Update of Operational Forecasting Systems in China

Guimei LIU

National Marine Environmental Forecasting Center (NMEFC)

Ministry of Natural Resources, Beijing, China

8th Nov., 2023

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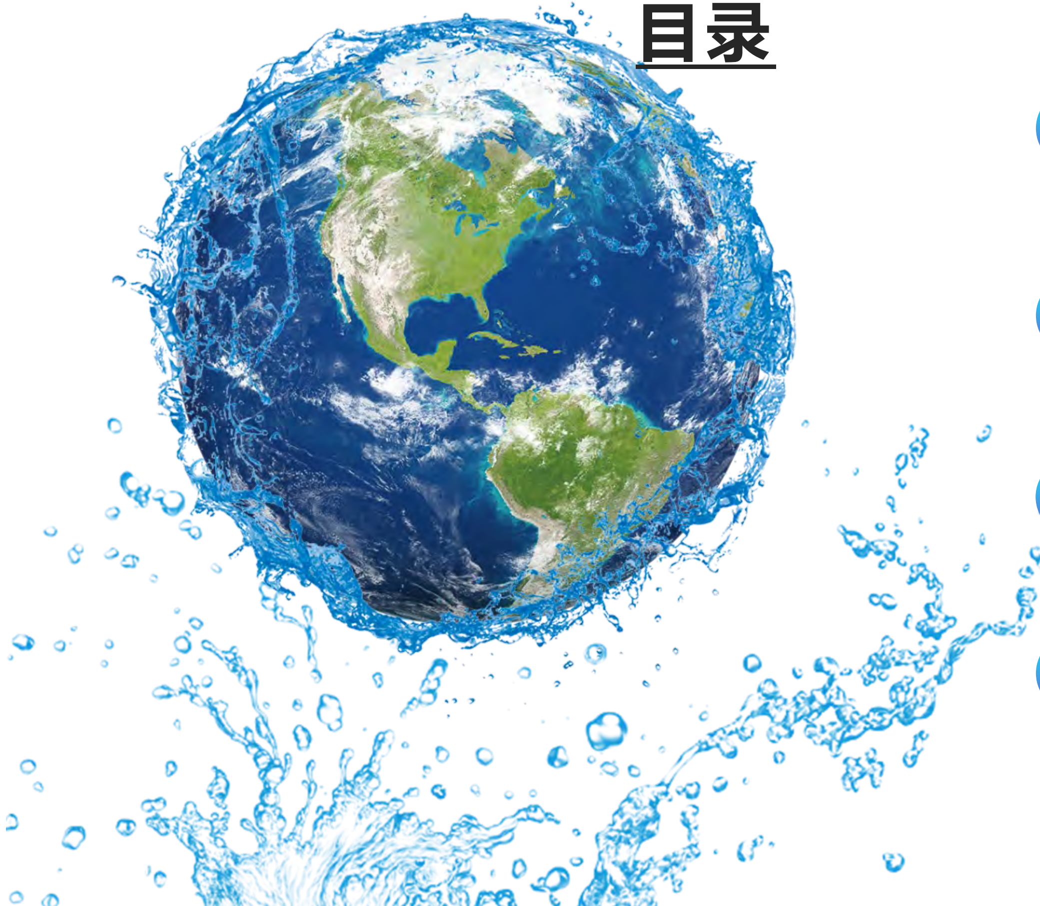


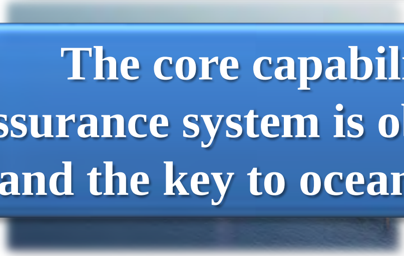
PART 1

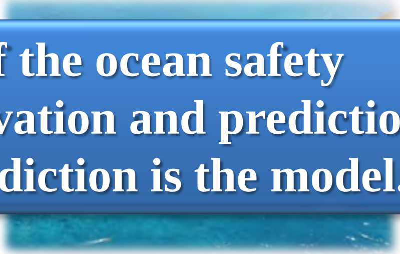
BACKGROUND

Marine safety assurance is the cornerstone of supporting the development of the marine economy

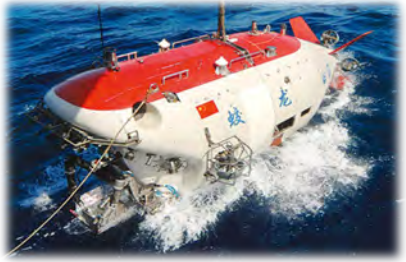
Assist in the development of the marine economy:

- Ocean polar exploration, deep-sea resource development, ocean shipping, ocean fishing, ocean ranching, maritime military and other marine environmental protection needs;
- Major offshore engineering construction, offshore wind power construction, offshore oil development and construction, and other marine economic construction needs.





The core capability of the ocean safety assurance system is observation and prediction, and the key to ocean prediction is the model.



PART 2

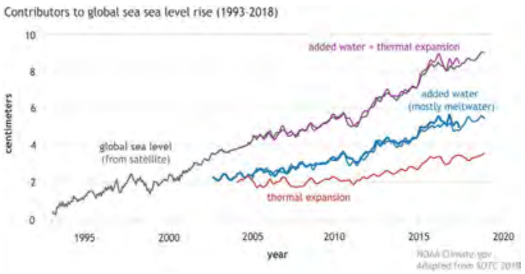
Progress in Ocean Forecasting Model and Systems

