15th ODC Training Course

# New generation ocean to climate coupled models and their applications

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**First Institute of Oceanography, MNR, China**
**1st Sep, 2026 @ Qingdao of China**

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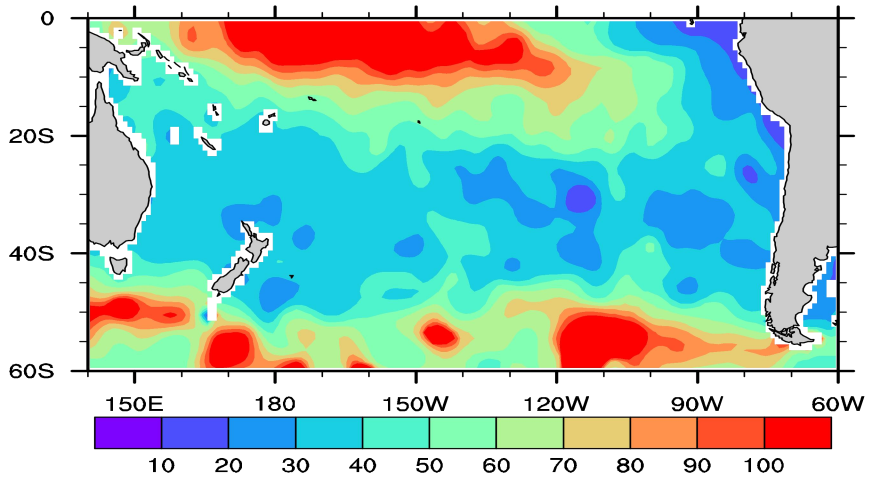
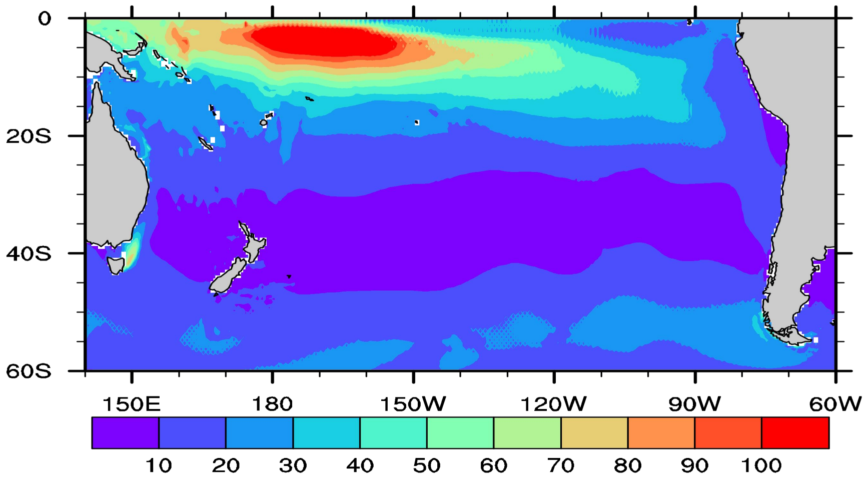
# Challenge 1: Common biases in OGCMs



