The effect of atmospheric instability on wave growth

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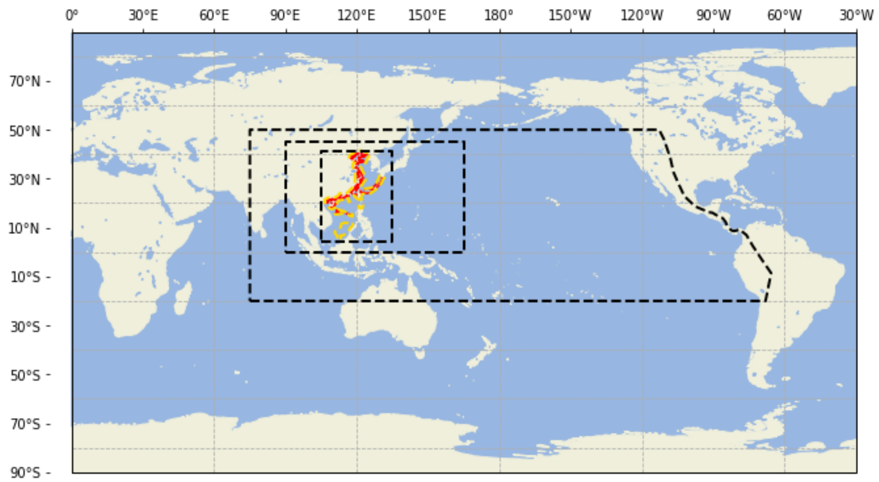
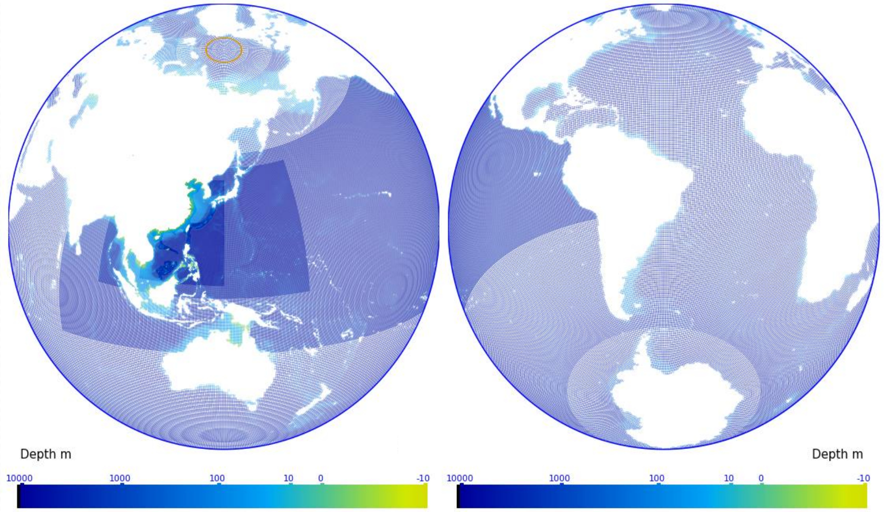
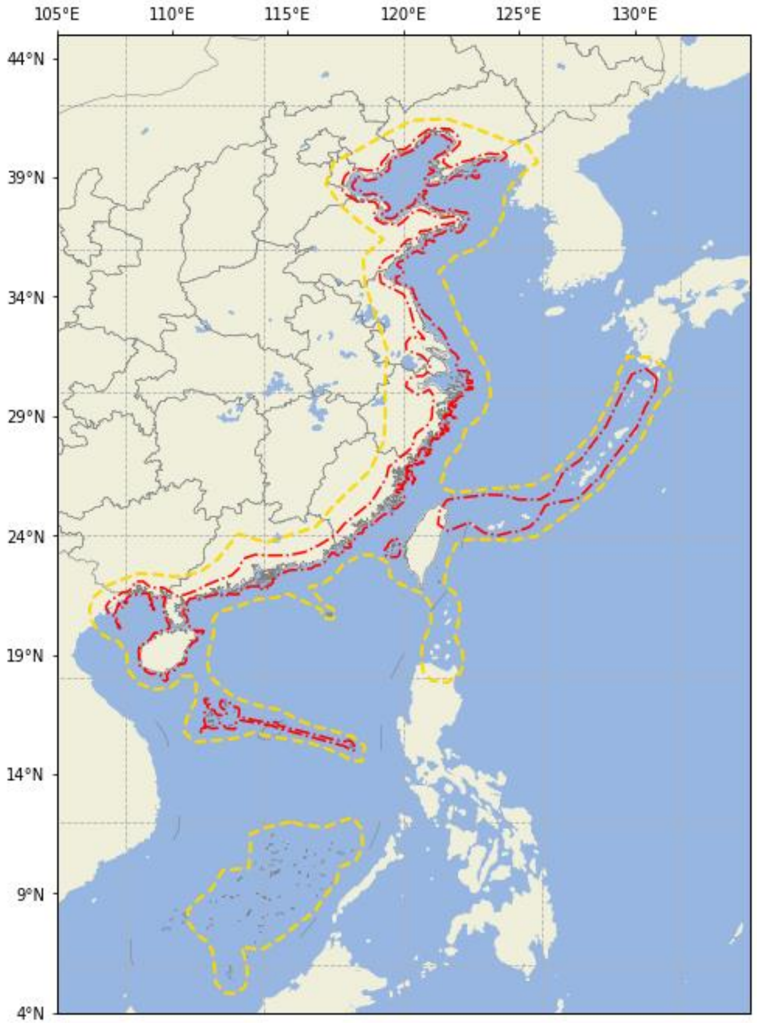
Outline

- Research purpose
- Background
- Methodology
- Results and Discussion

Motivation





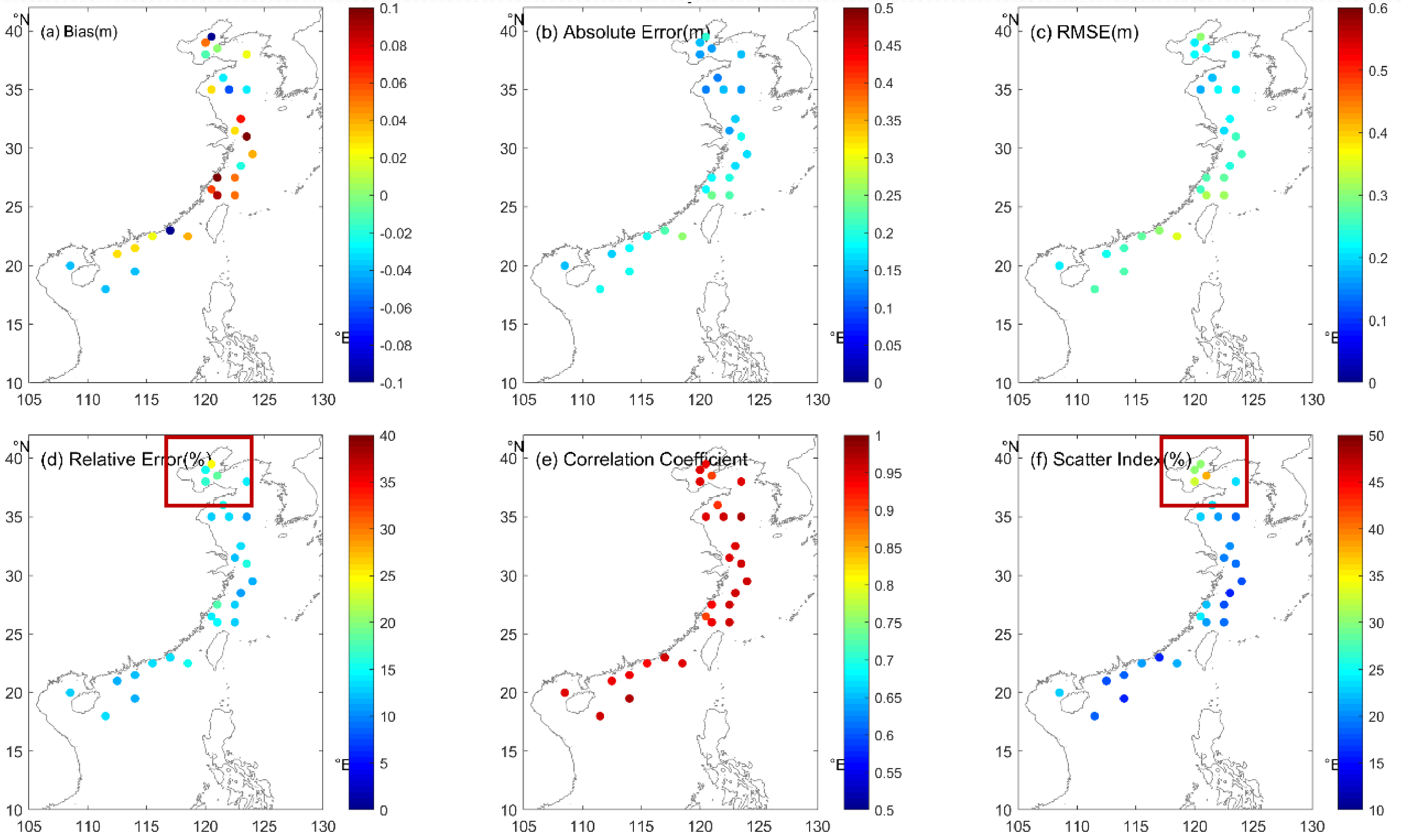


Model: WaveWatch III (6. 17)
Source Term: ST4
Wind Force: GRAPES/ECMWF/GFS
Forecast Hours: +192

CPU: AMD EPYC 7742
Elapsed time: 3400 seconds

6-level SMC grid	
Region	Resolution/degree
Nearshore(within read line)	Lat: 0.014,Lon:0.021
Offshore(within yellow line)	Lat:0.028,Lon:0.042
China sea	Lat:0.058,Lon:0.087
Northwest Pacific	Lat:0.116,Lon:0.174
North Pacific	Lat:0.232,Lon:0.348
Global	Lat:0.464,Lon:0.696

