AI deep learning for weather-climate forecasts

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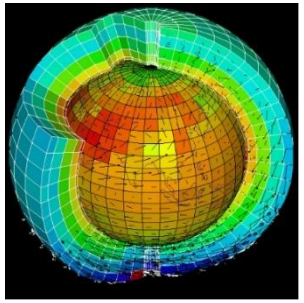
School of AI and Future Technology
Nanjing University of Information Science & Technology (NUIST)
Nanjing, China

Collaborators:

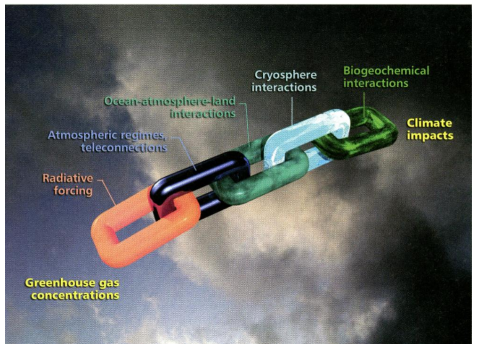
Fenghua Ling, Shuxian Yang, Song Yang, Lei Bai, Yoo-Geun Ham, Pumeng Lvu, Zijie Guo, ...

Current status of dynamical forecast systems and imperfections



Numerical models based on N-S equations

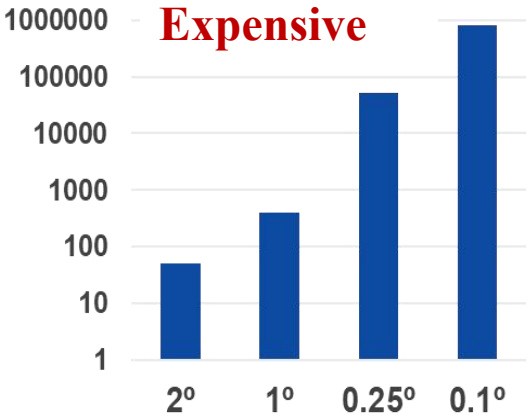
Super computers



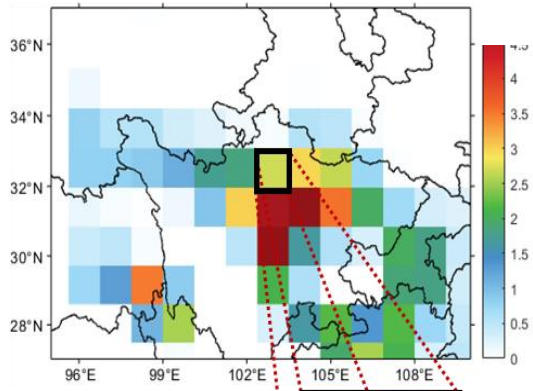
Weather-climate seamless forecasts

Main defects

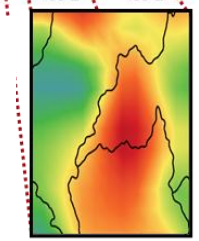
Required CPU hours per model year running



Horizontal resolution

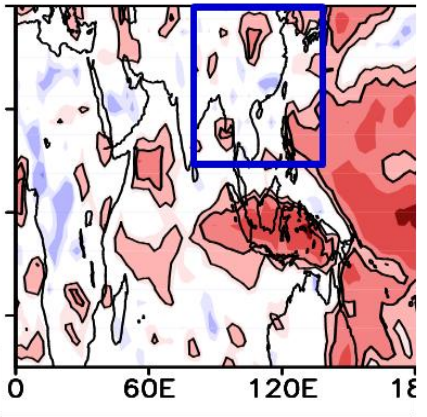


Global model (~100km)
Coarse



Societal demand (~1km)

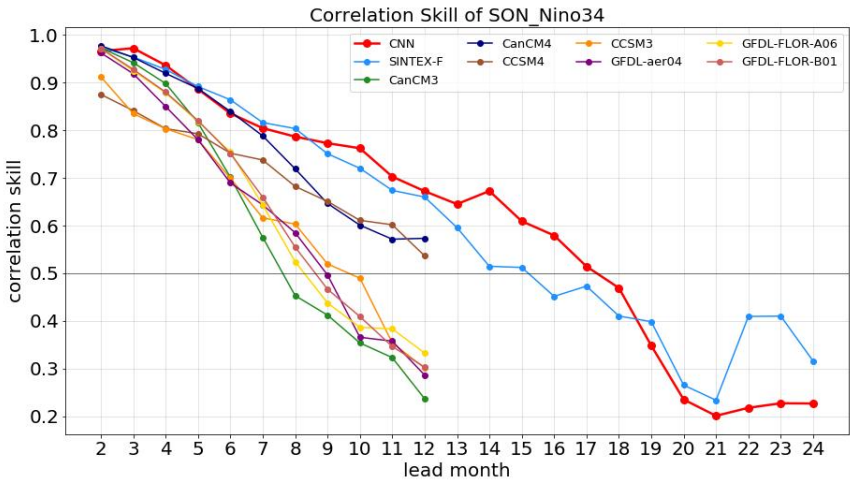
Summer rainfall prediction skill



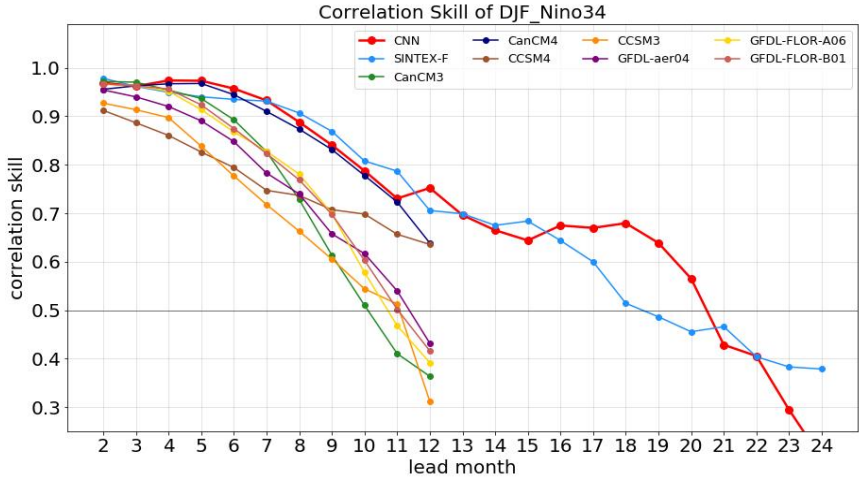
Poor skill

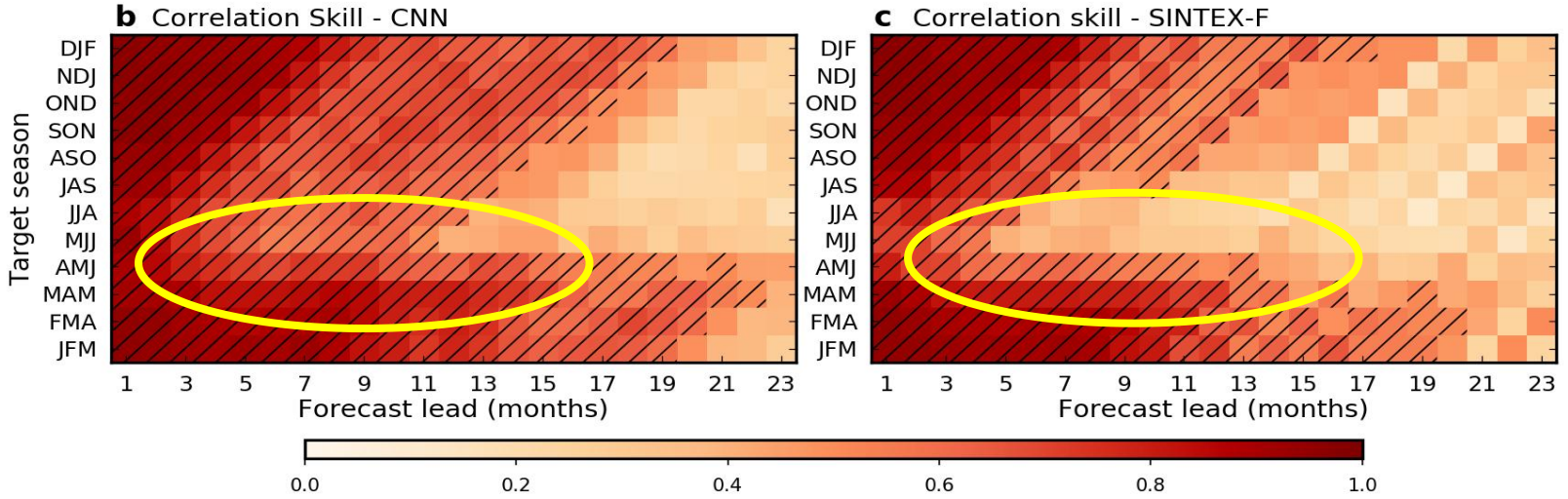
ENSO prediction based on LeNet-5 CNN and CGCMs

Prediction of SON Nino3.4 SSTA (1982-2019)



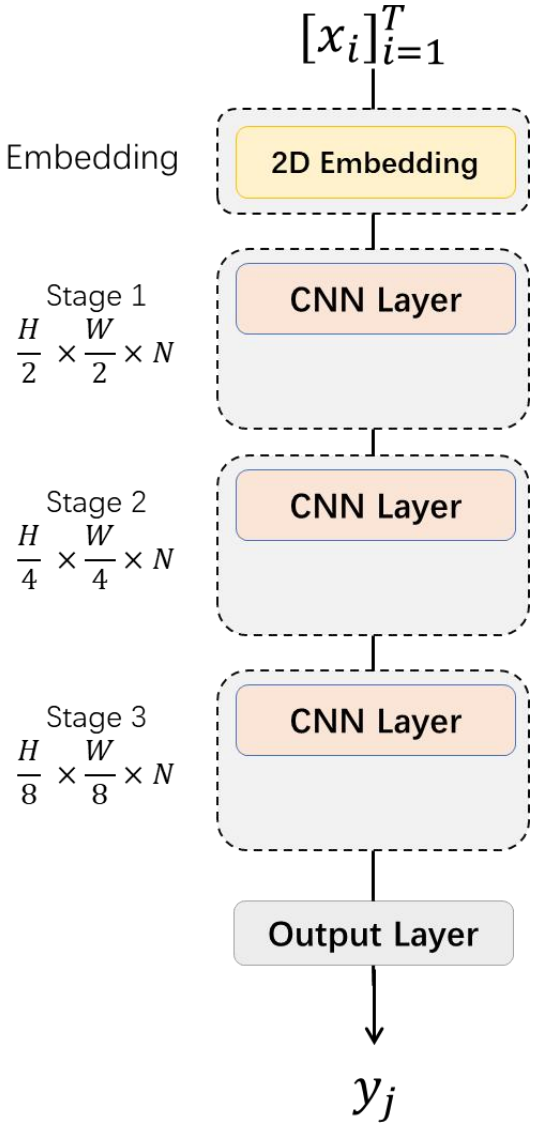
Prediction of DJF Nino3.4 SSTA (1982-2019)

