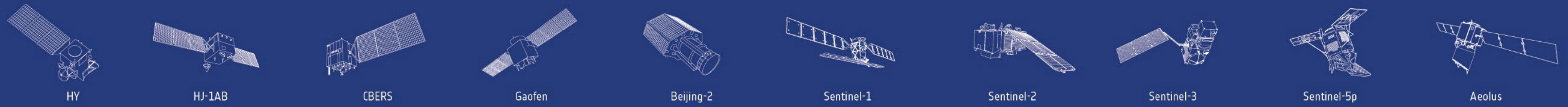
Dragon 5 3rd Year Results Project



Big Data Intelligent Mining and Visual Analysis of Ocean Mesoscale Eddies

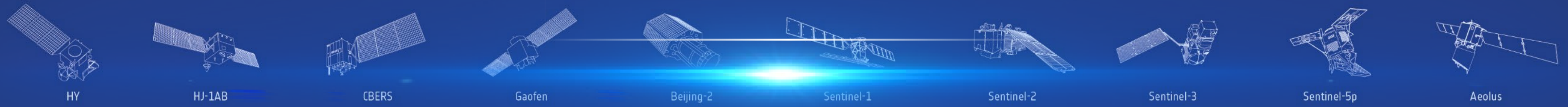
Presented By: Fenlin Tian   Project ID. 58393

2023 Dragon 5 Symposium

11-15 September 2023

2023/09/13

Contents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Aeolus

Basic Information

Information

PROJECT ID: NO.58393

PROJECT TITLE: Big Data Intelligent Mining and Visual Analysis of Ocean Mesoscale Eddies

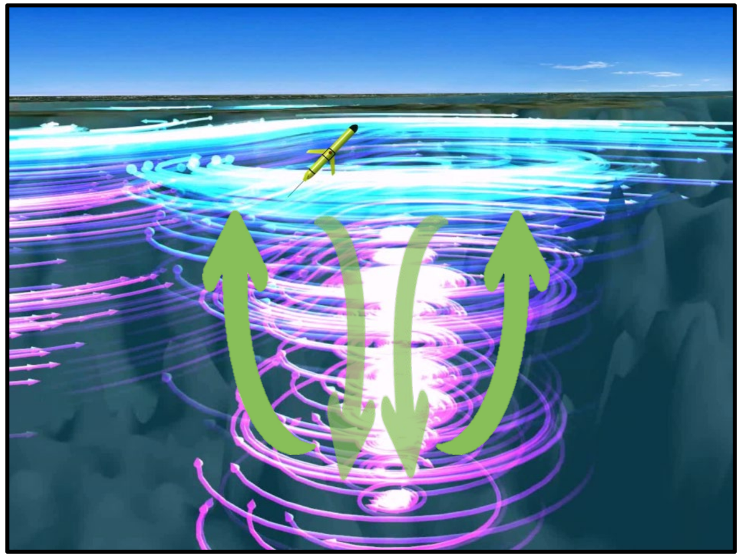
PRINCIPAL INVESTIGATORS: Fenlin Tian

CO-AUTHORS: Qiu He, Shuang Long, Shuai Wang

PRESENTED BY: Fenlin Tian

Basic Information

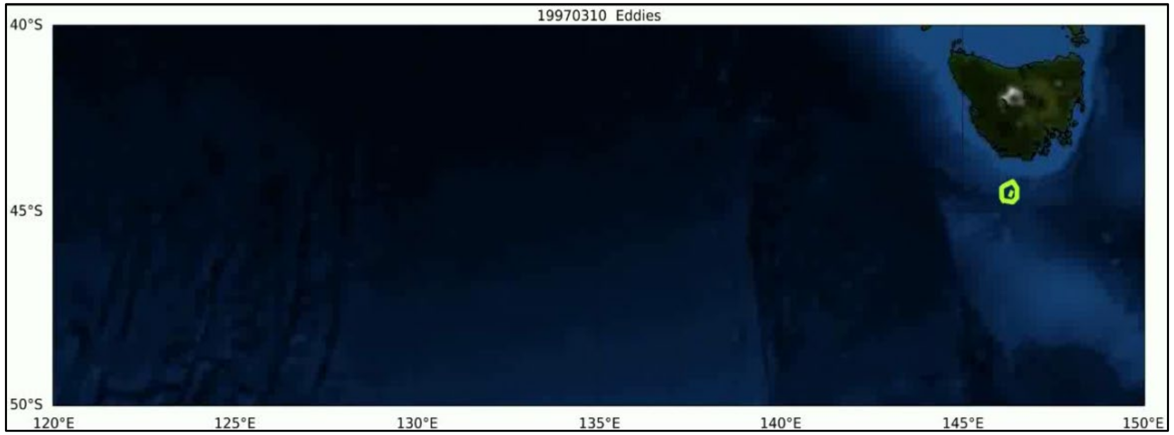
Research background



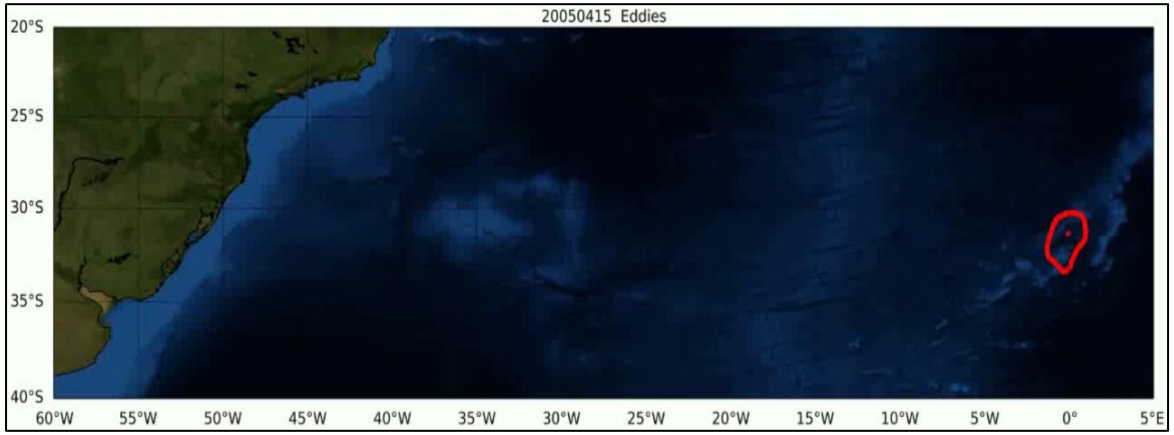
3-D structure of an eddy

Mesoscale Eddy

- The coherent rotating water body with radial scales ranging from tens to hundreds of kilometers and lifetimes ranging from tens to hundreds of days.
- In the Southern Hemisphere, anticyclonic eddy (AE) rotates anticlockwise while cyclonic eddy (CE) rotates clockwise.
- One of the most common movement form in the ocean and play an important role in the oceanic material transfer and energy exchange.



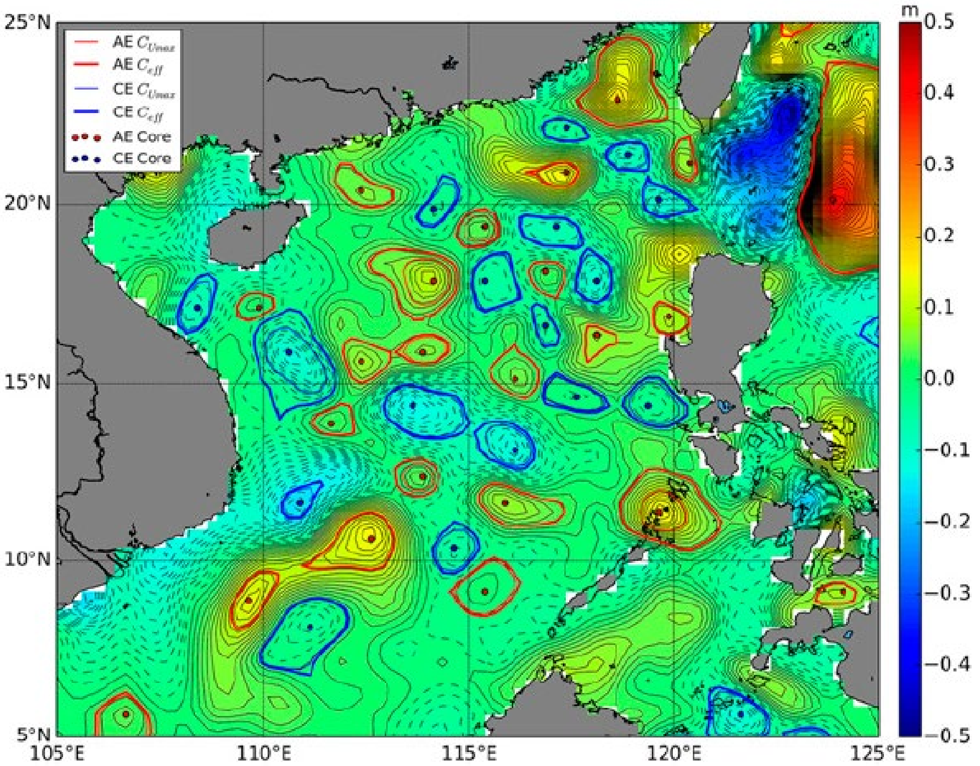
South Pacific: 1997.03.09-2000.02.14 (CE, 1073 days, 2.94 years)



South Atlantic: 2005.04.14-2008.03.11 (AE, 1063 days, 2.91 years)

Basic Information

Research background



Eddy detection result of the South China Sea on 8 Aug 2004: areas surrounded by blue (red) lines are CEs (AEs). (Liu et al., 2016)

● Eulerian eddies:

Based on instantaneous velocities and oceanic features (such as the vorticity and geometric topological structure), the major circular structure of mesoscale eddies can be detected, which are called Eulerian eddies.

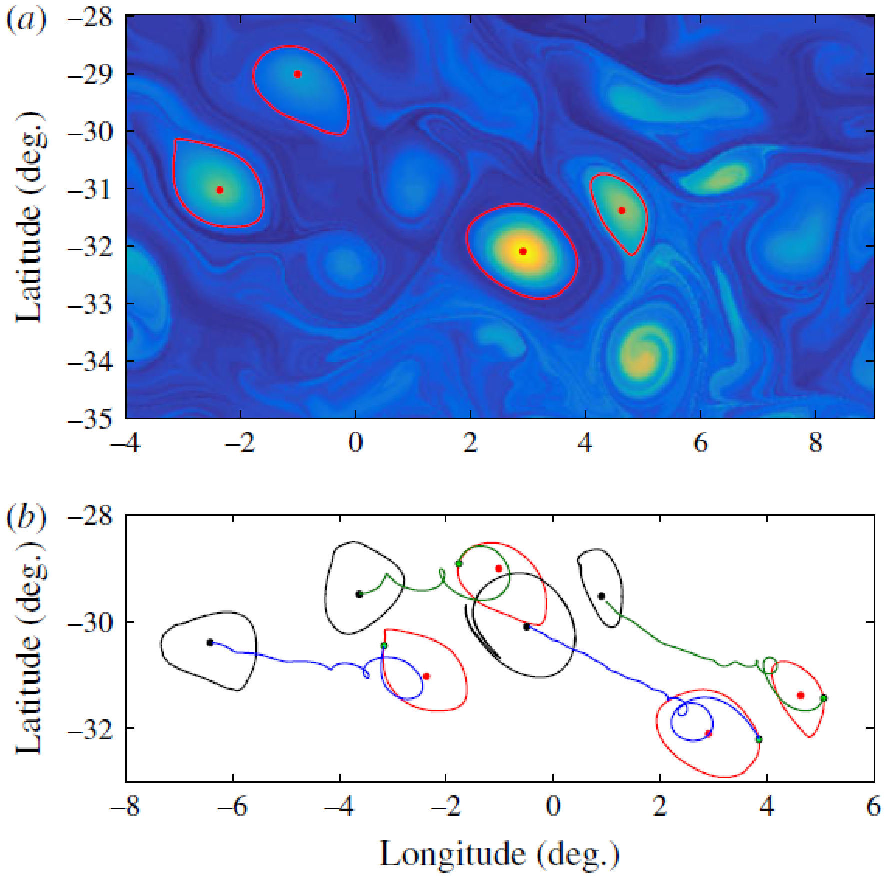
● Challenge:

a) Some algorithms lack the computational efficiency of contour iterations or have complex calculation processes.

b) Because of the low Coriolis effect strength when calculating the geostrophic speed of eddies, eddy detection becomes unreliable in the equatorial region.

c) Eulerian detection methods depend on a reference frame and an artificial threshold, which means that Eulerian eddy boundaries will develop substantial material filaments during their lifetime.

