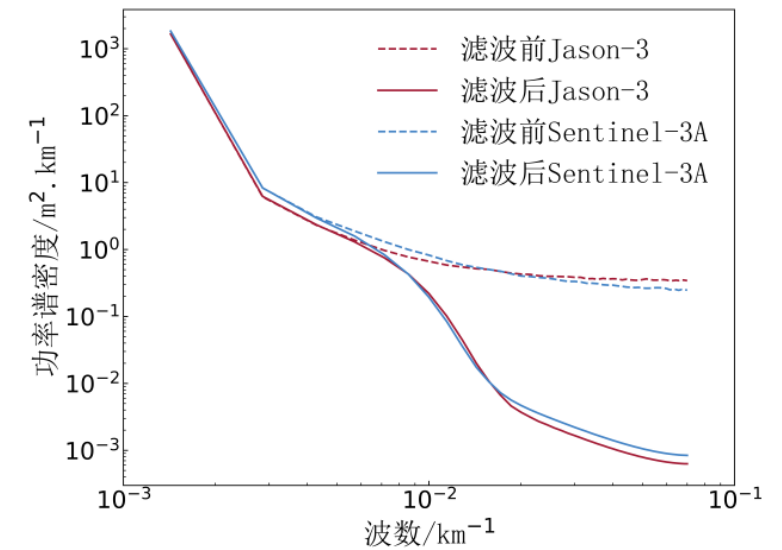
Power spectrum analysis of filtering and non-filtering SWH data



Jason-3 and CFOSAT



Jason-3 and HY-2C



Jason-3 and Sentinel-3A

Comparison of power spectral density between multi-source satellites and Jason-3



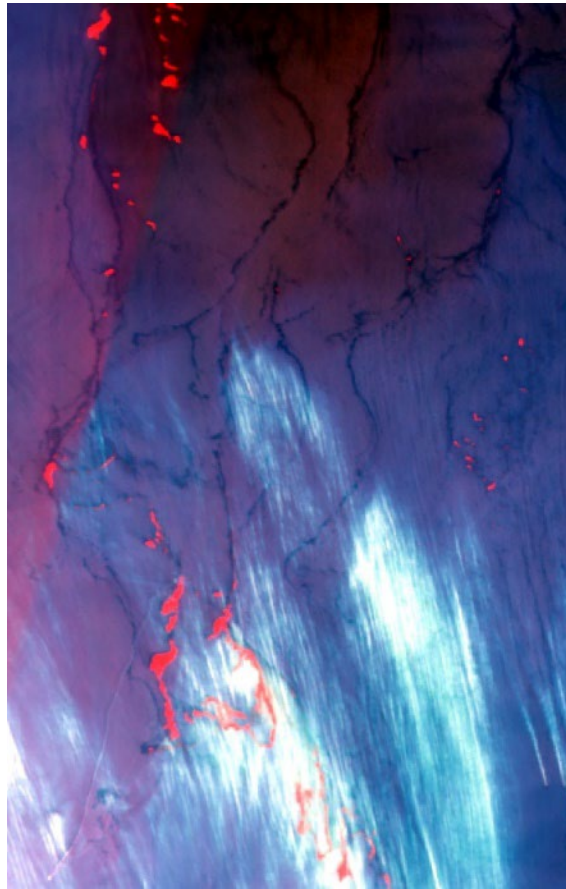
Along track sea surface wind, significant wave height and sea surface temperature data will be fused to generate gridded data. These fusion data will be analysed to investigate the ocean dynamic environment of marine disasters.



Monitoring micro algae with different satellites.



16 m resolution



50 m resolution



16 m resolution



50 m resolution



Monitoring micro algae with different satellites.



16 m resolution



50 m resolution

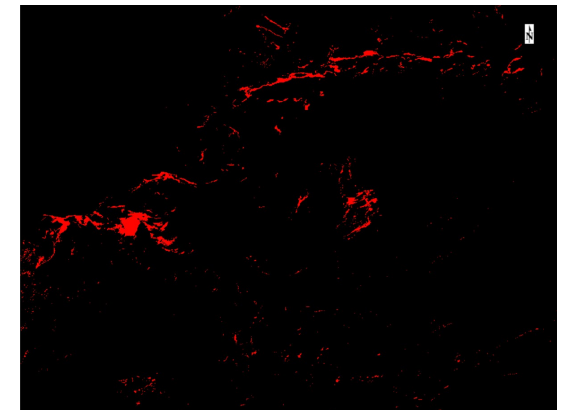
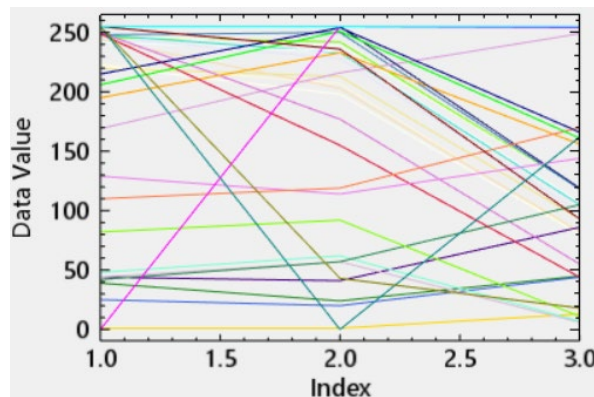
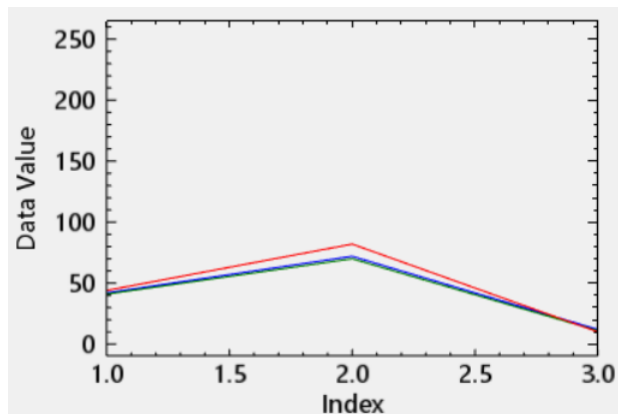