New model developed

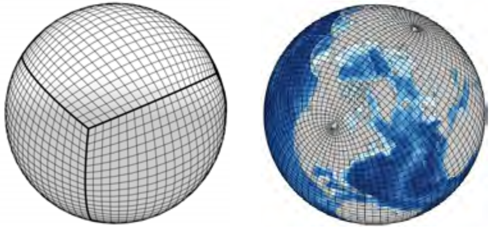
Mass Conservation Ocean Model

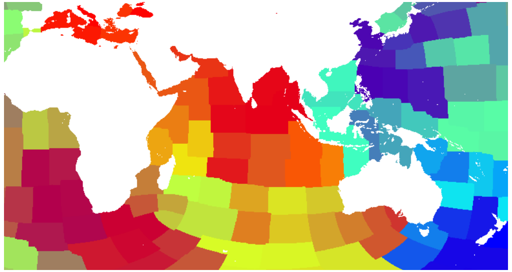
MaCOM

1 Mass Conservation

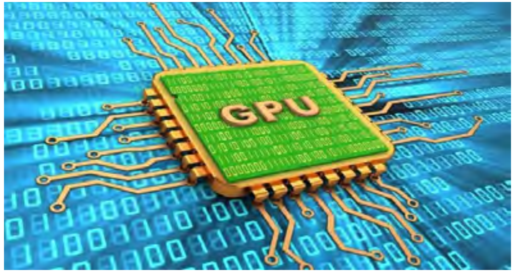


2 Flexible grid support





3 Heterogeneous computing



1st Advantage
More accurate and direct simulation of sea level changes

2nd Advantage
More precise definition of salinity

3rd Advantage
Seafloor pressure observations can be directly assimilated

- Support for various grid forms such as Cubic Sphere, Tripolar
- Helpful to eliminate land points, which can reduce storage and calculation by up to 28%.
- Flexible and intelligent boundary division reduces parallel communication.

The global ten-kilometer (1/12°) ocean circulation numerical forecast can use a single 8-card GPU server to replace the traditional 40-60 CPU computing nodes (2048 cores)

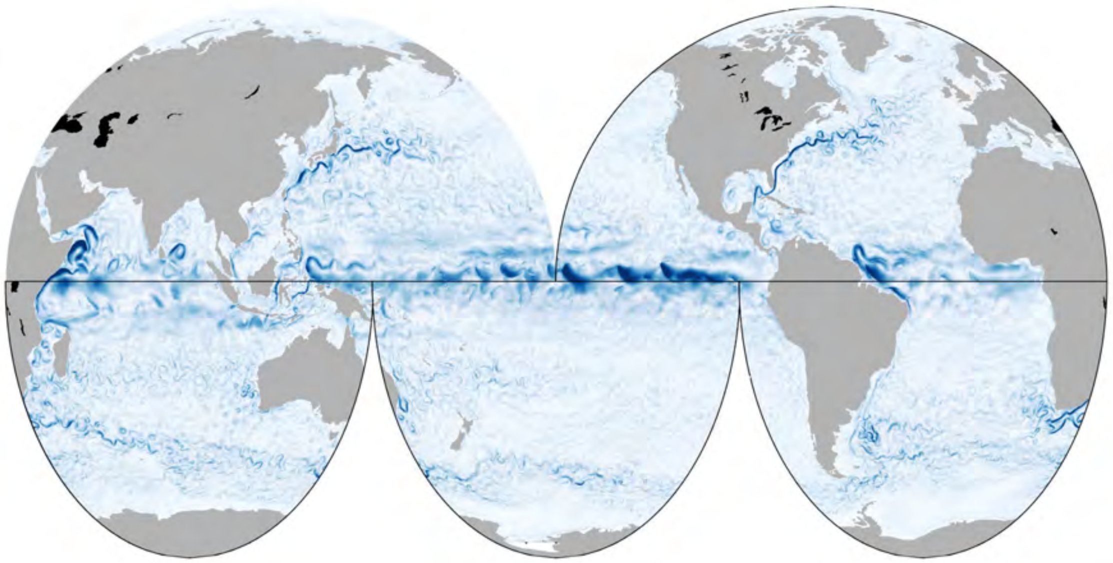
✓Equipment purchase cost reduced by 2/3

✓Computing energy consumption reduced by 90%

Application of MaCOM in global ocean

Accurate simulation of Enthalpy

Accurate simulation of Salinity



Global application technology

- Cubic Sphere or Tripolar
- Supports up to 1/24° horizontal resolution
- MCM or VCM
- Tidal potential M_2, S_2, N_2, K_1, O_1, P_1, Q_1, K_2
- Sea ice

Operational configure

- Cubic Sphere
- 1/12° horizontal resolution
- MCM
- 4 A100 GPU
- No tide and ice till now

IVTT Class 4: method

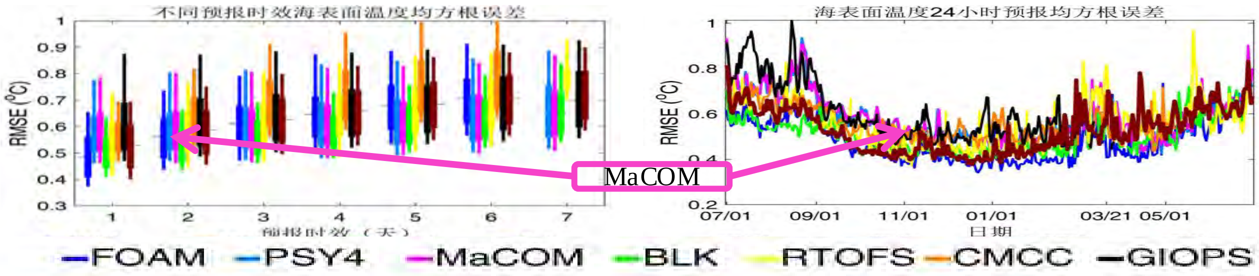
The IVTT International Operational Forecast System Comparison Program was initiated by the international program GODAE OceanView (now known as OceanPredict). It aims to promote countries to improve the technical level of operational oceanography through international comparison of four types of products. The inspection data covers the IVTT USGODAE on-site drifting buoy. , IVTT along-track altimeter J-1/2, Cryosat AltiKa and Argo thermohaline profile.