Research background



(a) Rotationally coherent Lagrangian vortices at time t_0=11 November 2006, using the contours of LAVD with T=90 days. (b) Initial (red) and final (black) positions of the Lagrangian vortex boundaries at time t0+T, along with representative inertial particle trajectories. Heavy particles (blue) converge to the centres of AEs. Light particles (green) converge to the centres of CEs. (Haller et al., 2016)

● Lagrangian eddies:

They are the cumulative results of the state of the fluid within a given time scale, which can maintain material coherence over the specified time intervals.

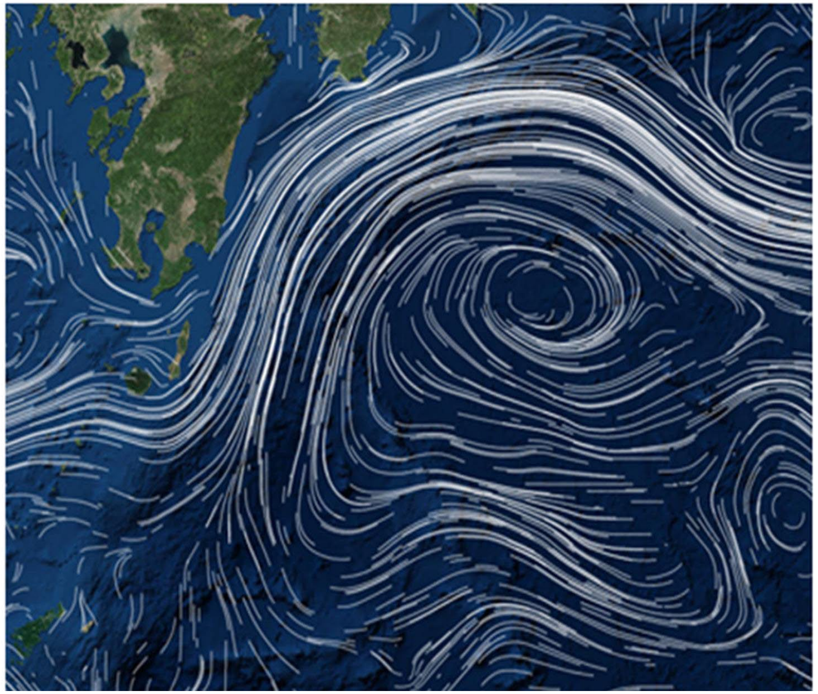
● Challenge:

a) High calculation cost during the integration process has become a bottleneck, especially when the data resolution is improved or the study area is enlarged.

b) Compared with Eulerian eddy detection methods, Lagrangian methods have more complex calculation processes y with lower computation efficiency.

Basic Information

Research background



Visualization of 2-D flow field (Yu et al., *International Journal of Geo-Information, 2019*)

● Flow Field Visualization

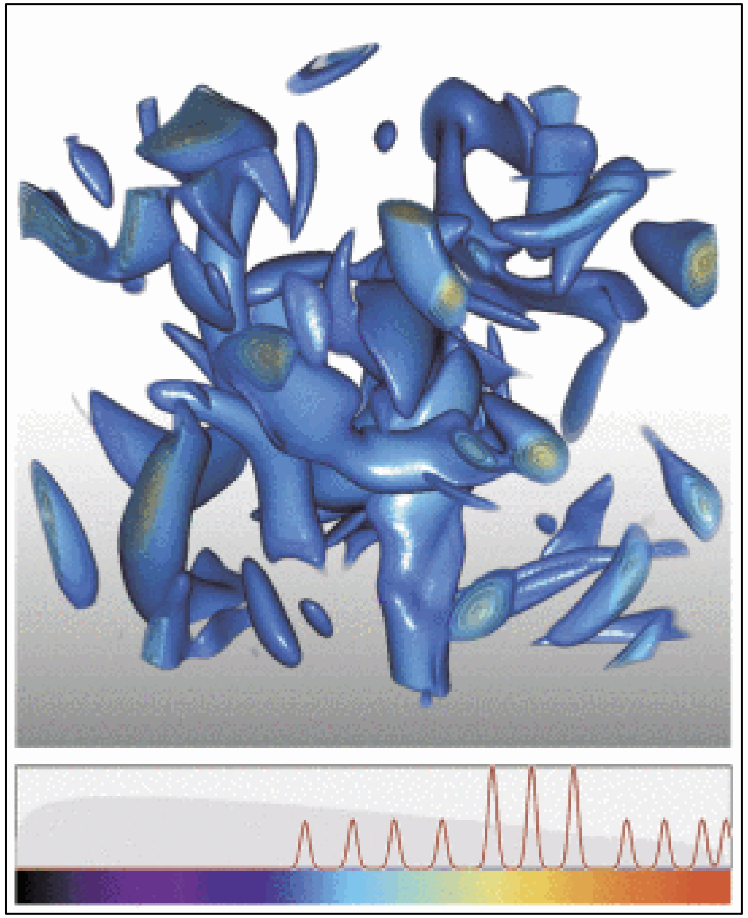
Using symbols such as arrows and lines to express flow characteristics such as seawater flow direction and velocity, or using spiral or closed flow lines (or traces) to display vortices ,dynamic primitives are used to visually represent the dynamic changes in the flow field.

● Challenge:

a) For the spatiotemporal continuous visualization of mesoscale vortex based on transfer function, the streamline on each frame in the pathline-streamline spatiotemporal continuous framework is spatiotemporal continuous only at the first vertex of the streamline, so this framework can not be used to represent the whole spatiotemporal continuous motion process of ocean mesoscale vortex

b) Most of the eigenvalues applied to the extraction of ocean vortices are seriously affected by the threshold, and the visualization of vortices using interactive transfer function depends more on the user's experience. There is no standard transfer function for the ocean mesoscale vortices in specific sea areas.

Research background



Schematic diagram of transfer function (Correa C D , and Ma K L ., *IEEE Pacific Visualization Symposium, 2009*)

● Scalar Fields Visualization

Utilizing scalar data such as ocean temperature, salinity, density, and pressure to characterize ocean temperature and salinity anomalies, the material transport patterns of mesoscale eddies are revealed.

● Challenge:

a) Due to the features of time-varying, large volume, high complexity and high data dispersion, it is a great challenge to use ocean data reasonably and effectively to display some complex ocean information directly through abstract data, and there is a lack of methods to pre-process or batch process ocean 3-D data, resulting in low efficiency in exploring ocean information.

b) Transfer function is an important tool for converting numerical intervals into color space in the process of scientific visualization, and its design quality directly affects the performance of ocean data. However, the existing transfer function design methods are cumbersome and time-consuming, which to a certain extent restricts the development of ocean 3-D data visualization.

Basic Information

Research contents

① Based on global long-term daily satellite altimetry data, the new effective algorithms for parallel identification and tracking of mesoscale eddies are proposed and the corresponding datasets are provided by using space segmentation and the parallel computing technology.

② In term of the long-term global mesoscale eddy datasets, eddy-eddy interaction is further studied, such as splitting process, merging process and dipolar structure. The typical eddy-eddy interaction processes are filtered and statistically analyzed, and the sea surface temperature and sea surface salinity within eddies during the process are normalized. In the meanwhile, the Lagrangian eddies are used assess the material transport capacity more effectively.

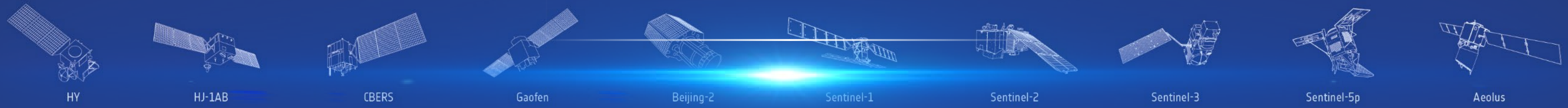
③ The transfer function standard form model for ocean mesoscale eddy visualization is constructed, which reduces the difficulty of interactive analysis of ocean mesoscale eddy by using transfer function. GPU implementation schemes are proposed to help the 2-D/3-D structure visualization of eddies in real time.

Basic Information

Research innovations

- By using space segmentation and the parallel computing technology, the global Eulerian eddies and Lagrangian eddies are both identified in a much faster manner.
- For the tracking of Eulerian eddies, a new hybrid method that integrates both physical and geometric eddy properties (including the distance between eddies, the area and amplitude of eddy, and the shape of the eddy edge), via the output of detection and the calculation of Hausdorff distance is proposed to enable to describe the similarity better between eddy boundaries.
- For real time visualization of 2-D/3-D of mesoscale vortices flow field, the pathline-pathline whole space-time continuous framework is firstly put forward, which projects the pathline in space-time to the instantaneous space slice, and all the eddies of the pathline on each frame are spatio-temporal continuous, so as to enhance the time continuity of mesoscale vortex visualization.
- A transfer function standard form model for ocean mesoscale eddy visualization is constructed, which reduces the difficulty of interactive analysis of ocean mesoscale eddy by using transfer function.

Contents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Project performance

EO Data Delivery

ESA Third Party Missions	No. Scenes
Sea Level Anomaly (SLA)	ftp
Sea Surface Temperature (SST)	ftp
Sea Surface Salinity (SSS)	ftp
Chlorophyll-*a* (Chl-*a*)	ftp
Total: 4 datasets	~1 TB
Issues: none	

Project performance

EO Data Delivery

Variables	Temporal Coverage	Spatial Coverage	Time Scale	Spatial Scale
SLA	1993.01~ongoing	Global Ocean	Daily	0.25°×0.25°
SST	1981.12~ongoing			0.25°×0.25°
SSS	2011.01~2020.12			0.25°×0.25°
Chl-*a*	1997.09 ~2021.12			4 km

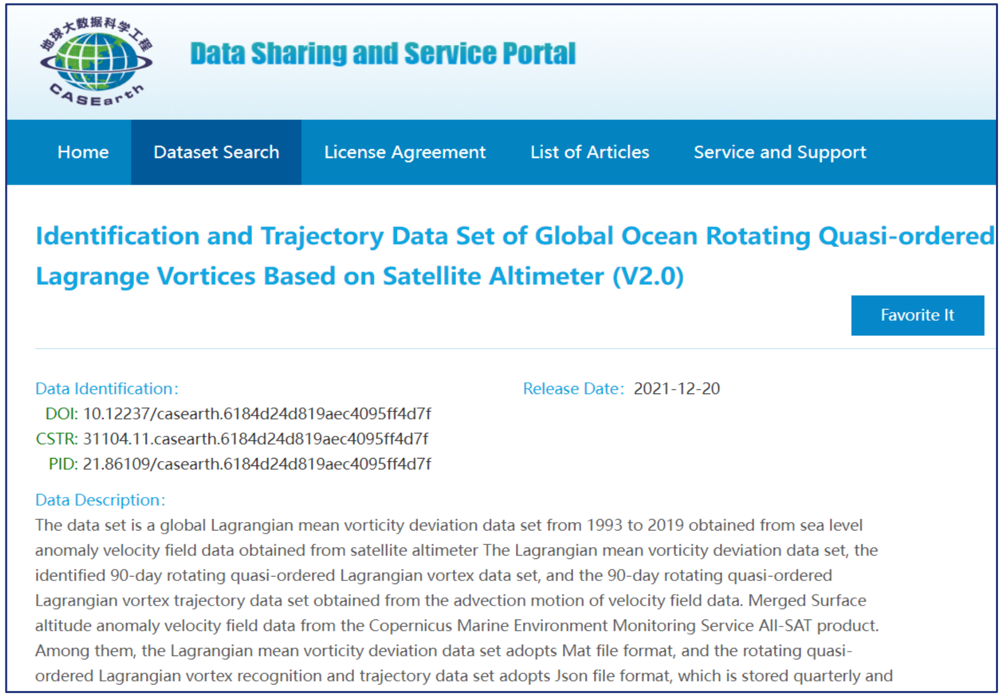
Project performance

Implementation of Project

Number	Research Content	Achievement
1	A New Algorithm for Parallel Identification Method of Mesoscale Eddies from Global Satellite Altimetry Data	**Algorithm implementation**
2	A New Algorithm for Tracking Method of Mesoscale Eddies from Global Satellite Altimetry Data	**Algorithm implementation**
3	Global Long-time-scale Eddy Identification Data Products	**2 public datasets**
4	Multiple Papers	**11 papers**
5	Young scientists in Dragon 5	**3 doctoral students and 9 postgraduates**

