SST Analysis and its Application

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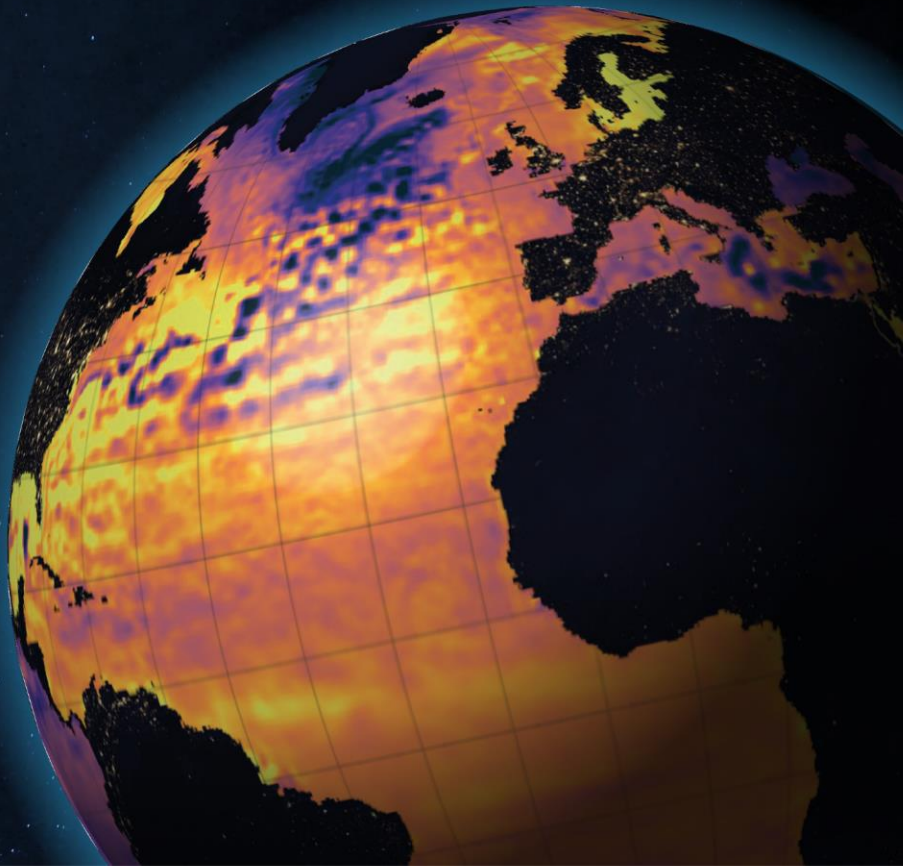


Ocean Predict

Outline

01 Backgrouds

02 SST Fusion Analysis

03 AI Forecast

04 Marine Heat Waves

05 Future plan

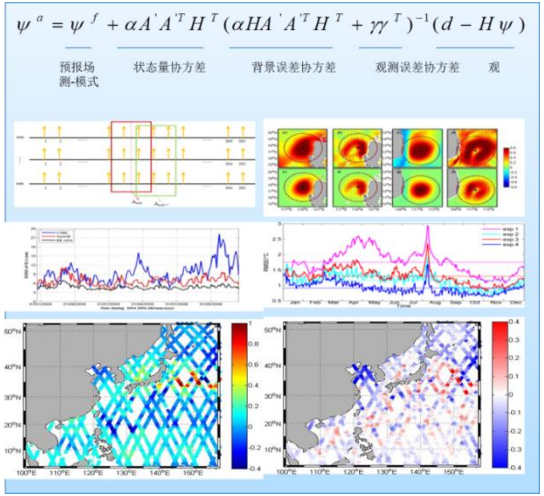
SYMPOSIUM OP'24

In partnership with unesco Intergovernmental Oceanographic Commission

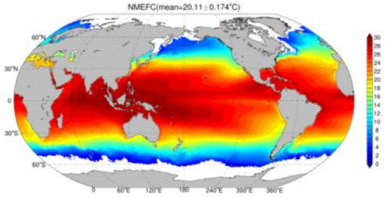
2021 2030 United Nations Decade of Ocean Science for Sustainable Development

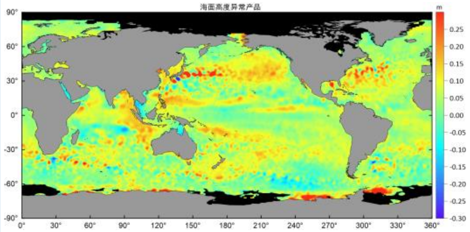
NMEFC

Data assimilation（SST、SLA）

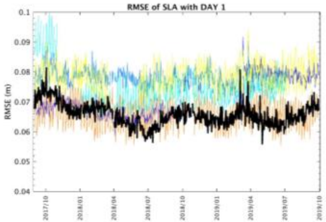


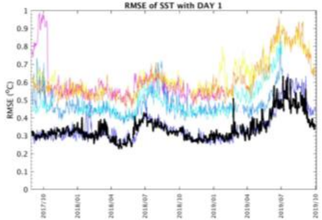
Analysis（SST、SSS、SLA）



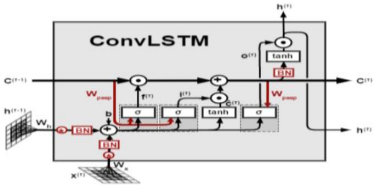


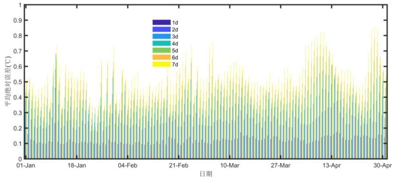
Validation（SST、SLA）





Artificial Intelligence（SST）

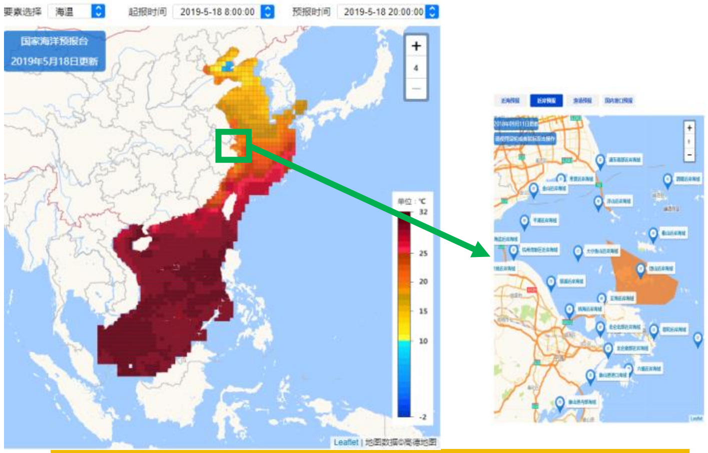




Applications in Ocean Modeling

SST data	country	resolution	insitu data	satellites	method
MGDSST	Japan	0.25°	buoy、ship	AVHRR、AMSR2	OI
GAMSSA	Austrilia	0.25°	GTS-buoy、GTS-ship	VIIRS_NPP、VIIRS_N20、AVHRR、AMSR2	OI
GMPE	EU	0.25°	mean of All		
OISST	USA	0.25°	GTS-buoy、GTS-ship	AVHRR、AMSR	OI
NASA_K10	USA	0.1°		VIIRS_NPP、ABI、SEVIRI、AHI、AVHRR、AMSR	2D VAR
CMC	Canada	0.1°	GTS-buoy、GTS-ship	VIIRS_NPP、VIIRS_N20、AVHRR、AMSR2	OI
DMI_OI	Denmark	0.05°		VIIRS_NPP、SEVIRI 、AVHRR、AMSR2	OI
NOAA_GEO	USA	0.05°		VIIRS_NPP、ABI、SEVIRI、AHI、AVHRR	Multi-scale OI
OSTIA	UK	0.05°	GTS-buoy、GTS-ship	VIIRS_NPP、VIIRS_N20、SEVIRI 、AVHRR、AMSR2	2D VAR
NMEFC	China	0.25°	GTS-buoy、GTS-ship Stations	H1C、H2B、AVHRR、AMSR2	OI