- $Bias = \frac{1}{N}\sum_{i=1}^{N}(F_i - O_i)$
- $RMSE_{FCT} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(F_i - O_i)^2}$
- $RMSE_{per} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(B_i - O_i)^2}$
- $PSS = 1 - \frac{RMSE_{FCT}}{RMSE_{per}}$
- $CSS = 1 - \frac{RMSE_{FCT}}{RMSE_{clim}}$
- $AC = \frac{\sum(F-C)(O-C)}{\sqrt{\sum(F-C)^2}\sqrt{\sum(F-O)^2}}$

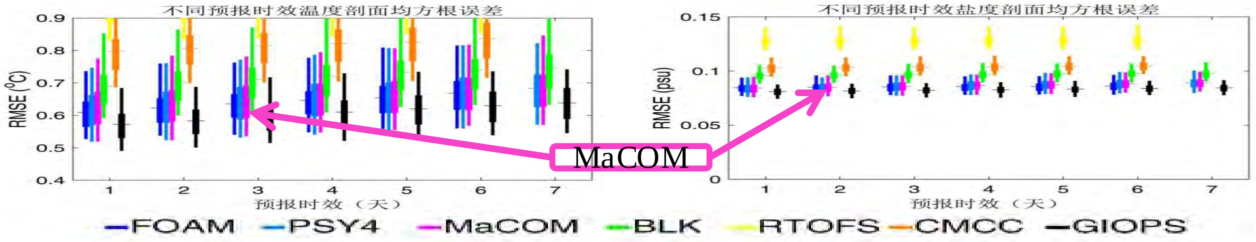
Country	System	Model
Canada	GIOPS- CONCEPTS	NEMO 1/4
France	PSY3 & PSY4	NEMO 1/4 &1/12
Australia	BLUElink- OceanMAPS	MOM4 10km around Australia but low resolution further out
U.K.	FOAM	NEMO 1/4
USA	RTOFS Global	HYCOM 1/12
China	NMEFC- MaCOM	MaCOM 1/12

F – Forecast, O – Observation, C – Climatic, B - Best estimate

IVTT Class 4: SST

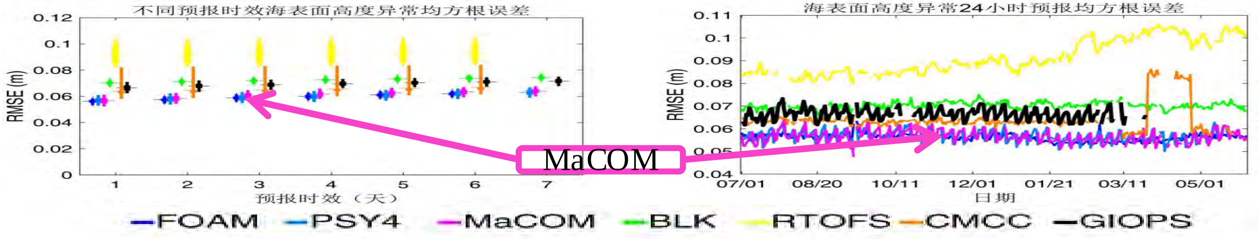


RMSE of MaCOM SST is about 0.56～0.64℃



RMSE of MaCOM T profile is about 0.63—0.69℃

RMSE of MaCOM S profile is about 0.08PSU

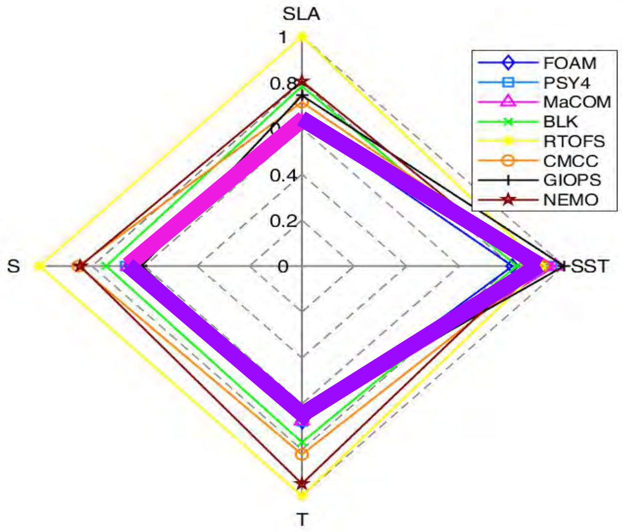


RMSE of MaCOM SLA is about 0.06m

July 1st 2021--June 30th 2022

Intercomparision and Validation

IVTT class4



RMSE of 24-hours forecasting

□ □ □ □	T(℃)	S(psu)	SST(℃)	SLA(m)
FOAM	0.61	0.08	0.49	0.06
PSY4	0.63	0.08	0.58	0.06
MaCOM	0.63	0.08	0.59	0.06
BLK	0.70	0.10	0.50	0.07
RTOFS	0.94	0.13	0.56	0.09
CMCC	0.80	0.10	0.56	0.06
GIOPS	0.57	0.08	0.61	0.07
NMEFC_NEMO	0.79	0.12	0.53	0.07

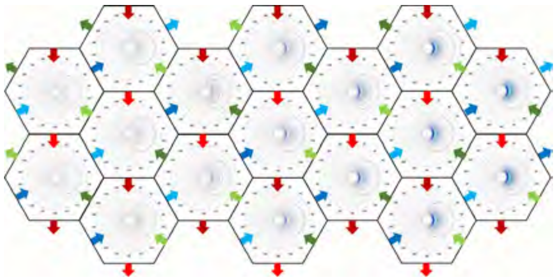
July 1st□ 2021--June 30th□ 2022

2.2 Finite-Volume WAve Model (FVWAM)

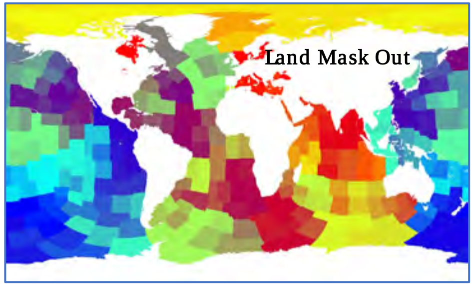
a GPU-accelerated, WAM-family ocean wave model based on unstructured Voronoi meshes