Implementation of Project: Datasets

Number	Datasets
1	*Global EddyGraph*: The Tracking Dataset of Mesoscale Eddy Splitting and Merging Events Based on Satellite Altimeter (1993-2020). DOI: 10.12237/casearth.60cc550f819aec69f61fe8f9
2	Identification and Trajectory Data Set of Global Ocean Rotating Quasi-ordered Lagrange Vortices Based on Satellite Altimeter. DOI: 10.12237/casearth.6184d24d819aec4095ff4d7f



Implementation of Project: Articles

SCI: 6 papers

Number	Articles
1	Tian F, Li Z, Yuan Z, et al. *EddyGraph*: The Tracking of Mesoscale Eddy Splitting and Merging Events in the Northwest Pacific Ocean[J]. Remote Sensing, 2021, 13(17).
2	Tian F, Yang X, Liu X, et al. Analysis of black-hole eddy on material transport in the western pacific[J]. Haiyang Xuebao, 2021, 43(12): 1–14.
3	Tian F, Yuan Z, Liu W, et al. An automatic recognition algorithm of global mesoscale dipole based on eddy tracking data[J]. Haiyang Xuebao, 2021, 43(1): 122–136.
4	Han G, Tian F, Ma C. The geometry of mesoscale eddies in the South China Sea: characteristics and implications[J]. International Journal of Digital Earth, 2021, 14(4), 464-479.
5	He Q, Tian F, Yang X, et al. Lagrangian eddies in the Northwestern Pacific Ocean[J]. Journal of Oceanology and Limnology, 2022, 40(1):66-77.
6	Tian F, Wang M, Liu X, et al. SLA-based orthogonal parallel detection of global rotationally coherent Lagrangian vortices[J]. Journal of Atmospheric and Oceanic Technology, 2022, 39(6): 823-836.
7	Tian F, Xiang H, Long S, et al. Statistical Characterization of Global Eddy Splitting and Merging Events[J]. Marine Science Bulletin. (Accepted)
8	Tian F, Mao Q, Zhang Y, et al. i4Ocean: transfer function-based interactive visualization of ocean temperature and salinity volume data[J]. International Journal of Digital Earth, 2021, 14(6):23.
9	Tian F, Wang H, Liu W, et al. Real time visualization of 2D/3D whole spatiotemporal continuous ocean mesoscale vortices flow field based on transfer function[J]. Marine Sciences.(Accepted)
10	Tian F, Cheng Y, Liu W, et al. Visualization of three-dimensional thermohaline and pressure anomaly structure of ocean eddies based on standard morphological models of transfer functions[J]. Marine Science Bulletin. (Accepted)
11	Ma Y, Tian F, Liu W, et al. Geographical Information Visualization on a Panoramic Sphere in an Immersive Environment[J]. Journal of Ocean University of China, 2023, 22(4): 961-974

Project performance

Implementation of Project: Young Scientists

3 doctoral students
9 postgraduates

Name	Institution	Poster Title	Contribu	search Period
Shuang Long Hongzhu Xiang	Ocean University of China	Global EddyGraph: Tracking Mesoscale Eddy Splitting and Merging Events	• Data download and process; • Code improvement; • Paper writing; • Mesoscale Eddy Splitting and Merging Events Dataset construction	2022.05-2023.05
Zhijiao Li	Ocean University of China	None		2021.08-2022.08
Qiu He				2020.08-2022.06
Mengjiao Wang				2022.08-2023.05
Ying Ma Xiaolong Zhu Yu Wang	Ocean University of China	None	• Data download and process; • Code improvement; • Paper writing; • Visual Effects System Integration	2021.08-2022.05
Jinyu Li Yaqiang Chen	Ocean University of China	None	• Data download and process; • Code improvement; • Paper writing; • Scalar data of eddy visualization	2021.08-2022.06
Moran Tang Hao Wang	Ocean University of China	None	• Data download and process; • Code improvement; • Paper writing; • Vector data of eddy visualization	2021.08-2022.06

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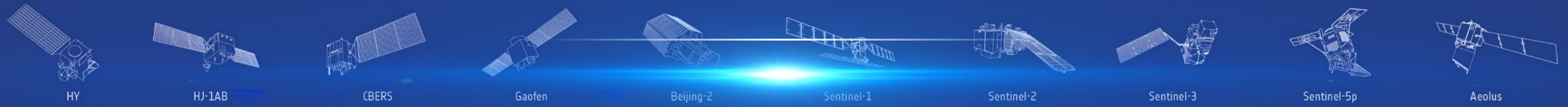
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Major Results

Result 1: Eulerian Eddy—Eddy Splitting and Merging events Identification and Tracking

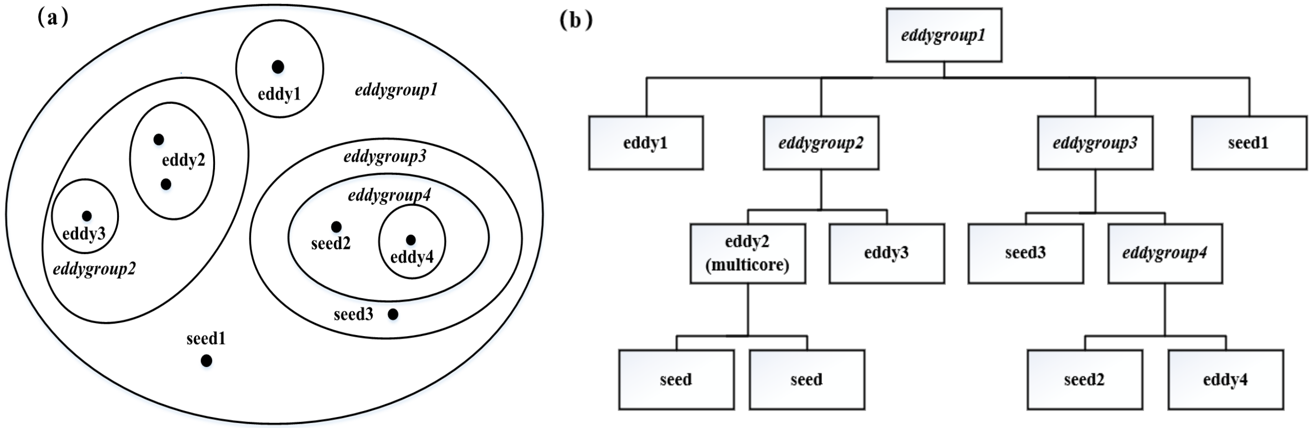


Diagram of the (a) *eddygroup* and (b) *eddytree*.

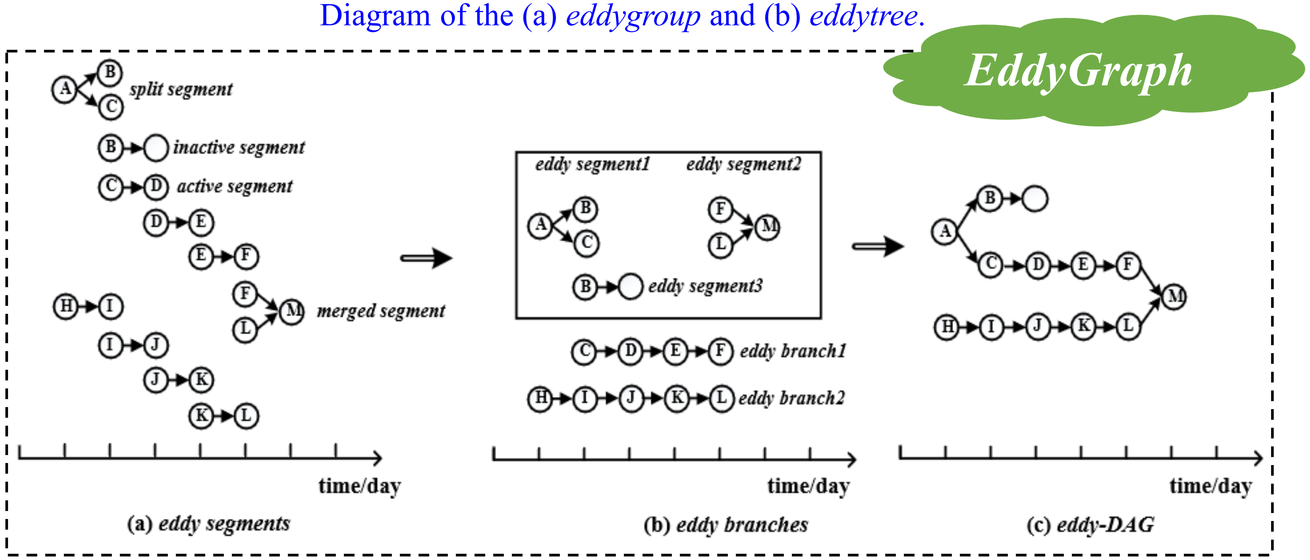


Diagram of the *eddy segment*, *eddy branch* and *eddy-DAG*. Circles with letters are eddies or eddy seeds.

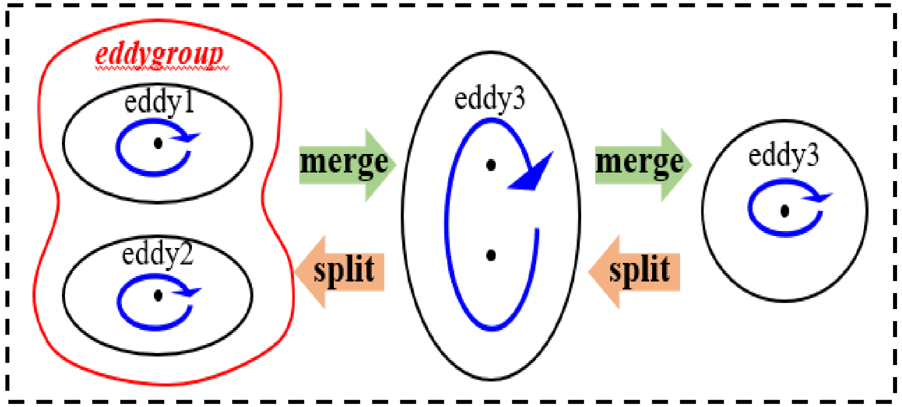
- ***Seeds*** are the local SLA maximum or minimum points.
- ***Eddies*** are the closed SLA contour with only seeds contained.
- ***Eddygroups*** are the closed SLA contours with eddies, seeds or eddygroups contained.
- ***Eddytrees*** are the topological relationships between eddy seeds, eddies and eddygroups.

- Based on SLA, the ***eddytrees dataset*** are obtained by building a spatial topological tree structure of closed SLA contours with mononuclear eddies, multicore eddies and eddy seeds as the leaf nodes and eddygroups as the intermediate nodes.
- Based on ***eddytrees dataset***, the ***nearest method*** and ***the area overlap method*** are combined to track eddy splitting and merging processes, construct eddy trajectories with complex topological relationship, and obtain the global eddy trajectory dataset.

Tian et al., *Remote Sensing*, 2021.
Tian et al, *Periodical of Ocean University of China (accepted).*

Major Results

Result 1: Eulerian Eddy—Eddy Splitting and Merging events Identification and Tracking



A diagram of the eddy merging and splitting processes.

- Based on the *EddyGraph* algorithm, the dataset of global mesoscale eddy splitting and merging events over the past 28 years (1993-2020) is available.