- Improve the numerical forecast

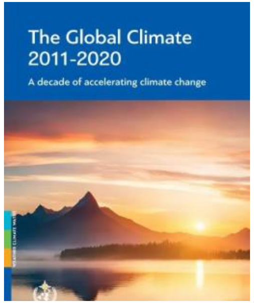


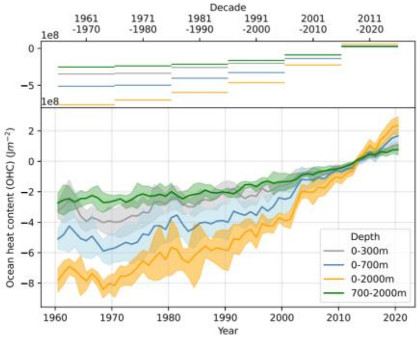
	large grid	AI grid	regions
grid	1143	250000	18
resolution	25km	10km	all
update time	8:00	8:00 16:00	8:00
time scale	**3h**	**3h**	**1d**

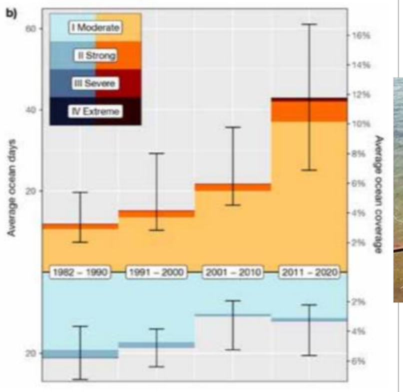
- Provide the AI forecast

	unit	island	beach
number	213	35	/
resolution	site	site	site
update time	8:00	8:00	16:00
time scale	**1h**	**1d**	**1d**

Marine heat waves have devastating impacts on Marine Environment, Marine ecology and Marine fisheries and so on.







Globally averaged annual days on which the ocean experienced a MHW or MCS (left Y-axis), also expressed as the average percentage of the ocean that this could cover for the entire year (right Y-axis). (***The Global Climate 2011-2020***)

- Over the past 60 years, the global ocean heat content has continued to increase, and the rate of ocean warming has increased significantly in the past 20 years.
- Globally averaged annual days on which the ocean experienced a MHW also increased significantly.
- In Feb. 2024, NOAA reported that in the past 12 months, MHWs caused more than 54% of the world's coral reef areas to suffer bleaching, affecting vast areas of ocean in at least 53 countries and territories;
- In 2018, the MHW event in Bohai Sea caused the death of a large number of sea cucumbers, and the direct economic loss of 6.87 billion yuan.

Outline

01 Backgrouds

02 SST Fusion Analysis

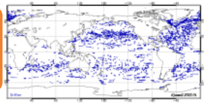
03 AI Forecast

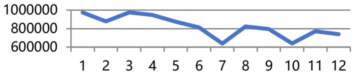
04 Marine Heat Waves

05 Future plan

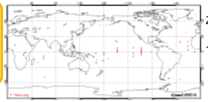
In-situ Data

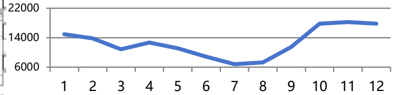
Drifter



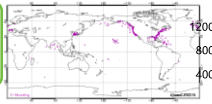


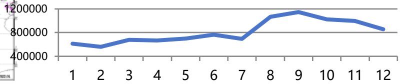
T-Mooring



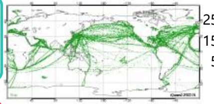


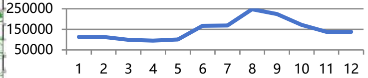
C-Mooring





Ship



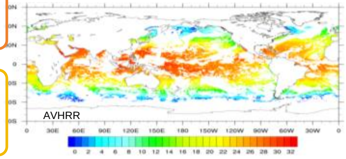


Stations

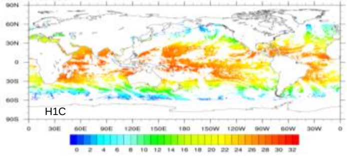
125 stations

Satellites

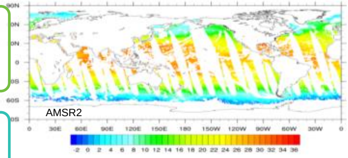
Infrared Sensor AVHRR



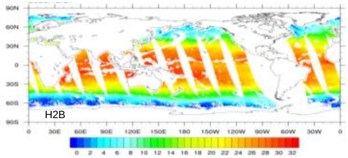
Infrared Sensor H1C



Microwave Sensor AMSR2



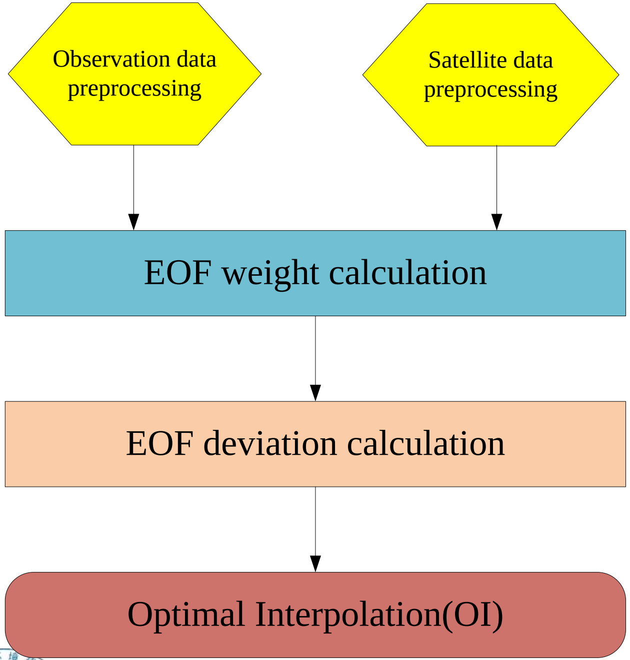
Microwave Sensor H2B



Instrument	Satellite	Producer	Data Level	Spatial Resolution
COCTS	HY-1C	NSOAS	L3	9km
CMR	HY-2B	NSOAS	L3	25km
AVHRR	MetOp-B	OSI SAF	L2P	4km
AMSR	GCOM-W	REMSS	L2P	25km

Data Prepare

Optimal Interpolation



Assuming that background values, observed values, and analyzed values are unbiased estimates

$$r_k = \sum_{i=1}^{N} w_{ik} q_i$$

The horizontal correlation of background field error satisfies the exponential decrease with the increase of horizontal distance

$$\rho(r,t) = \left(1 - \frac{r_a r_b}{ab}\right) exp\left(-\frac{r_a r_b}{ab}\right)$$

a: correlation scales along longitude , 200 km
b: correlation scales along latitude , 150 km

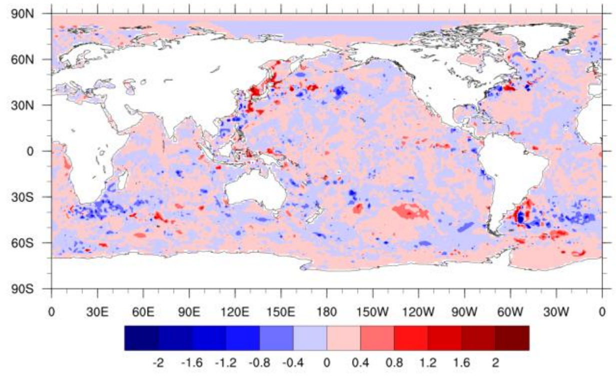
Version 1

Experiment design

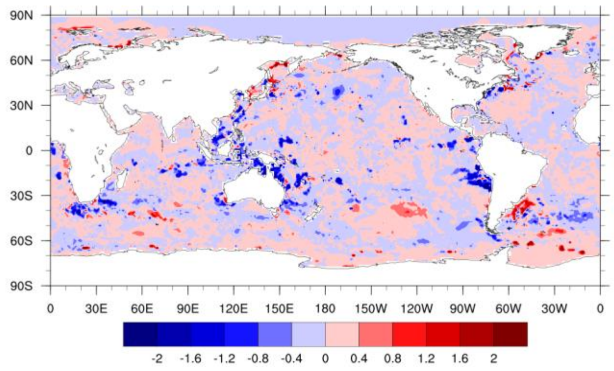
Different satellite data	Different in-situ data
AVHRR、AMSR	GTS in-situ
H1C、H2B	
AVHRR、AMSR、H1C、H2B	GTS in-situ、Chinese station in-situ

The satellite data control group: Satellites data respectively.