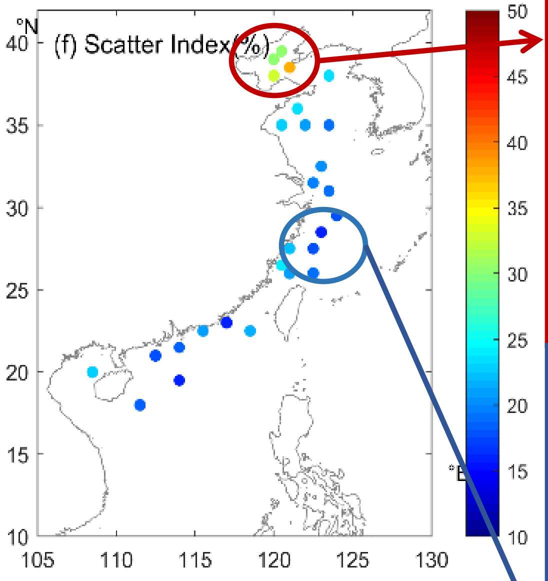
Background

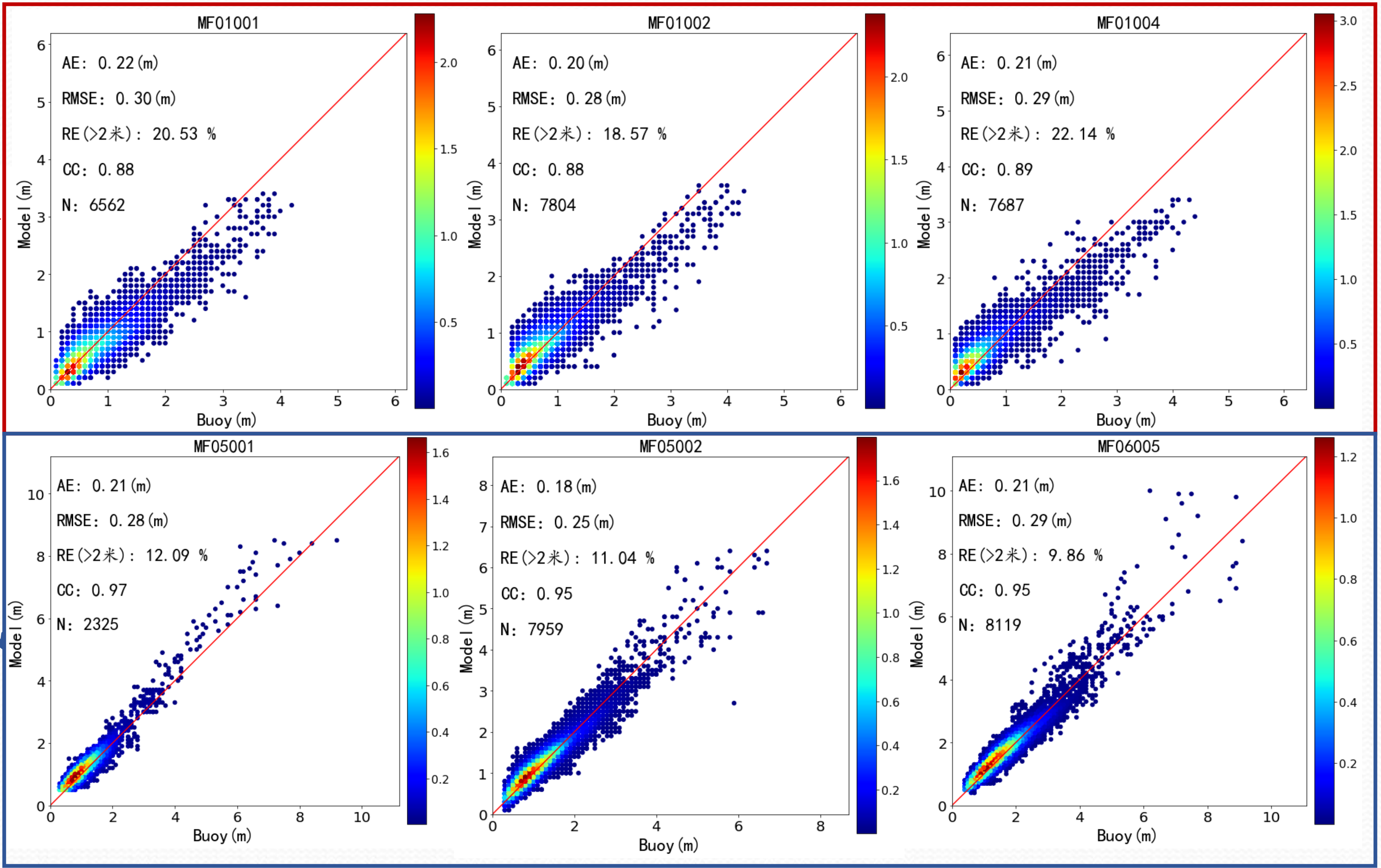


our model performed not well in Bohai and Yellow Sea , and that can be seen from relative error and scatter index

Background

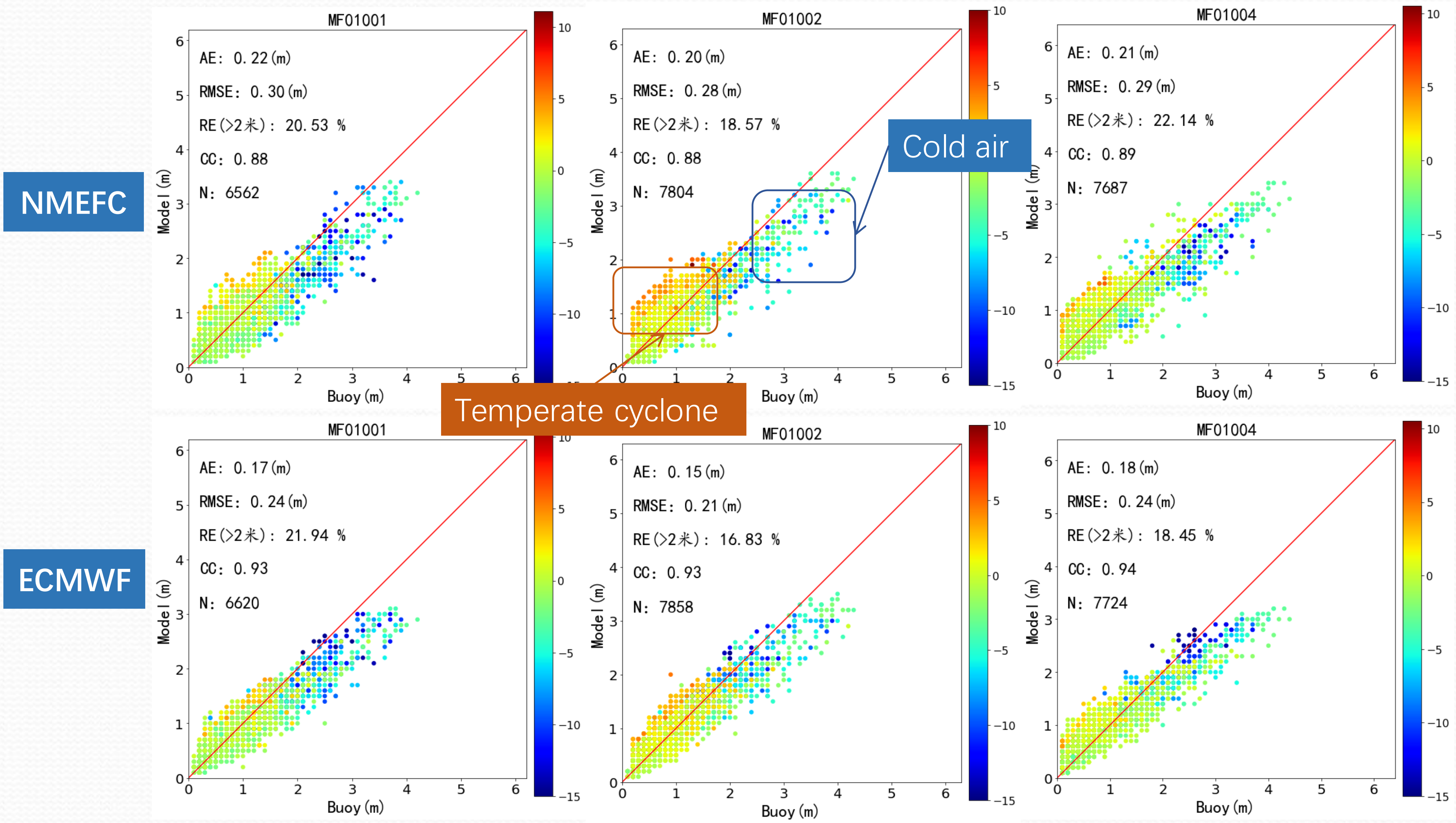
Bohai Sea





East China Sea

Background


NMEFC
ECMWF
MF01001
AE: 0.22 (m)
RMSE: 0.30 (m)
RE (>2米): 20.53 %
CC: 0.88
N: 6562
MF01002
AE: 0.20 (m)
RMSE: 0.28 (m)
RE (>2米): 18.57 %
CC: 0.88
N: 7804
MF01004
AE: 0.21 (m)
RMSE: 0.29 (m)
RE (>2米): 22.14 %
CC: 0.89
N: 7687
Cold air
Temperate cyclone
MF01001
AE: 0.17 (m)
RMSE: 0.24 (m)
RE (>2米): 21.94 %
CC: 0.93
N: 6620
MF01002
AE: 0.15 (m)
RMSE: 0.21 (m)
RE (>2米): 16.83 %
CC: 0.93
N: 7858
MF01004
AE: 0.18 (m)
RMSE: 0.24 (m)
RE (>2米): 18.45 %
CC: 0.94
N: 7724
Model (m)
Buoy (m)

Background

ST4 Parameterization scheme

$$S_{in}(k,\theta)=\frac{\rho_a}{\rho_w}\frac{\beta_{\max}}{\kappa^2}e^Z Z^4\left(\frac{u_*}{C}+z_\alpha\right)^2\cos^{Pin}(\theta-\theta_u)\sigma N(k,\theta)+S_{out}(k,\theta)$$

$$Z=\log(kz_1)+\kappa/[\cos(\theta-\theta_u)(u_*/C+z_\alpha)]$$

$$z_1=\alpha_0\frac{\tau}{1-\tau_w/\tau}$$

$$U_{10}=\frac{u_*}{\kappa}\log\left(\frac{z_u}{z_1}\right)$$

It seems that atmospheric instability was not taken into account when calculating the friction velocity.