数据共享服务系统

首页 搜索数据集 政策声明 论文成果 服务与支持

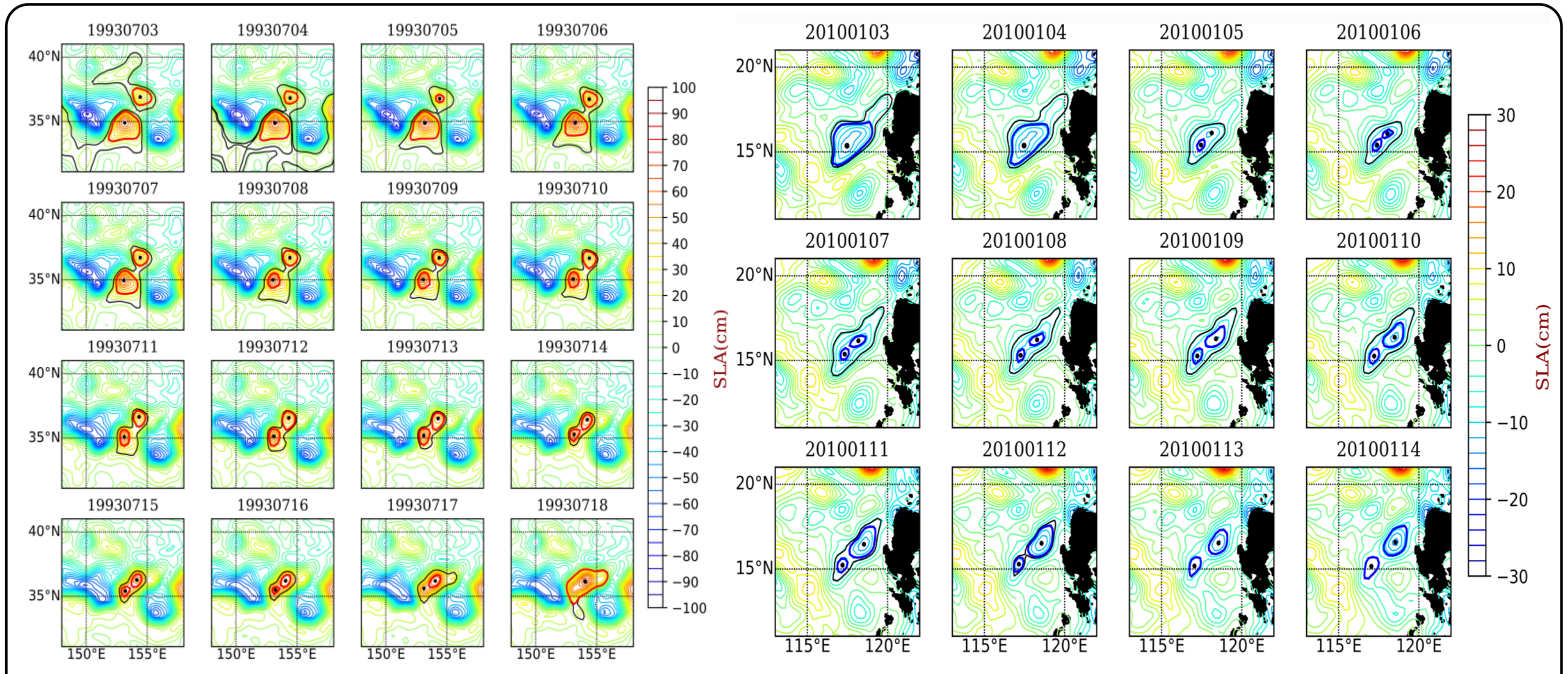
Global Eddy Graphs：基于卫星高度计的全球中尺度涡旋分裂与合并追踪数据集 收藏数据集

数据标识： DOI: 10.12237/casearth.63369940819aec34df2674d8 发布日期：2022-10-18
CSTR: 31104.11.casearth.63369940819aec34df2674d8
PID: 21.86109/casearth.63369940819aec34df2674d8

数据简介：涡旋追踪数据集 EddyGraph 包含了 1993 年 1 月至 2020 年 12 月的涡图 (Eddy-DAG)轨迹数据，其中的涡和涡群的属性信息可以在多层次涡旋识别数据集中查询到。由于分裂和合并事件发生在具有相同极性涡旋之间，反气旋涡旋和气旋涡旋的追踪轨迹被分开存储。此外，还提供了典型的涡旋分裂与合并事件的数据。识别数据集以 h5 格式进行存储，追踪数据集和典型事件数据集都以 json 格式进行储存。FTP下载地址：obsftp.cstcloud.cn 用户名：p2-xda19090202-016 密码：1c63ddee32

引用地址：田丰林；相红竹；龙霜；陈戈.Global Eddy Graphs：基于卫星高度计的全球中尺度涡旋分裂与合并追踪数据集,北京:中国海洋大学; 青岛海洋科学与技术试点国家实验室,2022.doi:10.12237/casearth.63369940819aec34df2674d8

开始日期：1993-01-01 结束日期：2020-12-31

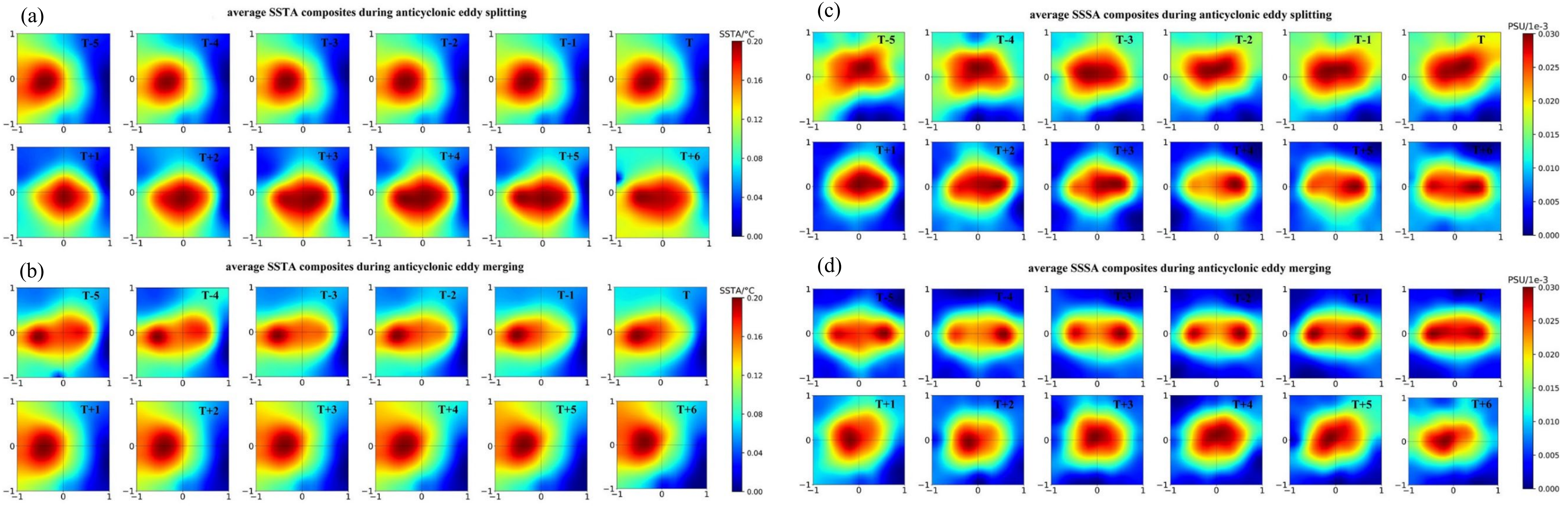


The examples of merging event of AE (left) and splitting event of CE (right).

Major Results

Result 1: Eulerian Eddy—Eddy Splitting and Merging events Identification and Tracking

- Based on the typical splitting and merging events extracted from the global *EddyGraph* dataset, the normalized results of SSTA and SSSA are used to verify the reliability of the dataset and the effect of the interaction between eddies on marine material distribution.

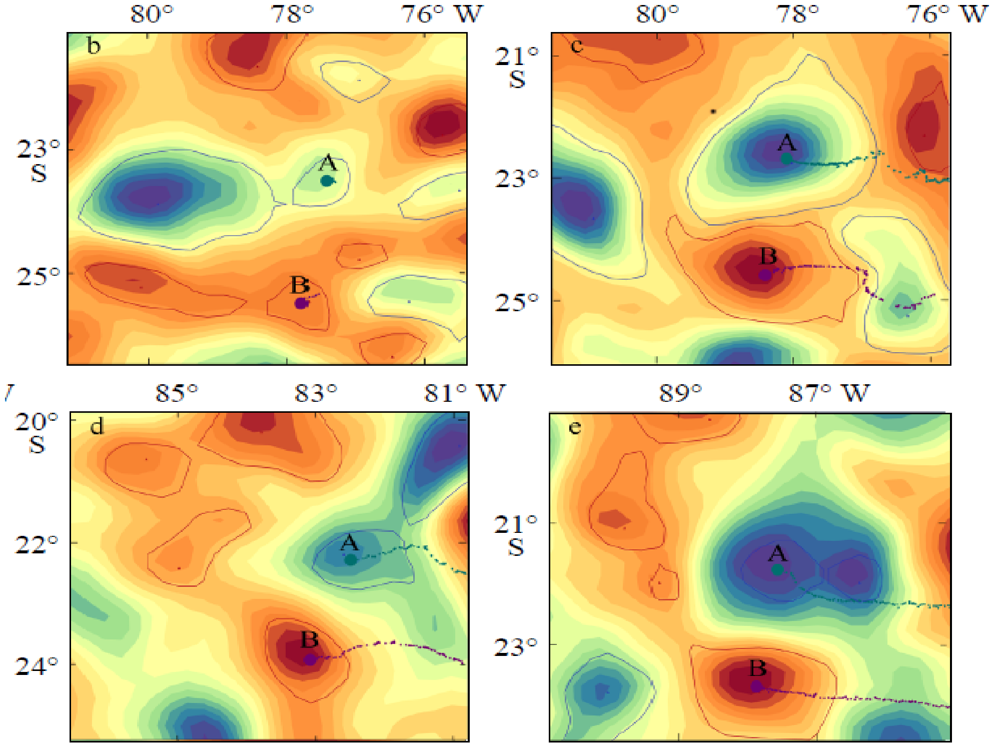


The average composite of SSTA during anticyclonic (a) splitting events and (b) merging events and of SSSA during anticyclonic (c) splitting events and (d) merging events..

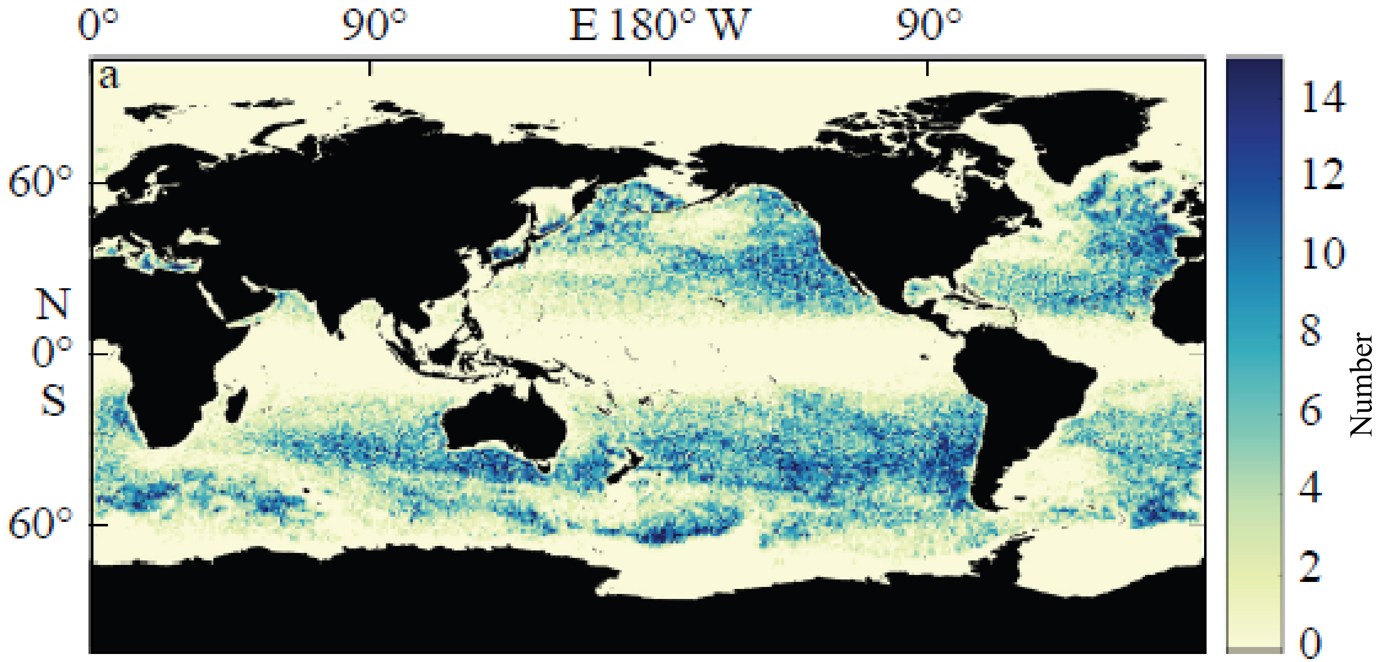
Major Results

Result 2: Eulerian Eddy—Automatic Recognition Algorithm of Global Mesoscale Dipoles

- An automatic recognition method of global mesoscale dipoles is proposed by using the K-D tree for cutting space.
- Through analyzing typical fast propagation dipoles, it is found that the dipole eddies cause the change of the marine environment steadily and has an internal uniform temperature and salinity structure.



A mesoscale dipole on 7 Jan, 16 Apr, 2 Sep and 26 Dec 2015. The shaded color represents SLA (unit: cm). A(B) is an AE (a CE). The bold dotted lines represent their historical track.