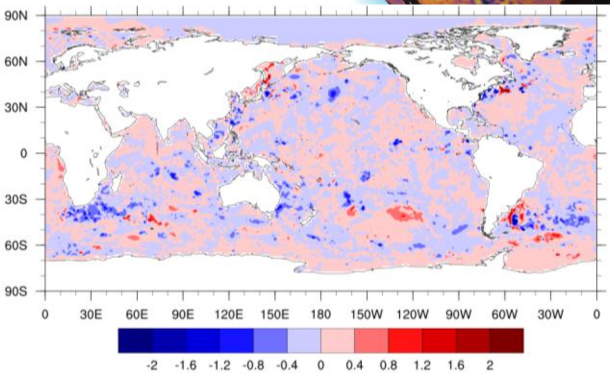
Observation data control group: GTS data and Chinese stations data respectively.



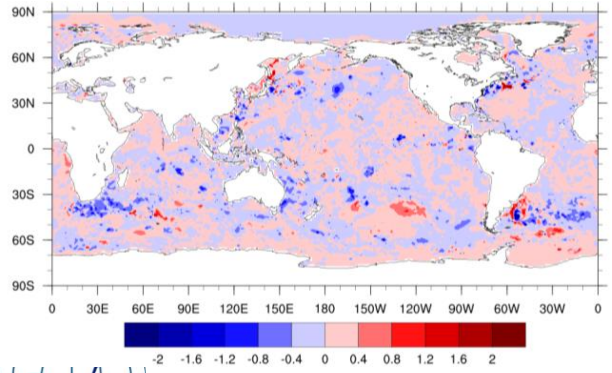
AVHRR+AMSR



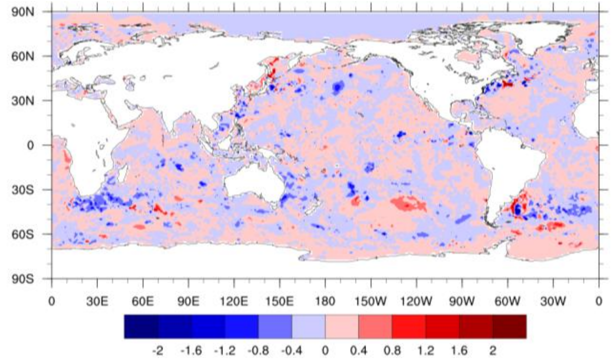
H1C+H2B



AVHRR+AMSR+H1C+H2B



AVHRR+AMSR+H1C+H2B
GTS in-situ

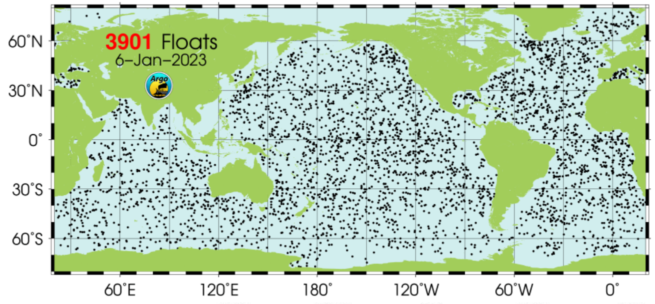


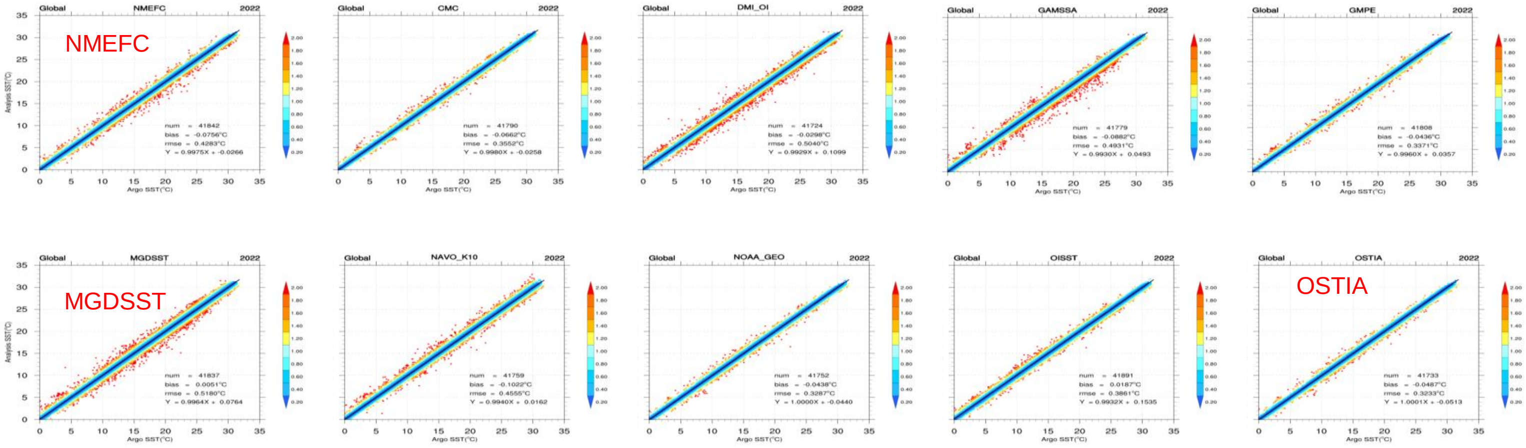
AVHRR+AMSR+H1C+H2B
GTS + Chinese station in-situ

The addition of in-situ data from Chinese stations has improved the fusion results near the coastal areas of China.

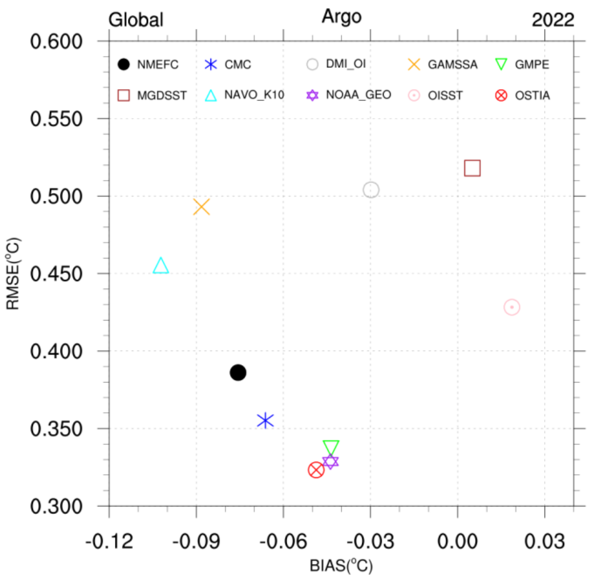
Compared with other SST data sets

The analysis was compared using Argo surface SST data, from iQuam. Total 9 sets, which were compared with GMPE products。
GMPE products were proposed the multi product ensemble product in GHRSST in 2012. GMPE had a horizontal resolution of 0.25 degree, and different SST fusion products were interpolated into the same resolution grid. At each grid point, the ranking of different fusion products was taken as the median value, rather than the mean value. GMPE products had advantages such as smaller errors among different fusion products.