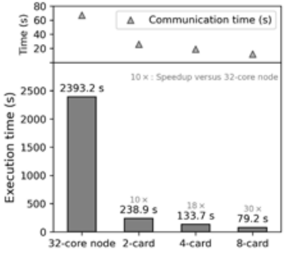
FVWAM is a WAM-family model with the following features:

- WAM-family: source terms entirely from WAM6 (Mywave project)
- Finite Volume Approach based on the unstructured Voronoi meshes is ported to the WAM6 for wave propagation.
    - Seamless integration of global to regional modeling
- Efficient domain decomposition for scalability, and GPU acceleration empowered by OpenACC.
    - Lightweighted and “Green”



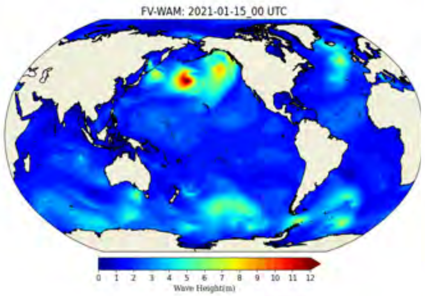
Propagation scheme based on FVM

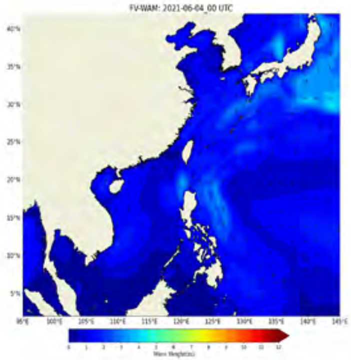


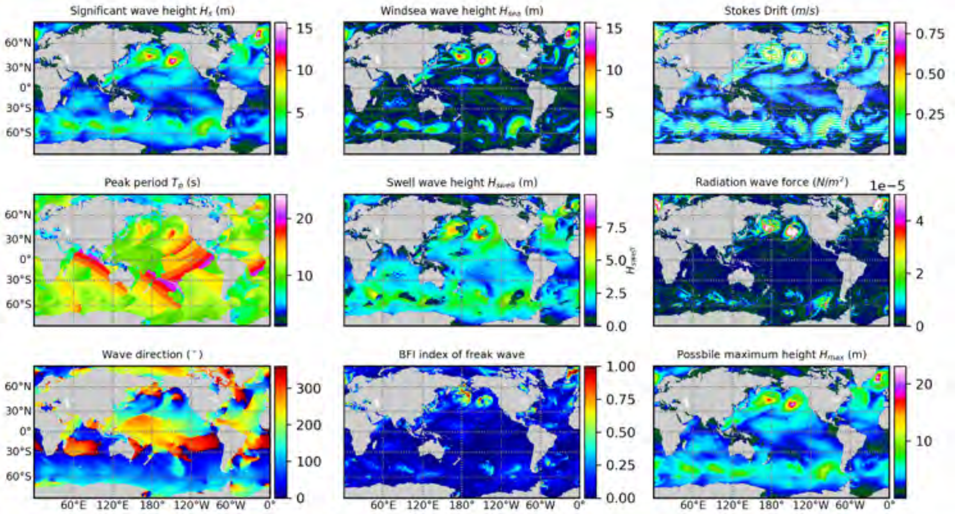


Model Application: Routine Forecasts

Daily operation, Twice	
Wind force	GRAPES/CMA, GFS/NCEP, or Holland parametric wind model
Spatial resolution	Global10km -> NWP 6km
Spectral resolution	36 Directions &35 Frequencies 0.0375□ 1.0Hz
Time step	120 s
Forecast valid	7 d
Updated at	00UTC□ 12UTC
Output	SWH, Tp, Direction
Output interval	1hrs







Model validation

- Model Runs: FVWAM 10km Global Wave Hindcast of 2021

  (H_s, T_m) Wind Force□ ERA5 Wind $(U_{10m}^{Neutral})$

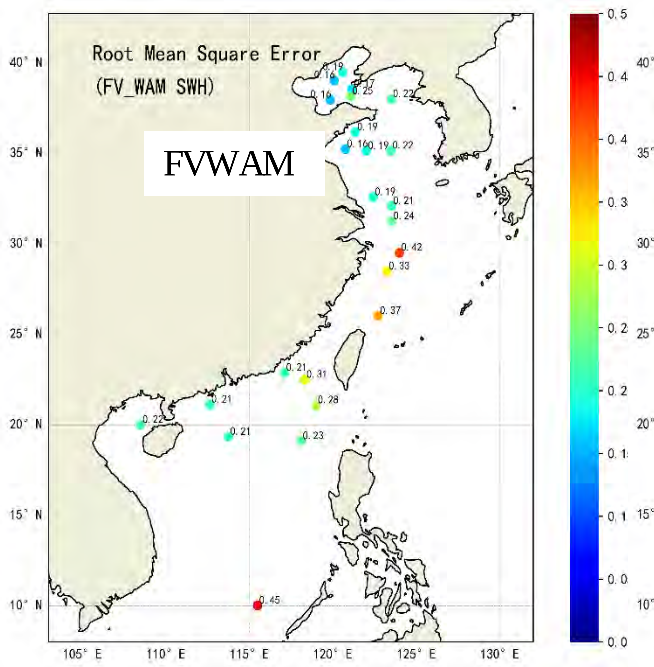
- Observations: HY-2B scatter, altimeter & CFOSAT

  Buoy (SOA, China; NDBC, NOAA)