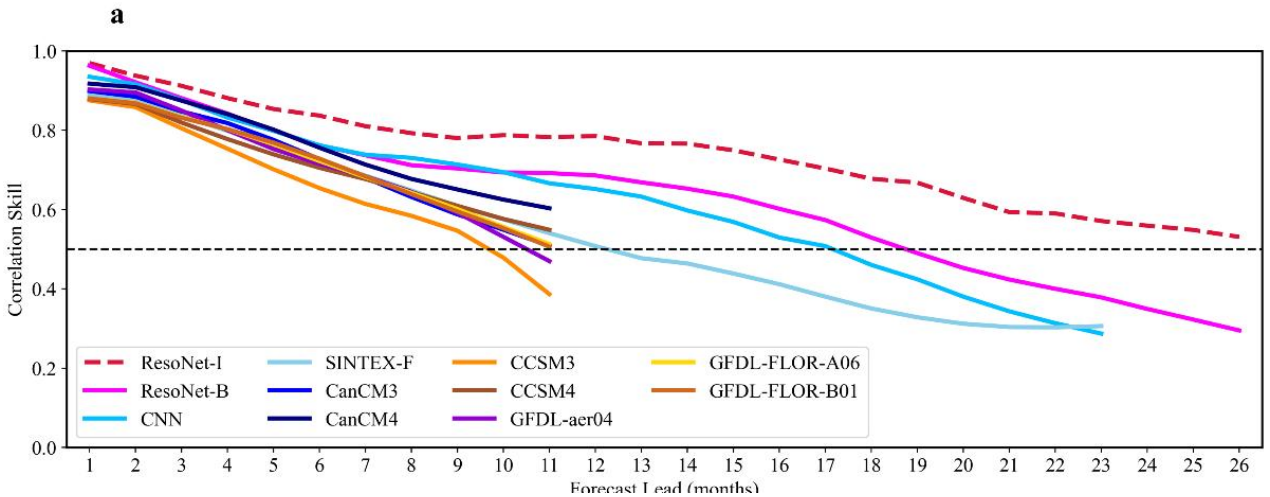


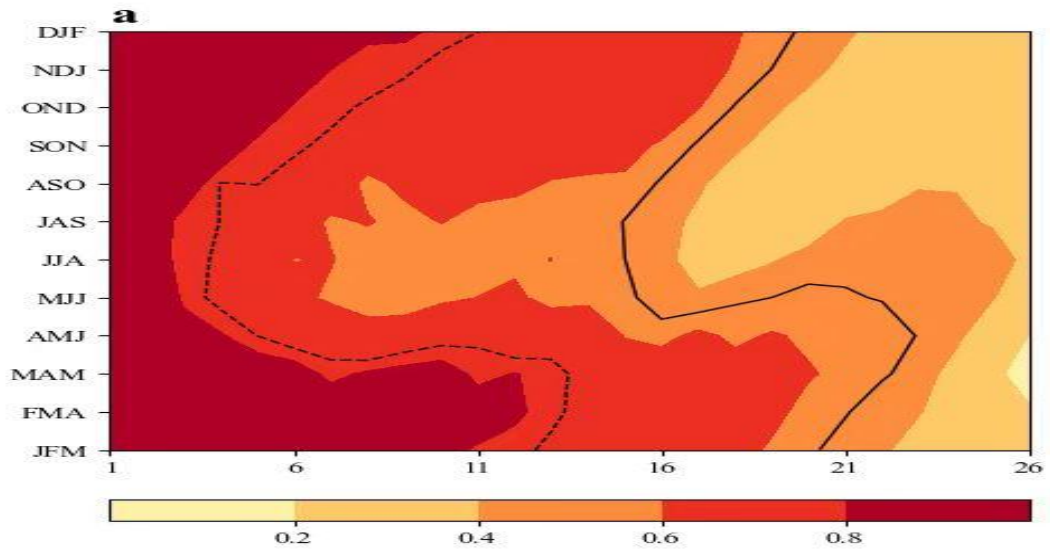


Y-G Ham, J-H Kim, J-J Luo, *Nature*, 2019, 573 (7775), 568-572.

ResoNet: Combining CNN and Transformer for ENSO forecast



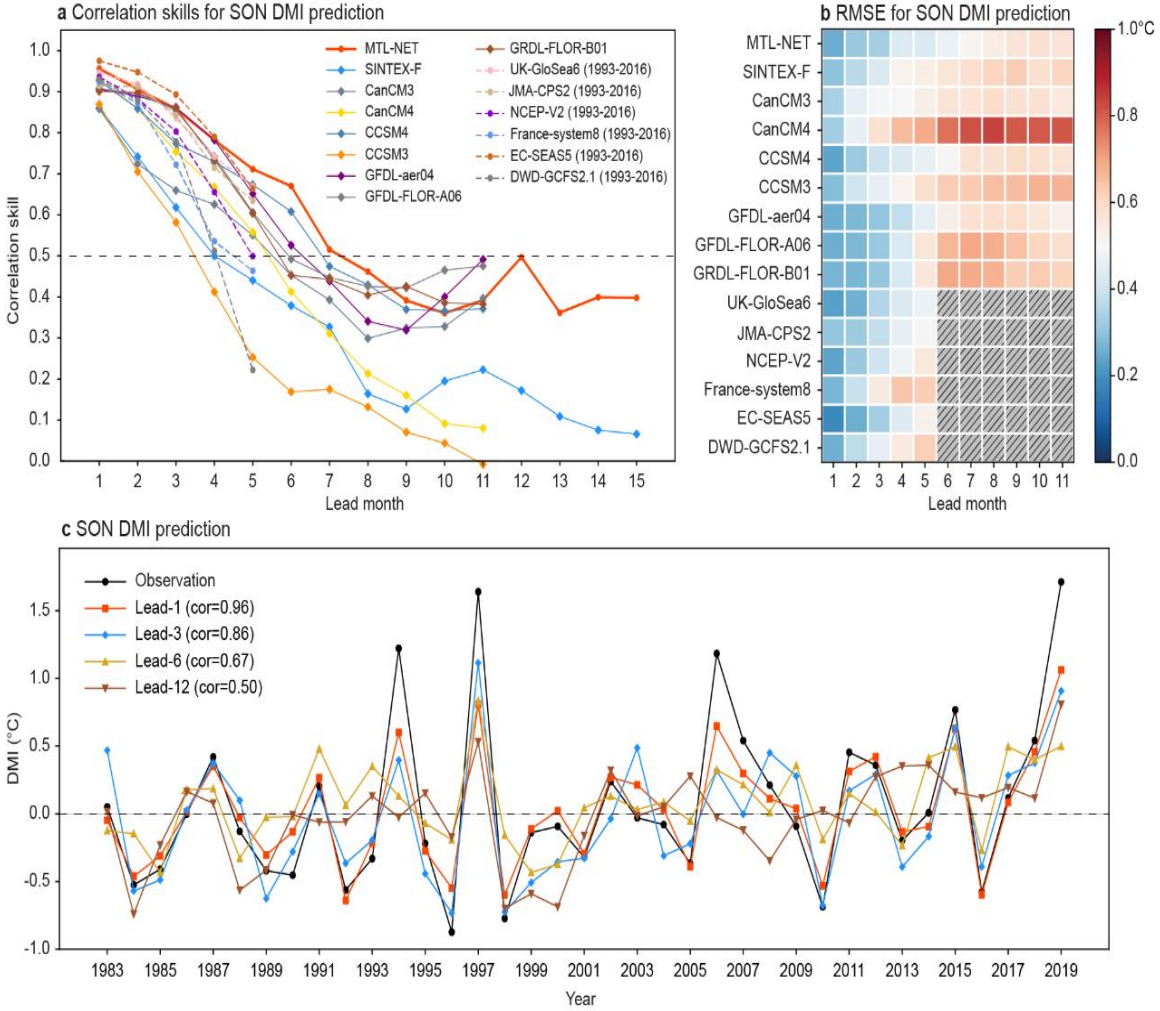




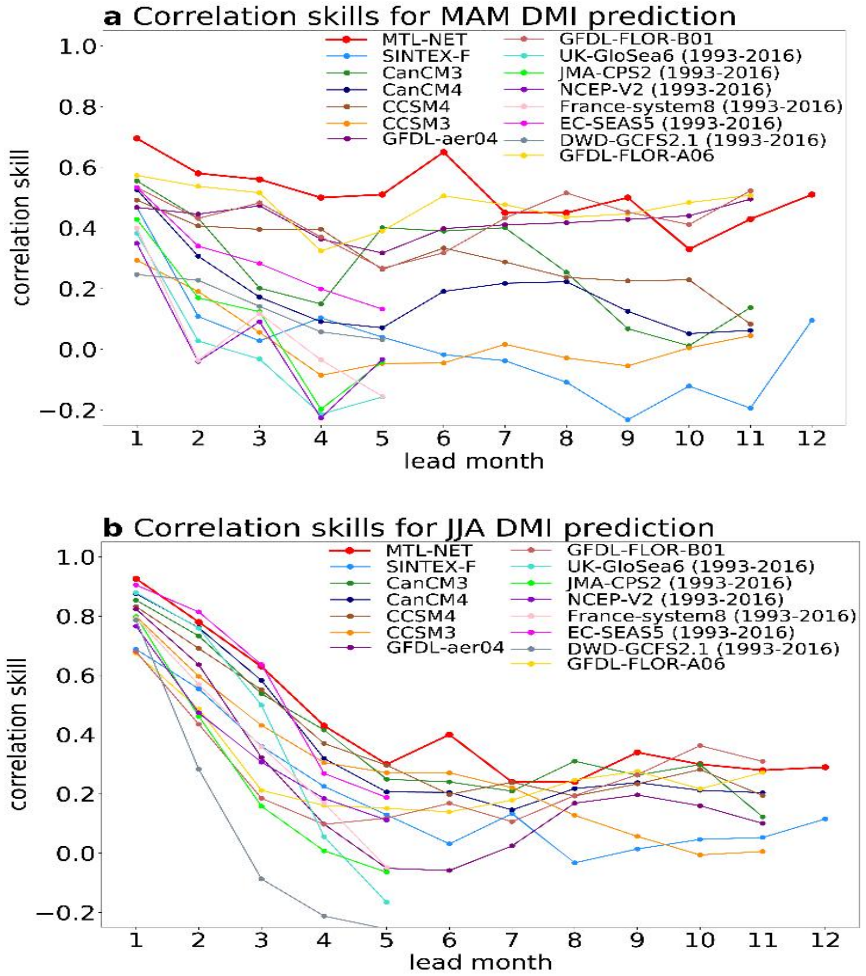
P Lyu, T Tang, F Ling, J-J Luo, N Boers, W Ouyang, and L Bai, *AAS*, 2024, 41 (7), 1289-1298.