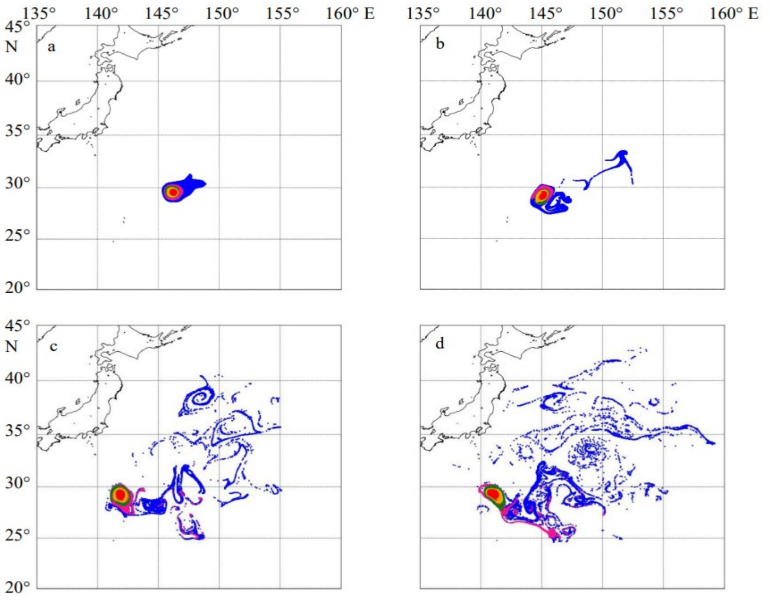


Distribution of the number of global dipoles with cumulative pairing days over 60 days.

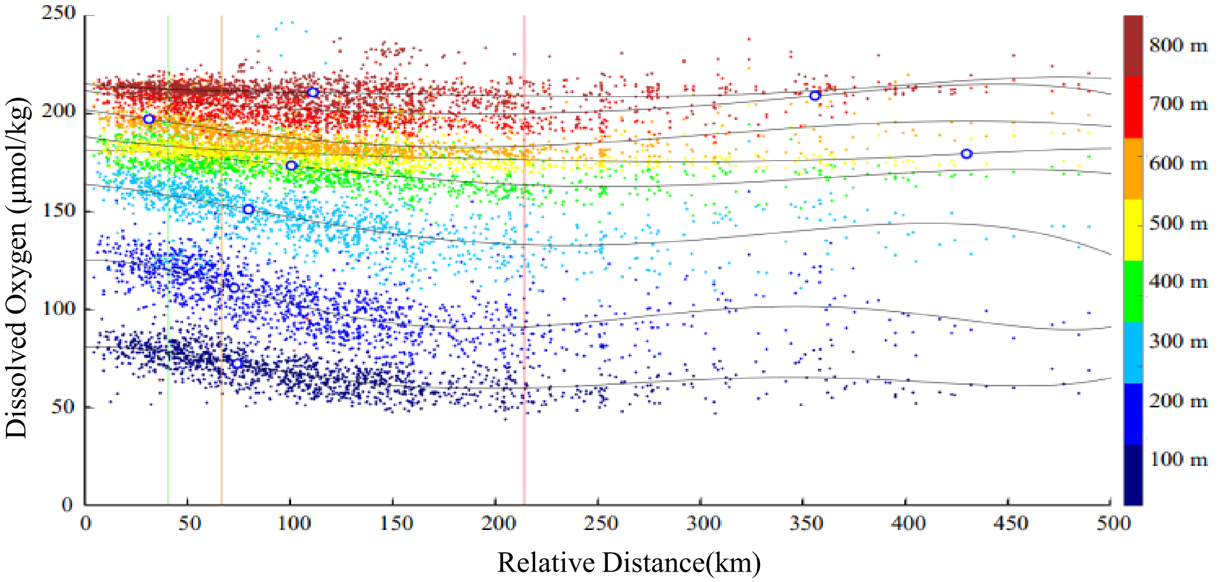
Tian et al., *Haiyang Xuebao,* 2021.

Result 3: Lagrangian eddies—Black-hole eddy on material transport in the Western Pacific

- Using the method of elliptic Lagrangian Coherent Structures (eLCSs) and choosing a targeted eddy (Eddy A) in the Western Pacific Ocean to analyze. SST, SSS and Chl-*a* concentration data are used to verify that the Eddy A is coherent in horizontal material transport.
- The temperature, salinity and dissolved oxygen (DO) data obtained by Argo in different depths are used to prove the coherence in vertical of Eddy A.



Eddy boundaries of the black-hole (pink, green, orange, and red are T=30 d, 60 d, 90 d, and 120 d), and Eulerian A (blue) filled with virtual particles moves with the geostrophic flow.



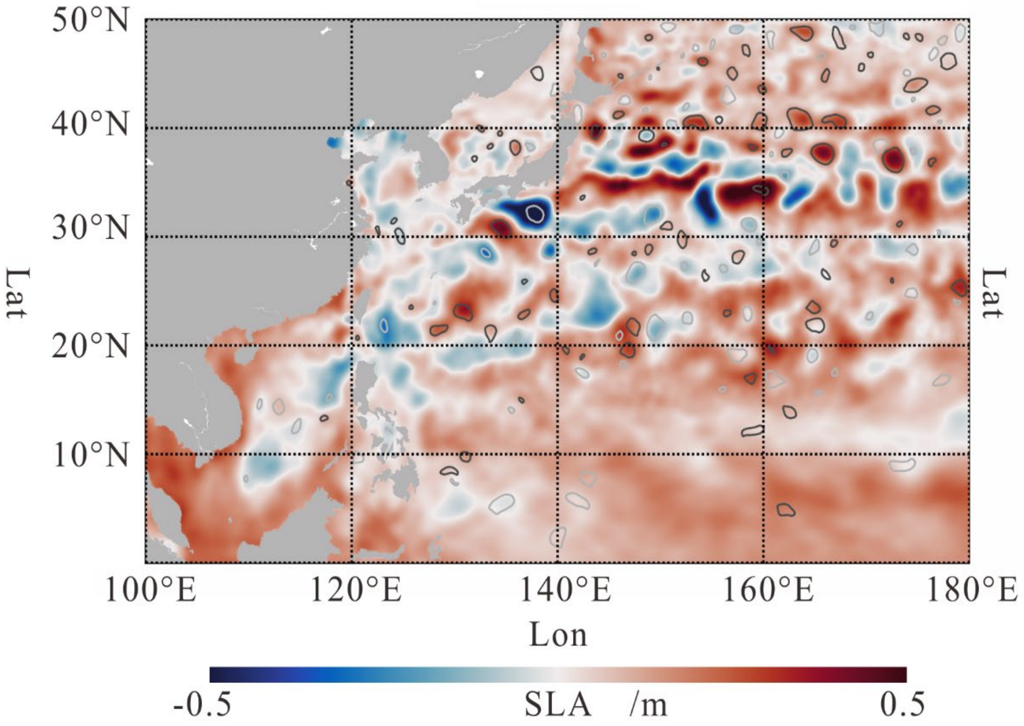
The statistical graphs of the relative distance between the Argo data point of DO and the eddy center. The color of points represents the depths.

Tian et al., *Haiyang Xuebao*, 2021.

Major Results

Result 4: Lagrangian eddies—Lagrangian eddies in the Northwestern Pacific Ocean

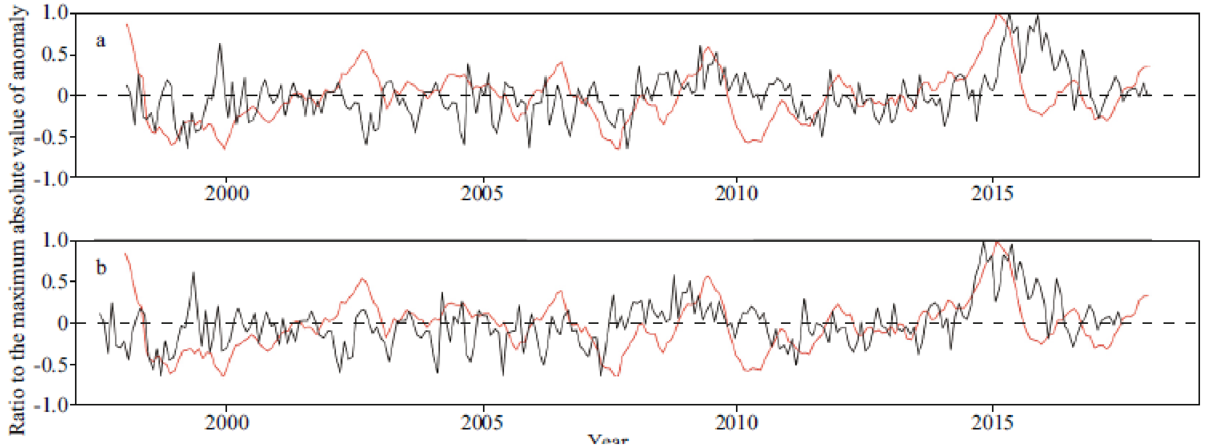
- The Lagrangian eddies in the western Pacific Ocean are identified based on Maps of SLA data from 1998 to 2018.
- The relationship between the number of Lagrangian eddies and the El Niño phenomenon is described quantitatively. This finding shows that the Lagrangian eddy has secular variations and is closely related to El Niño.



Lagrangian eddies in the western Pacific Ocean on 1 Jan 2018.

Table 1 Covariance between Lagrangian eddy number and El Niño coefficient

Month lag	-1	0	1	2	3	4	5	6	7	8	9	10
Niño 3.4	1.18	1.43	1.68	1.90	2.03	2.06	2.12	2.20	2.21	2.14	1.83	1.52
Niño 3	1.02	1.26	1.58	1.82	1.99	2.15	2.25	2.39	2.37	2.10	1.79	1.51
Niño 4	1.00	1.19	1.41	1.59	1.61	1.50	1.40	1.30	1.28	1.26	1.16	0.96

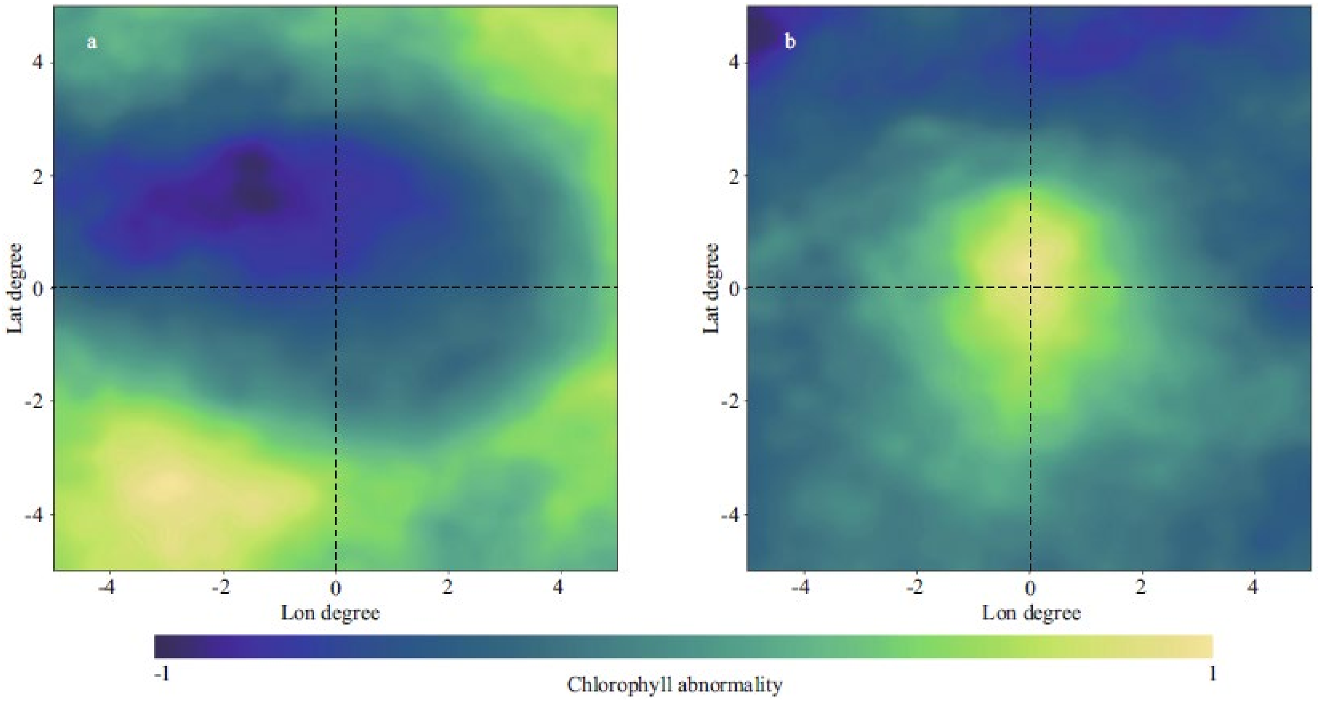


Secular variation in Lagrangian eddies with El Niño 3.4.