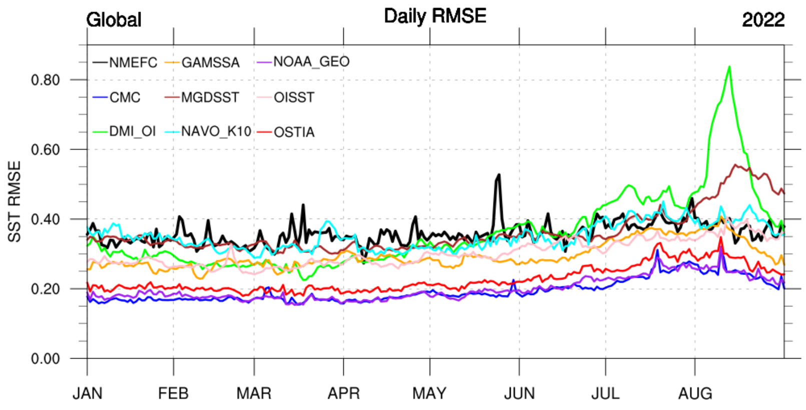
No.	Analysis	Bias	RMSE
1	OSTIA	-0.0487	0.3233
2	NOAA_GEO	-0.0438	0.3287
3	GMPE	-0.0436	0.3371
4	CMC	-0.0662	0.3552
5	NMEFC	-0.0756	0.3861
6	OISST	0.0187	0.4183
7	NAVO_K10	-0.1022	0.4555
8	GAMSSA	-0.0882	0.4931
9	DMI_OI	-0.0298	0.504
10	MGDSST	0.0051	0.5180



Through the analysis of bias and the RMSE distribution diagram between SST fusion products and Argo in-situ data, the RMSE ranges are from 0.3233 (OSTIA) to 0.5180 (MGDSST). The RMSE between NMEFC fusion products and Argo in-situ data is 0.3861, which is at the middle level of comparative analysis of SST products, ranking fifth out of 10 fusion products.

Compared to GMPE

No.	Analysis	Bias	RMSE
1	CMC	-0.0131	0.1579
2	NOAA_GEO	-0.0013	0.1687
3	OSTIA	-0.0093	0.1855
4	GAMSSA	-0.0311	0.2121
5	OISST	0.0538	0.2590
6	NMEFC	-0.0445	0.3040
7	MGDSST	0.0436	0.31
8	DMI_OI	0.0222	0.3113
9	NAVO_K10	-0.0507	0.3199



Analysing the daily variation of the RMSE of each SST analysis product, it is found that the daily variation of the RMSE of NMEFC fusion products is at the intermediate level.

Update method and resolution

- Resolution 1/4 degree
- Accuracy is below middle
- In the optimal interpolation algorithm, B is steady

Version 1

update

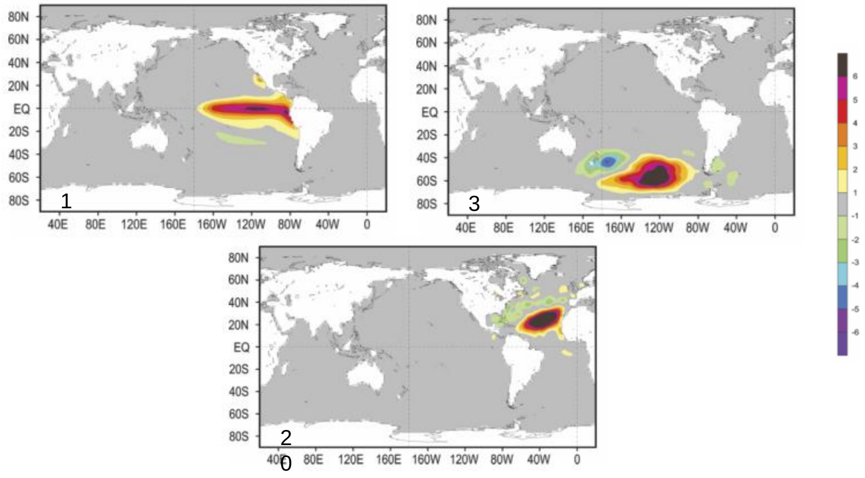
- Resolution increased to 1/10 degree.
- Using variational algorithm, the error variance of background field changes in space
- Time variation deviation correction algorithm

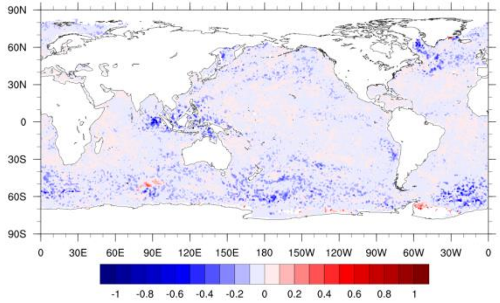
Version 2

Observation deviation adjustment

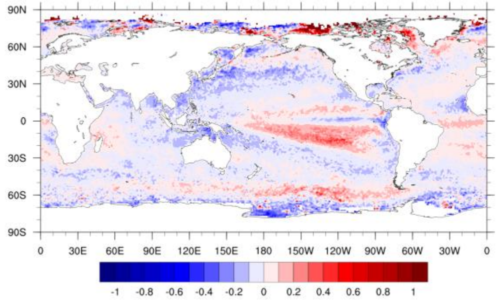
Based on 20 years of daily SST data from OSTIA (2002-2021), the top 25 global (SST) modes are obtained by using EOF.

Each satellite product is adjusted for deviation
Deviation adjustment mode: 2DVAR
Deviation background field error variance: 0.1





The deviation of the infrared satellite (AVHRR and H1C)



The deviation of the microwave satellite (AMSR and

The 3rd mode covers the Southern Ocean, and observation data are scarce, so it is not used for satellite data deviation adjustment.

Background errors adjustment

Background errors relaxed to Climatology

The background error matrix is constructed by relaxing the background errors to the climatology, and the covariance matrix of uncorrelated observation error is constructed by sparring, which is also the method used by various organizations for SST data fusion.

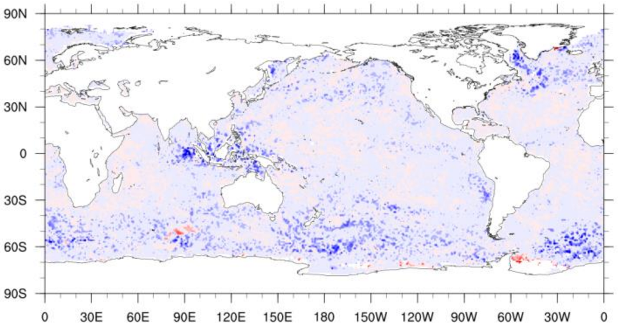
The background errors is relaxed to the climatology, and the non-Gaussian distribution errors are filtered out by Gaussian filter. The conventional Gaussian filter does not consider the existence of NAN value of horizontal distribution, and the kernel function of Gaussian filter is rewritten.