u_* Friction velocity is a const turbulent velocity scale that controls momentum transport within the z-altitude layer

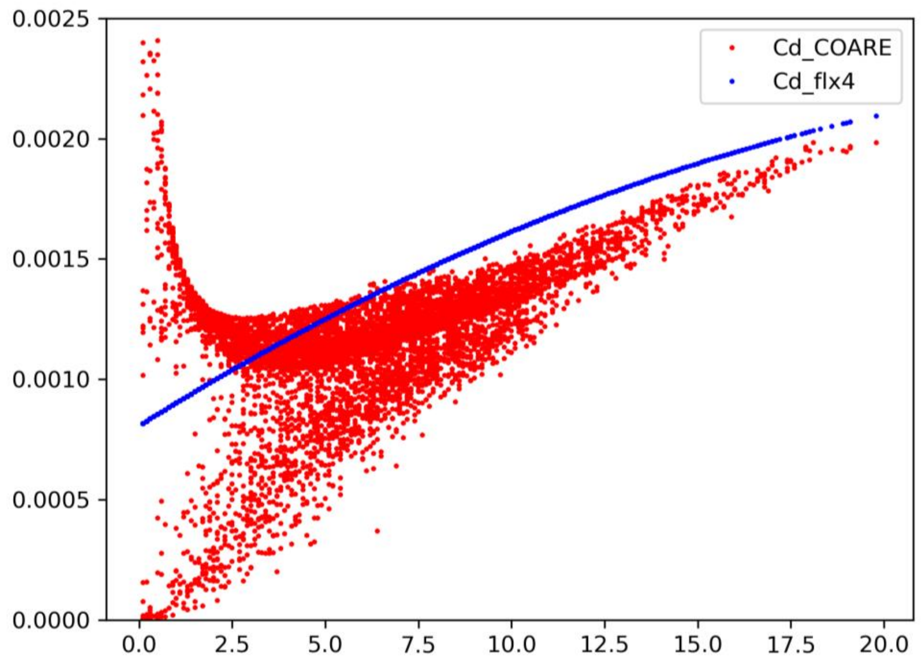
The calculation of friction velocity is based on the assumption of **Constant Flux Layer**, which overly simplifies the physical process of the air sea interface.

Factors such as **wave steepness, wave breaking, gusts, spectral width, and swell** can all affect the calculation of friction velocity, and friction velocity does not seem to be an isotropic constant.(Ortiz-Suslow,2021;Mahrt et al.,2018;(Kudryavtsev and Makin,2004;Chia-Huan Ting,2012)

Methodology

	Methodology	Effect
ST4 （STAB3）	Parameterization considering gust effects	Maybe improved result for high wind speeds
ST2 （STAB2）	Parameterization considering stability correction	Improved underestimation of ST2
COARE3.5	A comprehensive model for calculating wind stress	Inconsistent with the friction wind speed in the model
Young， 1998	Correction formula fitted from observations	The correction effect is not ideal, especially under high wind speeds

Comparison of Friction velocity from Coare and FLx4



In general, although various methods take atmospheric instability into account in different forms to calculate or correct u*, there has been no improvement in forecast accuracy in the Bohai Sea region in practical applications.

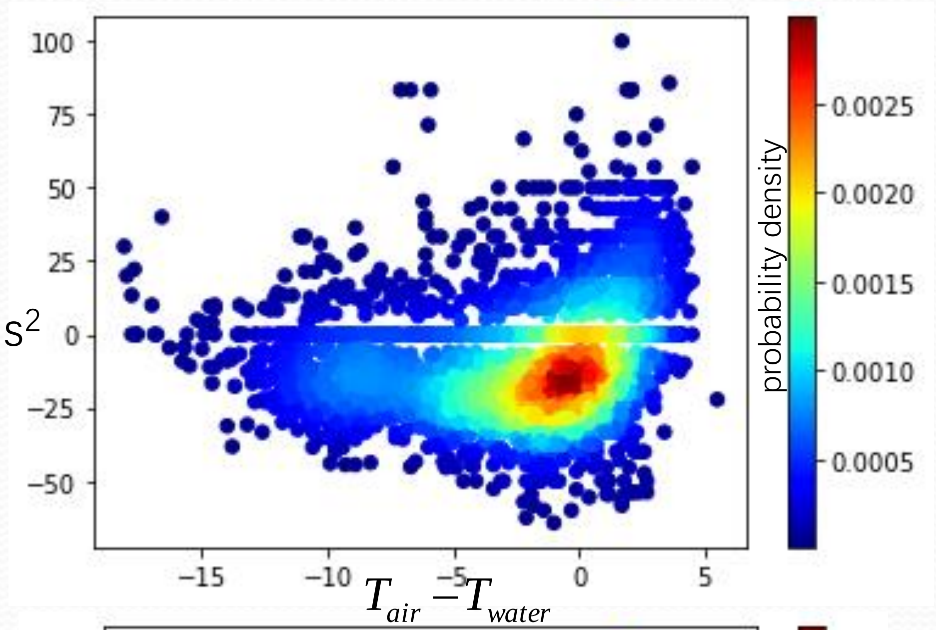
coefficient of correction from Young(1998)

$$R_b = \frac{g(T_a - T_w)}{z_t T_a (u/z)^2}$$

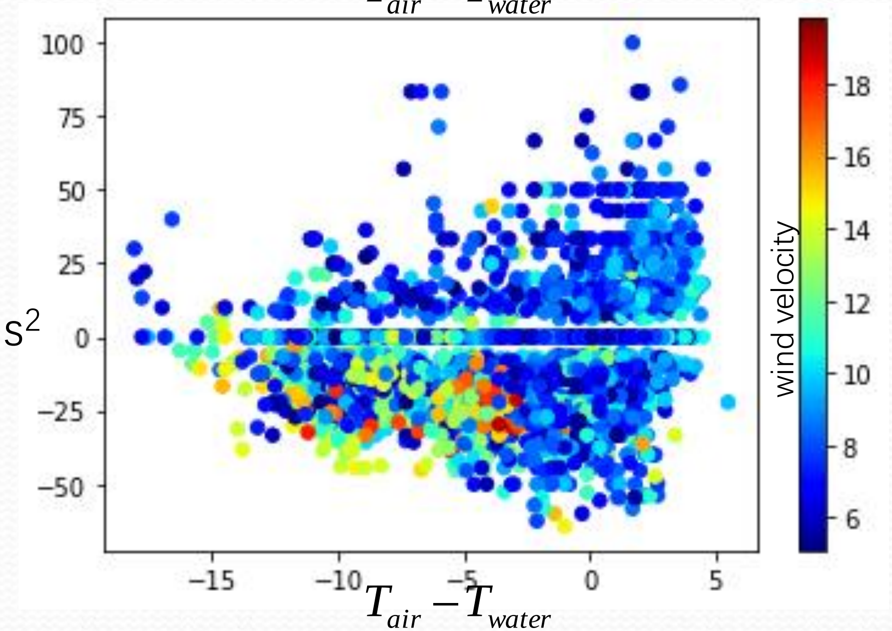
$$\xi = -1.22 R_b + 0.01$$

Methodology

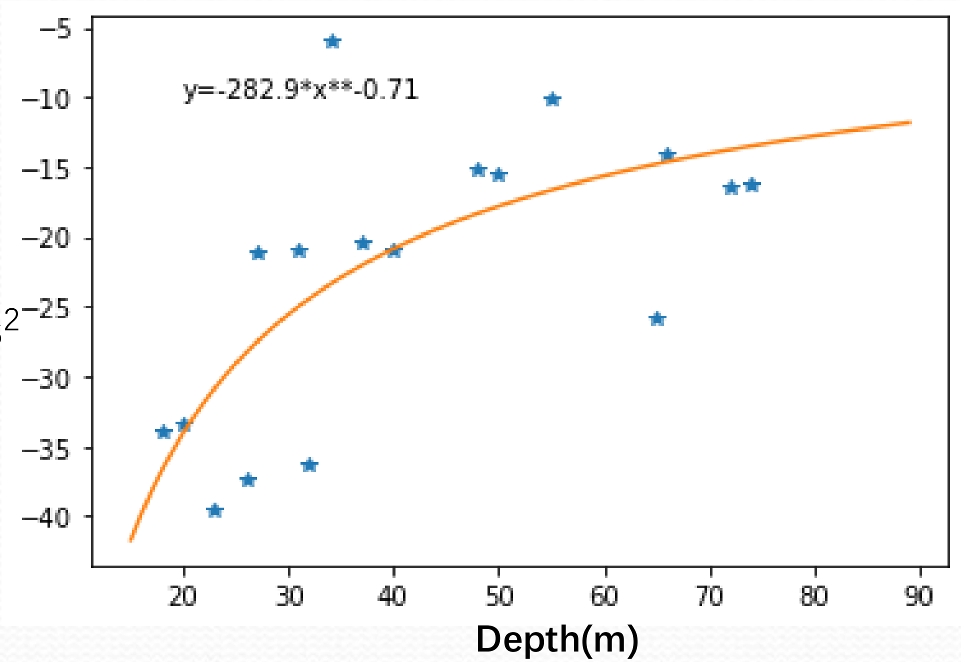
RE of Hs^2



RE of Hs^2



RE of Hs^2



$$\mathrm{RE} = \frac{Hs^2_{\mathrm{model}} - Hs^2_{\mathrm{buoy}}}{Hs^2_{\mathrm{buoy}}} * 100\%$$

- The error of significant wave height is related to the temperature difference between sea and atmosphere, but it is not a linear relationship.

- The relative error of wave heights square is related to water depth and can be approximated by a power function.