SPSAM model

Monitoring marine environmental disasters



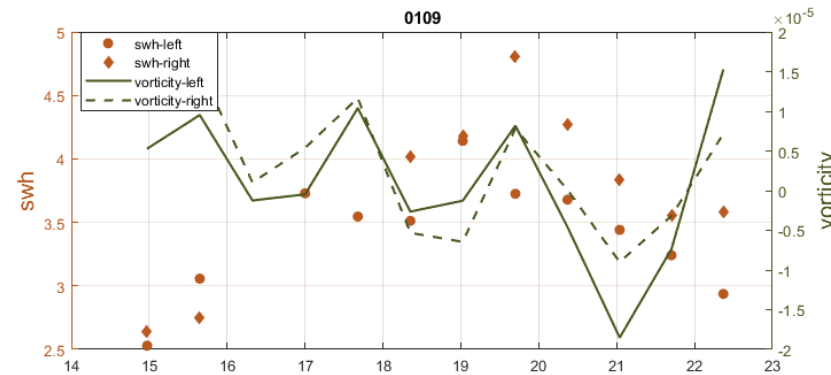
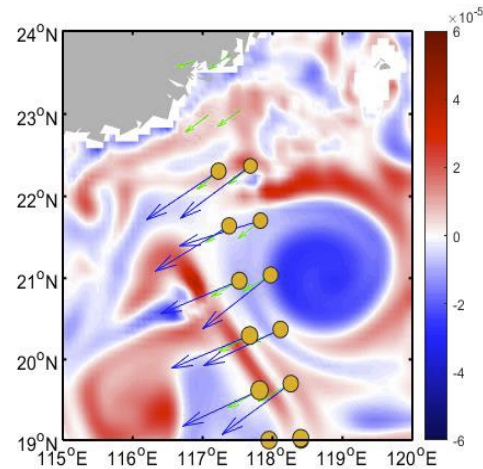
Traditional indices such as NDVI and FAI will be used to extract information about macroalgae. Besides these, we will establish an artificial intelligence model based on multi-source satellite images to improve the extraction of micro algae. A subpixel endmember spectra extraction method using multi-sensor images will be applied to improve the accuracy of extracting micro-algae.



Endmember spectra of micro algae and non micro algae

Extraction test results

Multi-scale dynamic analysis will be introduced to characterize the related Wind, Wave and Current Interactions (W2CI) and better understand their potential mechanisms in marine environment disaster. Such as extracting ocean surface currents with development of machine learning based optical flow and this will be validated from monitored algal blooms.



Effects of ocean eddies on surface wave features



Global distribution of seasonal averaged swell wave for JASON dataset.
(Gao et al., 2023 Front. Mar. Sci.)

When total significant wave height and U10 are available.

and are extracted from JASON

Validation of swell and wind-wave separation for the NDBC buoy 51100.
Huang , Schmitt, Xu, et al., in preparation 2025



Comparison of separated
swell and wind wave for
AVISO merged production
and ERA5 for 2nd Jan. 2014.

Products
CFOSAT, SWOT, HY, JASON, Sentinel.....

Final Goal

Reconstruction swell and wind-wave only from U10!

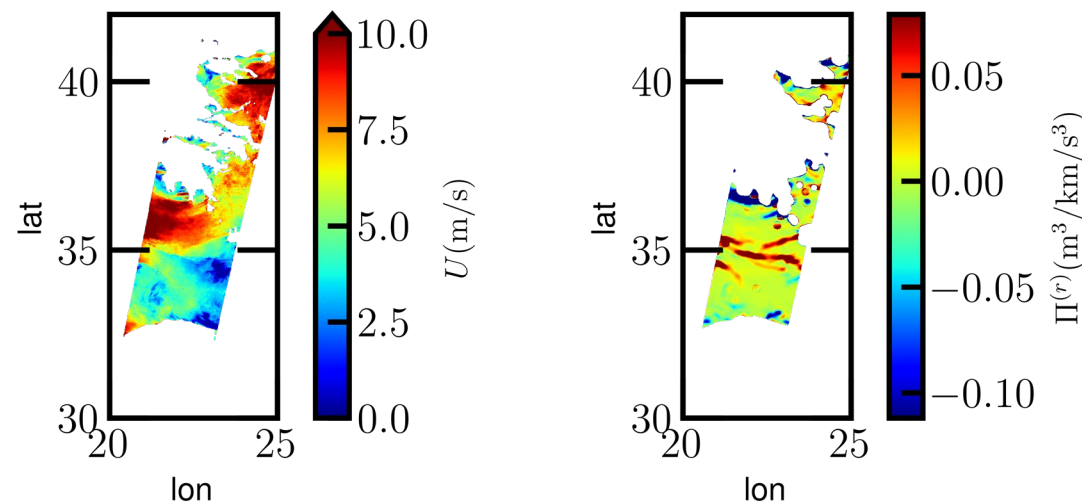
Wind-Wave-Current Interaction (W2CI)



2020-12-21

$$\Pi_{\theta}^{(r)}(x, t) = - \sum_{j=1,2} \left[(u_j \theta)^{(r)} - (u_j^{(r)} \theta^{(r)}) \right] \frac{\partial \theta^{(r)}}{\partial x_j}$$

Scale-to-scale interaction via coarse-graining approach.



Left: high-resolution (1km) wind field provided by Sentinel-1 in the Mediterranean Sea
Right: scale-to-scale energy transfer at scale $r=10$ km.