Variance of Background errors

Innovation diagnostics (Desroziers2005)

$$\left(\widetilde{\sigma_i^{\mathrm{b}}}\right)^2 = (\mathbf{d}_{\mathrm{b}}^{\mathrm{a}})_i^{\mathrm{T}}(\mathbf{d}_{\mathrm{b}}^{\mathrm{o}})_i/p_i$$

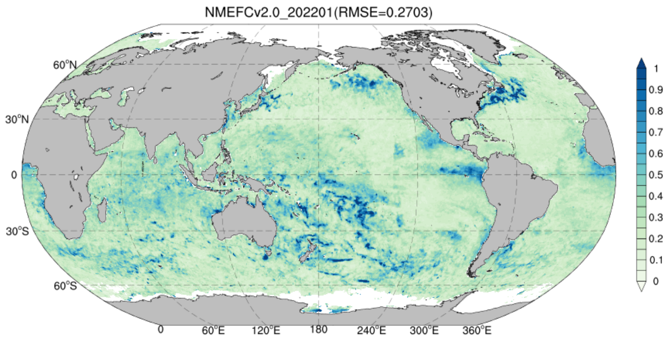
$$= \sum_{j=1}^{p_i} \left(y_j^{\mathrm{a}} - y_j^{\mathrm{b}}\right)\left(y_j^{\mathrm{o}} - y_j^{\mathrm{b}}\right)/p_i$$



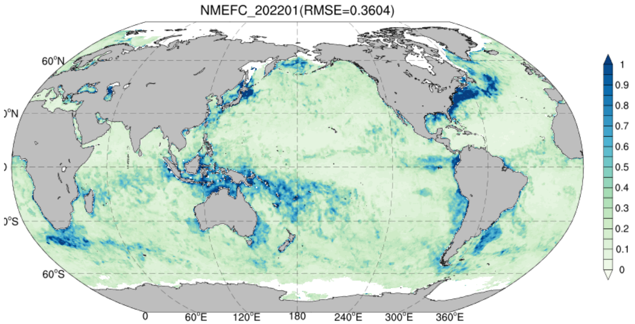
Solar altitude angle calculation

This product calculates foundation SST, so it does not take into account satellite observations with significant diurnal variation, so it determines the day and night observation data by calculating the solar altitude Angle.

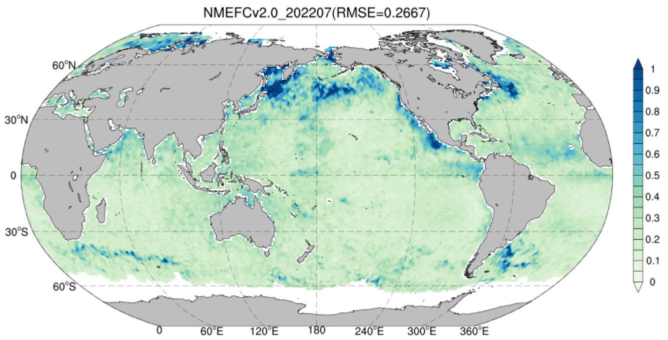
```
;*******************************************************************
function solar_atitude(lon, lat, dn, hour)
local f,p3,l_lat
begin
;**********************************
; 第一步：计算太阳倾角
;**********************************
    pi = 3.1415926
    f0 = 360.*dn/365.
    f0 = f0*(pi/180.)                              ;转为弧度
    f1 = 0.006918
    f2 = 0.399912*cos(f0)
    f3 = 0.070257*sin(f0)
    f4 = 0.006758*cos(f0*2)
    f5 = 0.000907*sin(f0*2)
    f6 = 0.002697*cos(f0*3)
    f7 = 0.001480*sin(f0*3)

    f = (f1-f2+f3-f4+f5-f6+f7)*(180./pi)           ;转为角度
;**********************************
; 第一步：计算太阳倾角
;**********************************
    p3     = 15.*hour + lon - 300.
    p3     = p3*(pi/180.)                          ;转为弧度
    l_lat  = lat*(pi/180.)                         ;转为弧度
    f      = f*(pi/180.)                           ;转为弧度，切记！
    h0     = asin(sin(l_lat)*sin(f) + cos(l_lat)*cos(f)*cos(p3))
    h0     = h0*(180./pi)                          ;转为角度

    return (h0)
;**********************************
end
```



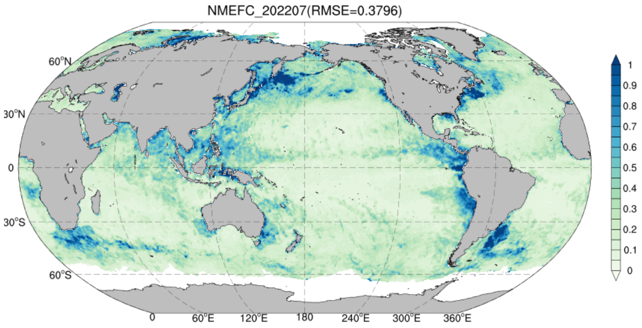
RMS error of 1/10 degree in Jan, 2022



RMS error of 1/4 degree in Jan, 2022



RMS error of 1/10 degree in Jul, 2022



RMS error of 1/4 degree in Jul, 2022

By comparing with the previous 1/4 degree product, the RMS error of 1/4 degree in January 2022 was 0.3604, that of the 1/10 degree variational product (NMEFCv2.0) was 0.2703, and the RMS error was reduced by 0.0901.

In July 2022, the RMS error of the global 1/4 degree was 0.3796, that of the 1/10 degree variational product (NMEFCv2.0) was 0.2667, and RMS error was reduced by 0.1129.

Ocean Predict

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SYMPOSIUM OP'24

In partnership with

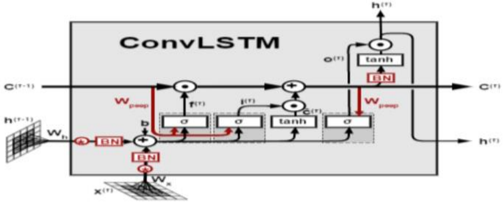
unesco Intergovernmental Oceanographic Commission

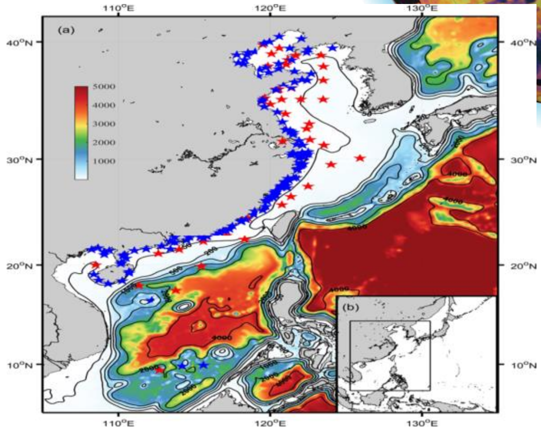
2021 2030 United Nations Decade of Ocean Science for Sustainable Development

NMEFC NATIONAL MARINE ENVIRONMENTAL FORECASTING CENTER 国家海洋环境预报中心

☐Method: Convolutional LSTM Network (ConvLSTM)

- ☐ Long short-term memory (LSTM) is a special RNN, mainly to solve the problem of gradient disappearance and gradient explosion during long sequence training. Compared with ordinary RNN, LSTM can have better performance in longer sequences.
- ☐ ConvLSTM is an extension of LSTM. The ConvLSTM layer not only retains the advantages of LSTM, but also applie ıt convolutional structure.