Predictions of IOD using a multi-tasking DL model

SON



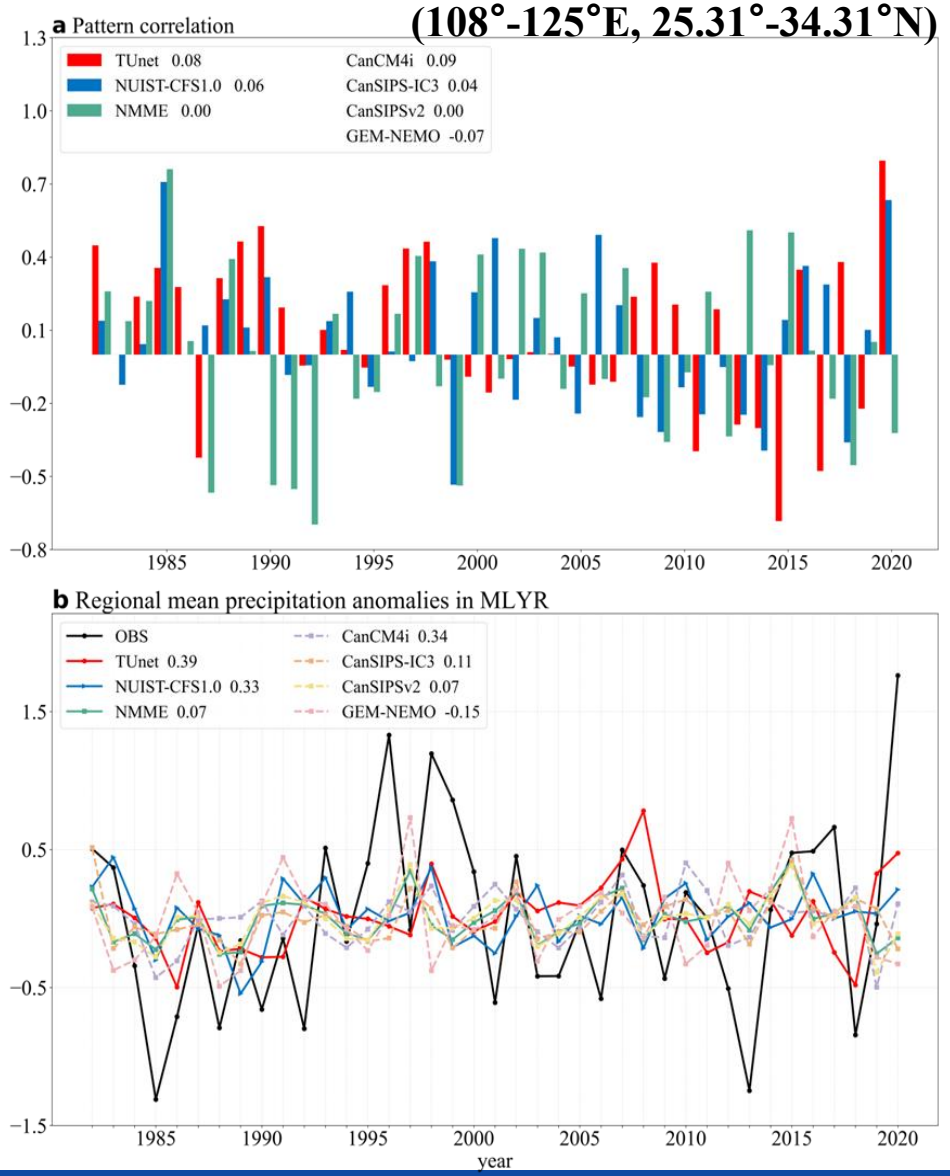
MAM & JJA

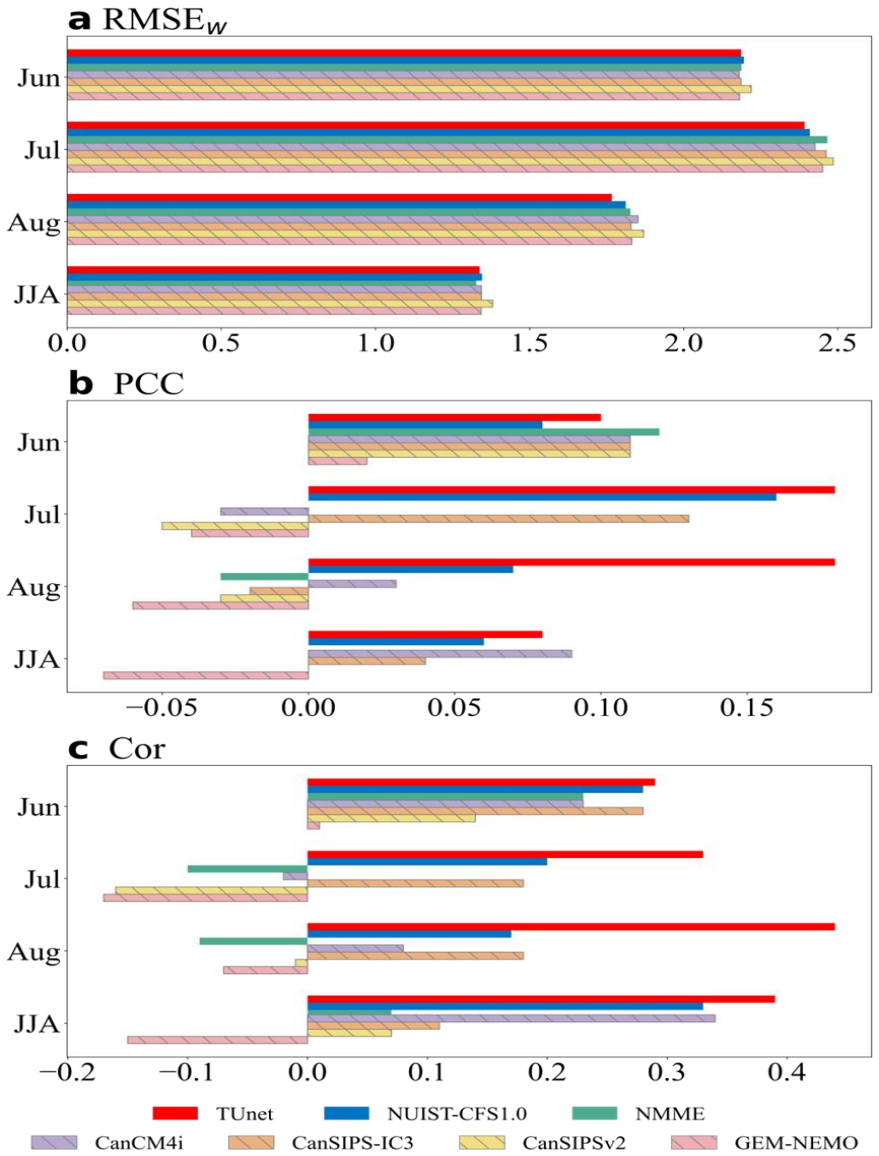


F Ling, J-J Luo, Y Li, T Tang, L Bai, W Ouyang, and T Yamagata,
Nature Communications, 2022, https://doi.org/10.1038/s41467-022-35412-0

Improve JJA precipitation prediction using two-step UNet

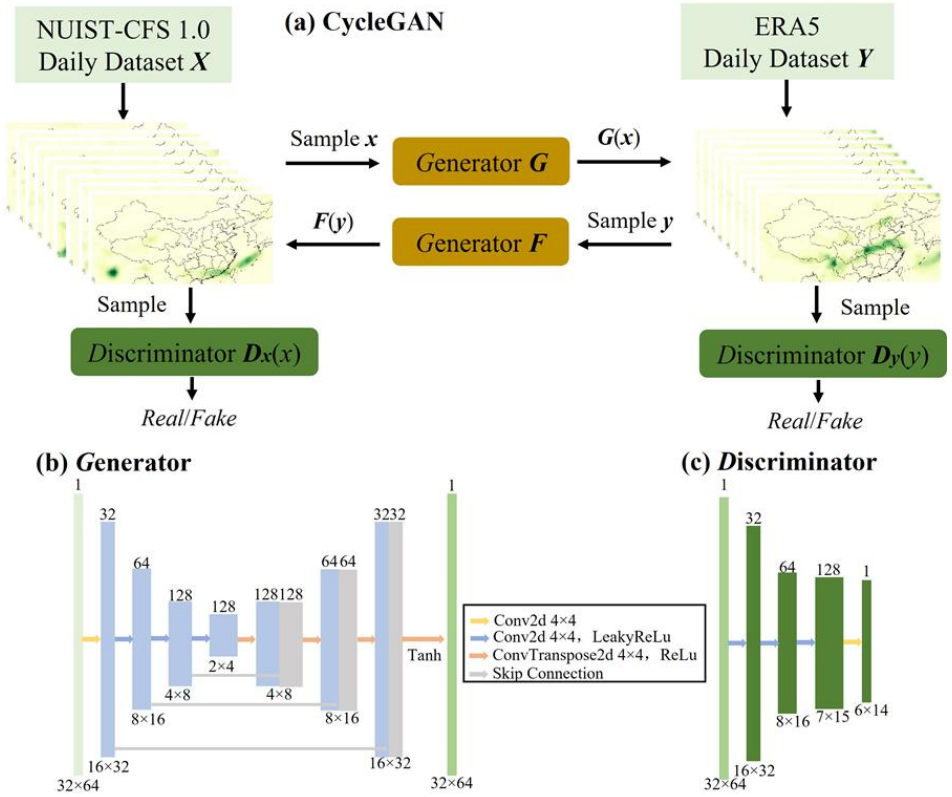
(108°-125°E, 25.31°-34.31°N)

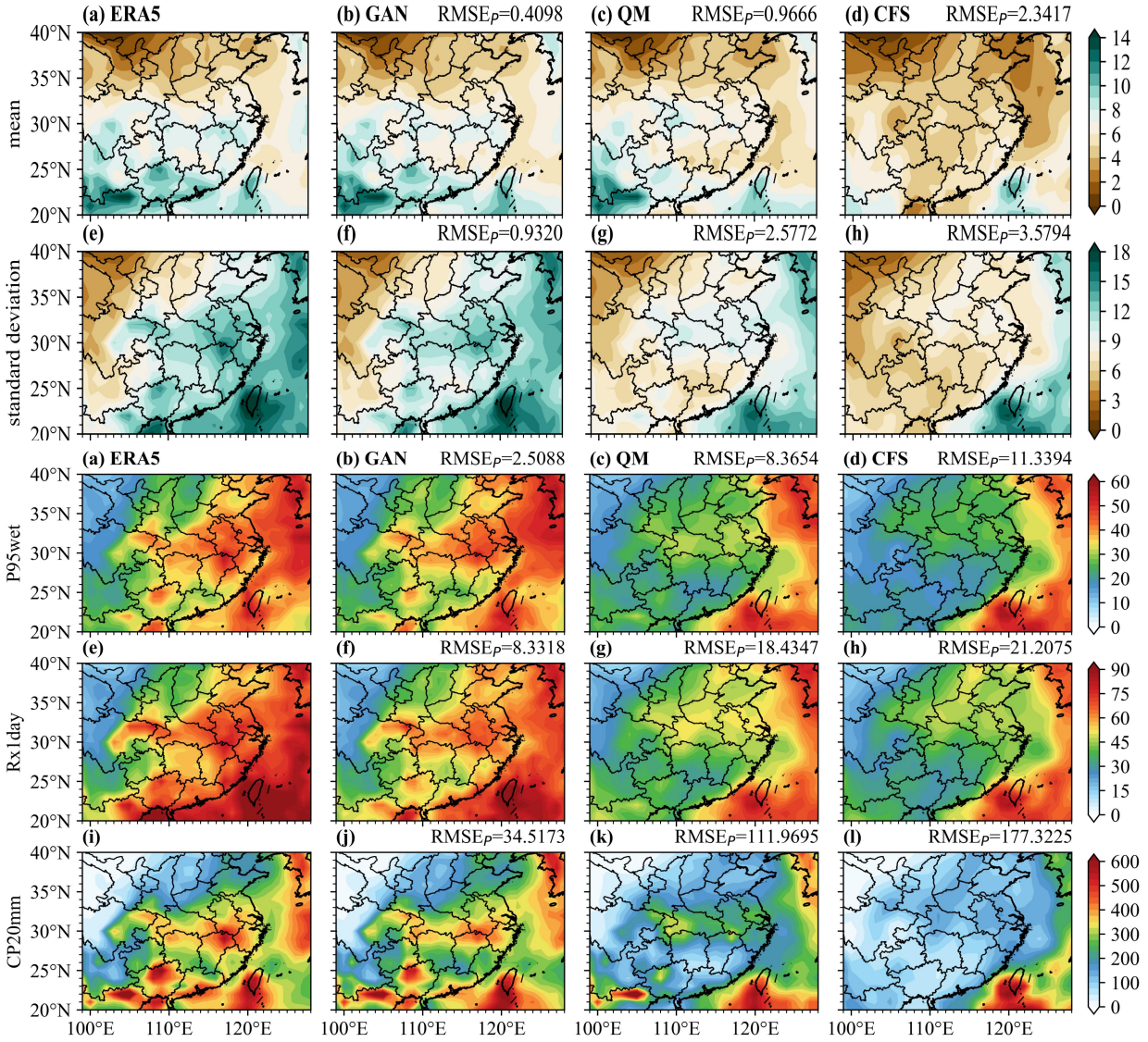




S Yang, F Ling, Y Li, and J-J Luo, *AI for the Earth Systems*, 2023, https://doi.org/10.1175/AIES-D-22-0078.1

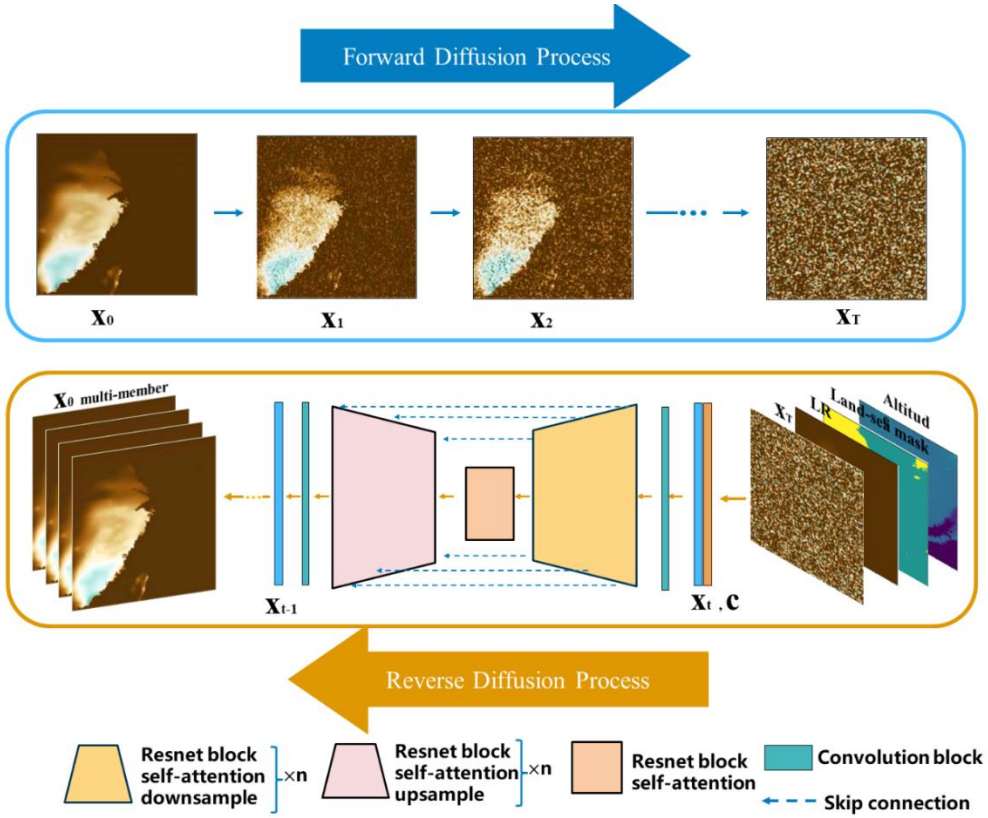
CycleGAN for correcting extreme precipitation forecast over China





S Yang, F Ling, J-J Luo and L Bai, *AAS*, 2025, https://doi.org/10.1007/s00376-024-4003-3

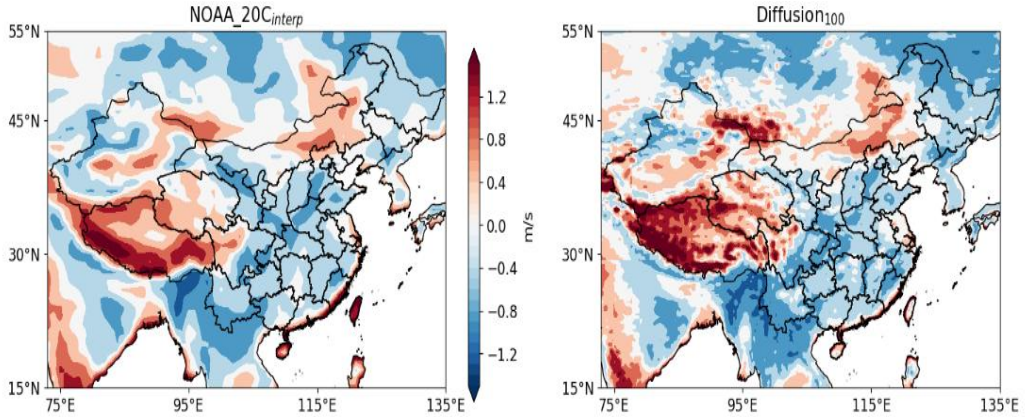
Diffusion probabilistic model for climate downscaling