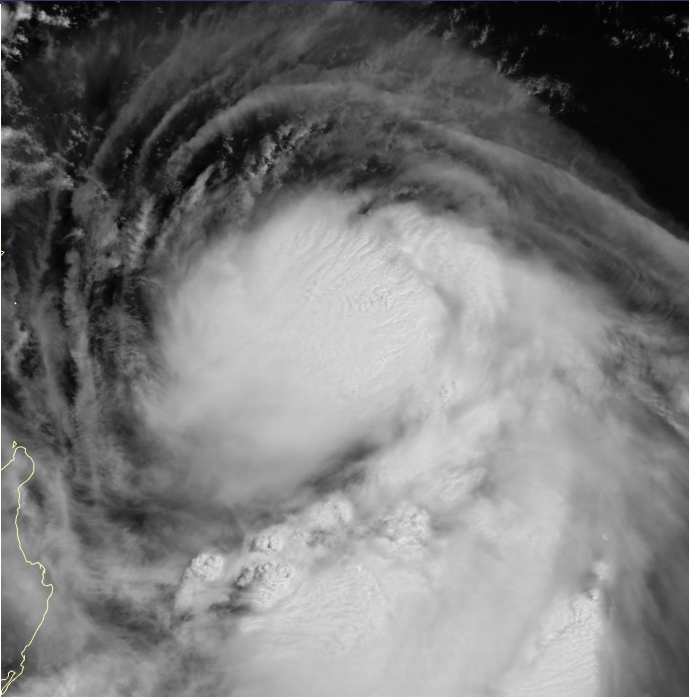
Huang et al., in preparation 2025

The scale-to-scale interaction will be applied to wind-wave-current fields to have a better understanding of their multiscale dynamics.

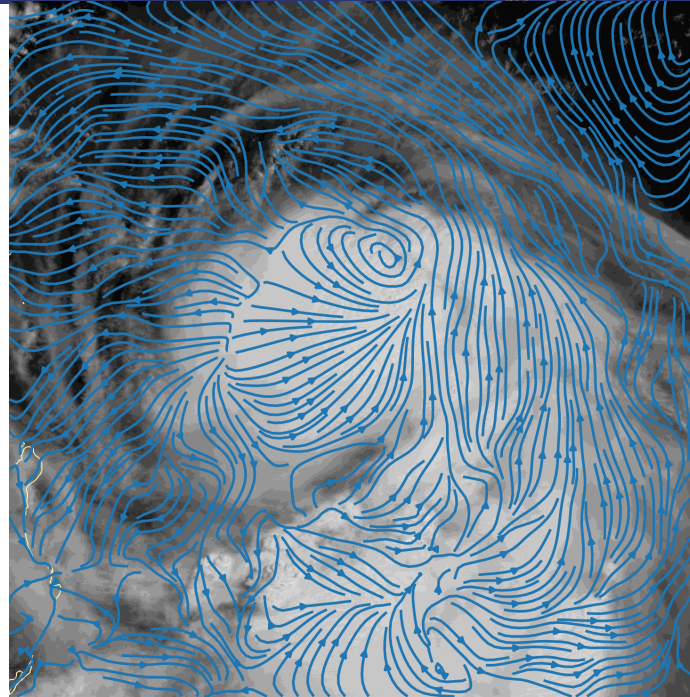
Averaged scale-to-scale energy transfer at scale 100 km for JJA.
Zhang et al., Front. Mar. Sci. 2024

Products
SWOT, Sentinel.....

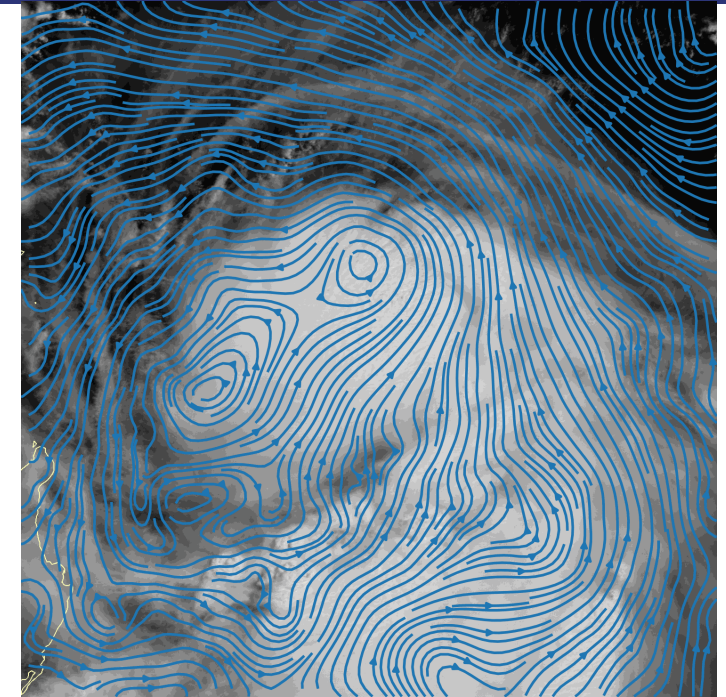
Machine learning based optical flow



Cloud image provided by geostationary satellite



Wind field derived from the Optical flow



Wind field after Helmholtz-Hodge Decomposition.

Correction the wind field via Physics-Informed Neural Networks

Products (Geostationary satellite)
Gaofen, Sentinel.....