Methodology

$$\xi = C_1 * U_{10}^{C_2} * Sign(T_{2m} - SST) * \left(\left|T_{2m} - SST\right| + C_3\right)^{C_4} + C_5$$

$$u_* = u_* * \xi; \quad Hs_{buoy} = Hs_{model} * \xi$$

Data filtering

(1) $Depth < 50\,(m)$ &

(2) $Hs_{mod} > 0.3$ &

(3) $Hs_{mod} - Hs_{buoy} < -0.2$ & $T_{2m} - SST < 0$ &

(4) $Hs_{mod} - Hs_{buoy} > 0.2$ & $T_{2m} - SST > 0$ &

(5) $.not.(U_{10} < 8$ & $Hs_{mod} > 2.5)$ &

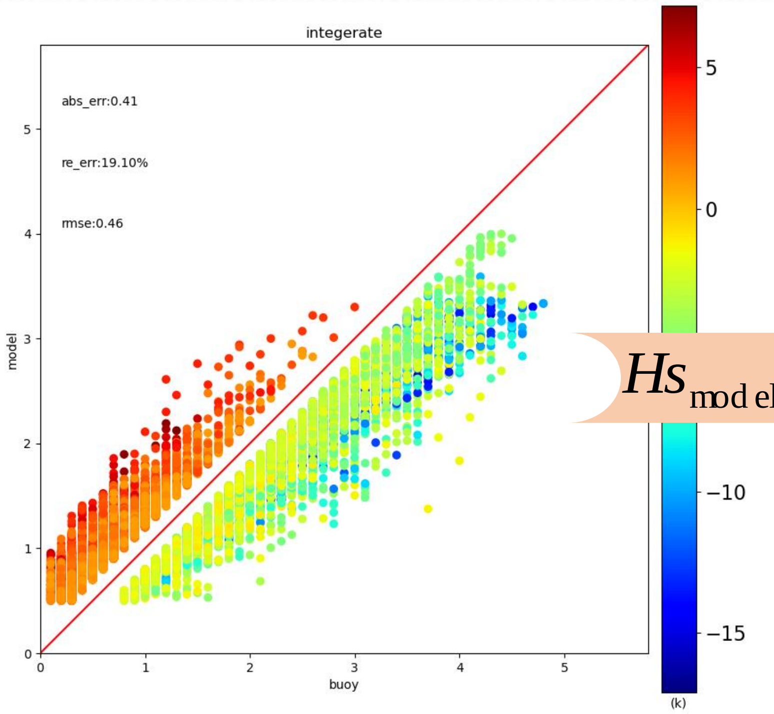
(6) $.not.(U_{10} > 12$ & $Hs_{mod} < 0.8)$

u_*	Friction velocity
ξ	coefficient of correction
U_{10}	10 meters wind speed
T_{2m}	2 meters temperature
SST	Sea surface temperature

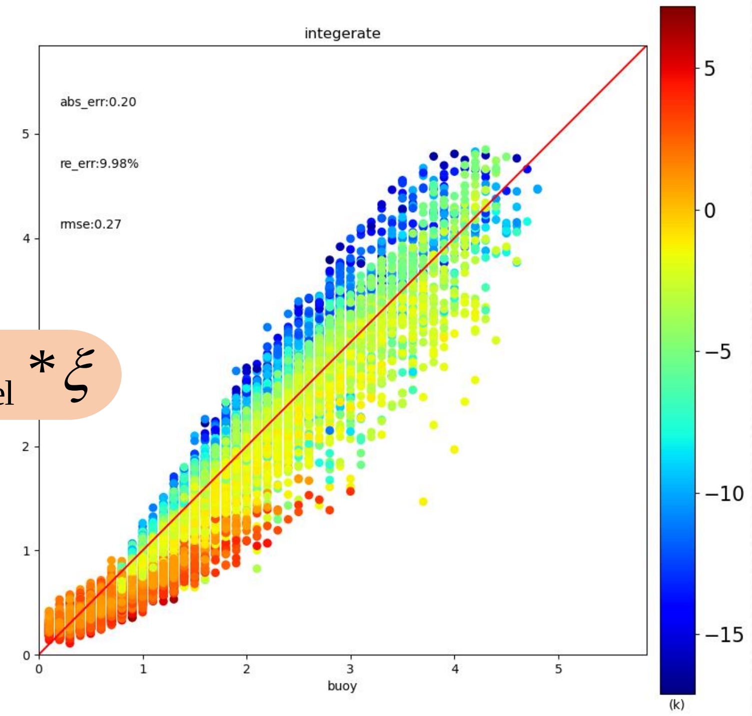
Regression fitting

$$C_1 = -0.53; C_2 = -0.28; C_3 = -1; C_4 = 0.357; C_5 = 0.5$$

Preliminary fitting results

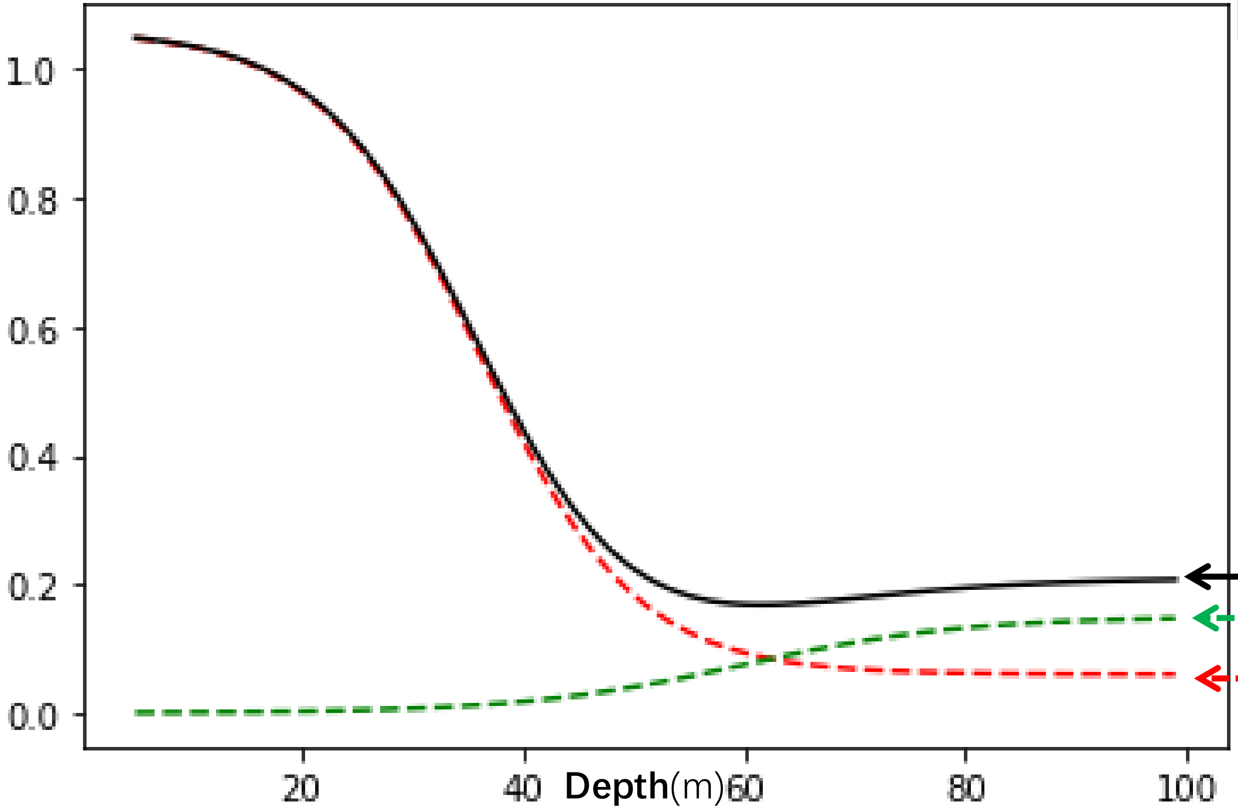


$$Hs_{model} * \xi$$



Methodology

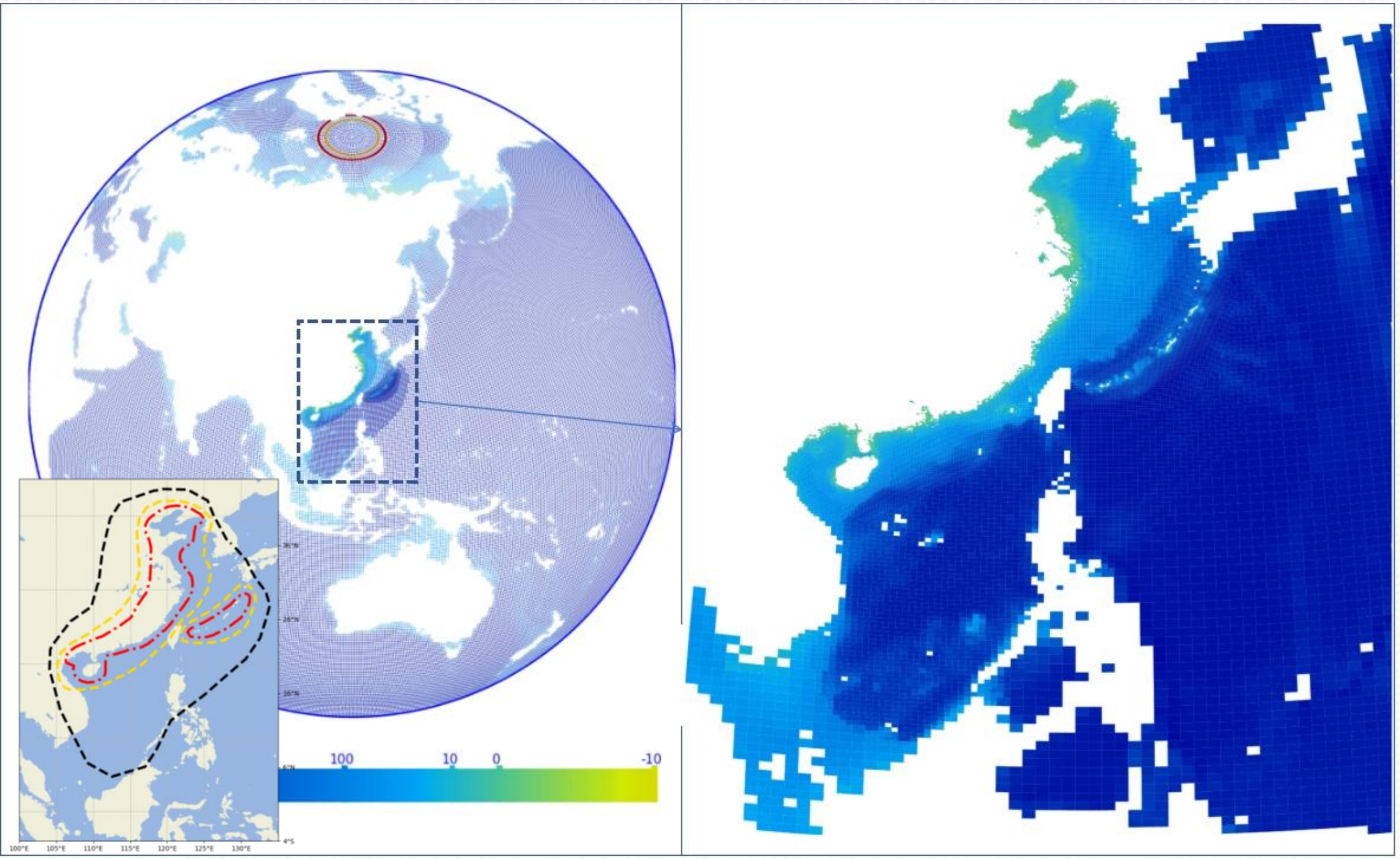
In order to smoothly transition from shallow water to deep water, a function related to water depth was artificially set up