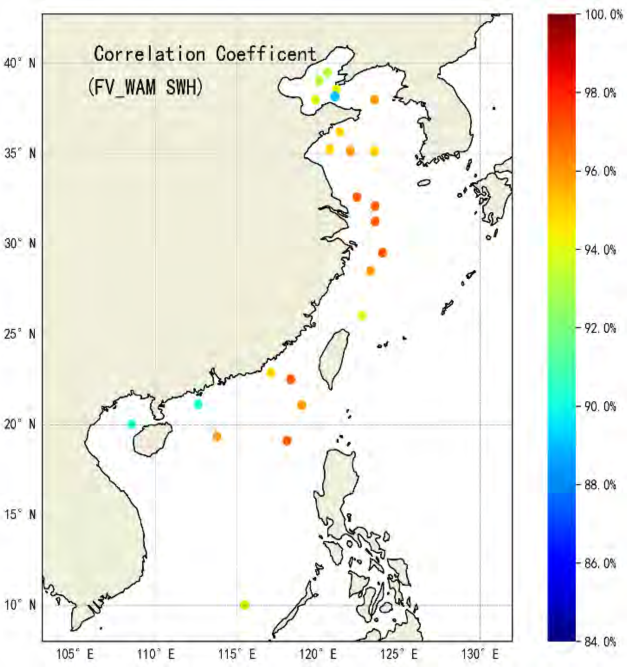
HY2B

CFOSAT
(Chinese-French Oceanography Satellite)
Payloads: SCAT, SWIM (wavelength&direction)

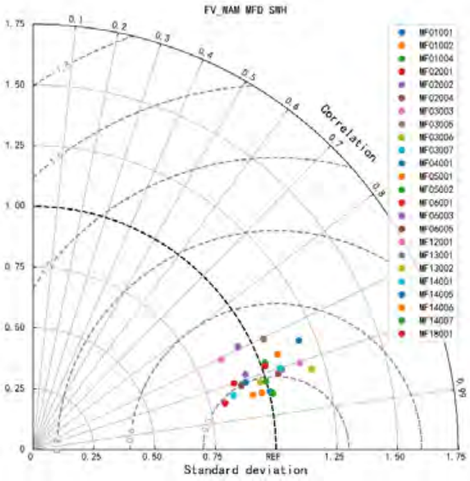
Model validation with offshore buoys (SOA, CHINA)



RMSE distribution off the Chinese coasts

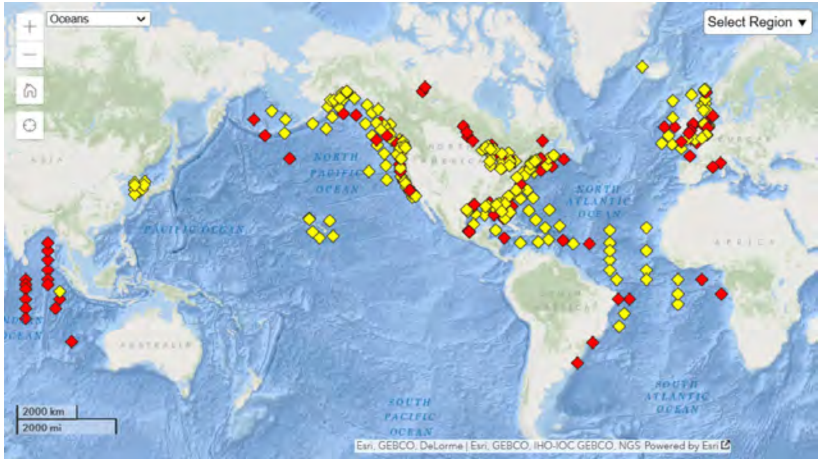


Correlation distribution off the Chinese coasts



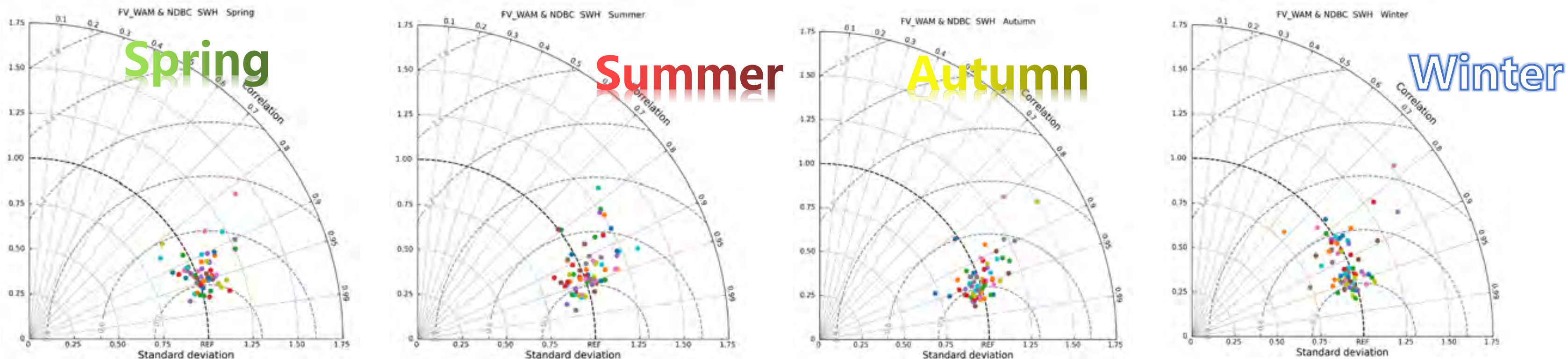
- FVWAM Correlation coef: 0.9~0.97; Modeling results and observations are similar in terms of nRMSE
- normalized RMSEs at each buoy mostly around 0.3, ranging from 0.2-0.4