Dragon 6 Batch-2 EO Data Request



Data access (list all missions and issues if any). NB. in the tables please insert cumulative figures for no. of scenes of high bit rate data (e.g. S1 100 scenes). If data delivery is low bit rate by ftp, insert “ftp”

ESA /Copernicus Missions	No. Scenes	ESA Third Party Missions	No. Scenes	Chinese EO data	No. Scenes
1. Sentinel-1	600	1.		1. HY-1 C/D/E	600
2. Sentinel-2	300	2.		2. HJ-2	300
3. Sentinel-3	600	3.		3. Gaofen	300
4. Sentinel-6	600	4.		4. HY-2 B/C/D	1000
5.		5.		5. CFOSAT	300
6.		6.		6.	
Total:	2100	Total:		Total:	2500
Issues: ESA		Issues:		Issues: National Satellite Ocean Application Service, MNR, Beijing China centre for resources satellite data and application, Beijing	



Planned in-situ data measurements and requirements

- For wind and wave in-situ data, using NDBC or available buoys
- For algae blooms, red tide or typhoon in-situ data, seeking some publicly available voyage data or site observation data

Project's schedule, planning, contribution of the partners



- **2024.07 -2024.12**, multiple satellite data preparation, acquisition and analysis, satellite data validation method study and data processing method study. Test MLBOF to retrieve the ocean surface velocity field.
- **2025.01-2025.12**, performing data fusion, algae bloom extraction and multiscale W2CI analysis.
- **2026.01-2026.12**, validation method and added value data generation method study, research on processing methods of microwave satellite data and ocean color satellite data; performing the multiscale W2CI analysis for Typhoon events and Kuroshio current; MLBOF to reconstruct the historical ocean surface velocity field.
- **2027.01-2027.12**, added value data generation, research on processing methods of microwave satellite data and ocean color satellite data; performing the multiscale W2CI analysis for the ACC; MLBOF to reconstruct the historical ocean surface velocity field.
- **2028.01-2028.06**, assessment of multiple satellite data and added value quality; release the historical ocean surface velocity; relative theoretical methods for the W2CI.



Additional projects to support exchange of researchers China-France

- Local Chinese funding to support researchers academic exchanges
- French side: invited professor positions to support Chinese researchers visit in France; CNES project entitled “Multiflux - Spatial and temporal multi-scale analysis of the interactions between turbulent wind forcing and wave height dynamics, using CFOSAT data” 2023-2026 will support also the exchange visits between France and China



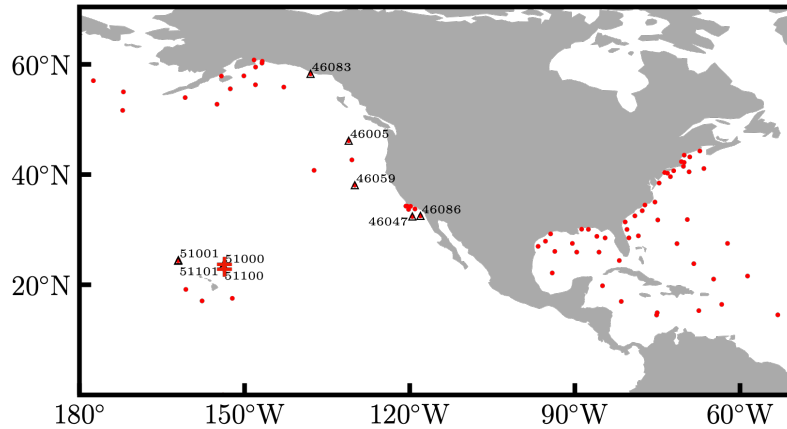
- Satellite Data Validation: One Master's students and one PhD student will meticulously validate wind-wave-current data from multiple satellites, ensuring physical oceanographic consistency.
- Algae Bloom Tracking: One Master's students and one PhD student will focus on detecting and tracking the Lagrangian features of algae blooms, thereby extracting ocean surface velocity data.
- Machine Learning based Optical Flow Analysis: One Master's students and one PhD student will develop a cutting-edge machine-learning-based optical flow approach to extract high-resolution marine surface current fields. This methodology will be validated using the data output from 2).
- Wind-Wave-Current Interaction: Two Master's students and one PhD student will delve into the complex interplay of wind, waves, and currents during algae blooms, providing valuable insights into the marine environment.



Thank you!



Wind and Waves

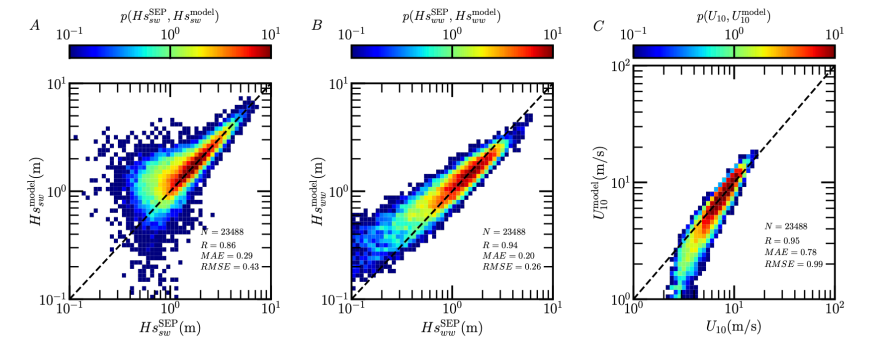


Verified by the NDBC buoys data

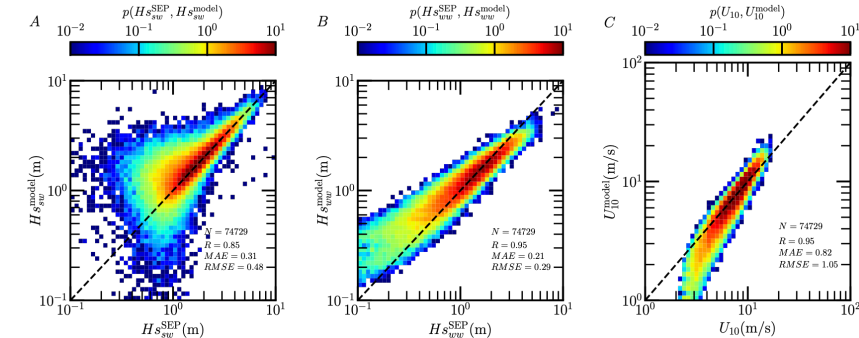
and are extracted from JASON

51100

$$H_{s_{sw}} = \left(H_s^2 - H_{s_{ww}}^2(U_{10}) \right)^{1/2} \quad H_{s_{ww}}(U_{10}) = \alpha_e U_{10}^{\beta_e} \quad U_{10} = (H_{s_{ww}}/\alpha_e)^{1/\beta_e}$$



51000



Validation of swell and wind-wave separation for the NDBC buoy 51100 and 51000.