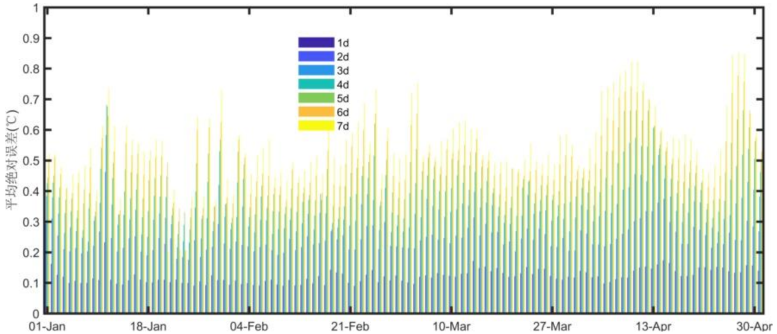


☐Observation data:

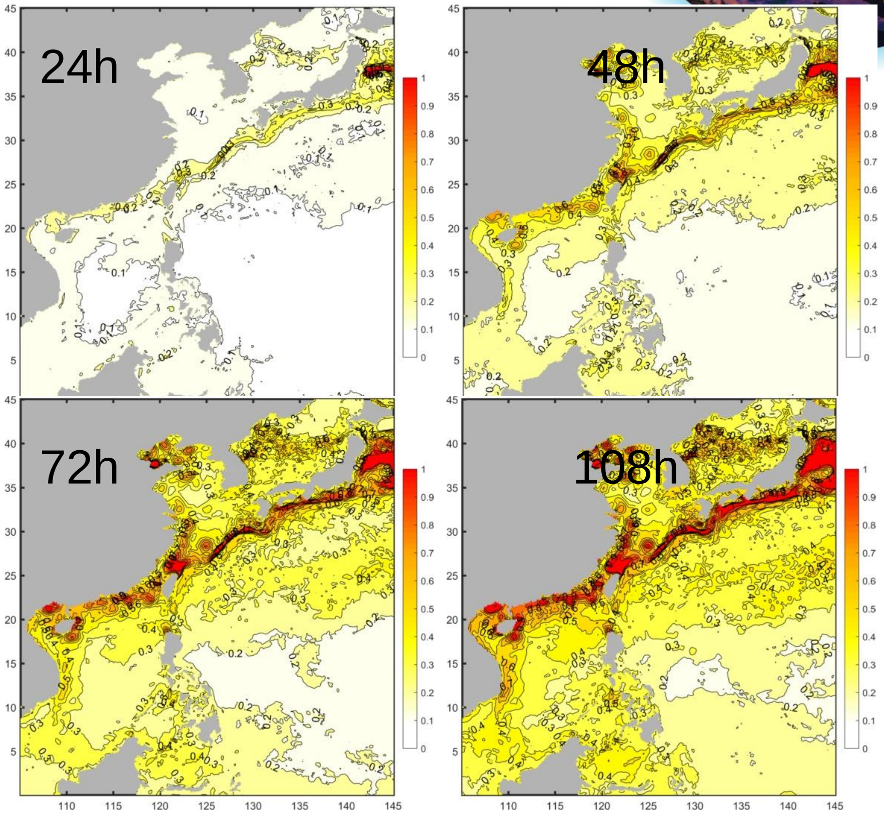
- ☐ Buoys and stations: based on Python to improve the collection, processing and fusion of offshore observation data.
- ☐ Meteorological elements: ERA5 re-analysis data, including temperature, pressure, specific humidity, net short-wave radiation, net long-wave radiation, wind speed, wind direction, precipitation and other eight elements.
- ☐ Satellite remote sensing of sea surface temperature: OSTIA and NMEFC SST

Region	105°~145.0°E, 0°N~45.0°N
Resolution	10km
Start	08/16 (Beijing Time)
Time interval	every 3 h
Validity	168 h
Format	NetCDF (180M/time)

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



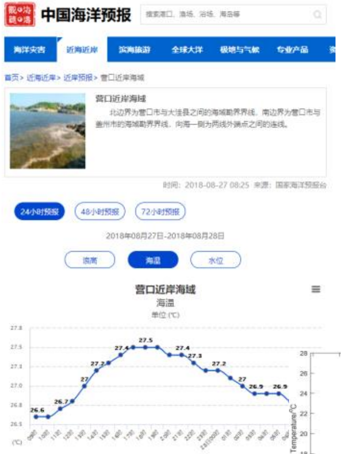
	1Day	2Day	3Day	4Day	5Day	6Day	7Day
AE	0.12	0.24	0.33	0.40	0.45	0.50	0.55
RMSE	0.18	0.37	0.48	0.57	0.64	0.71	0.77

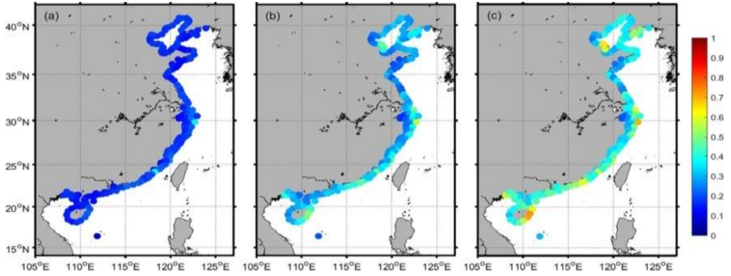


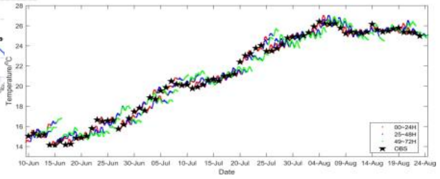
Application of AI forecasting products

- The AI grid SST forecast products have been widely used in offshore China, including near-shore base unit forecast, island SST forecast, city SST forecast, beach SST forecast and resort SST forecast.
- The mean absolute error of urban SST forecast decreased from 0.266℃ in 2018 to 0.189℃ in 2020, with an improvement of 28.9%.
- The MAE of 0~24 hours is less than 0.2℃.

Name	Basic Units	Fishing Grid	AI Grid	Island	Seas	Bathing beach
Points	213	1143	25万+	35	18	/
Distance Res.	Stations	25km	10km	Stations	Area	Stations
Update	8:00	8:00	8:00 16:00	8:00	8:00	16:00
Time Res.	1h	3h	3h	1d	1d	1d







leading time	0~24h	24~48h	48~72h
MAE	0.17	0.30	0.38

Outline

01 Backgrouds

02 SST Fusion Analysis

03 AI Forecast

04 Marine Heat Waves

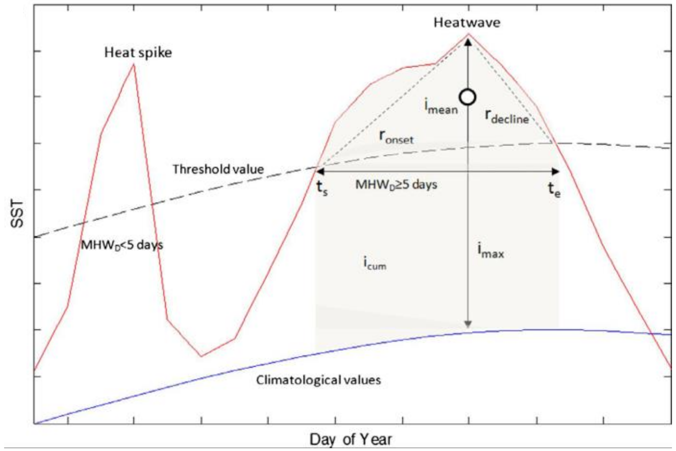
05 Future plan

Definition of Marine Heat Wave (MHW)

A MHW is defined as a“discrete prolonged anomalously warm water event at a particular location”.
(Hobday et al., 2016, Prog. Oceanogr.)

Metrics to characterise a MHW

- **Frequency**: the annual number of MHW events.
- **Duration**: Consecutive period of time that temperature exceeds the threshold.
- **Total days**: the annual total MHWs days.
- **Maximum intensity** (i_{max}): highest temperature anomaly value during the MHW.
- **Mean intensity** (i_{mean}): mean temperature anomaly during the MHW.