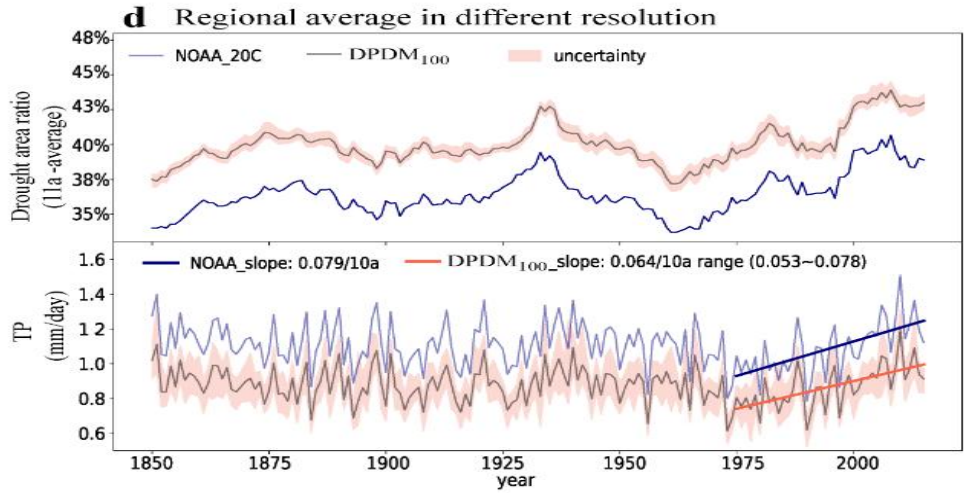


Reconstruction of past 180yr

Δx=100km

Δx=10km

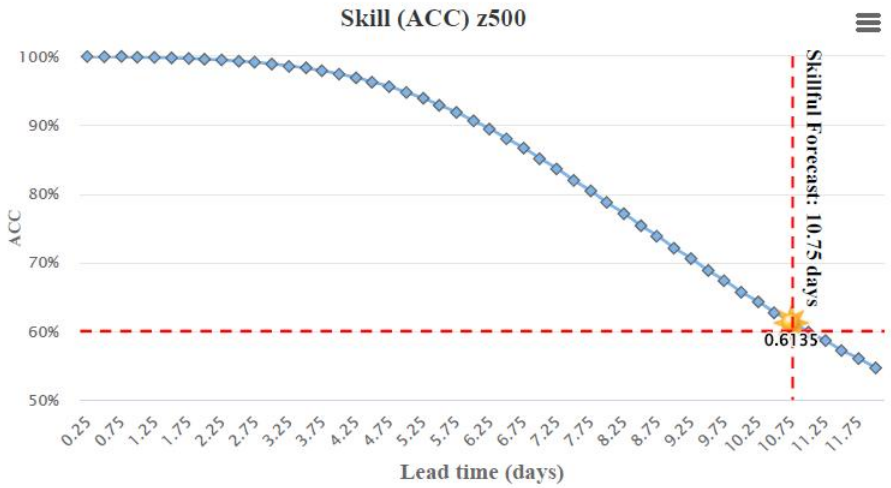


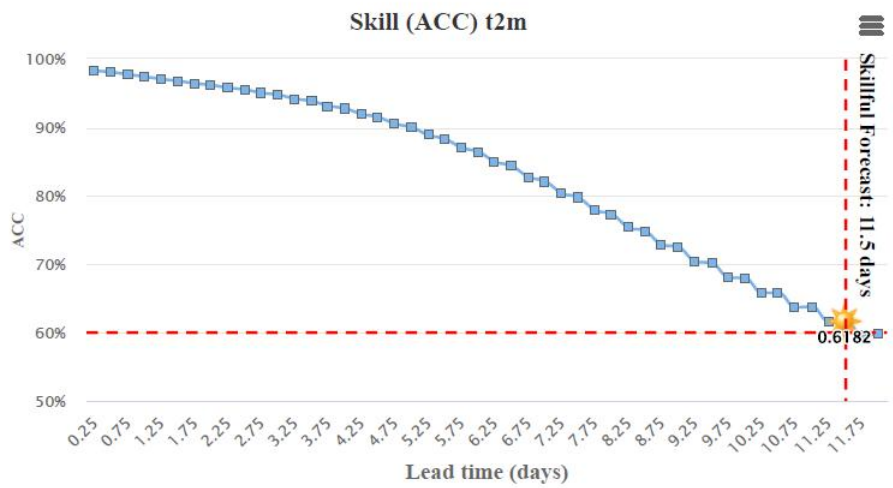


F Ling, Z Liu, J-J Luo, L Bai, SK Behera, D Jin, B Pan, H Jiang, T Yamagata,
npj Climate and Atmospheric Science, 2024, 7 (1), 131.

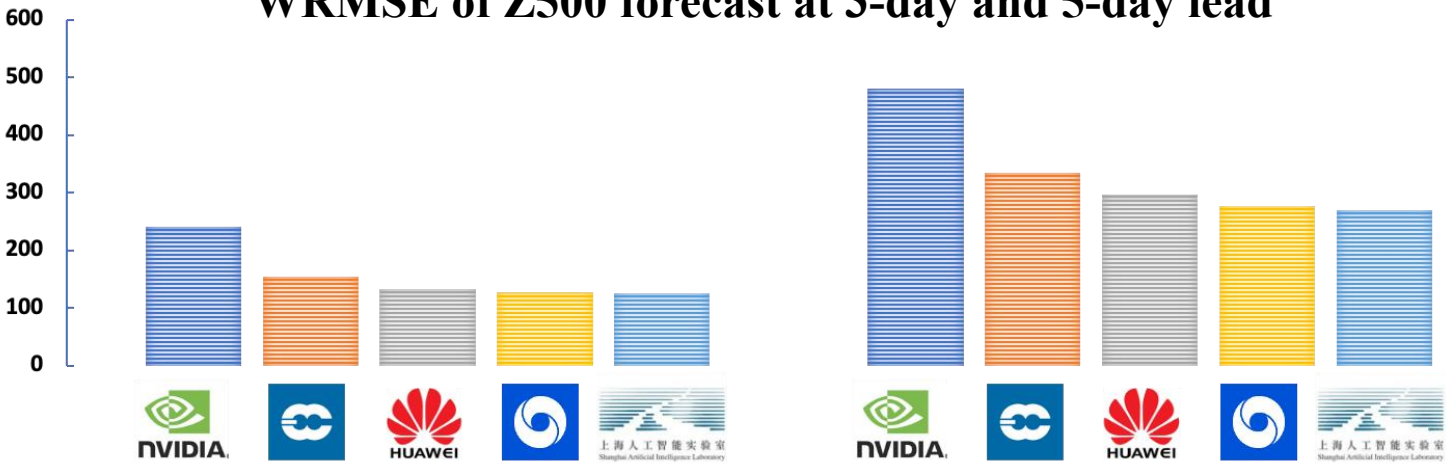
AI global weather forecast model (Fengwu)

0-14 days forecasts (Δx = 25 km, global)



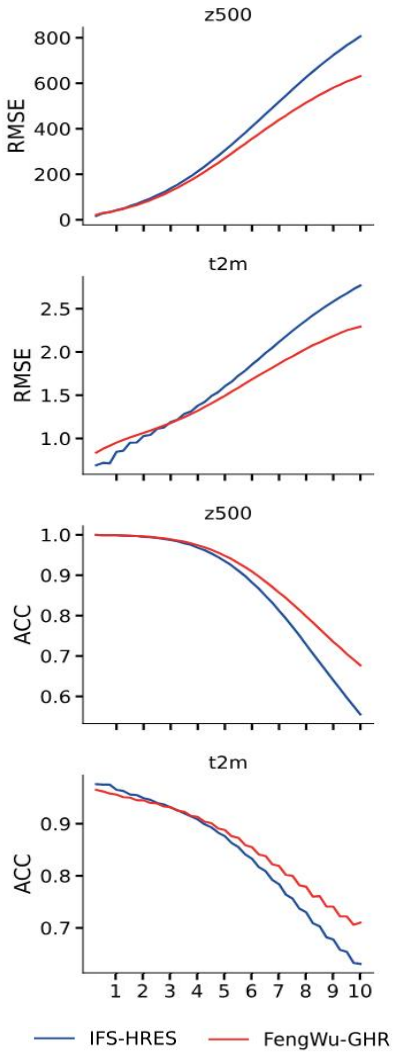


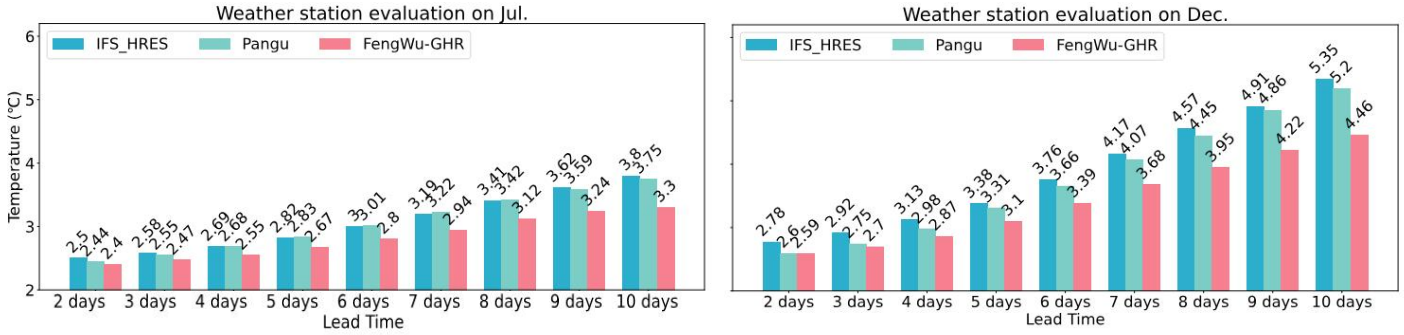
WRMSE of Z500 forecast at 3-day and 5-day lead

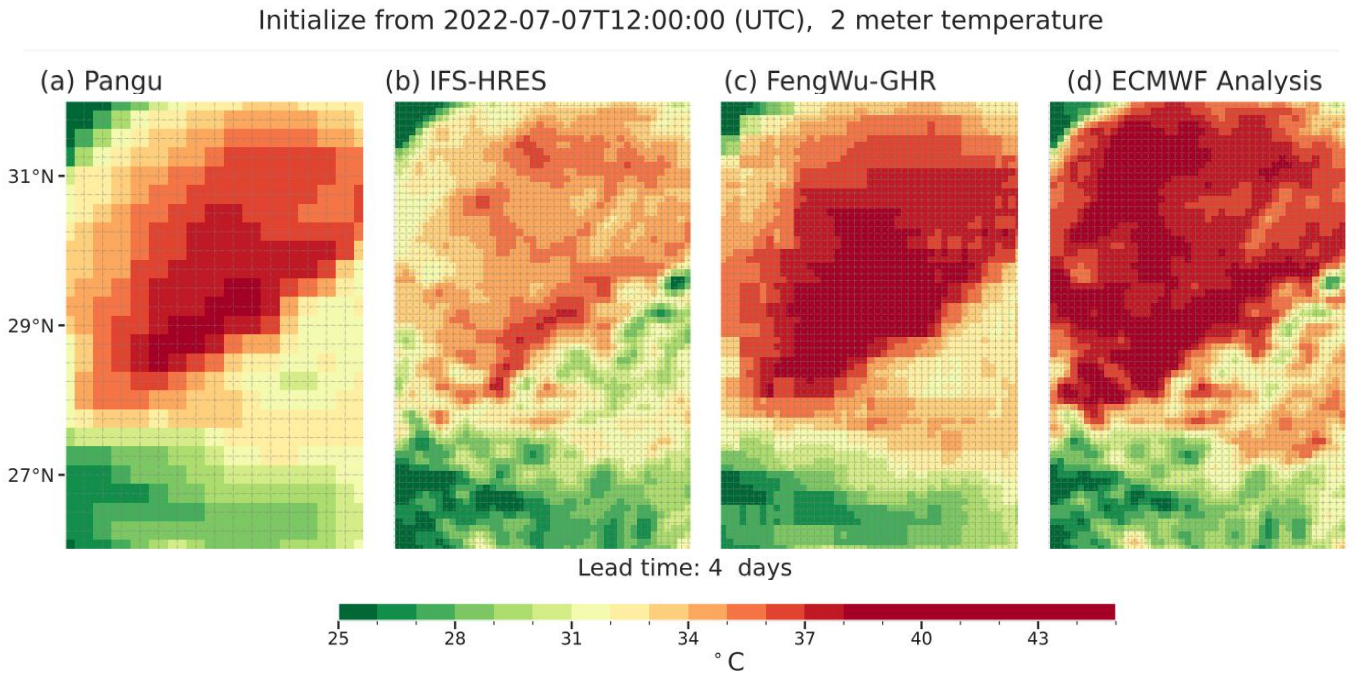


K Chen, T Han, F Ling, J Gong, L Bai, X Wang, J-J Luo, B Fei, W Zhang, X Chen, L Ma, T Zhang, R Su, Y Ci, B Li, X Yang, W Ouyang, 2025, Communications Earth & Environment, https://www.nature.com/articles/s43247-025-02502-y