Model validation with NDBC buoys

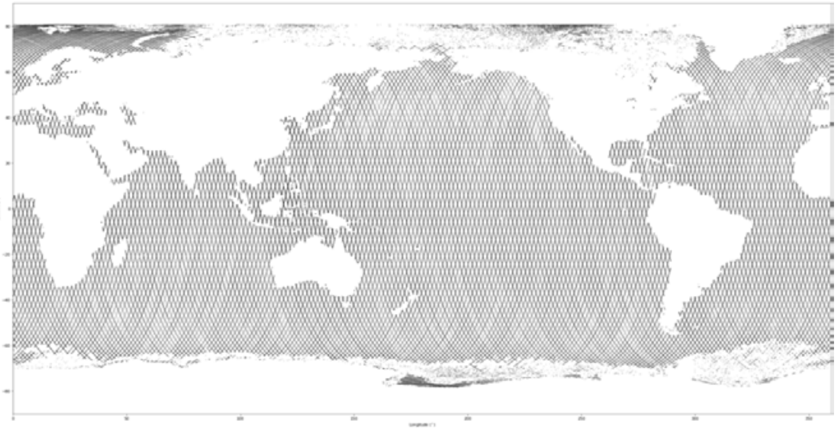


FVWAM Wave in-situ verification

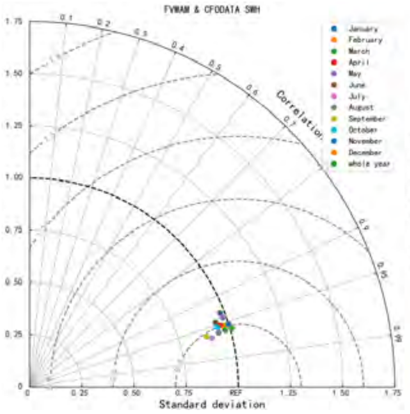
□ NDBC Buoy□

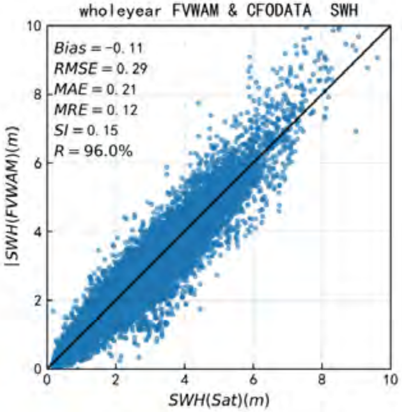


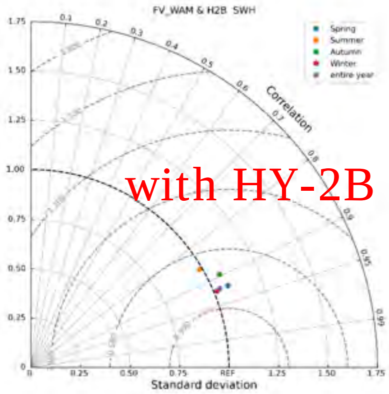
Model validation by satellite



with CFOSAT







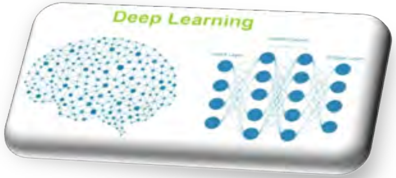
with HY-2B

	n	RMSE	MAE	MRE	R
Spring	30690	0.33	0.24	0.2	0.92
Summer	30225	0.41	0.24	0.24	0.86
Autumn	30622	0.47	0.3	0.22	0.90
Winter	29078	0.45	0.31	0.16	0.92
Entire Year	120615	0.42	0.27	0.21	0.92

PART 3

Progress in Ocean Artificial Intelligent Forecasting

3.1 Artificial Intelligent Wave Forecasting



1. Serialized parallel output of ocean wave forecast results for each time

Sequential model

Steps	T_{0-m}	.....	T_{0-1}	T_0	T_1	T_2	T_3	.....	T_n
Wind(u,v)		.....							
Wave(swh)									

AI Wave Model

Wave FCST

SWH_{T1}
SWH_{T2}
SWH_{T3}
.....
SWH_{Tn}

Same as traditional physics mode, using T0-m... T0…… The wind field sequence at time T0+n directly obtains T1...... Wave field prediction sequence at time T0+n