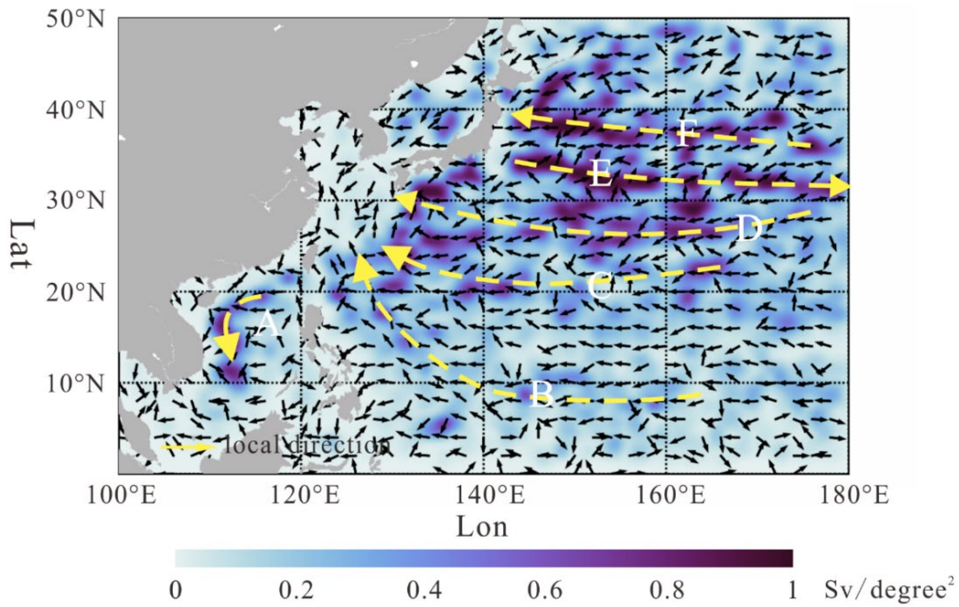
He et al., *Journal of Oceanology and Limnology*, 2022.

Result 4: Lagrangian eddies—Lagrangian eddies in the Northwestern Pacific Ocean

- Through normalized chlorophyll data, it is observed that Lagrangian eddies can cause chlorophyll aggregation and hole effects.
- The transportation volume of the Lagrangian eddy is calculated quantitatively, and several major transport routes have been identified. These findings demonstrate the important role of Lagrangian eddies in material transport.



The results of chlorophyll abnormalities caused by normalized eddies.

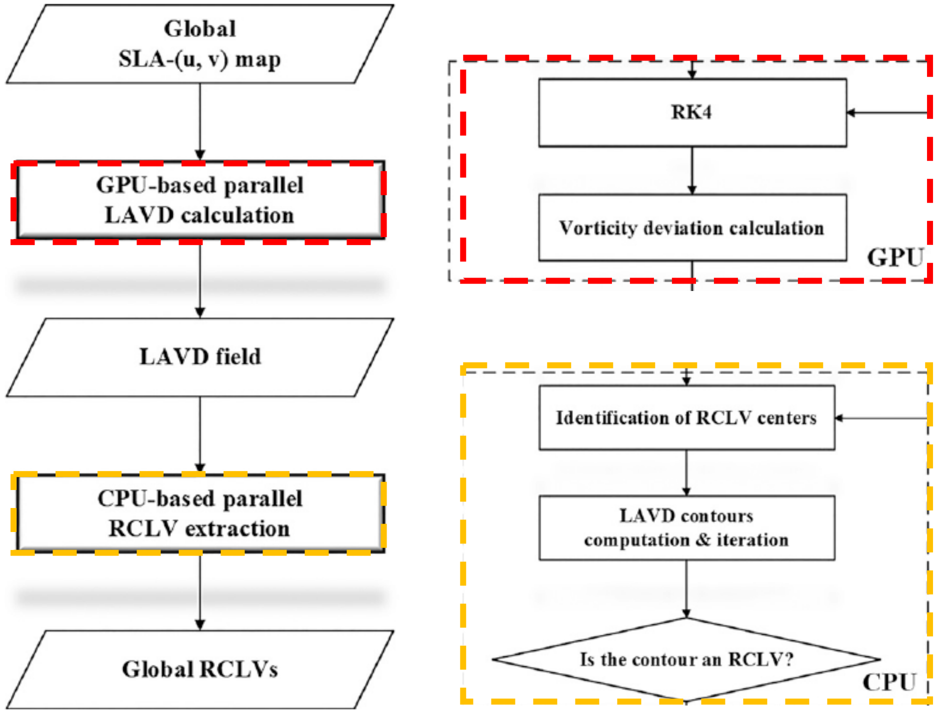


Average transport intensity of Lagrangian eddies in the Northwest Pacific. The large yellow arrows indicate the main transport corridors of Lagrangian eddies.

He et al., *Journal of Oceanology and Limnology*, 2022.

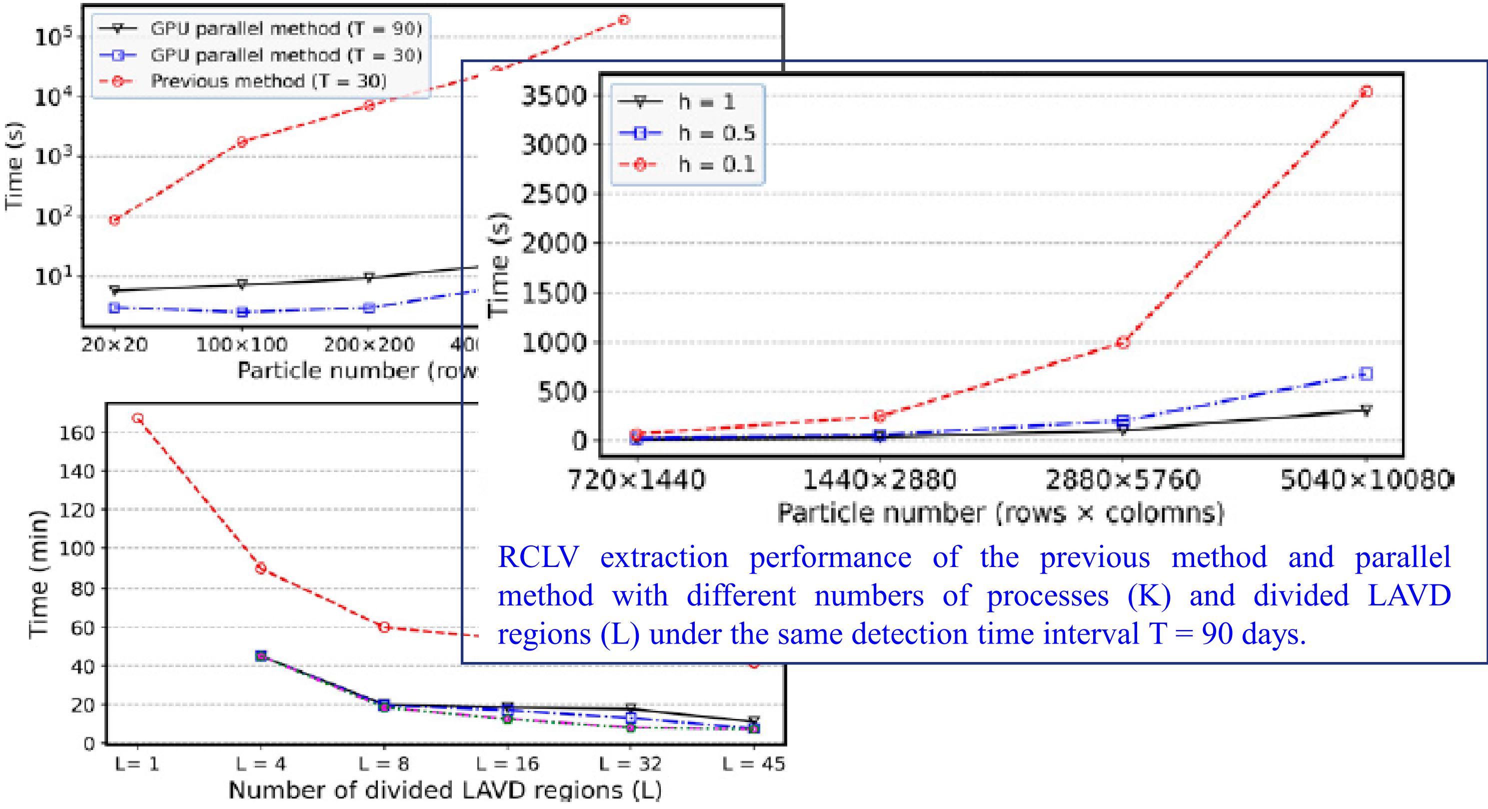
Result 5: Lagrangian eddies—Orthogonal parallel detection of global Lagrangian eddies

- Based on multi-thread GPU and multi-process CPU parallel technology, an effective parallel algorithm for the detection of global rotationally coherent Lagrangian vortices (RCLVs) derived from SLA data is presented, which makes the extraction process approximately 500 times faster than a nonparallel algorithm.



Flowchart of the orthogonal parallel RCLV detection algorithm

Tian et al., *Journal of Atmospheric and Oceanic Technology*, 2022.

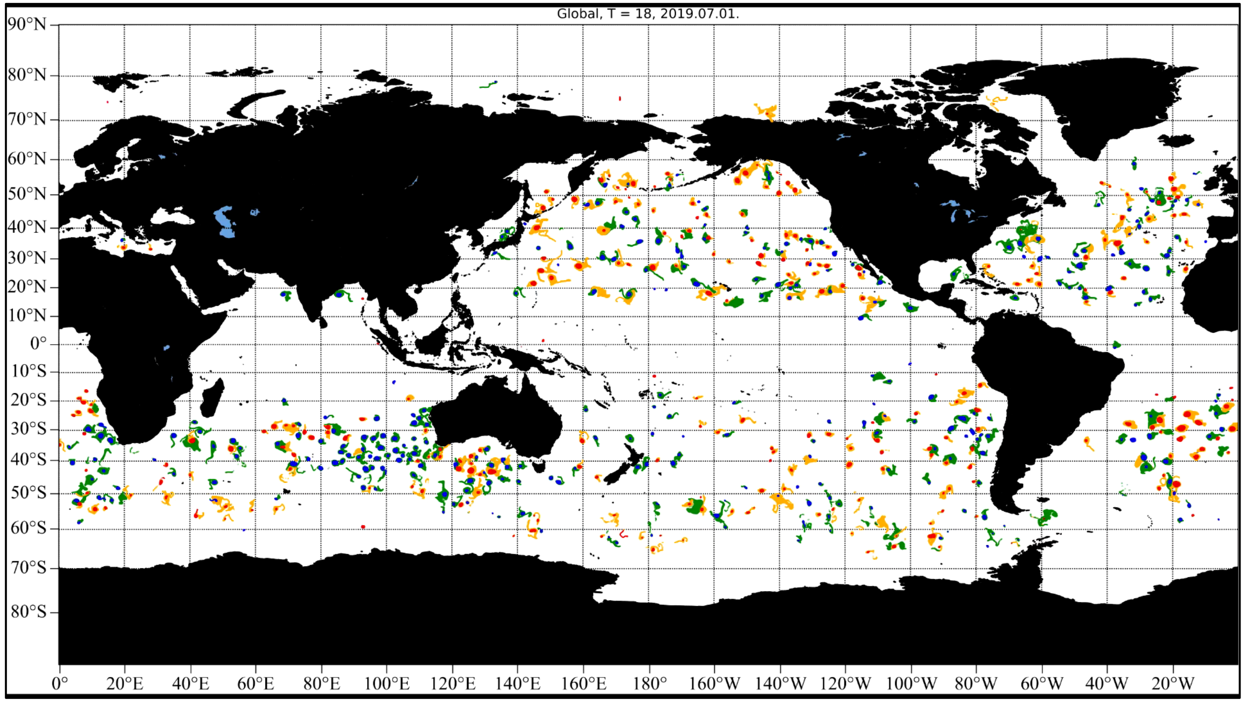


RCLV extraction performance of the previous method and parallel method with different numbers of processes (K) and divided LAVD regions (L) under the same detection time interval T = 90 days.