Huang , Schmitt, Xu, et al., in preparation 2025

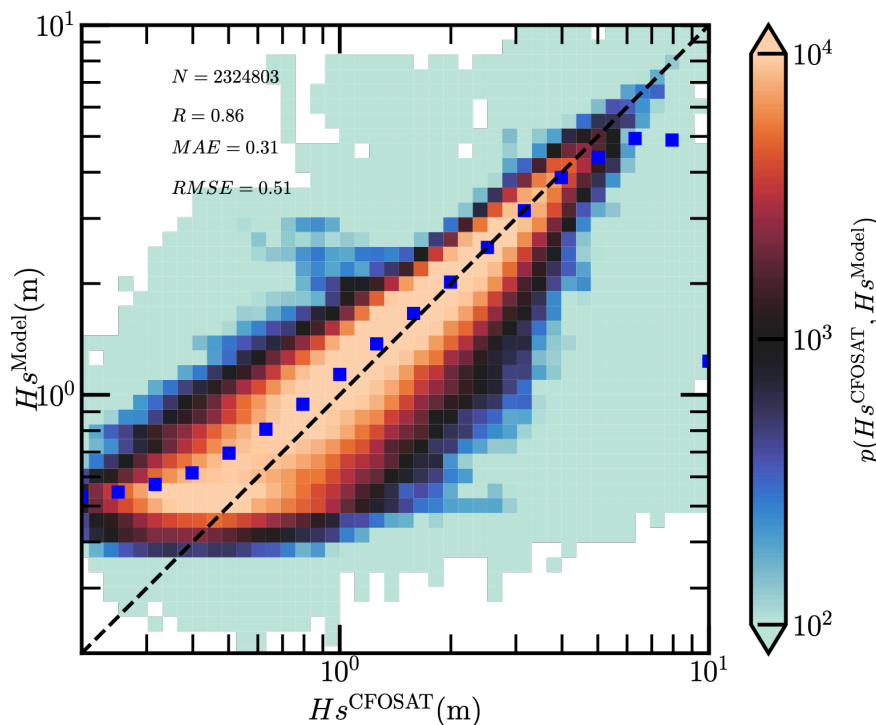


Prediction of Instantaneous Swell and Wind-Wave

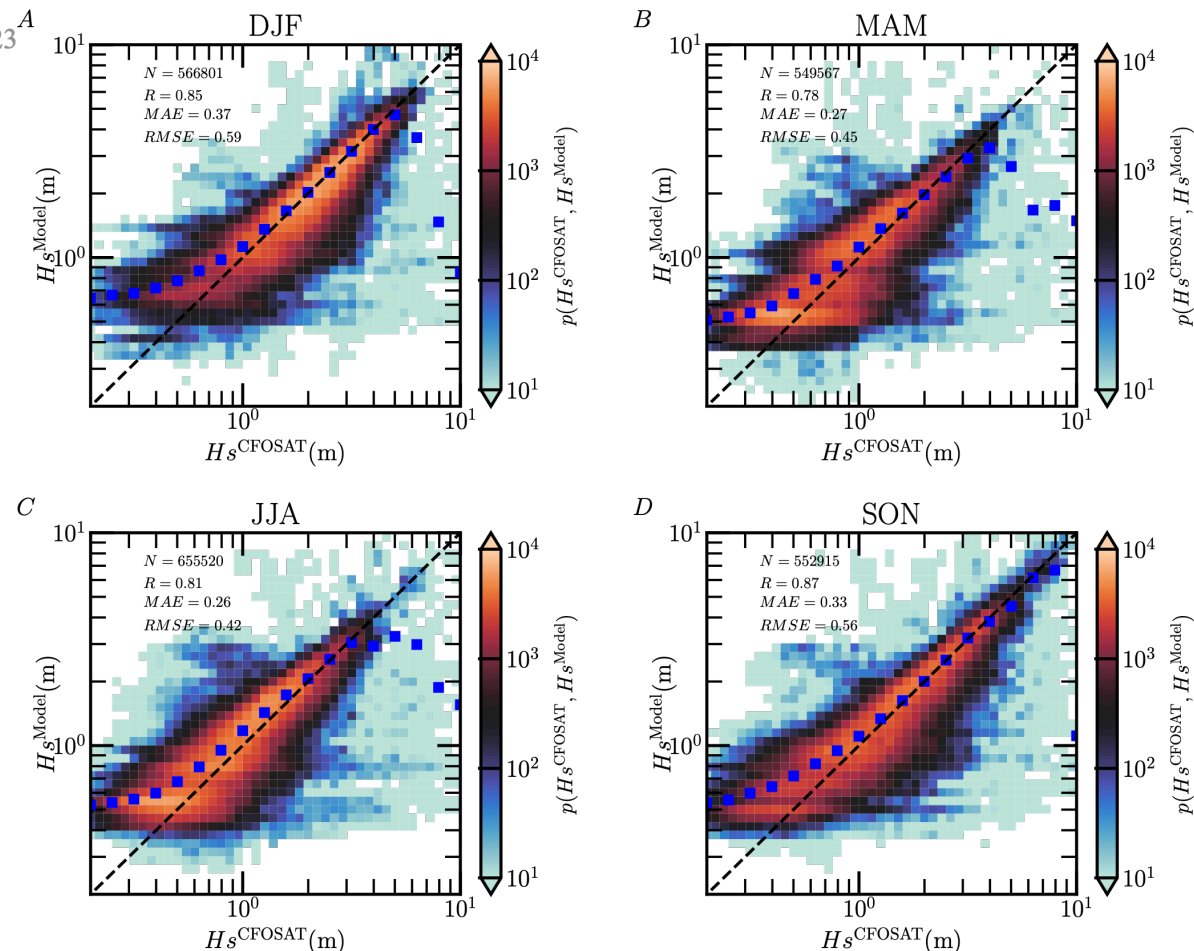
Parameters are provided in
Gao et al., Front. Mar. Sci., 2023