Fengwu-GHR model (Δx = 9 km, global)



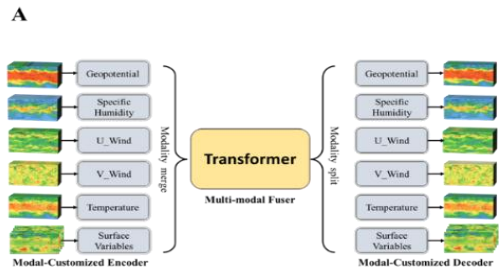




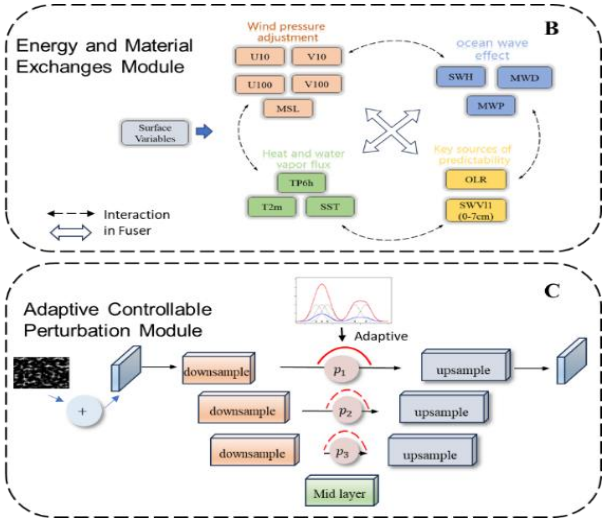
T Han, S Guo, F Ling, K Chen, J Gong, J-J Luo, J Gu, K Dai, W Ouyang, L Bai, 2024, https://arxiv.org/abs/2402.00059

Fengwu-W2S: weather-to-subseasonal ensemble forecast model

Model structure

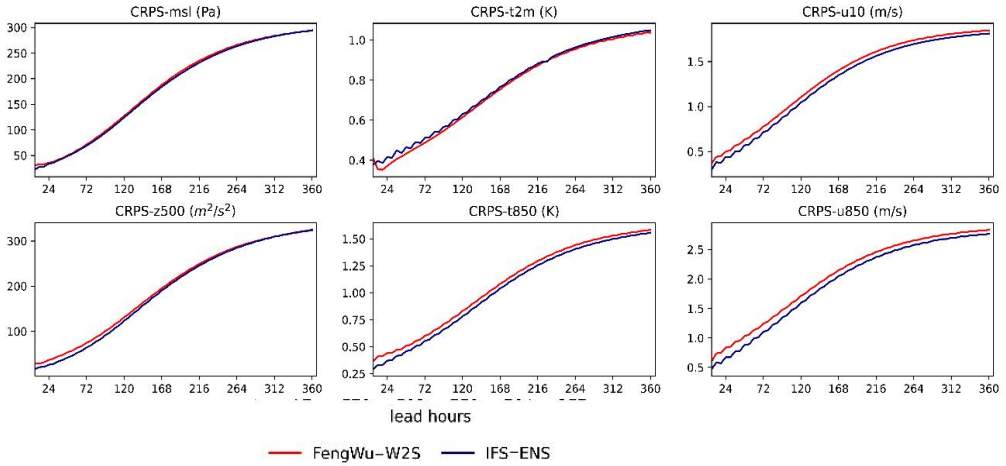


Multimodal Architecture



(Δx = 140 km, global)

Weather forecast skill

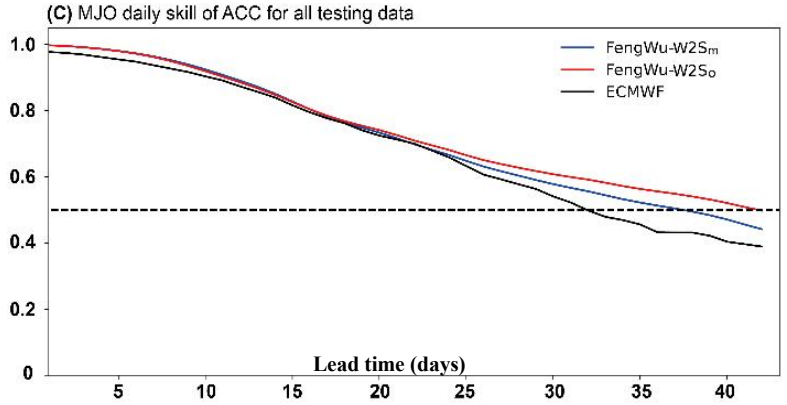


forecast variables

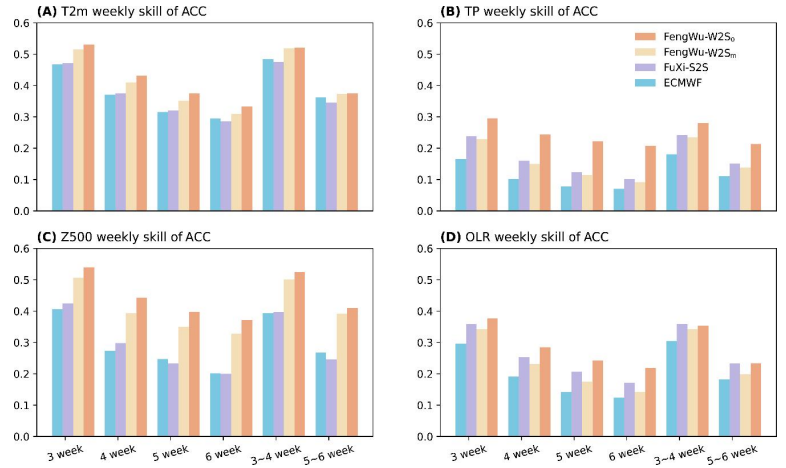
Supplementary Table 1 A summary of all variable names and their abbreviations

Type	Long name	Abbreviation
Upper-air variable (13 levels 50, 100, 150, 200, 250, 300, 400, 500, 600, 700, 850, 925, and 1000 hPa)	Geopotential	Z
	Temperature	T
	Zonal wind	U
	Meridional wind	V
	Specific humidity	Q
Single-air variable	Temperature at 2 meters	T2m
	Total precipitation	TP
	Mean sea-level pressure	MSL
	Zonal wind at 10 meters	U10
	Meridional wind at 10 meters	V10
	Zonal wind at 100 meters	U100
	Meridional wind at 100 meters	V100
	Outgoing longwave radiation	OLR
	Sea surface temperature	SST
Ocean variable	Significant wave height	SWH
	Mean wave direction	MWD
	Mean wave period	MWP
Land variable	Water volume in the soil layer from 0 to 7 cm	SWVL1
	Training period:1979-01-01~2016-12-31	
	Time resolution: 6 hourly	
	Spatial resolution:1.4° latitude/longitude	

MJO forecast skill



Subseasonal forecast skill

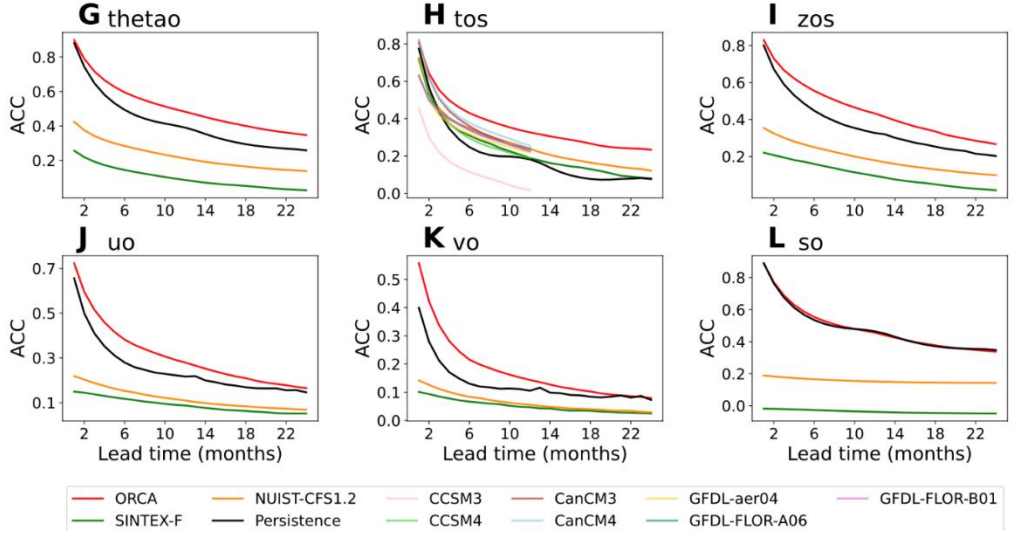


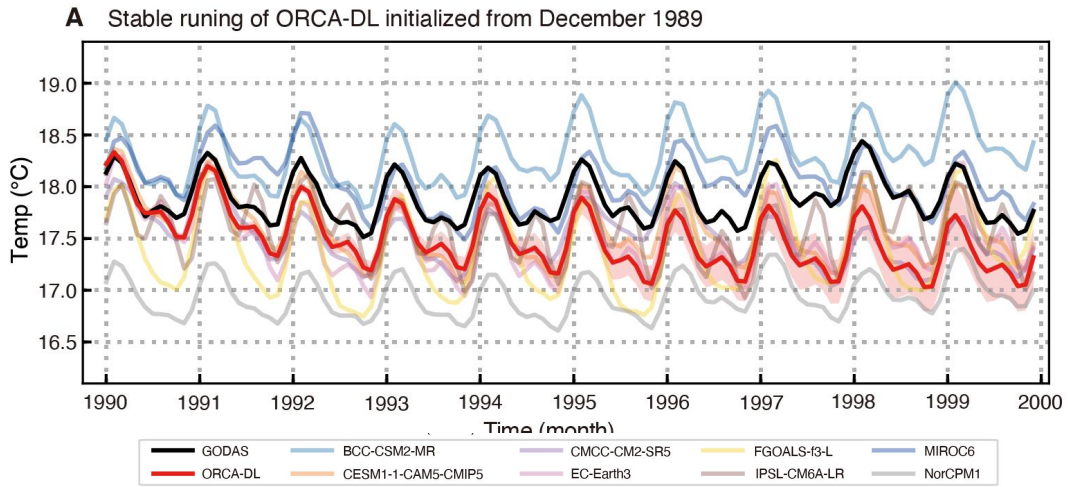
F Ling, K Chen, J Wu, T Han, J-J Luo*, W Ouyang, L Bai*, 2024, https://arxiv.org/pdf/2411.10191

ORCA-DL: A global ocean emulator for seasonal to decadal predictions

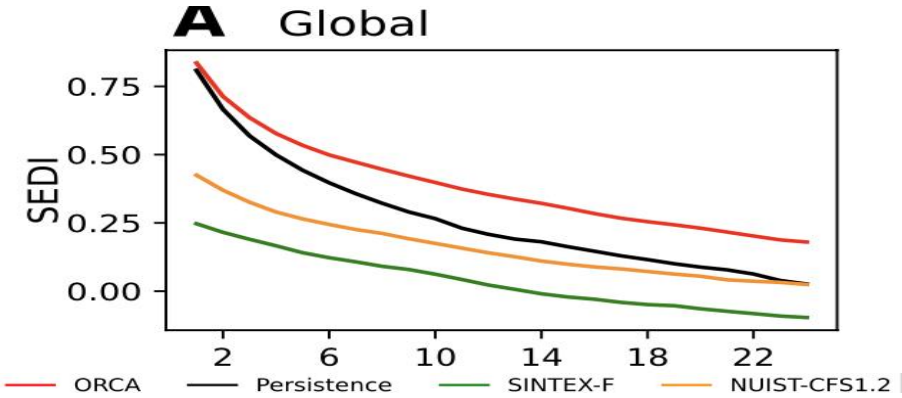
(Δx=100 km, 16 layers within 0-1000m)

Global ocean forecast

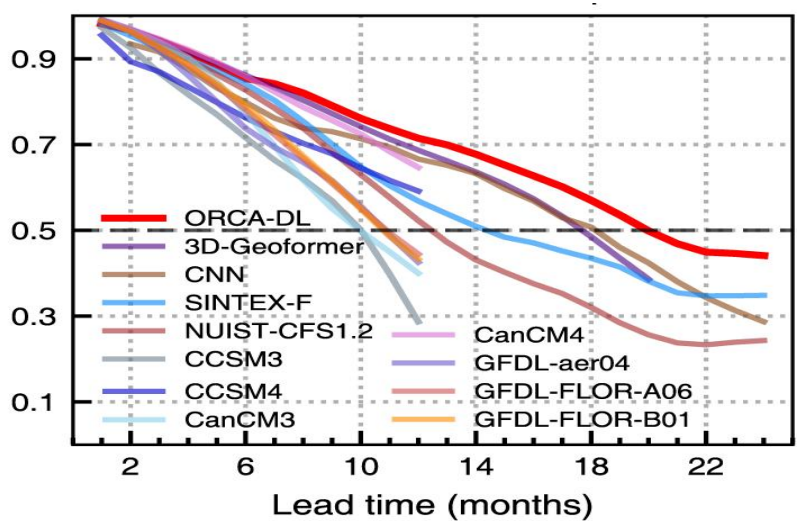




Global marine heatwave forecast



ENSO forecast



Z Guo, P Lyu, F Ling*, L Bai*, J-J Luo*, N Boers, T Yamagata, T Izumo, S Cravatte, A Capotondi, W Ouyang,
2025, https://arxiv.org/pdf/2405.15412, Science Advances *(accepted)*

Thank you!