Data

① OSTIA_Rep

- **Name**: Global Ocean OSTIA Sea Surface Temperature and Sea ice Reprocessed
- **Aim**：**Calculating SST climatology**
- **Time scale**：1992~2021
- **Longitude**：105.05°E ~ 145.05°E
- **Latitude**：0.05°N~45.05°N
- **Time resolution**：once a day
- **Spatial resolution**:1/20°

② OSTIA_Ana

- **Name**: Global Ocean OSTIA Sea Surface Temperature and Sea ice Analysis
- **Aim**：**MHW assessment**

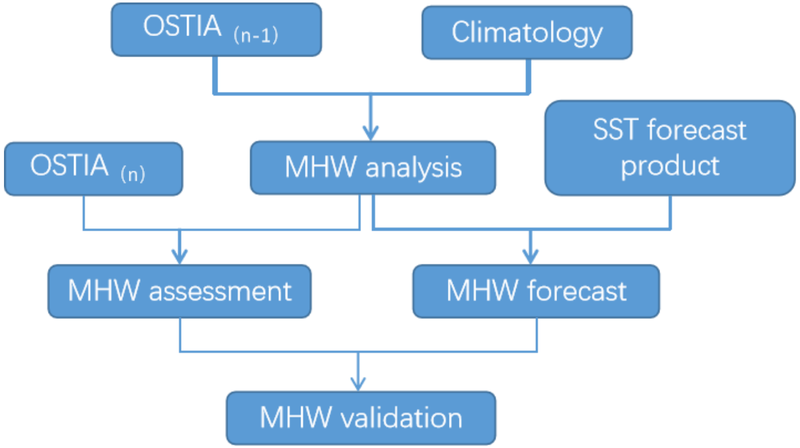
Name	**Global Ocean OSTIA Sea Surface Temperature and Sea ice Reprocessed(OSTIA_Rep)** **Global Ocean OSTIA Sea Surface Temperature and Sea ice Analysis(OSTIA_Ana)**
ID	SST_GLO_SST_L4_REP_OBSERVATIONS_010_011(OSTIA_Rep) SST_GLO_SST_L4_NRT_OBSERVATIONS_010_001(OSTIA_Ana)
Data source	Satellite observation
Spatial cover	Lat -89.97°~ 89.97° Lon-179.98°~ 179.98°
Rresolution	0.05°×0.05°
Time scale	1981.10.01~2022.05.31(OSTIA_Rep) 2007.01 till now(OSTIA_Ana)
variable	SST
Time interval	once a day
Format	NetCDF-4
Orgnization	Met Office(UK)

I. Climatology & Threshold value

The climatology was calculated based on OSTIA-rep data from 1991 to 2020, and the 90th percentile for each calendar day is calculated using daily SST over an 11-day window, centered on data for all years of the climate state period.

II. Process

- The MHW analysis data is obtained based on the previous day's OSTIA analysis data and climatology SST.
- The analysis data is updated to obtain the MHW assessment data.
- MHW assessment products will be used for validating the forecast productions.

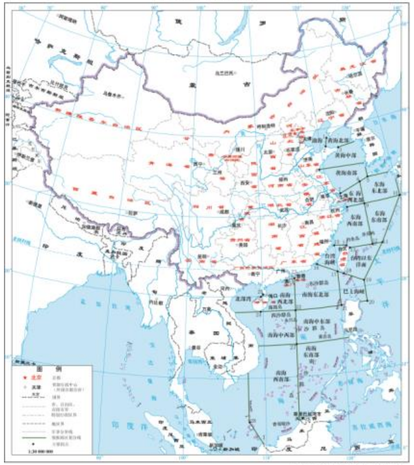


- **Forecast area**：
  China coastal sea and adjacent offshore waters
- **Forecast period**：
  7 days
- **Time resolution**：
  Once a week
- **Forecast products**：
  Intensity of MHWs
  Categaries of MHWs

$$N = \frac{I_{MHW}}{T_{threshold} - T_{clim}}$$

(Hobday et al., 2016, Prog. Oceanogr.)

近海预报海区划分

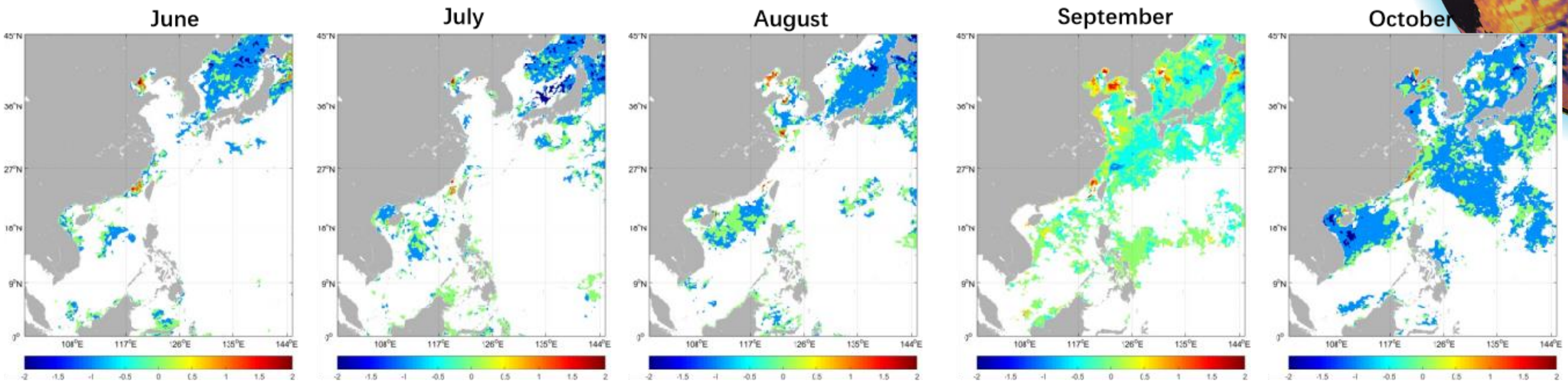


国家海洋环境预报中心 制作

Moderate MHWs	Strong MHWs
1<N≤2 The Moderate hot SST process has a certain impact on Marine ecological health and Marine fisheries	2<N≤3 The strongly hot SST process has relatively serious impact on Marine ecological health and Marine fisheries

Severe MHWs	Extreme MHWs
3<N≤4 The severe hot SST process has a serious impact on Marine ecological health and Marine fisheries	N>4 The extremely hot SST process has caused extremely serious effects on Marine ecological health and Marine fisheries