South China Sea

(e.g., 98.5°E-122.5°E, 0°N-25.5°N)



Joint PDF of H_s^{Model} from empirical power-law model and H_s^{CFOSAT} , where the blue squares are the conditional mean $\bar{H}_s^{\text{Model}}$.



Joint PDF of H_s^{Model} from empirical power-law model and H_s^{CFOSAT} , where the blue squares are the conditional mean $\bar{H}_s^{\text{Model}}$ in (A) DJF, (B) MAM, (C) JJA, (D) SON.

CFOSAT data without parameter tuning

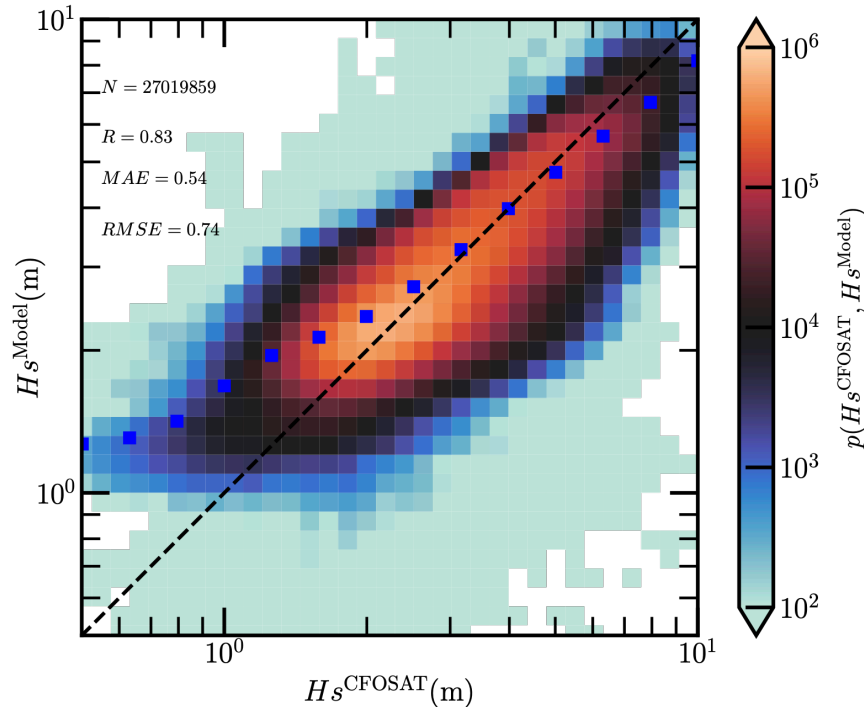


Prediction of Instantaneous Swell and Wind-Wave

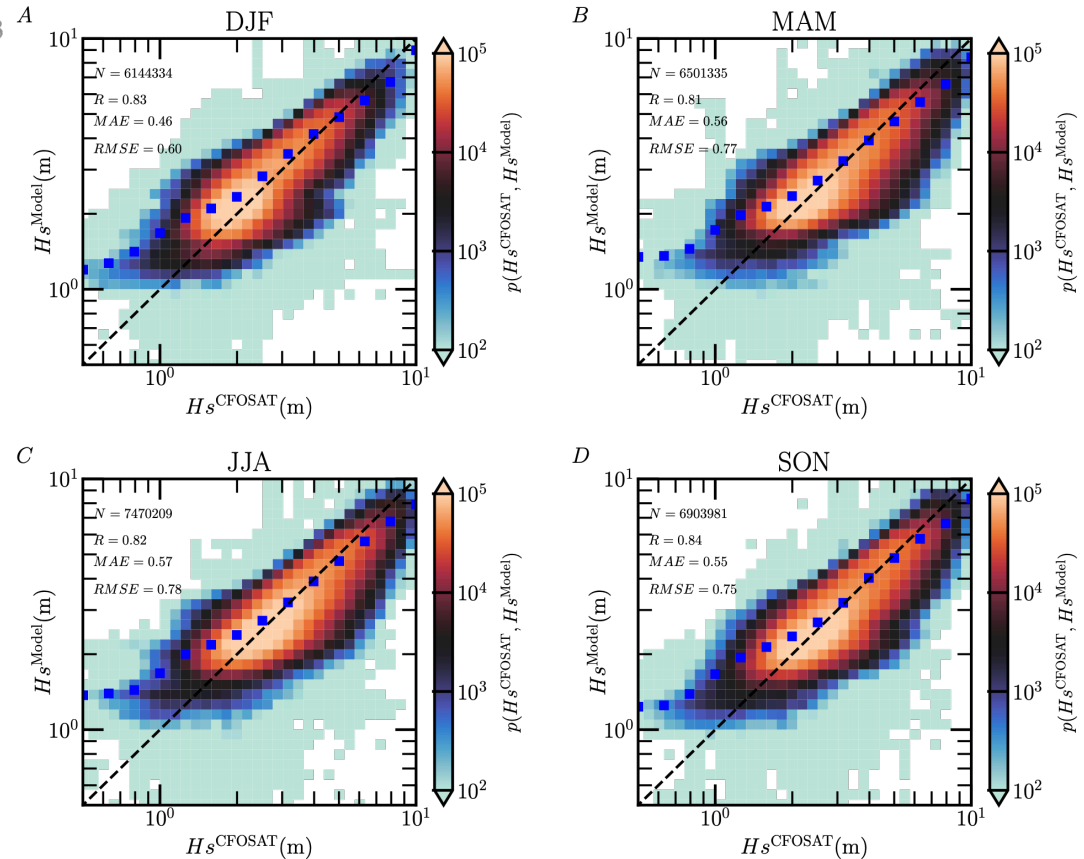
Parameters are provided in
Gao et al., Front. Mar. Sci., 2023