2. More direct and efficient use of observational information beyond physical model accuracy

Buoys in China Seas
Satellites data

Wave analysis data

Grided analysis data

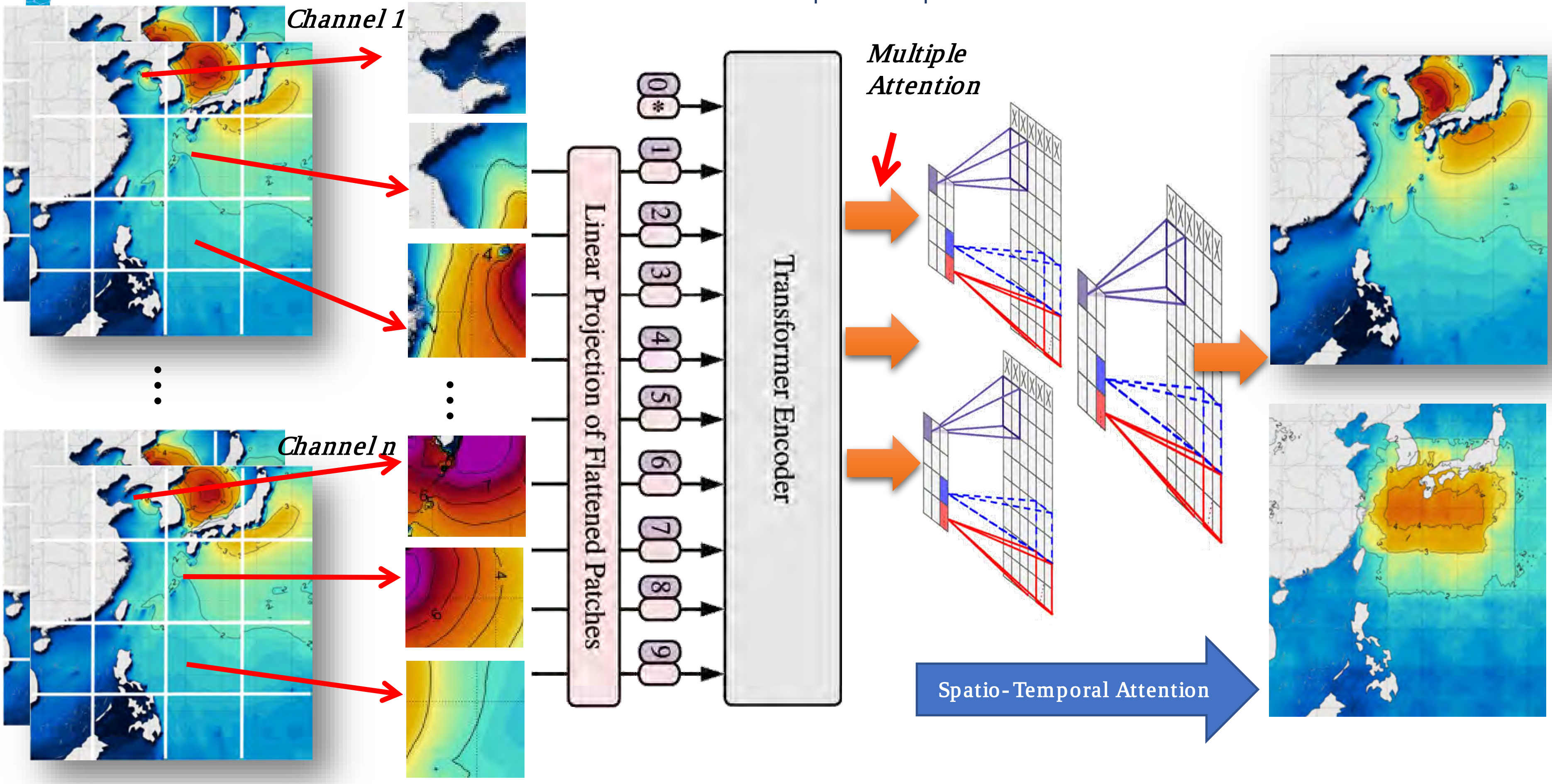
By using the actual forecast of wind field, the SWH accuracy in China Seas is better than that of ECMWF operational wave forecasting products

3. Order of magnitude reduction in computation time (subminute and lightweight) compared to numerical wave models

Artificial Intelligent Wave Forecasting

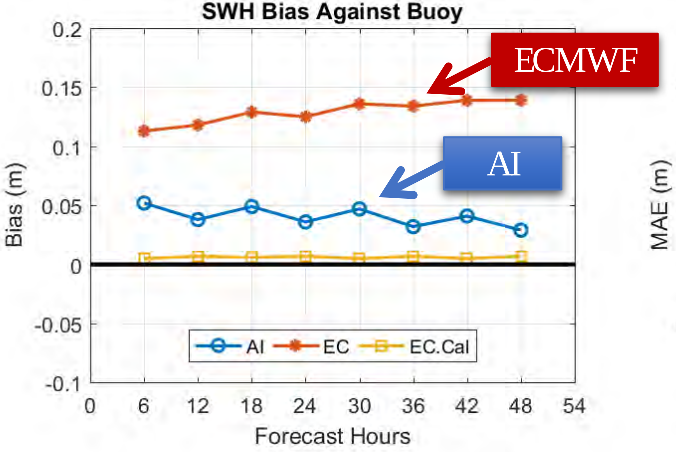
Data-driven intelligent ocean wave prediction system

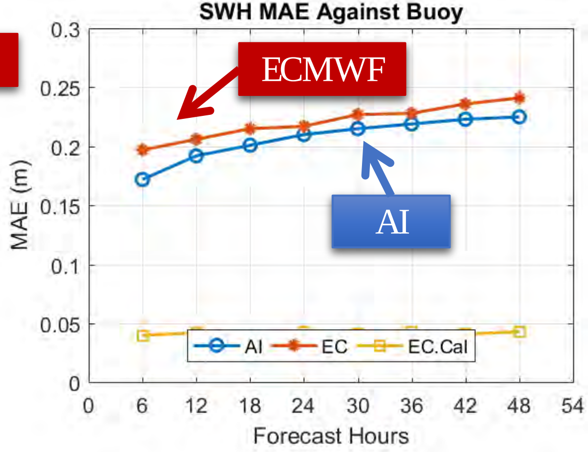
Building an Intelligent Wave AI Forecasting Model Based on Spatio-Temporal Attention Mechanisms