For future communications,

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Projected changes in population exposure to drought across the Philippines under CMIP6 forcing scenarios SJI Ignacio-Reardon, J Luo, AO Onyango Environmental Research Communications 7 (6), 065026		2025
Global warming increases the risk of crop yield failures driven by climate oscillations L Li, B Wang, P Feng, C Lu, J Jägermeyr, S Asseng, JJ Luo, MT Harrison, ... One Earth 8 (6)		2025
Two major sudden warming events in the unprecedentedly active stratosphere during the boreal winter of 2023/2024 and their distinct surface impacts over China J Xie, J Hu, X Li, JJ Luo, H Xu, Y Jia Atmospheric Research 319, 108032		2025

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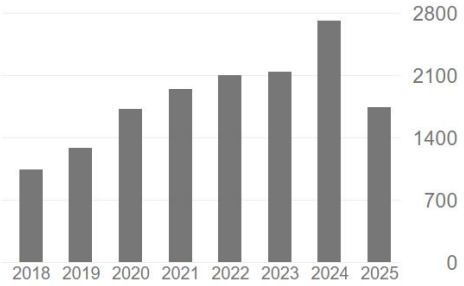

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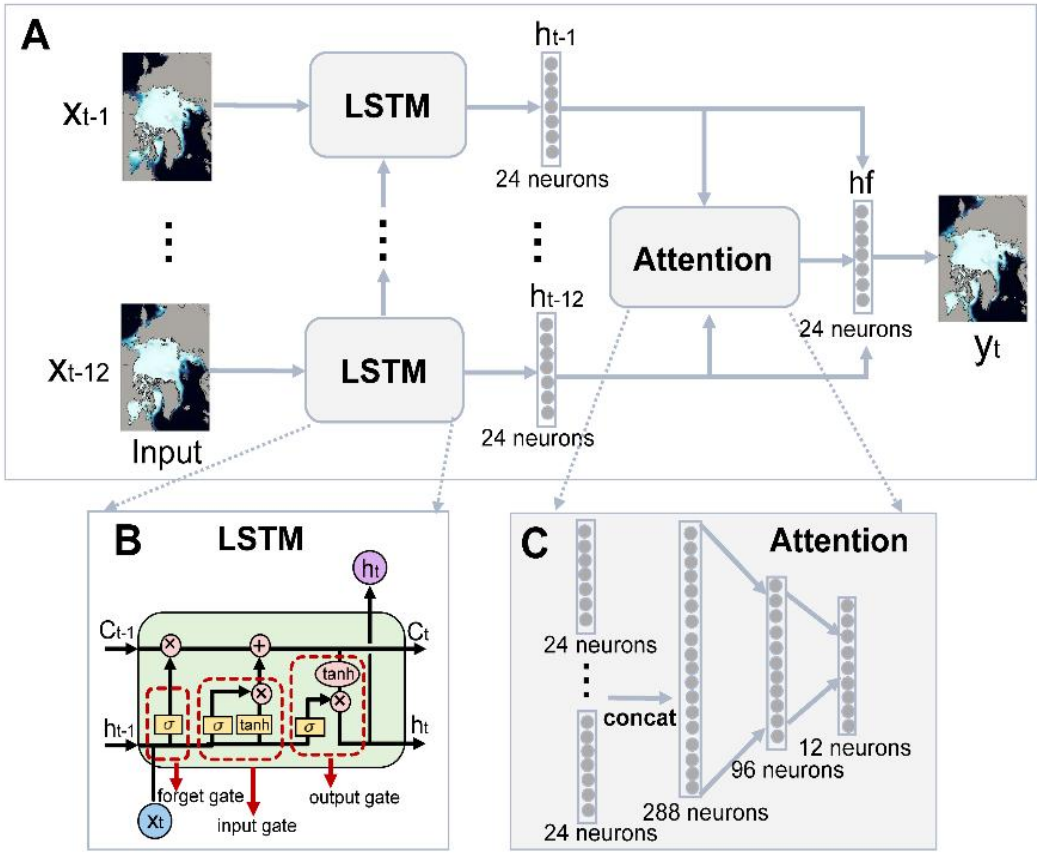
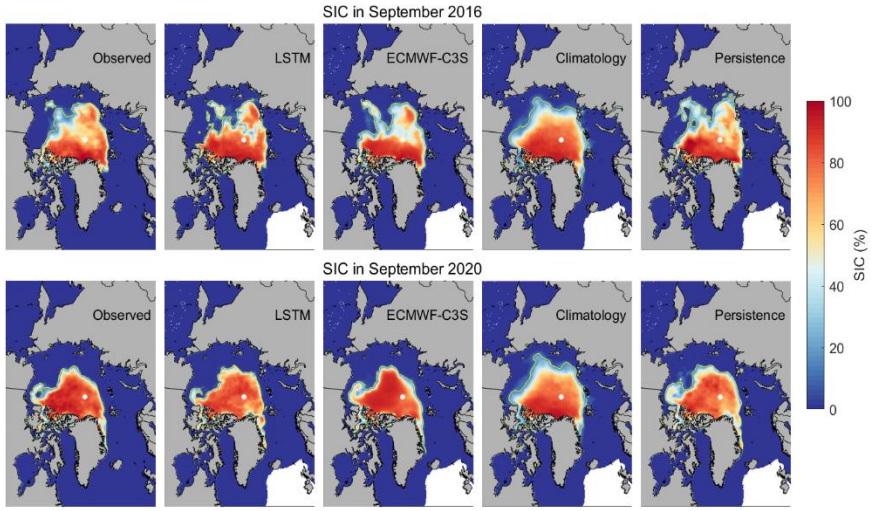
A LSTM model for Arctic sea ice prediction

The skill based on long short-term memory networks is comparable to ECMWF-C3S

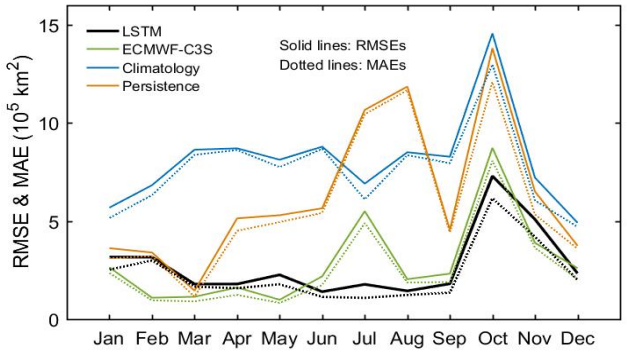
LSTM network structure



Predicted sea ice cover in Sep.

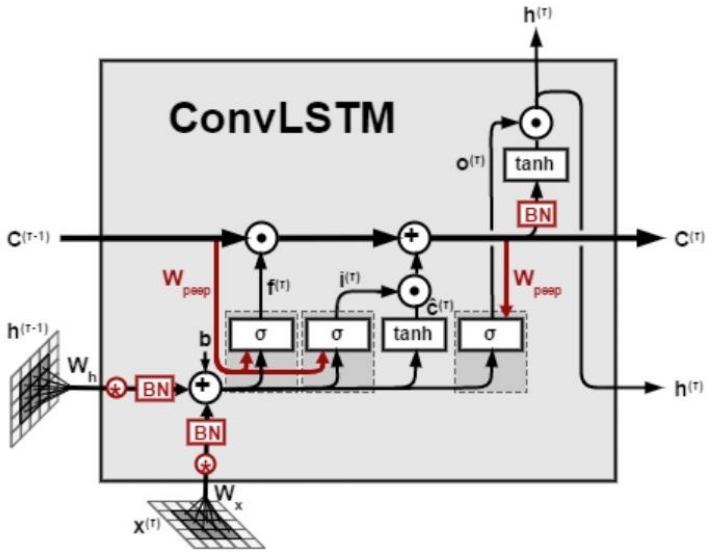


RMSE of 1-month lead prediction



J Wei, R Hang, and J-J Luo, *Frontiers in Marine Science*, 2022,
https://doi.org/10.3389/fmars.2022.860403

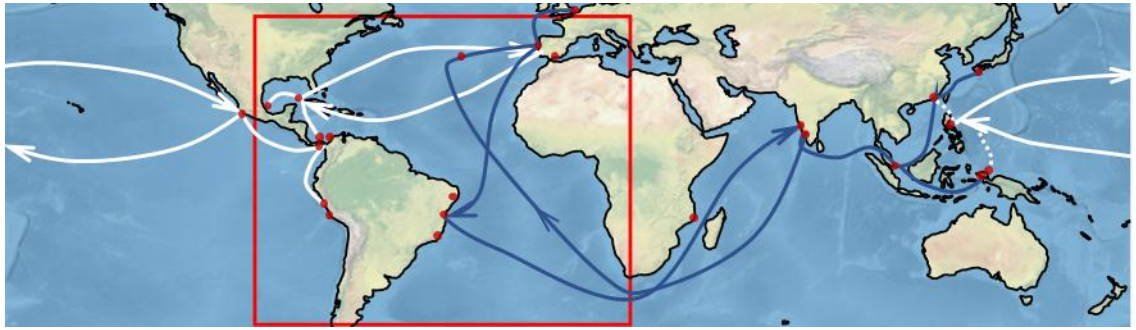
AI forecast of ocean wave



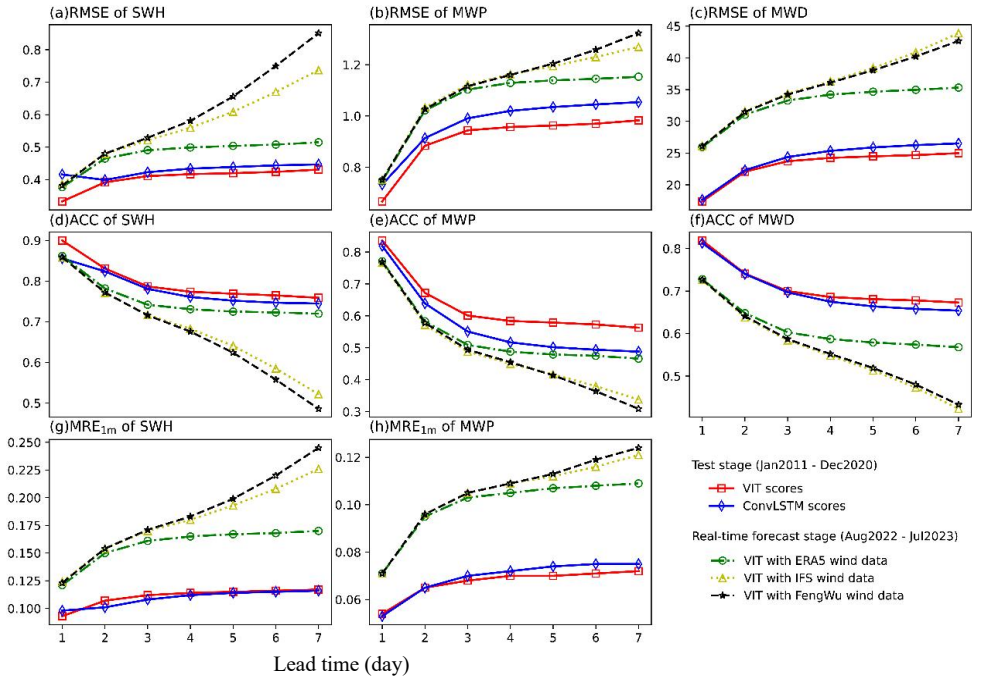
The Atlantic Ocean

	RMSE	ACC
SWH d1	0.27	0.941
SWH d2	0.351	0.879
SWH d3	0.388	0.827
MWP d1	0.555	0.909
MWP d2	0.875	0.733
MWP d3	0.999	0.617
MWD d1	28.038	0.871
MWD d2	36.143	0.769
MWD d3	39.767	0.698

L Ouyang, F Ling, Y Li, L Bai, and J-J Luo, *AOSL*, 2023, https://doi.org/10.1016/j.aosl.2023.100347