South Pacific Current

(e.g., 120°W-60°W, 0°S-60°S)



Joint PDF of H_s^{Model} from empirical power-law model and H_s^{CFOSAT} , where the blue squares are the conditional mean $\bar{H}_s^{\text{Model}}$.



Joint PDF of H_s^{Model} from empirical power-law model and H_s^{CFOSAT} , where the blue squares are the conditional mean $\bar{H}_s^{\text{Model}}$ in (A) DJF, (B) MAM, (C) JJA, (D) SON.

CFOSAT data without parameter tuning



$$\Pi^{(r)} = - \sum_{j=1,2} \left[\left(u_i u_j \right)^{(r)} - u_i^{(r)} u_j^{(r)} \right] \frac{\partial u_i^{(r)}}{\partial x_j}$$

Scale-to-scale interaction via coarse-graining approach.

Tropic Cyclone Goni 2020 October provided by Sentinel 1A



Helmholtz-Hodge decomposition the wind velocity field

$$\mathbf{U} = \nabla\psi + \nabla \times \boldsymbol{\phi} + \mathbf{U}_h$$

Divergence-free

$\mathbf{U}_{\text{cur}}$

Curl-free

$\mathbf{U}_{\text{div}}$

Harmonic

$\mathbf{U}_h$

Wind-Wave-Current Interaction (W2CI)



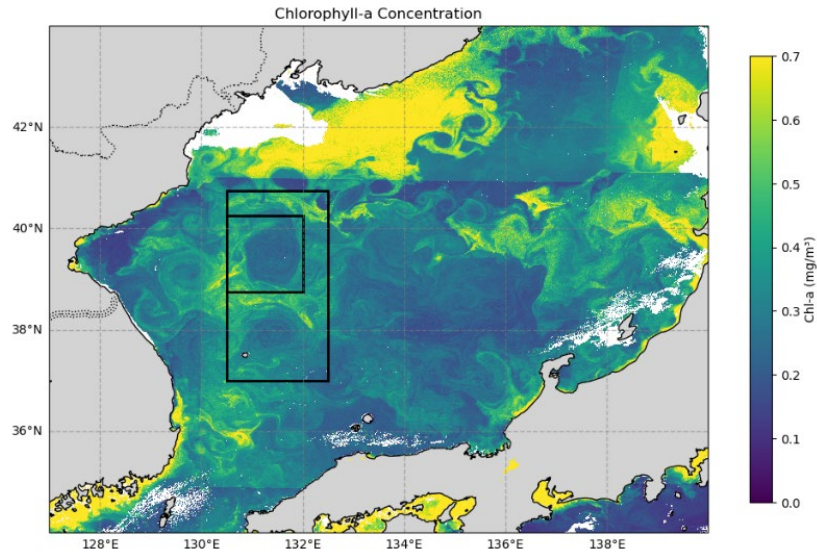
Energy flux at 50 km.

Radial average energy flux at scale 50 km.

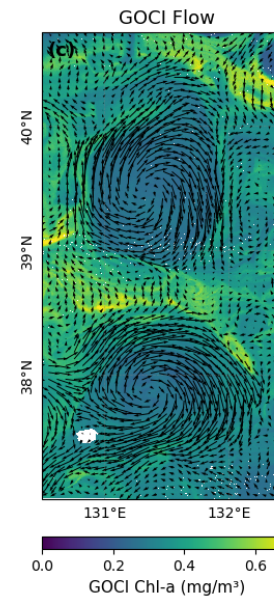
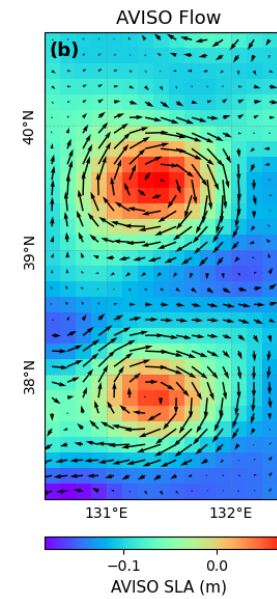
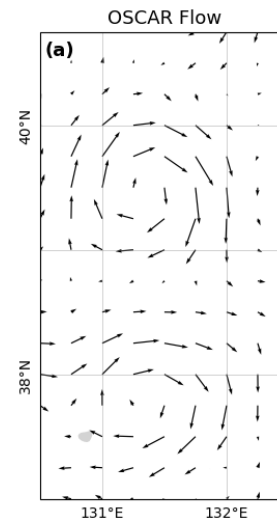
Tropic Cyclone Goni 2020 October provided by Sentinel 1A