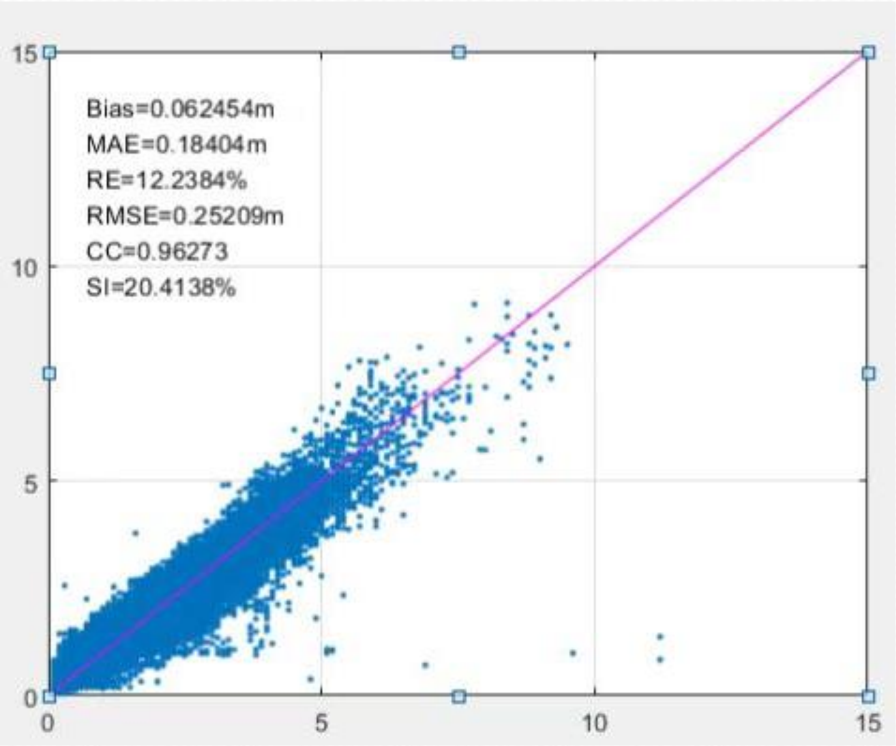


$$\xi_{depth} = (\xi - 1)\left(\boxed{\frac{1.015}{1+1.15^{Depth-36}} - 0.14} + \boxed{\frac{0.2}{1+\frac{1}{e^{0.1*(Depth-60)}}+0.12}}\right) + 1$$

Assumption:The impact of atmospheric instability gradually decreases as water depth increases.

Results



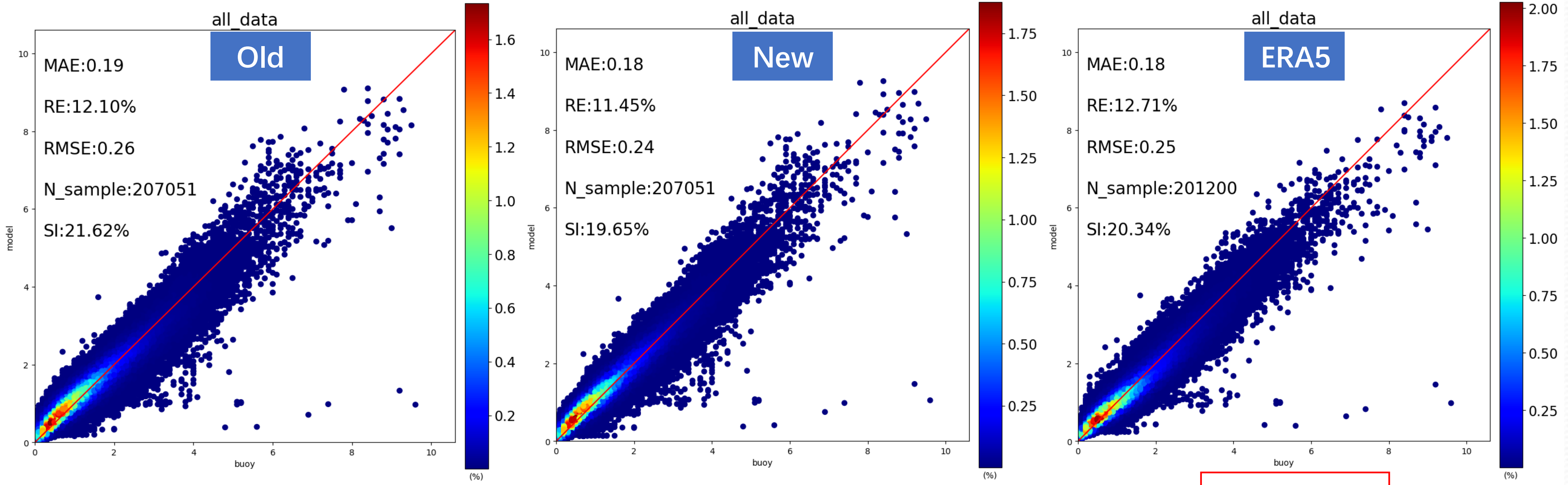


Region	Resolution
Within the red line range	lat:0.058,lon:0.087 (about 6km)
Within the yellow line range	lat:0.116,lon:0.174
Within the black line range	lat:0.232,lon:0.348
Global (Outside the black line range)	lat:0.464,lon:0.696

model	WW3
source term	(ST4+)
force wind	ERA (u10, v10,2t,sst)
time span	2021
time resolution	Hourly

Results

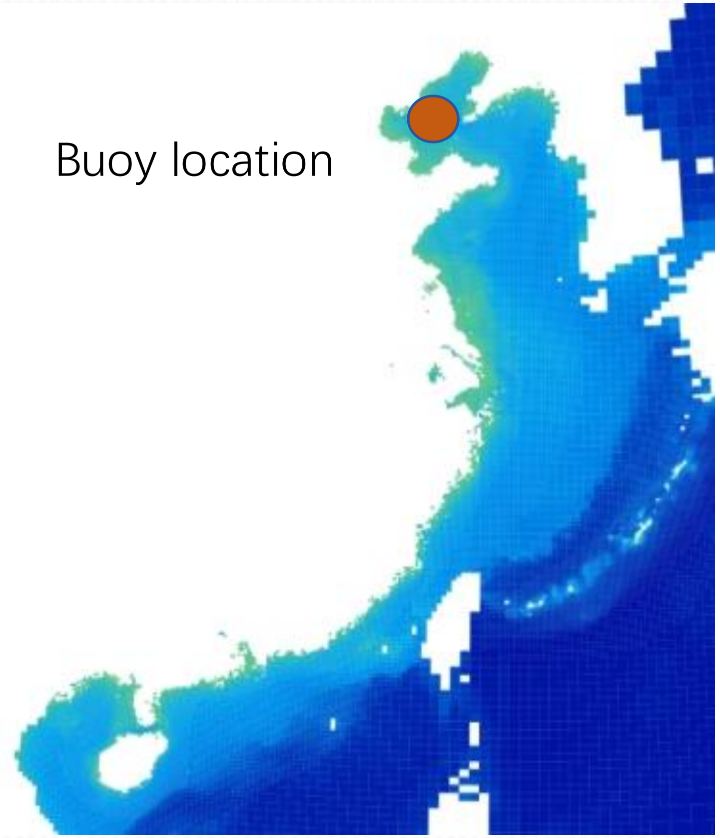
We used ERA5's 10 meters wind, 2 meters temperature, and sea surface temperature to calculate the hindcast Hs for 2021
No assimilation or fusion of observed data.
Removed buoys that are too close to the shore