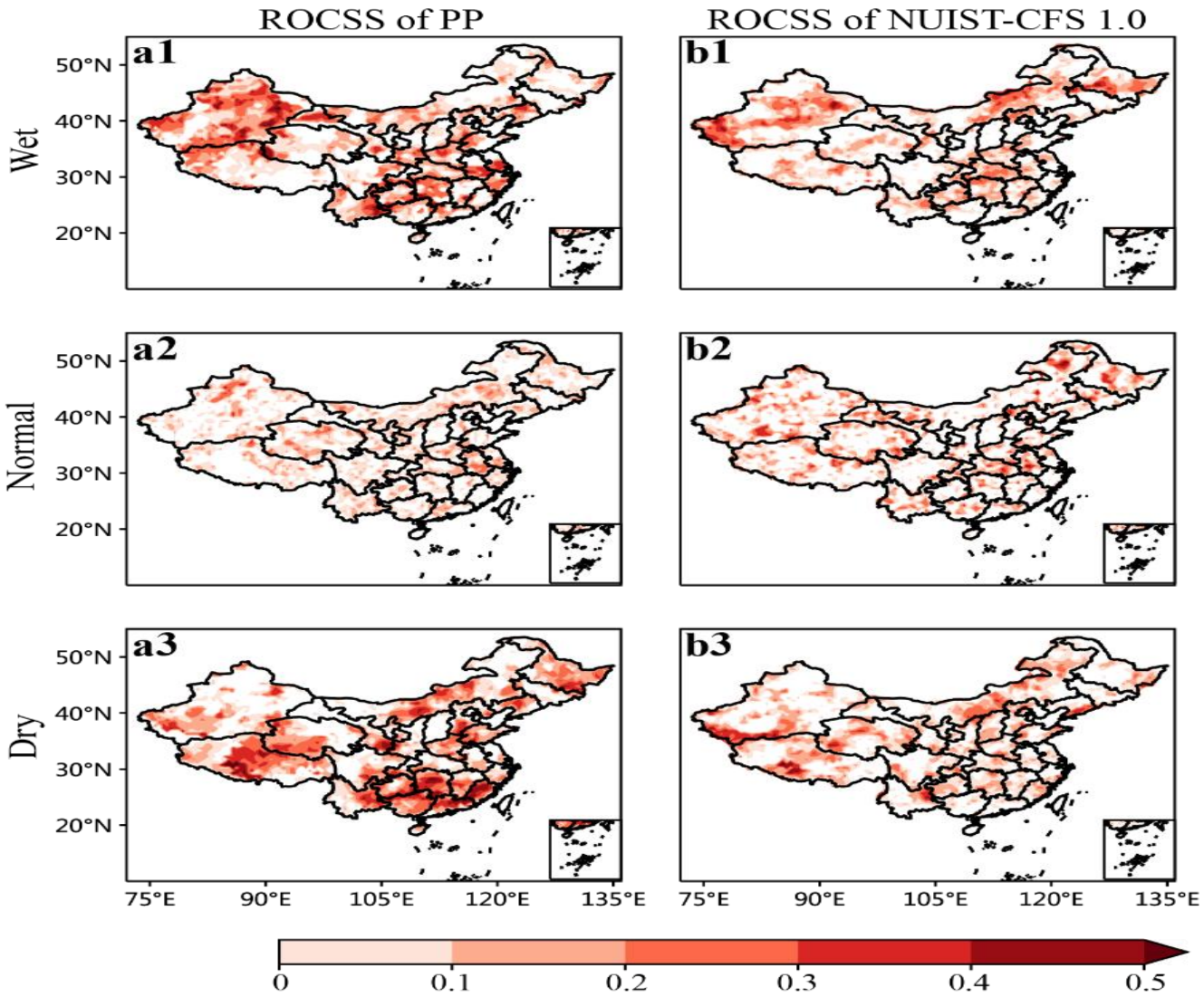


Vision Transformer (global)



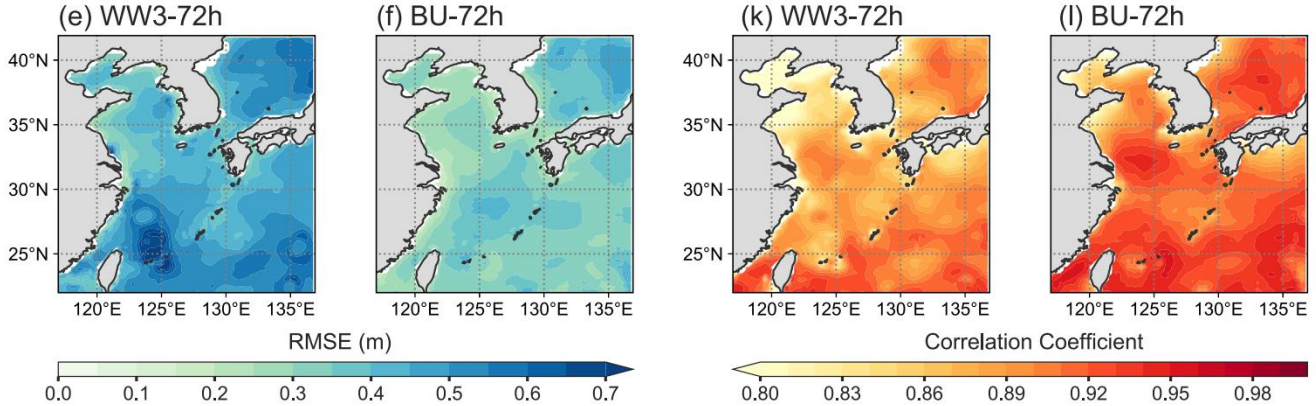
F Ling, L Ouyang, B R Larbi, J-J Luo, T Han, X Zhong, L Bai, *Science China Earth Sciences,* 2024, 10.1007/s11430-024-1452-3.

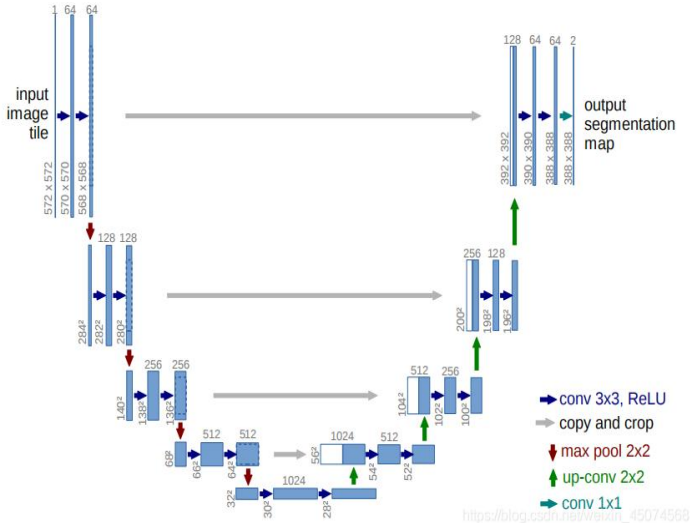
Improve probabilistic forecast of JJA precipitation using Conditional Variational auto-Encoder



F Ling, Y Li, J-J Luo, X Zhong, and Z Wang, *ERL*, 2022,
https://doi.org/10.1088/1748-9326/aca68a

AI correction of WW3 wave forecasts





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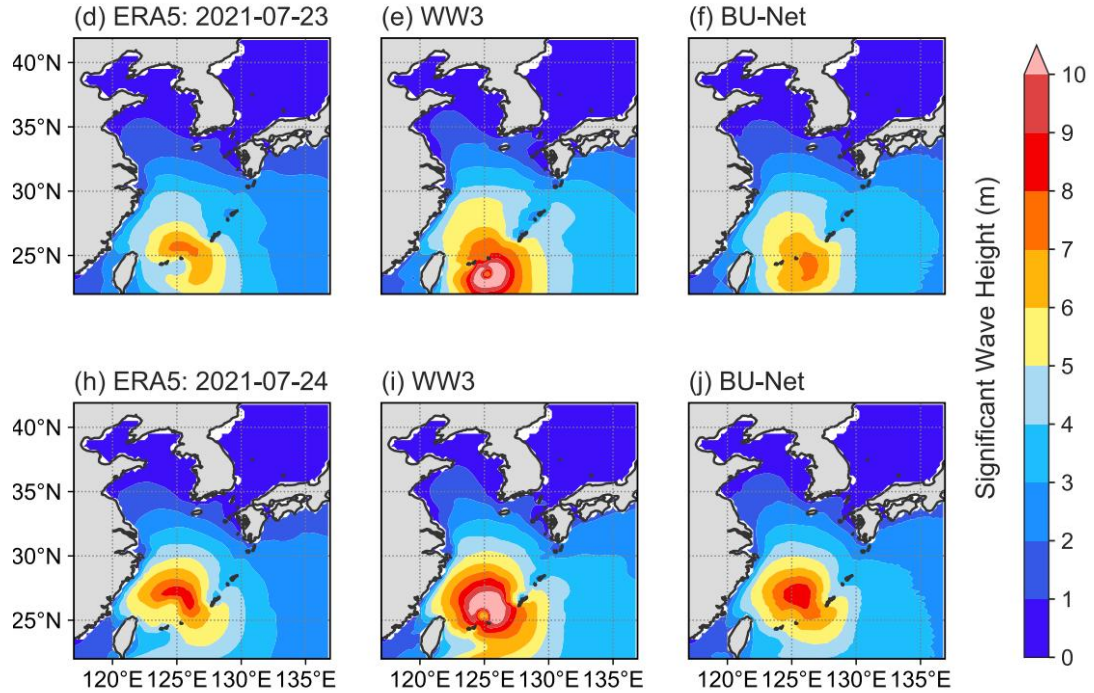
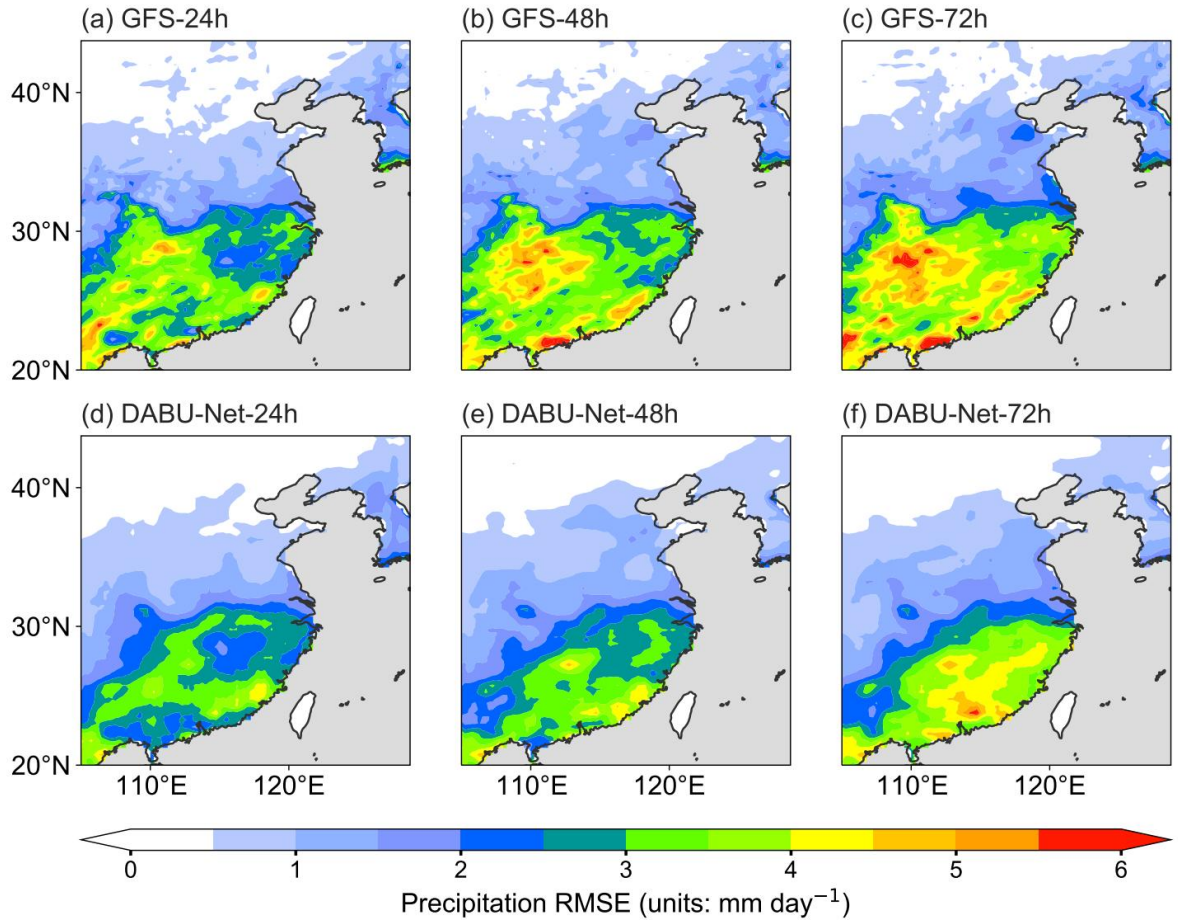
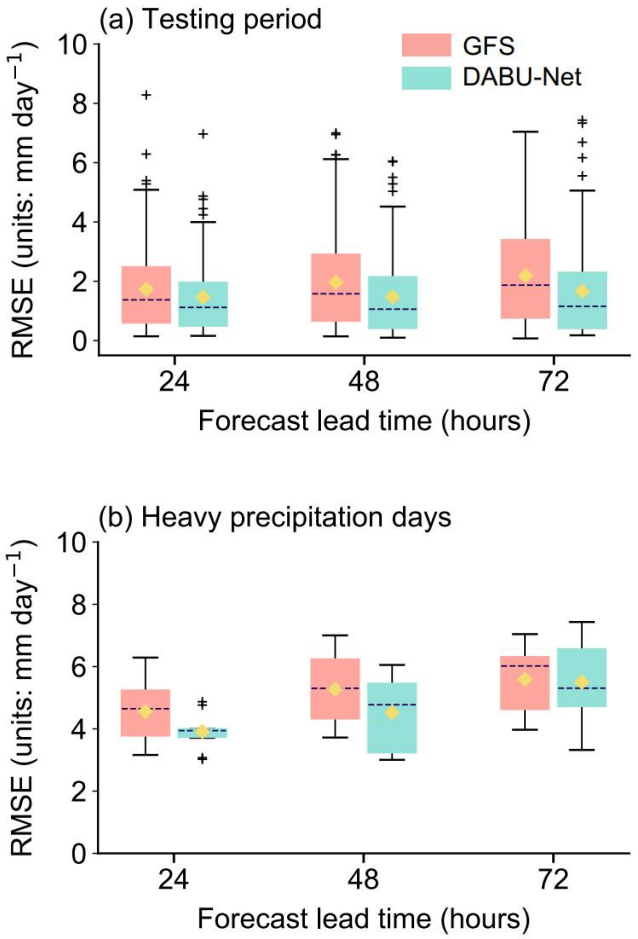