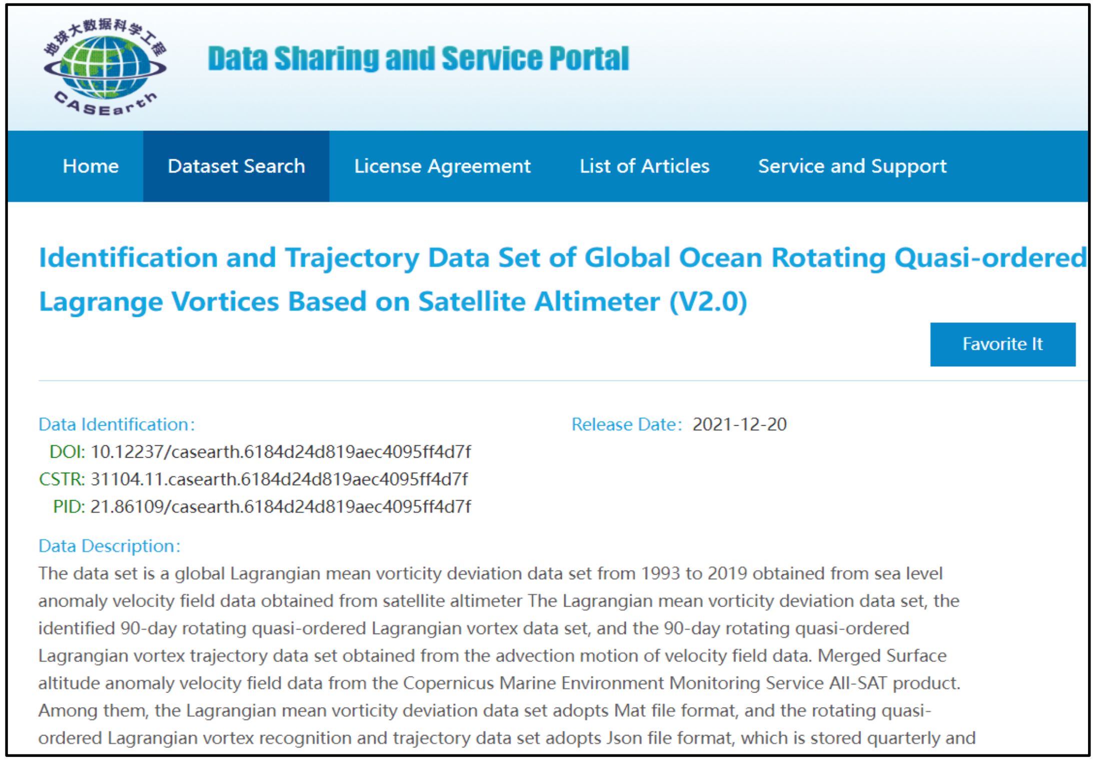
Performance of LAVD calculation by the GPU parallel method

Result 5: Lagrangian eddies—Orthogonal parallel detection of global Lagrangian eddies

- Based on the orthogonal parallel architecture, a long-time-scale global RCLVs product from 1993 to 2019 containing 52,567 vortices is produced with a 90-day time interval.



Cyclonic RCLVs (blue), anticyclonic RCLVs (red), cyclonic Eulerian eddies (green), and anticyclonic Eulerian eddies (orange) are filled with virtual particles on the original detection date (1 Jul 2019, T=90 days) extracted by the orthogonal parallel method using the LAVD contours.



Identification and Trajectory Data Set of Global Ocean Rotating Quasi-ordered Lagrange Vortices Based on Satellite Altimeter (V2.0)

Data Identification:

DOI: 10.12237/casearth.6184d24d819aec4095ff4d7f

CSTR: 31104.11.casearth.6184d24d819aec4095ff4d7f

PID: 21.86109/casearth.6184d24d819aec4095ff4d7f

Release Date: 2021-12-20

Data Description:

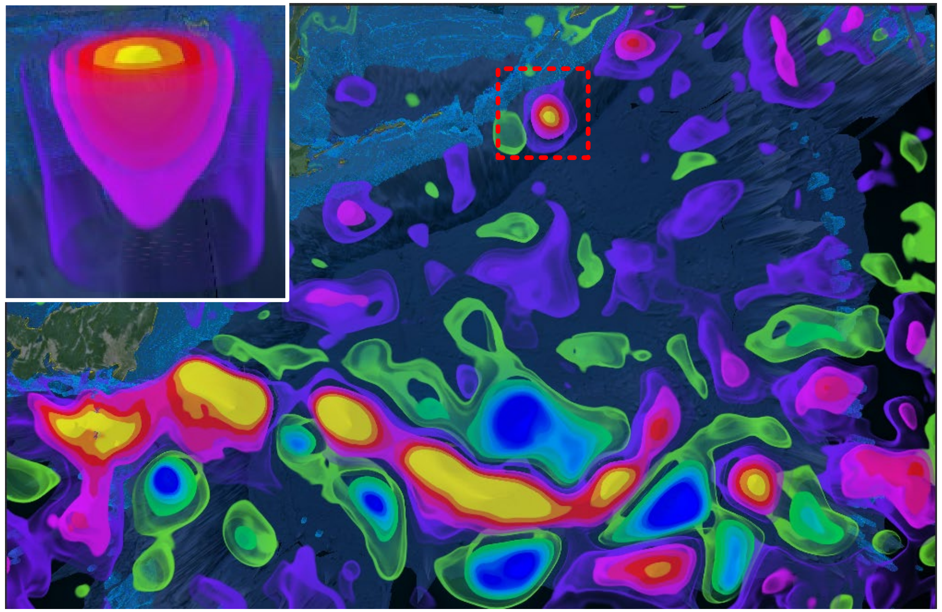
The data set is a global Lagrangian mean vorticity deviation data set from 1993 to 2019 obtained from sea level anomaly velocity field data obtained from satellite altimeter The Lagrangian mean vorticity deviation data set, the identified 90-day rotating quasi-ordered Lagrangian vortex data set, and the 90-day rotating quasi-ordered Lagrangian vortex trajectory data set obtained from the advection motion of velocity field data. Merged Surface altitude anomaly velocity field data from the Copernicus Marine Environment Monitoring Service All-SAT product. Among them, the Lagrangian mean vorticity deviation data set adopts Mat file format, and the rotating quasi-ordered Lagrangian vortex recognition and trajectory data set adopts Json file format, which is stored quarterly and

Tian et al., *Journal of Atmospheric and Oceanic Technology*, 2022.

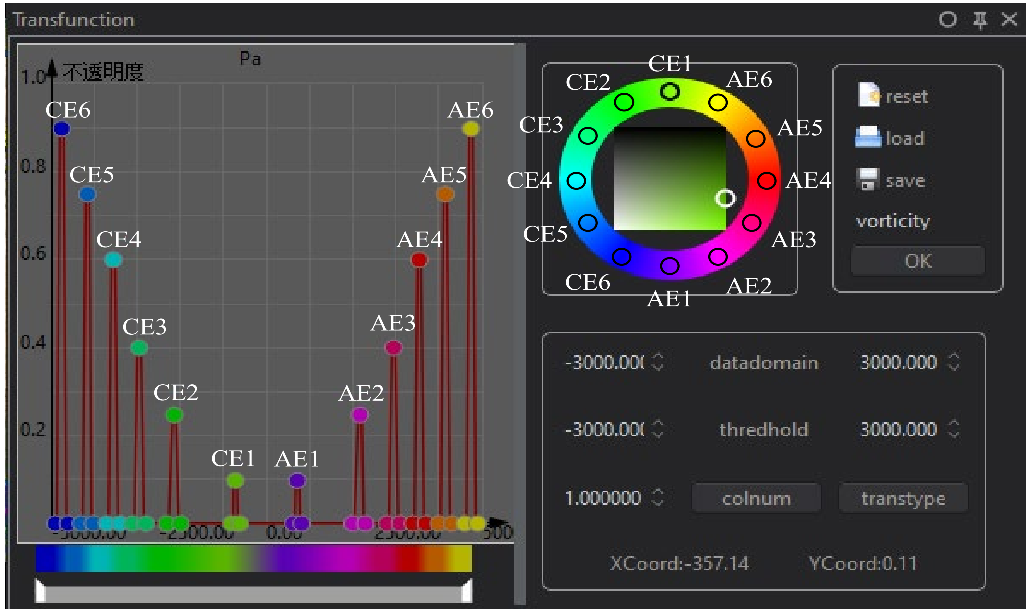
Major Results

Result 6: Scalar Fields—Mesoscale Eddy 3D Structure Visualization

- Based on volume rendering technology, with numbers of feature points, feature color mapping and the line shape to design a standard morphological model of the transfer function for ocean pressure anomaly data. It can intuitively and effectively represent the 3D pressure anomaly structure of mesoscale eddy.
- Optimized the ray casting algorithm, the rendering efficiency is increased by 2 times compared with the traditional algorithm without reducing the rendering quality.



Visualization of eddy pressure anomaly structure. The upper left is the enlarged side view of the eddy marked in the red frame area.

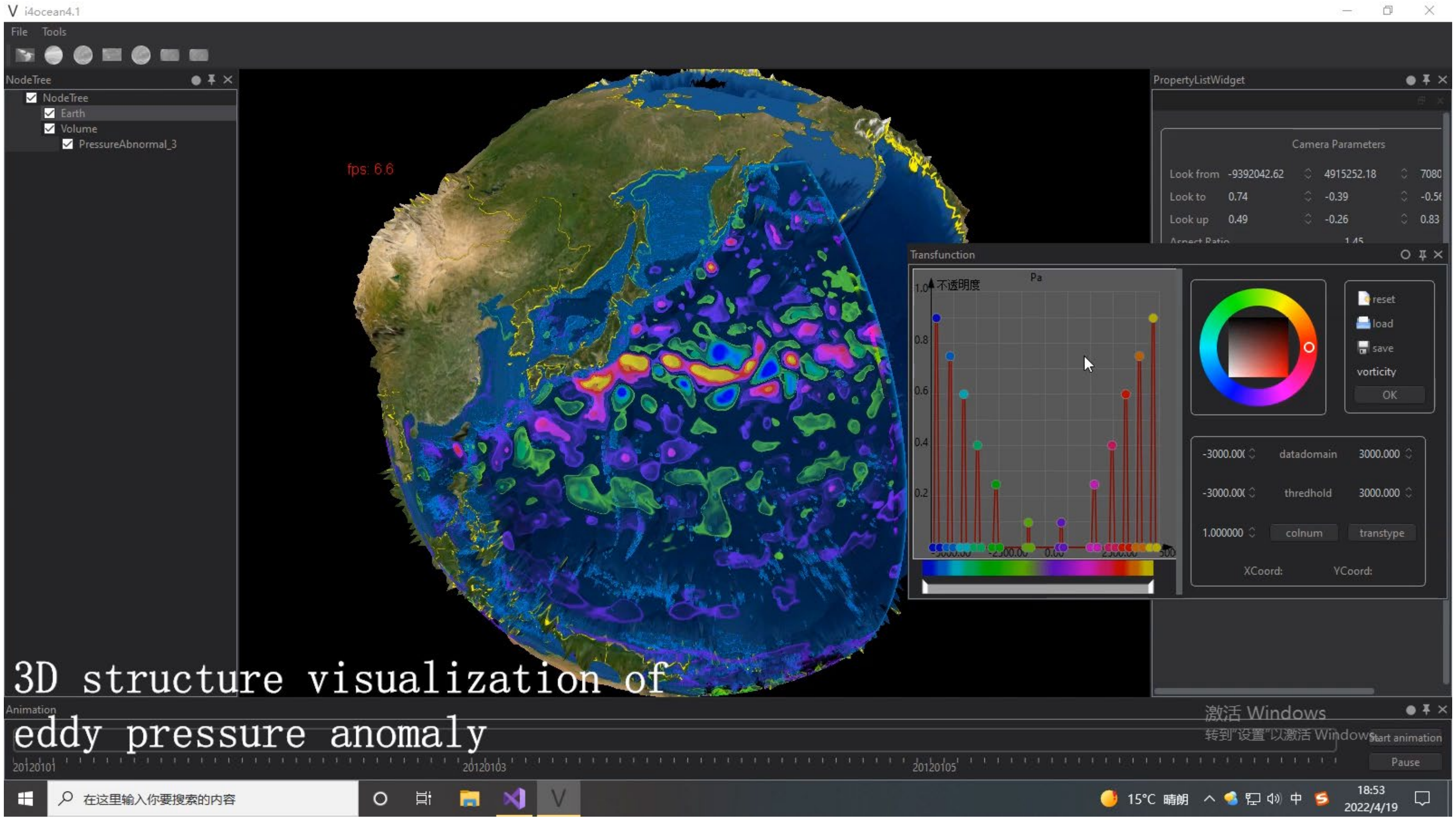


Transfer functions of eddy multi-structural features.

Tian et al., *Marine Science Bulletin*, accepted.