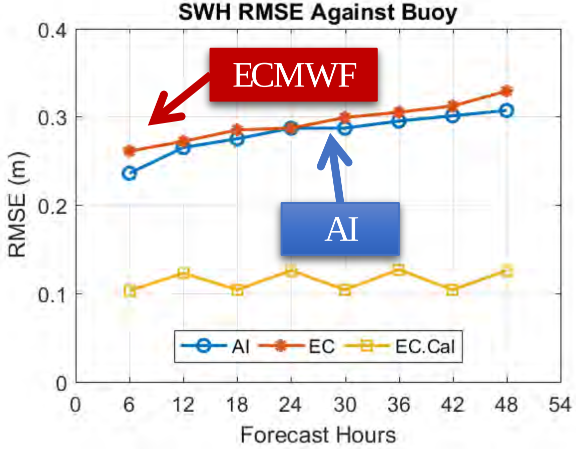


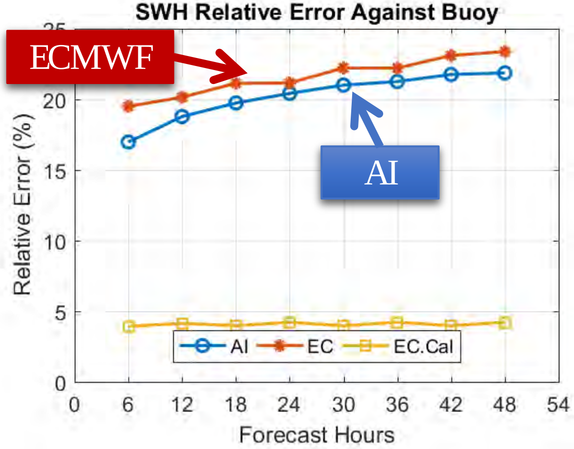
Artificial Intelligent Wave Forecasting

AI forecast prducts vs operational prducts from ECMWF





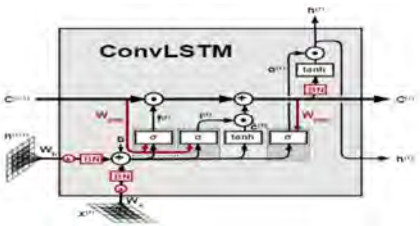




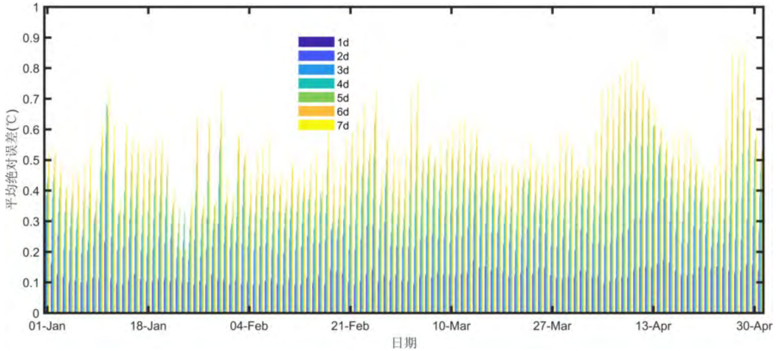
Based on buoy observation in China, the accuracy of AI wave prediction model is superior to ECMWF operational wave significant wave height product

MAE	AiWave	ECMWF	Imp.Per
+6 hr	0.172	0.197	12.7 %
+12 hr	0.192	0.206	6.8 %
+18 hr	0.201	0.215	6.5 %
+24 hr	0.210	0.217	3.2 %
+30 hr	0.215	0.227	5.3 %
+36 hr	0.219	0.228	3.9 %
+42 hr	0.223	0.236	5.5 %
+48 hr	0.225	0.241	6.6 %

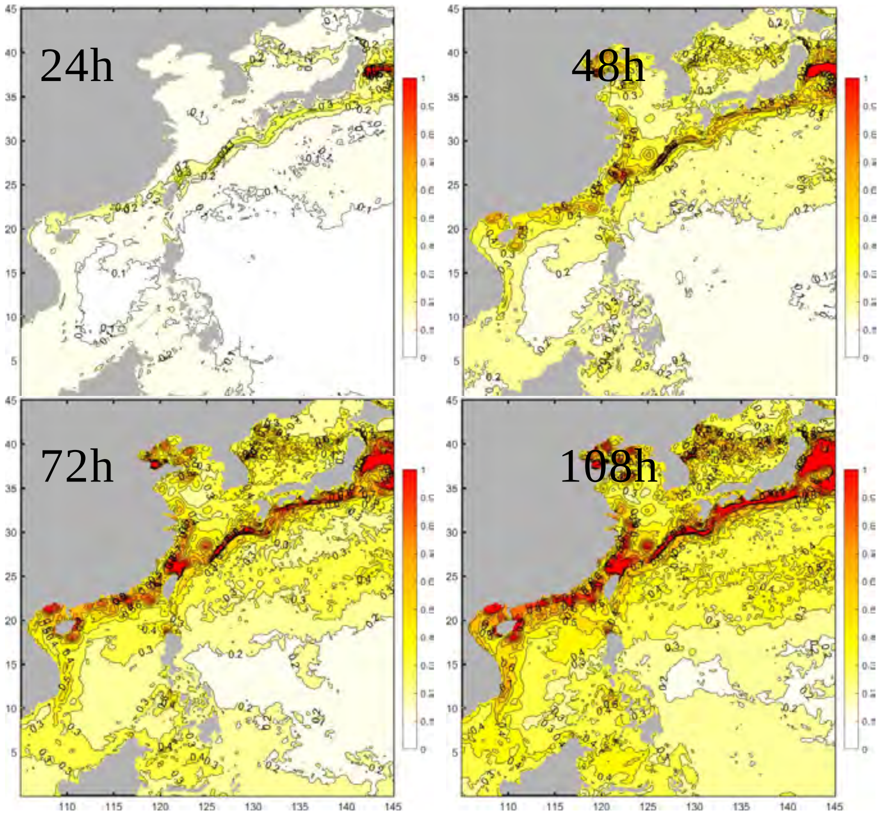
3.2 Artificial Intelligent SST prediction model



- Method: Convolutional LSTM Network (ConvLSTM)
- Validaiton Dataset: Using sea surface temperature observations (stations, buoys, volunteer ships) and MGDSST satellite remote sensing sea surface temperature fusion data;
- Validation Periods: January 1st to May 1st,2022
- Validation Results: 24-hour forecast RMSE is <0.2℃; The3-day forecast RMSE is <0.5℃; The 7-day forecast RMSE is <0.8℃.



	1Day	2Day	3Day	4Day	5Day	6Day	7Day
AE	0.12	0.24	0.33	0.40	0.45	0.50	0.55
RMSE	0.18	0.37	0.48	0.57	0.64	0.71	0.77



PART 4

Future perspective

Future perspective

- To develop a new large-scale GPU super-computing platform with multi-disciplinary integration of ocean, atmosphere and earth.
- To apply advanced technology such as supper data analysis, scientific engineering computing and artificial intelligence.

Thanks for your attention.