D Sun, W Huang, Y Luo, J-J Luo, J S Wright, H Fu, and B Wang,
GRL, 2022, https://doi.org/10.1029/2022GL100916

AI correction of GFS winter precipitation forecast





D Sun, W Huang, Z Yang, Y Luo, J-J Luo, J S Wright, H Fu, and B Wang,
GRL, 2023, https://doi.org/10.1029/2023GL104406

Fengwu-Adas for “end-to-end” forecast (Δx = 25 km)

Data assimilation

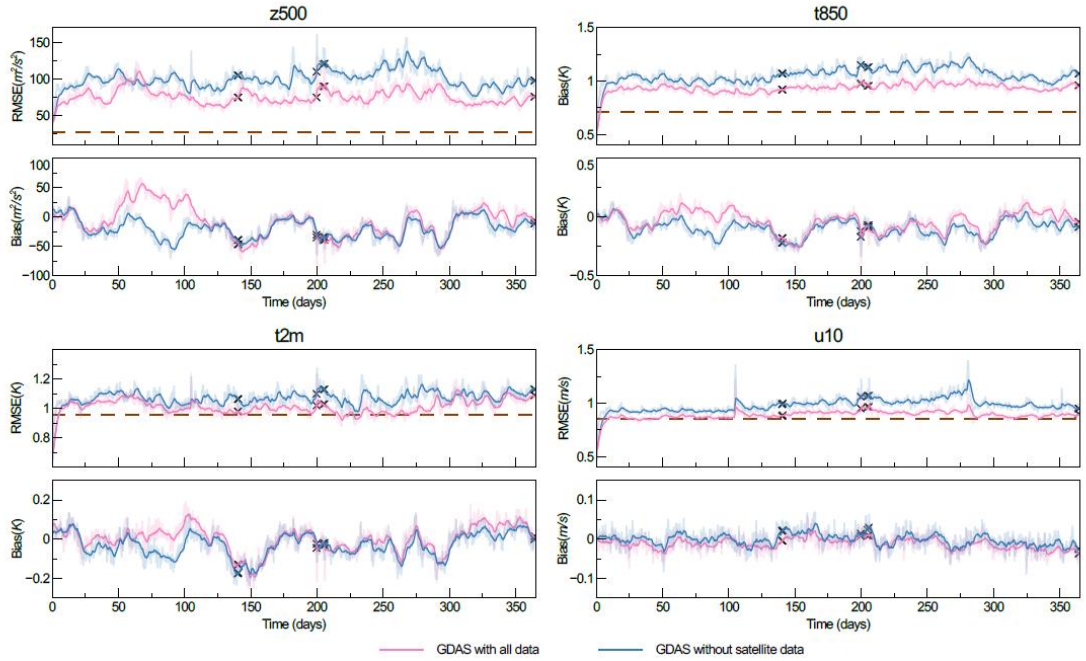
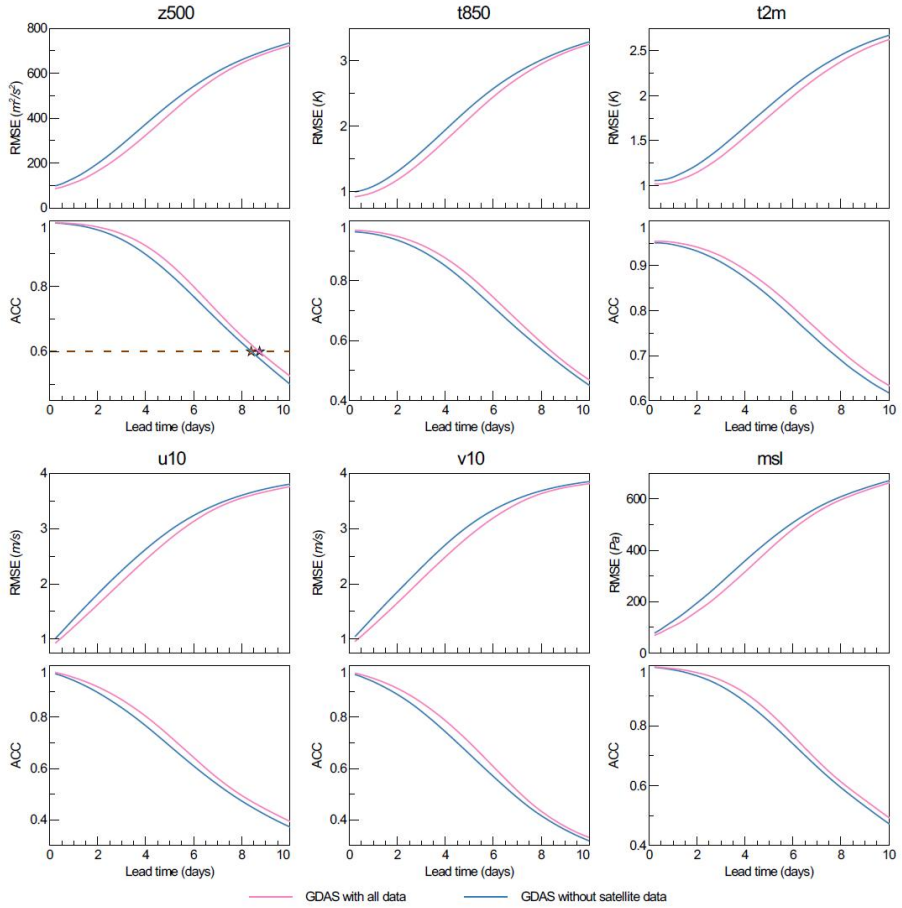


Fig. 5 RMSE and Bias skill of FengWu-Adas in GDAS experiments. Rows 1 and 3 show the RMSE of the analyses for main variables over the year, and rows 2 and 4 show the Bias for them. The different colors represent the analyses after assimilating all data and non-satellite data, as marked in the bottom, and the black crosses indicate that the observations at the corresponding time are missing. The results indicate the ability of our method to assimilate real observational data and the potential for practical applications. See the caption of Fig. 3 for all other details.

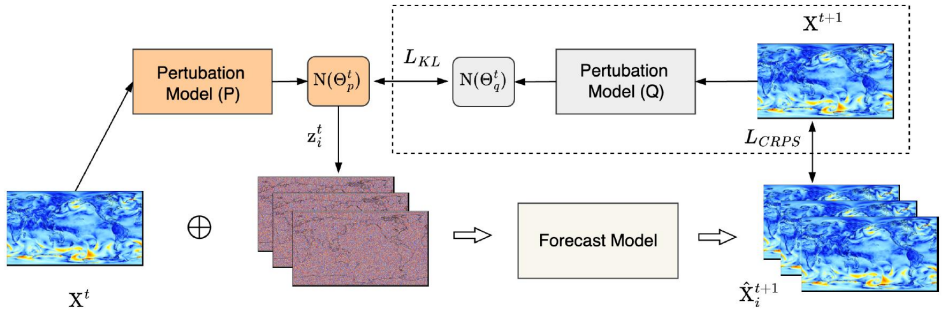
global forecast



K Chen, L Bai, F Ling, P Ye, T Chen, J-J Luo, H Chen, Y Xiao, K Chen, T Han, W Ouyang, 2024, https://arxiv.org/abs/2312.12462

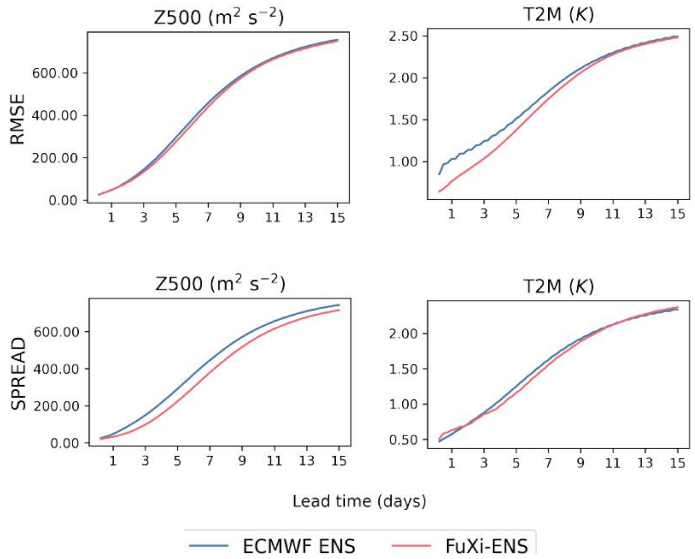
AI ensemble global weather forecast (FuXi-ENS)

Model structure

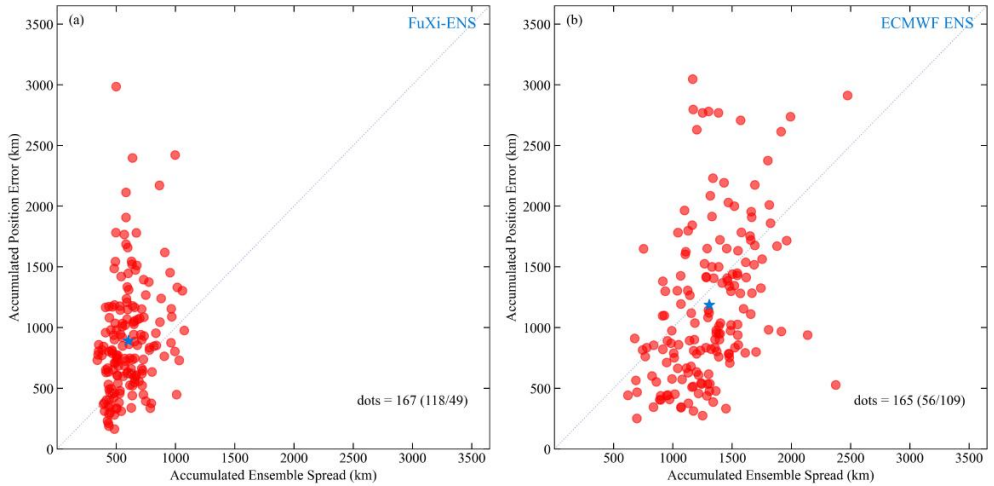


$$L = L_{CRPS}(\hat{X}_i^{t+1}, X_i^{t+1}) + \lambda L_{KL}(N(\Theta^t{}_p, N(\Theta^t{}_q))$$

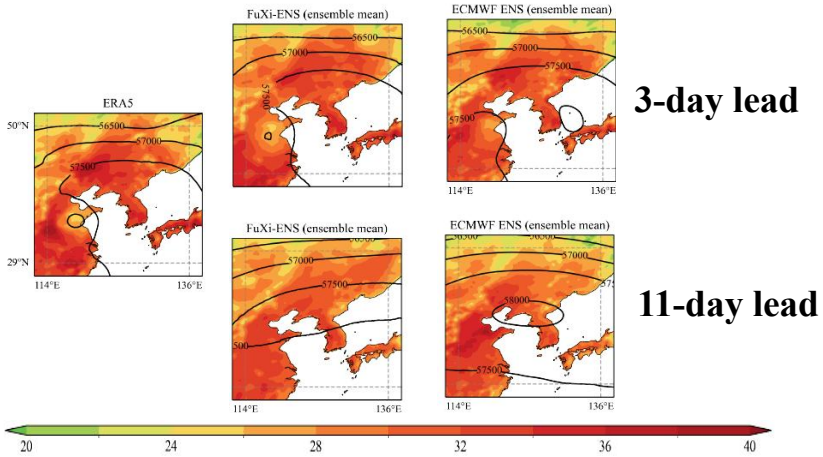
48 members



72-hr forecast of TC



Heat wave on July 23, 2018



X Zhong, L Chen, H Li, J Liu, X Fan, J Feng, K Dai, J-J Luo, J Wu, B Lu, 2024,
https://arxiv.org/abs/2405.05925, submitted to *Science Advances*