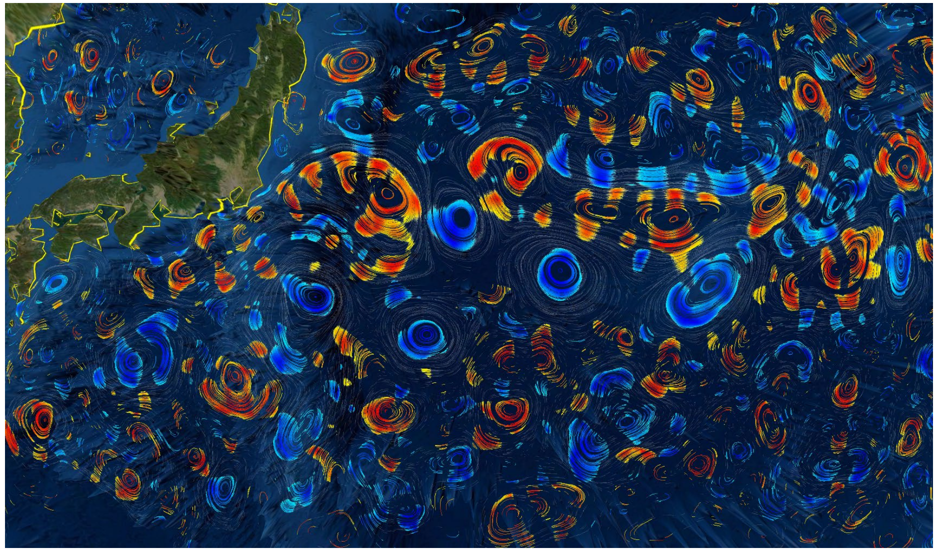
Major Results

Result 6: Scalar Fields—Mesoscale Eddy 3D Structure Visualization

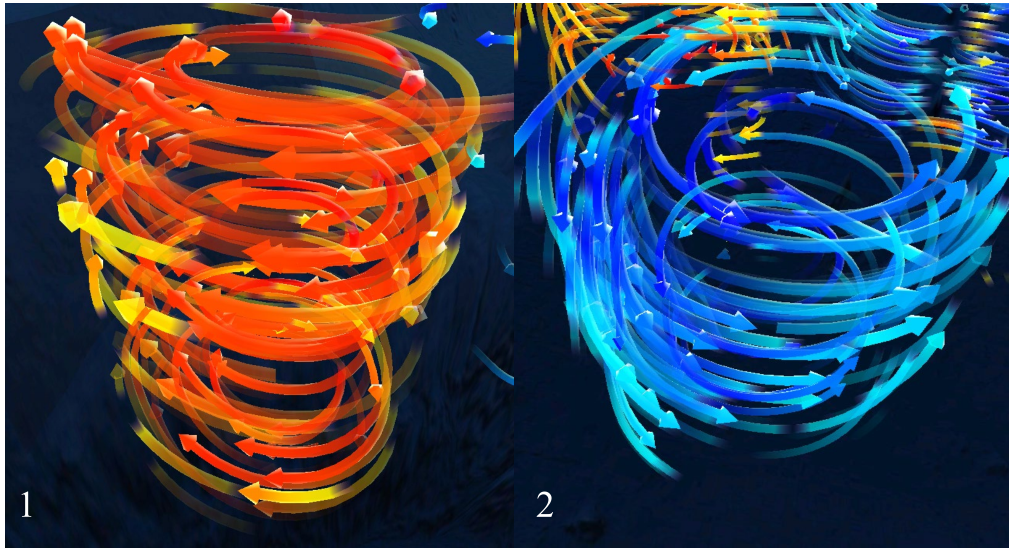


Result 7: Vector Fields—Ocean current field visualization

- Based on MSLA and Omega3D ocean data, we propose a visualization scheme of ocean current field oriented to ocean mesoscale eddies. By using the interactive transfer function and spatiotemporal continuous visualization framework, we have realized high perception 2D vortex visualization and 3D vortex visualization, which is convenient for users to intuitively understand ocean flow field data.



Effect diagram of 2D vortex visualization on 1 Jan 2012.Cold colors represent cyclonic vortices and warm colors represent anticyclonic vortices.

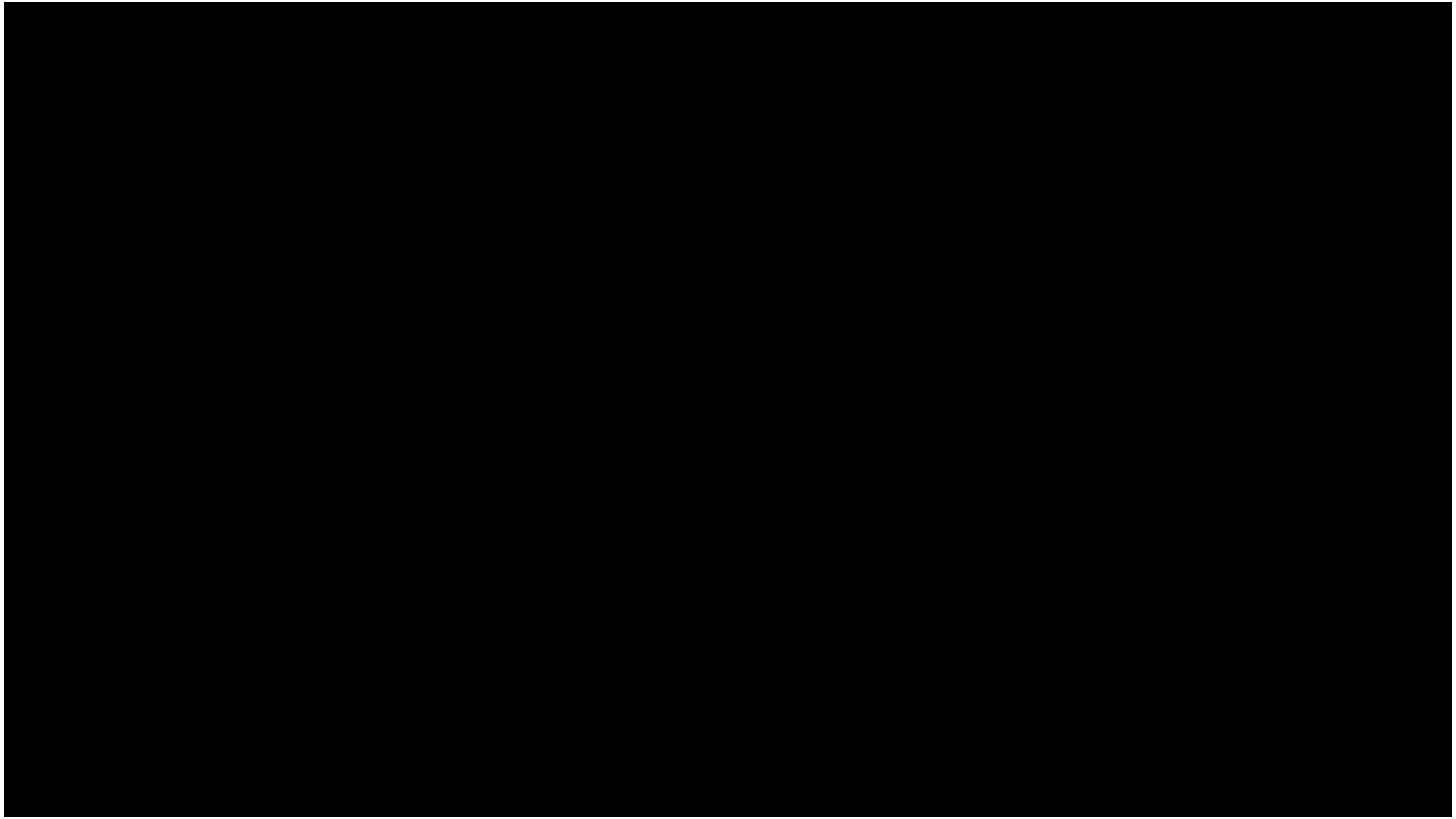


Effect diagram of 3D vortex visualization on 11 Jan 2012. No. 1 is the anticyclone vortex and No. 2 is the cyclone vortex.

Tian et al., *Marine Sciences,* accepted.

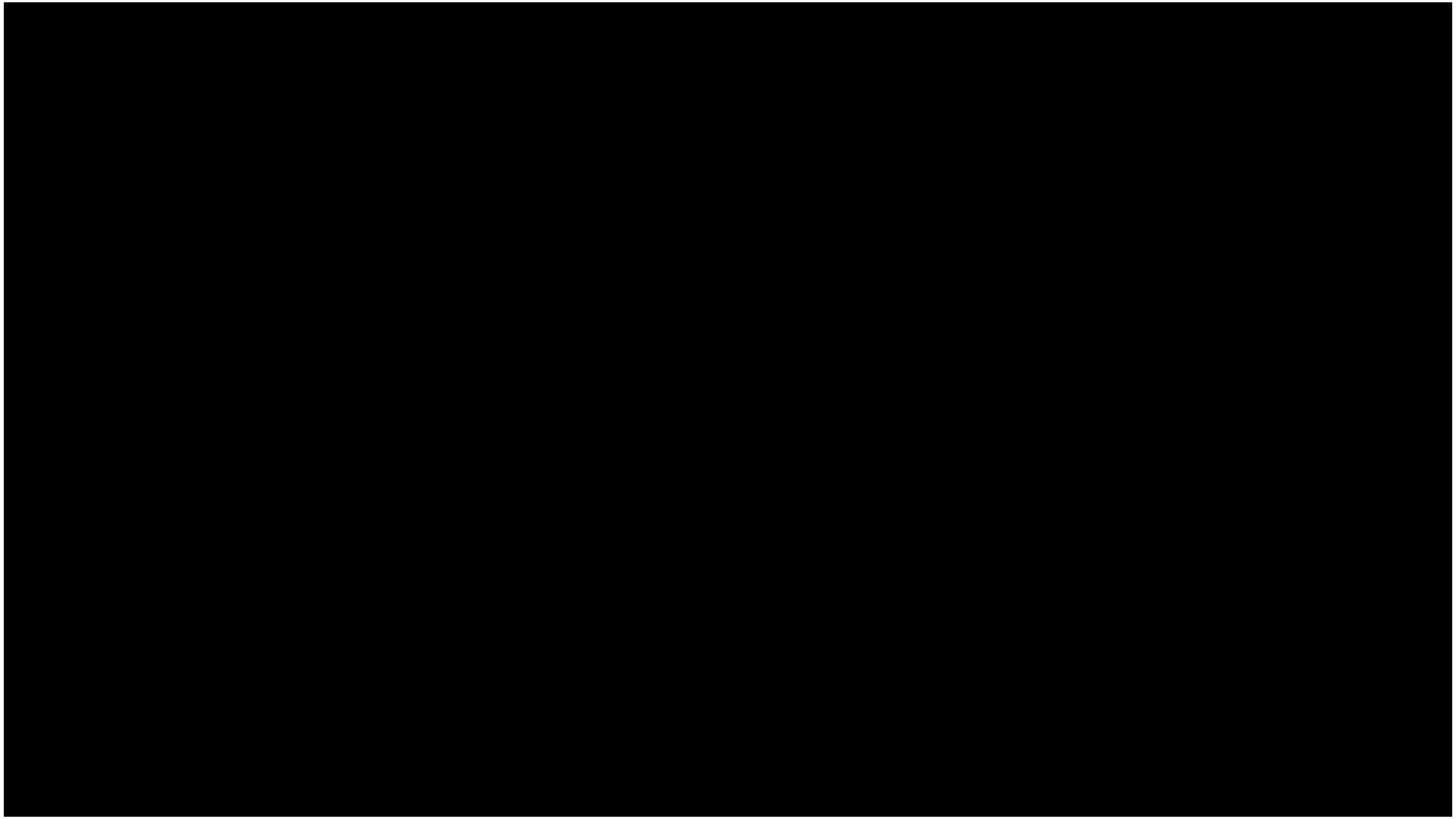
Major Results

Result 7: Vector Fields—Ocean current field visualization



Major Results

Result 7: Vector Fields—Ocean current field visualization



Key References

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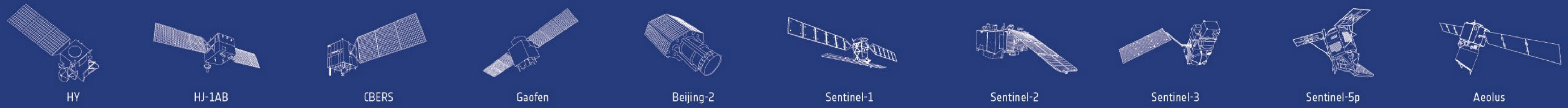

THANKS FOR YOUR ATTENTION !