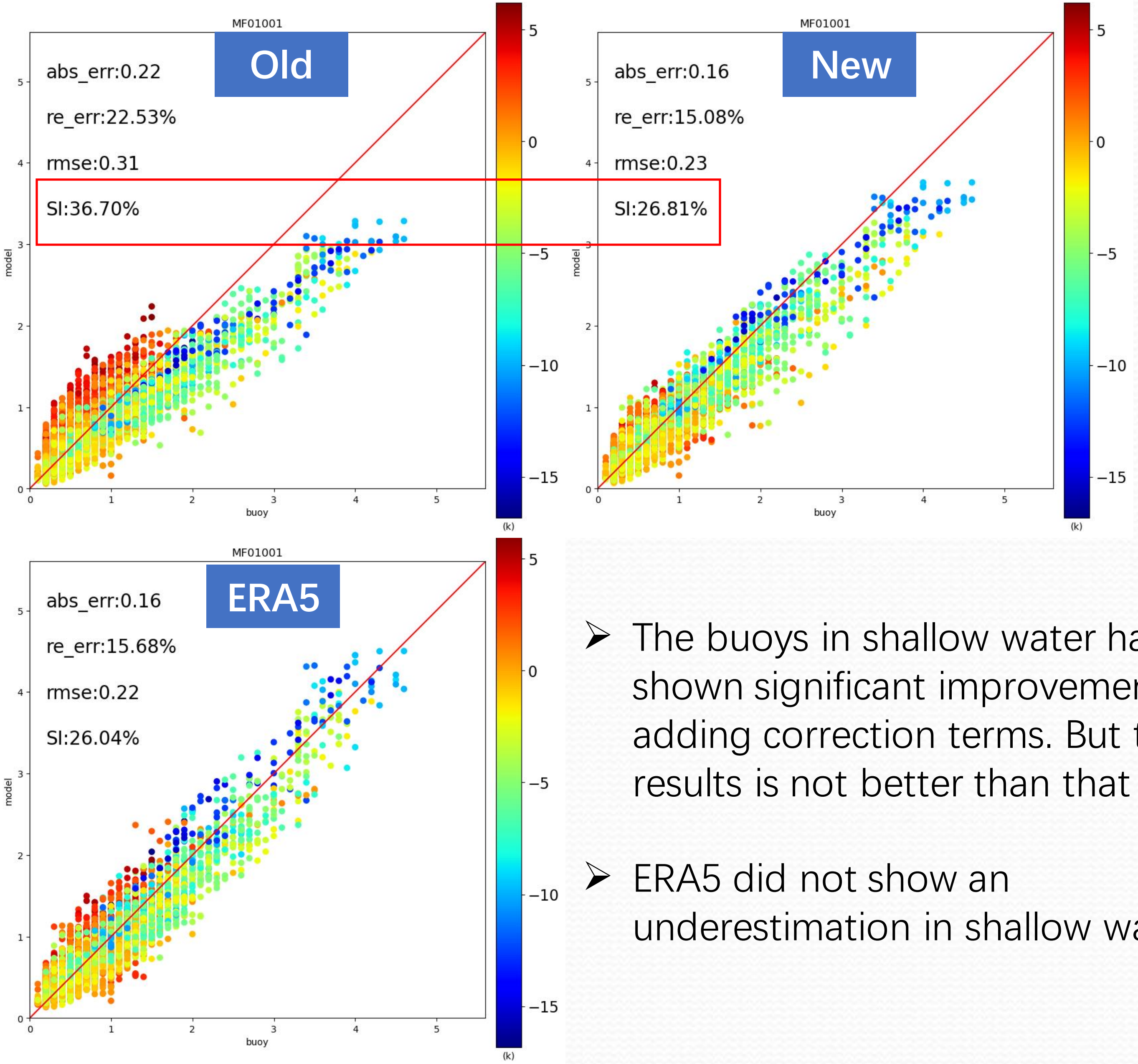


	MAE（米）	RMSE（米）	RE（Hs>1m）	SI（%）
NMEFC（old）	0.19	0.26	12.10%	21.62
NMEFC(new)	0.18	0.24	11.45%	19.65
ERA5	0.18	0.25	12.71%	20.34

Results

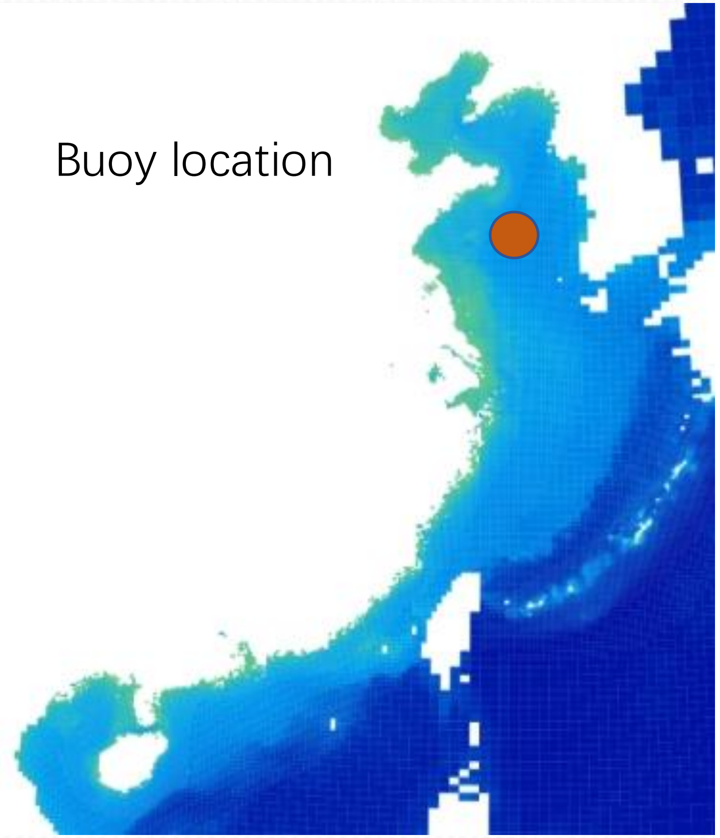
Buoy location

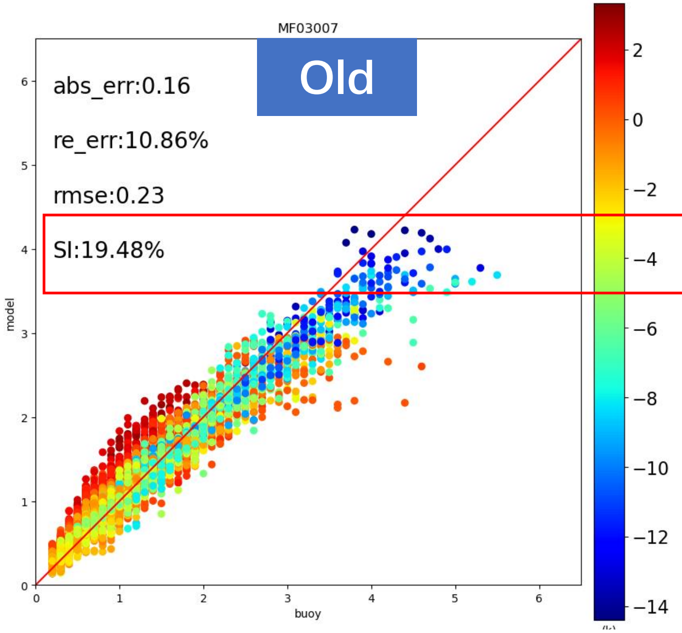


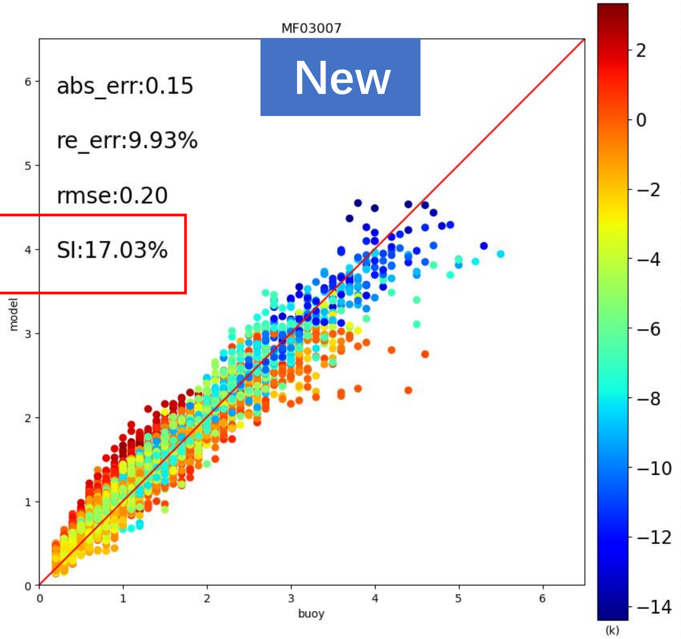


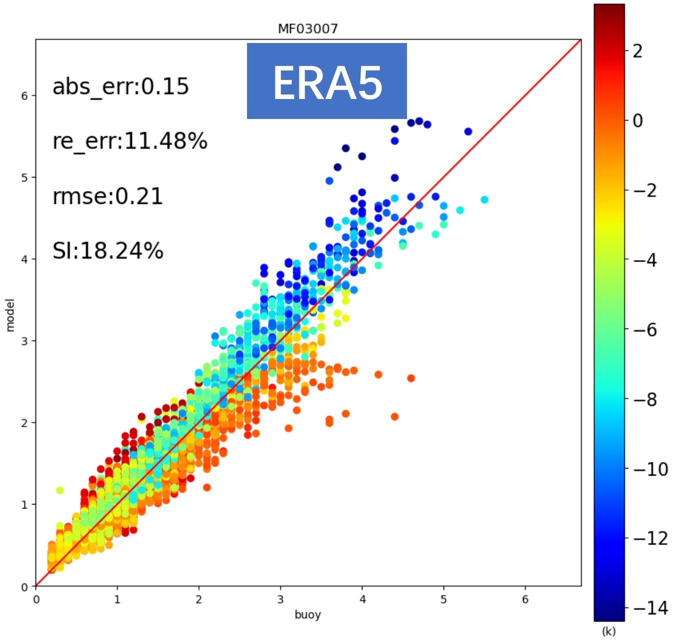
- ➢ The buoys in shallow water have shown significant improvement after adding correction terms. But the results is not better than that of ERA5.
- ➢ ERA5 did not show an underestimation in shallow water.