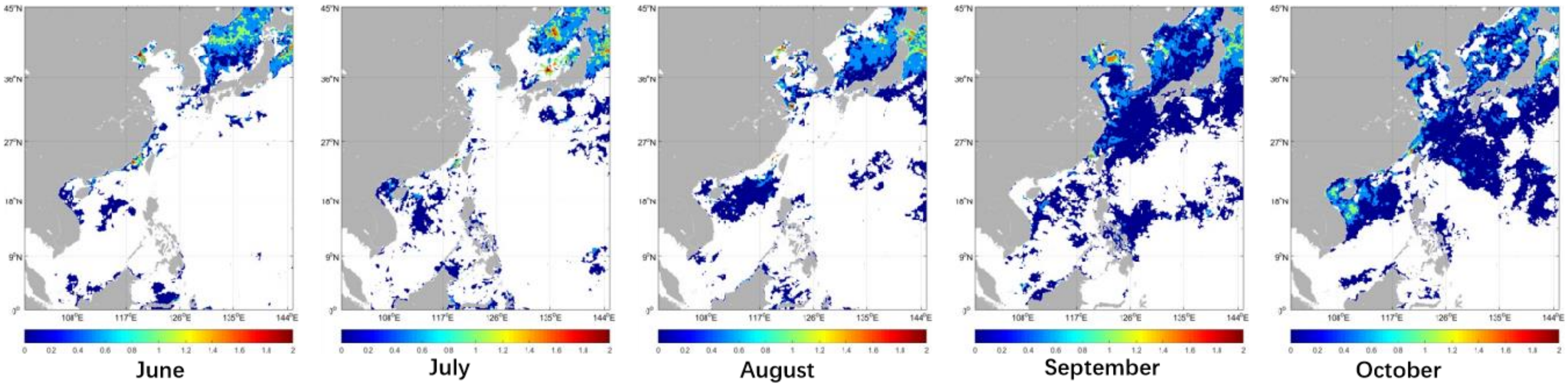
ME



Month	June	July	Aug	Sep	Oct	Mean
ME（℃）	-0.19	-0.19	-0.19	-0.04	-0.17	**-0.16**

Month	June	July	Aug	Sep	Oct	Mean
MAE（℃）	0.68	0.62	0.57	0.45	0.41	**0.55**

MAE



Ocean Predict

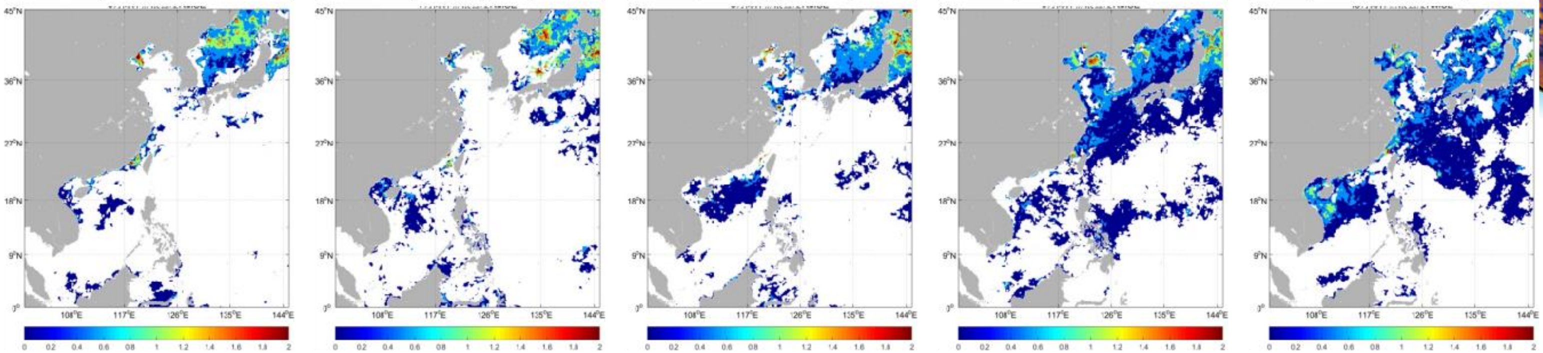
SYMPOSIUM OP'24

In partnership with unesco Intergovernmental Oceanographic Commission

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

RMSE

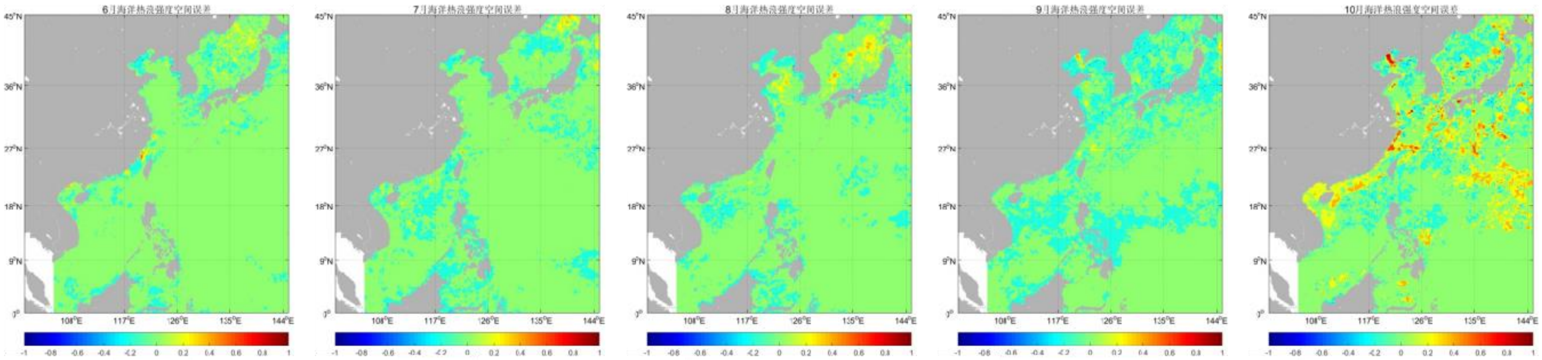
June | July | August | September | October



Month	June	July	Aug	Sep	Oct	Mean
RMSE（℃）	0.92	0.86	0.80	0.63	0.57	**0.76**

Month	June	July	Aug	Sep	Oct	Mean
SCE	0. 02	0. 03	0. 03	0. 03	0. 10	**0. 04**

Spatial consistency error



June | July | August | September | October

NMEFC 国家海洋环境预报中心 NATIONAL MARINE ENVIRONMENTAL FORECASTING CENTER

Method

The scoring criteria is adopted to evaluate the forecast effect, and the full score is 100.

The score formula for categories forecast result is as follows:

$$S_{fore} = 100-25|X| , \qquad |X|=0,1,2$$

$$S_{fore} = 0 , \qquad |X|\geq 3$$

$$X=A_i- B_j$$

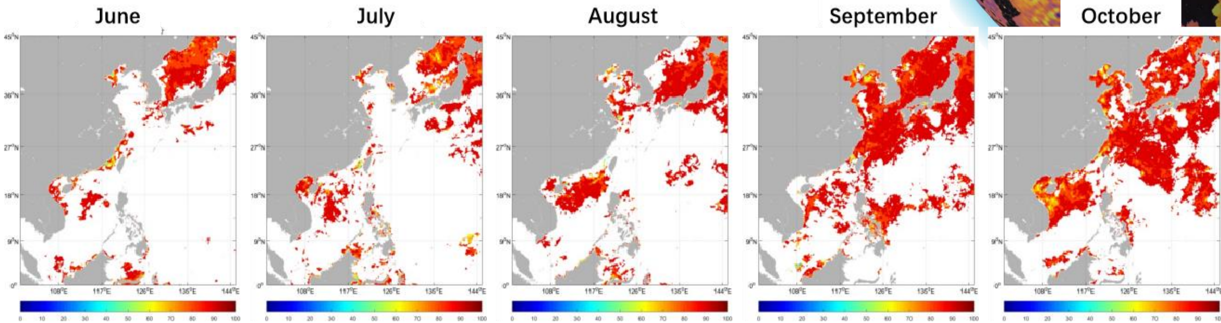
Where:

S_{fore}--The score of Marine heat wave forecast

X--The difference between the forecast category and the obseved category

Ai--Forecast values of no MHW, Category Ⅰ (moderate), Ⅱ(strong), Ⅲ(Severe), Ⅳ (Extreme) respectively (i=0,1,2,3,4)

Bj-- Observed values of no MHW, Category Ⅰ (moderate), Ⅱ(strong), Ⅲ(Severe), Ⅳ (Extreme) respectively (j=0,1,2,3,4)



Month	June	July	Aug	Sep	Oct	Mean
Score	87.9	87.6	90.7	91.1	90.3	89.5

On May 12, 2024, the NMEFC held a press conference on China's marine heatwave forecasting products, officially releasing weekly forecasts of MHWs intensity and categories to the public.
https://www.nmefc.cn/

Outline

01 Backgrouds

02 SST Fusion Analysis

03 AI Forecast

04 Marine Heat Waves

05 Future plan

01

- High resolution SST，SSS，SLA and SSC analysis data

02

- Improve AI forecast with dynamics-drived and data-drived

03

- User-based Operational Forecasting Services

www.nmefc.cn
www.oceanguide.org.cn

ADVANCING OCEAN PREDICTION SCIENCE FOR SOCIETAL BENEFITS

Thank you!

National Marine Environmental Forecasting Center