Zhang, Zhou, Xu, et al., in preparation 2025

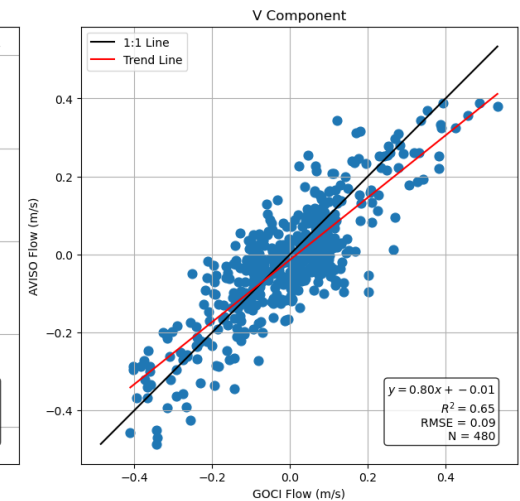
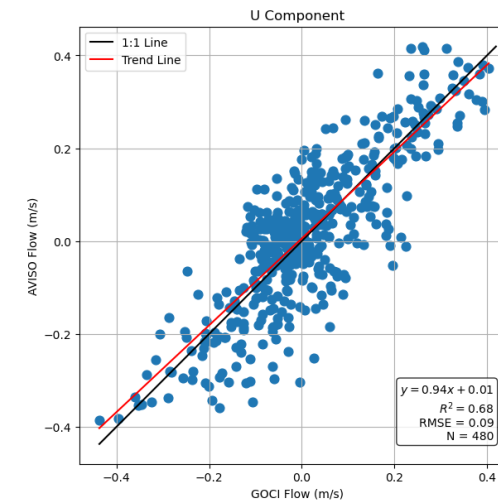
Machine learning based optical flow



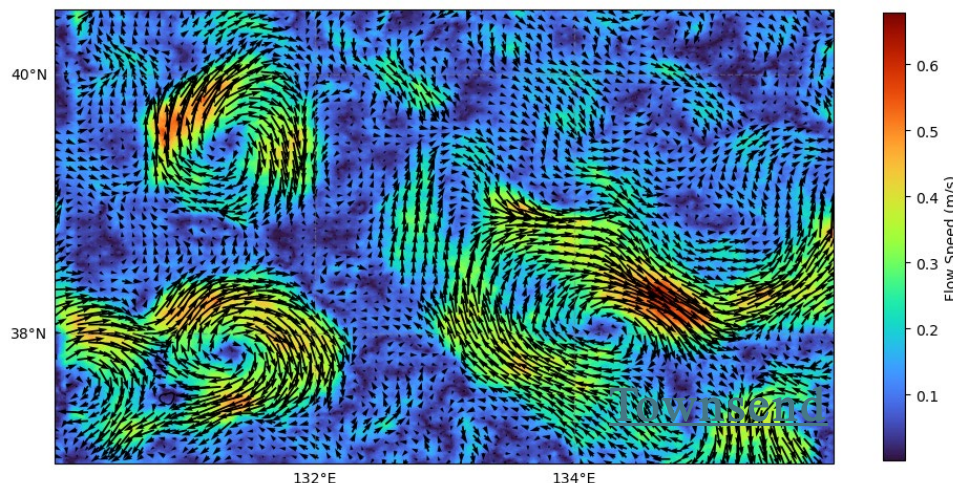
Chl-a concentration provided by GOCI.



Comparison of surface velocity field



Machine learning based optical flow



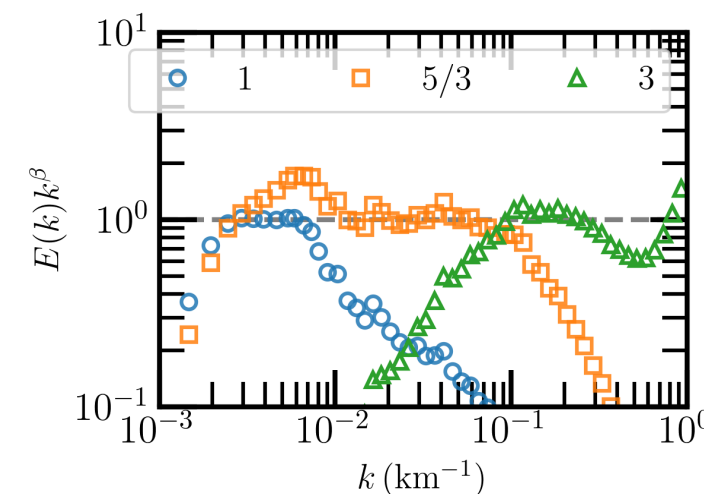
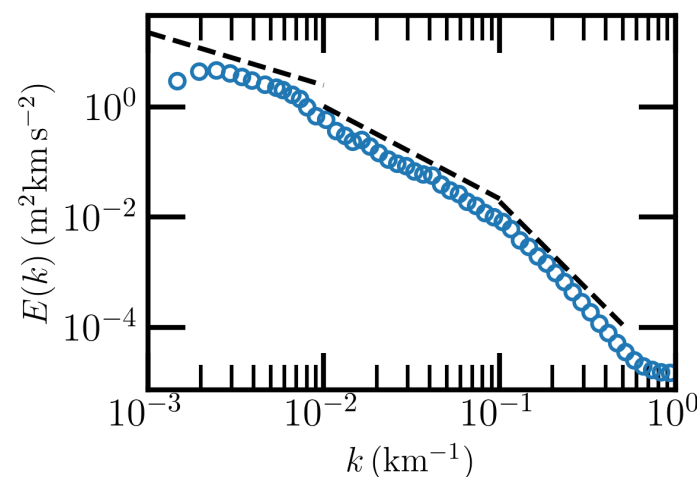
Daily averaged surface velocity field

$$E(k) \propto k^{-5/3}$$

$$E(k) \propto k^{-3}$$

Townsend, Attached Eddy Hypothesis in boundary layer, 1951,1961,1976

$$E(k) \propto k^{-1}$$



(a) Fourier power spectrum and (b) its compensated curves to emphasize the power-law behavior.