Results





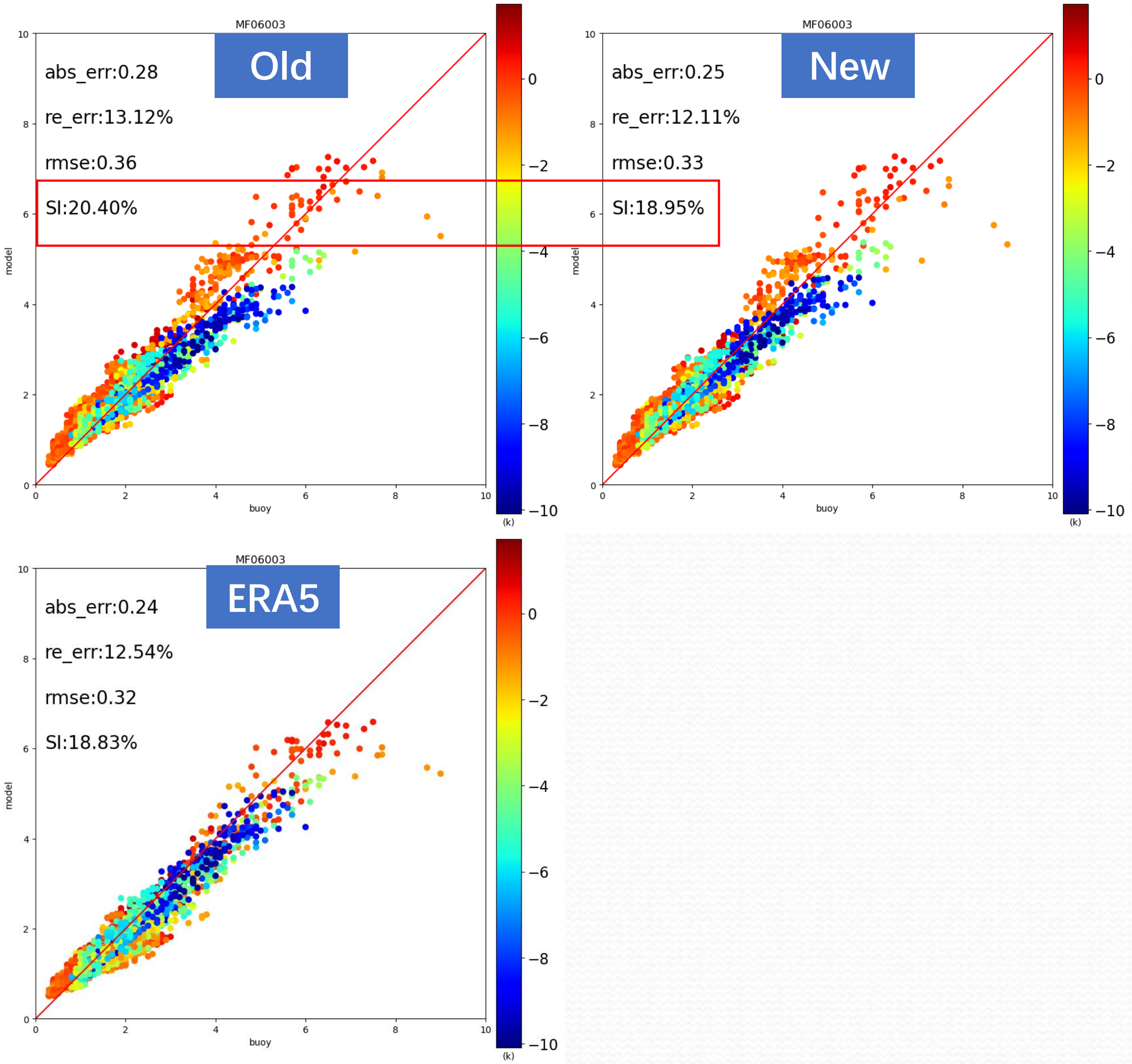




- The new parameterization reduces the overall scatter index.
- The impact of atmospheric instability considered by ERA5 appears to be stronger than the new parameterization .

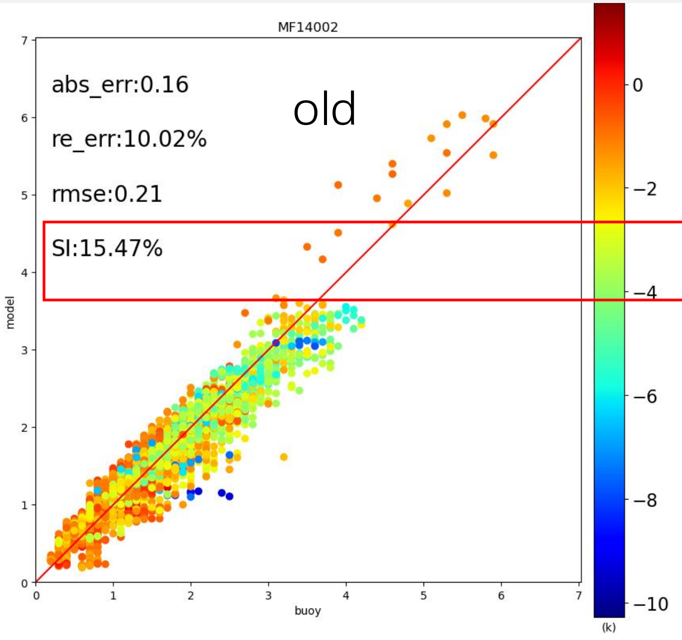
Results

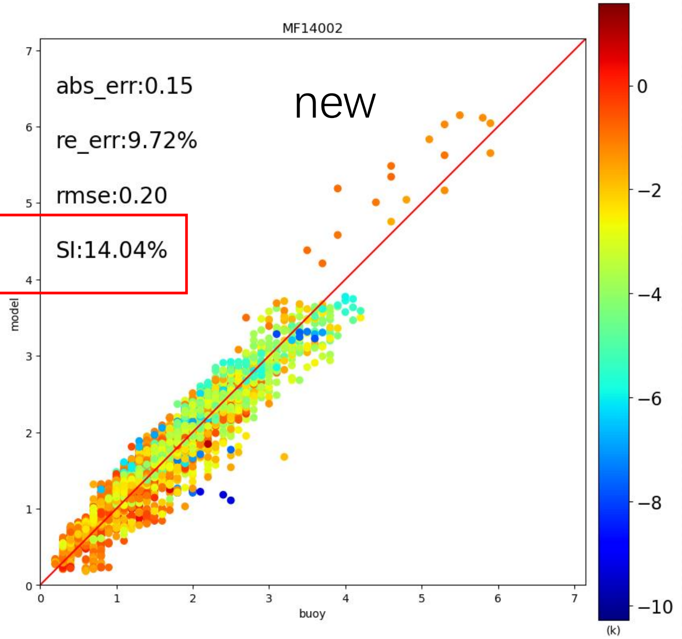
Buoy location

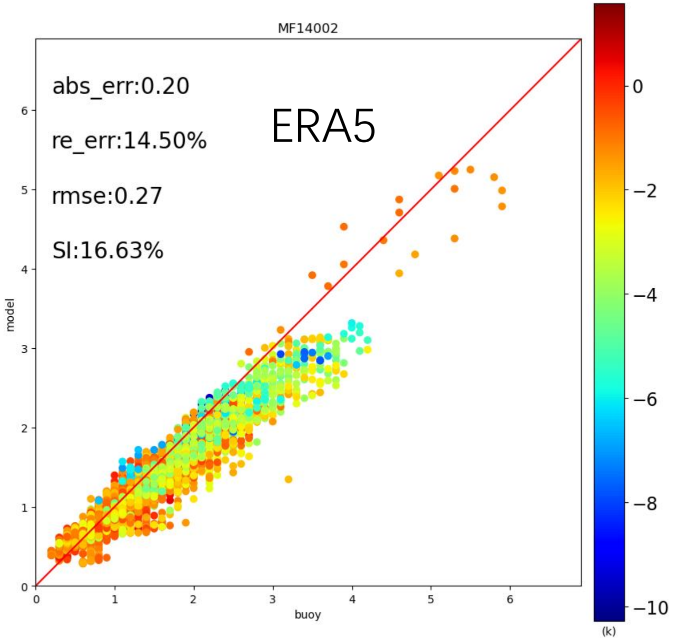


Results

Buoy location

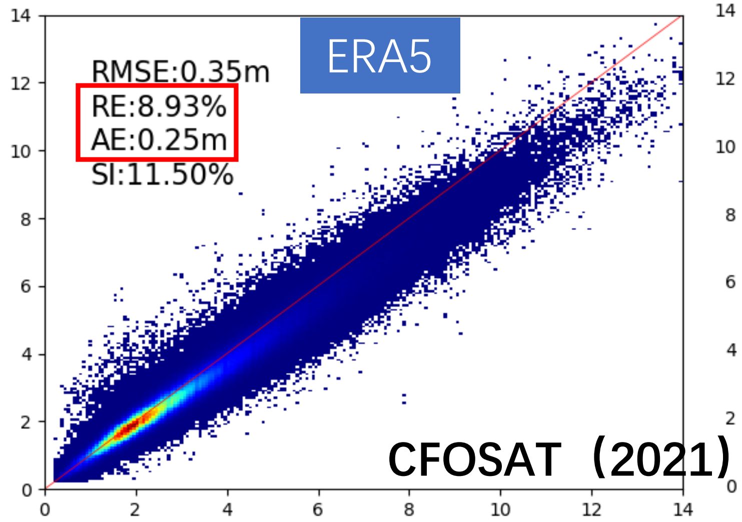




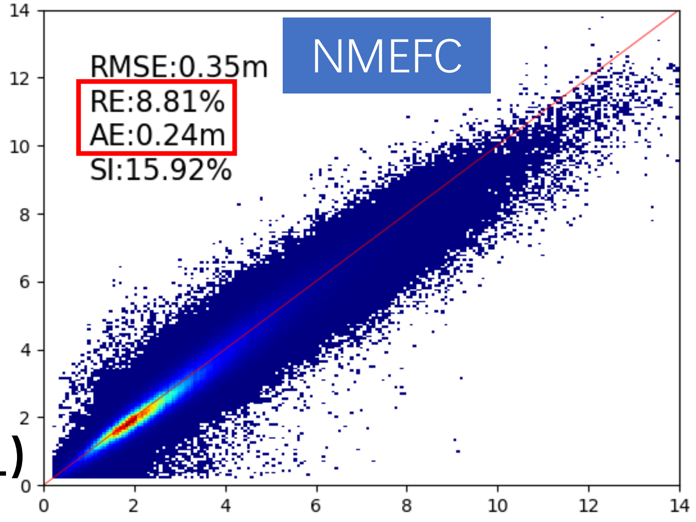


- ERA5 has an underestimation of wave height in south china sea

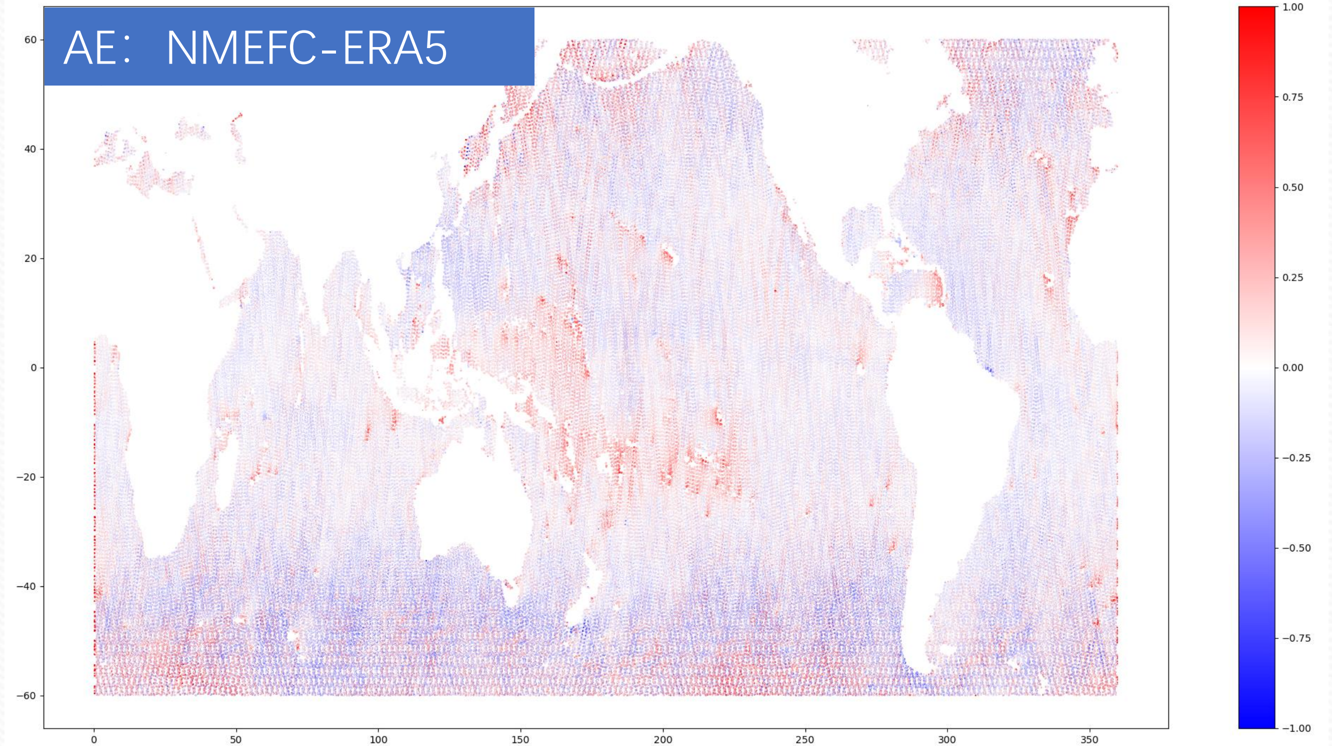
Results



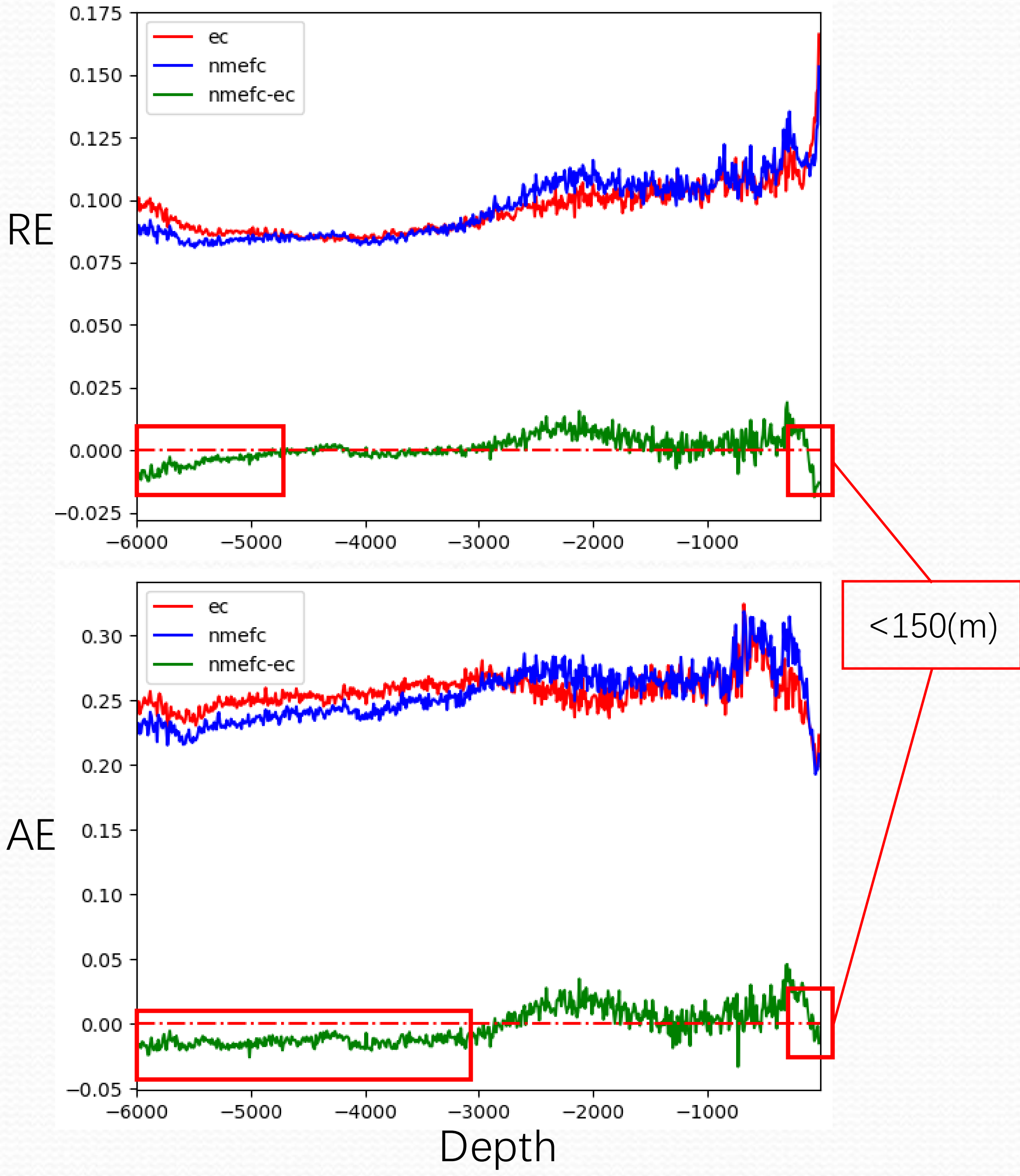
ERA5
RMSE:0.35m
RE:8.93%
AE:0.25m
SI:11.50%
CFOSAT（2021）



NMEFC
RMSE:0.35m
RE:8.81%
AE:0.24m
SI:15.92%



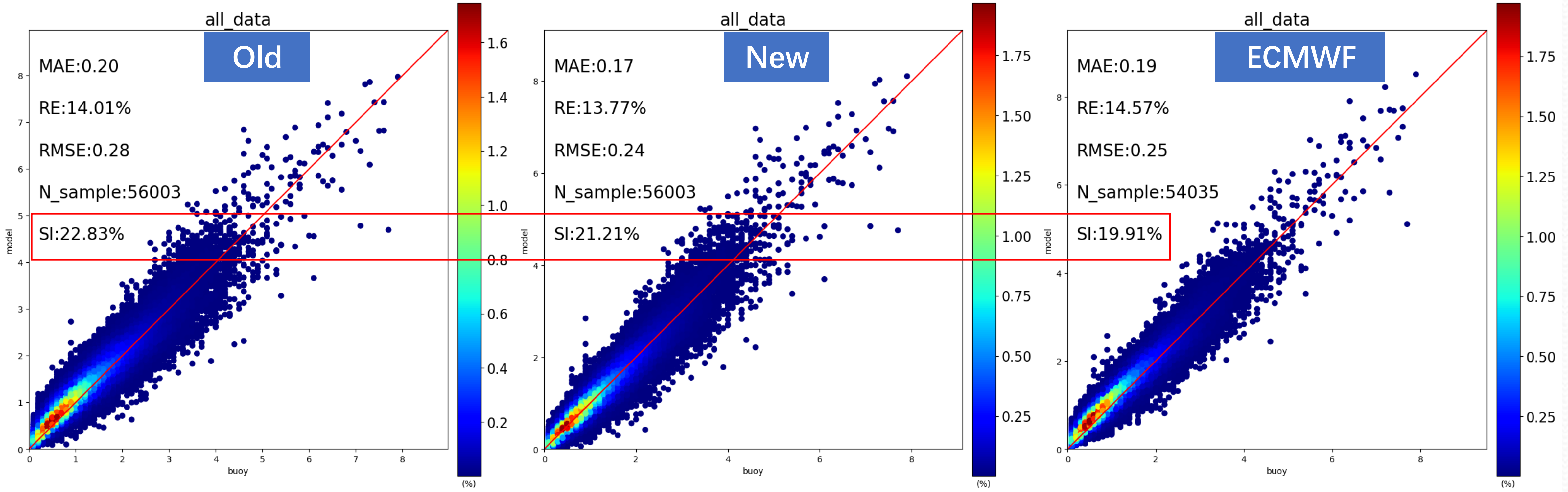
AE： NMEFC-ERA5



RE
ec
nmefc
nmefc-ec
AE
ec
nmefc
nmefc-ec
<150(m)
Depth

Results

The application of the new parameterization to the forecasting model



We used ECMWF's(0.4 degrees)forecasting **u10,v10,2t,skt** to calculate the Hs for 2023

- The parameterization which performed well in hindcasting model is not applicable to forecasting model.
- We have adjusted the parameters again, but the SI is still higher than ecmwf.(may be caused by the low resolution of the wind)
- Compared to the origional parameterization , there is still an overall improvement

Results and Discussion

Summary

- Compared to ST4 , the new parameterization has made overall improvements in both hindcasting and forecasting.
- The physical meaning behind the new parameterization is very ambiguous. This new parameterization scheme should only be a transitional method, and formulas based on the new boundary layer theories should be the correct solution
- There are subtle differences in the wind field between ERA5 and ECMWF's forecasting data, and thus the same parameterization cannot be directly applied to both.

Plan for the Next Step

- Further adjust the parameterization to make it more suitable for the forecasting model.
- Consider utilizing machine learning for parameters regression and fitting
- Apply for joining the (LC-WFV) project.

Thanks！