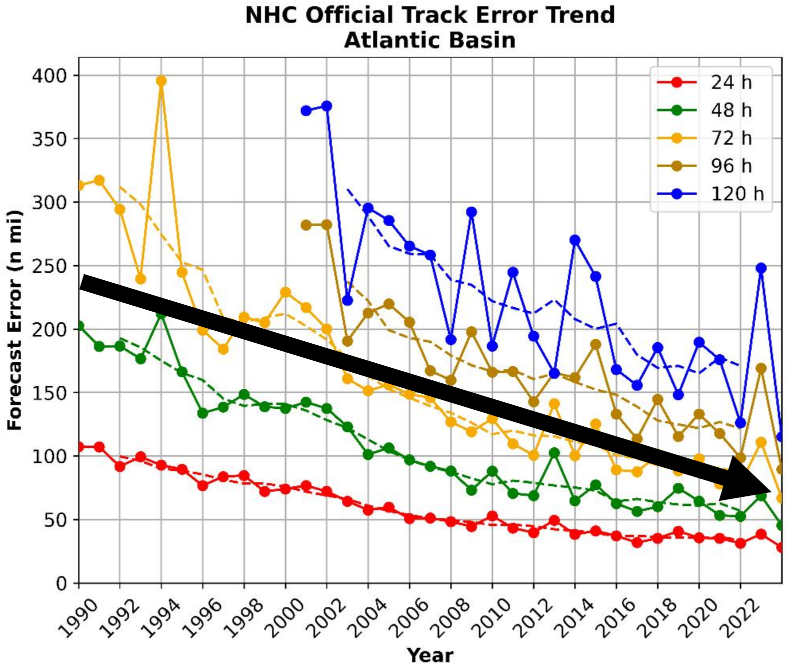

**Observed MLD**

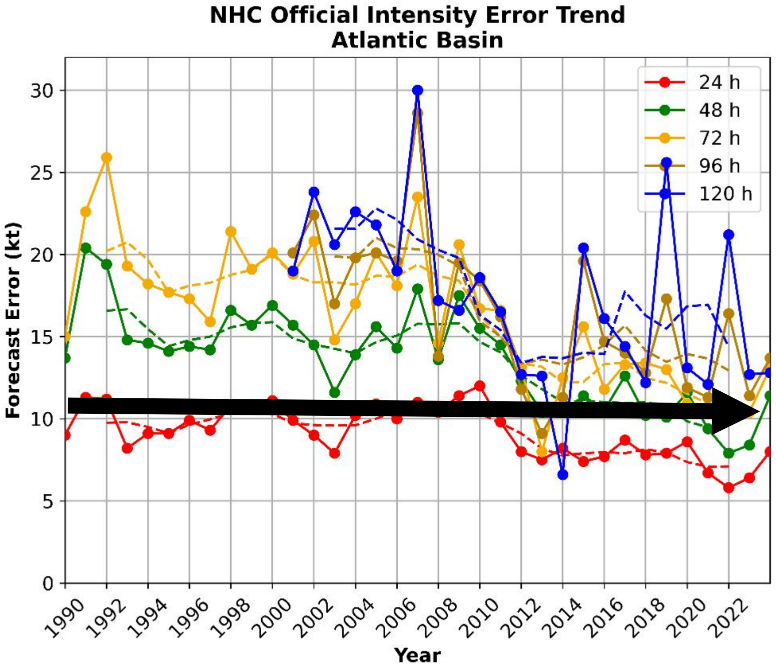



**Simulated MLD**

Qiao et al, 2010, 2016

# Challenge 2: Standstill in forecasting Typhoon intensity

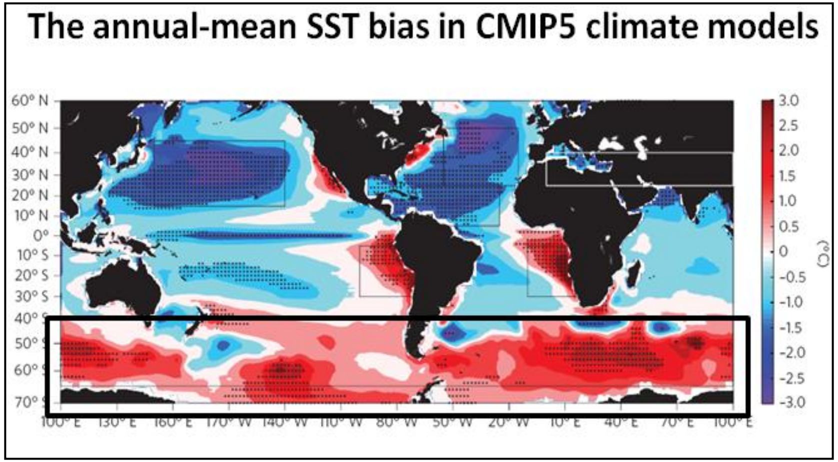


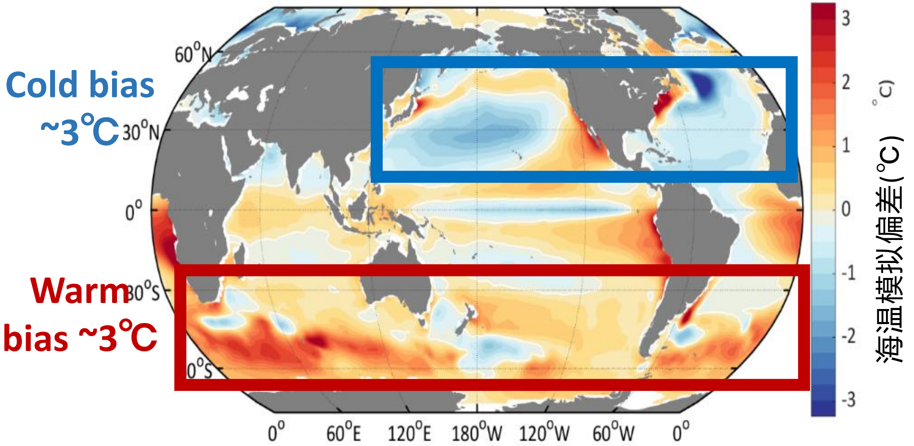

*NHC Annual Report 2024*

NHC https://www.nhc.noaa.gov/data/tcr/

# Challenge 3: Common biases in climate models



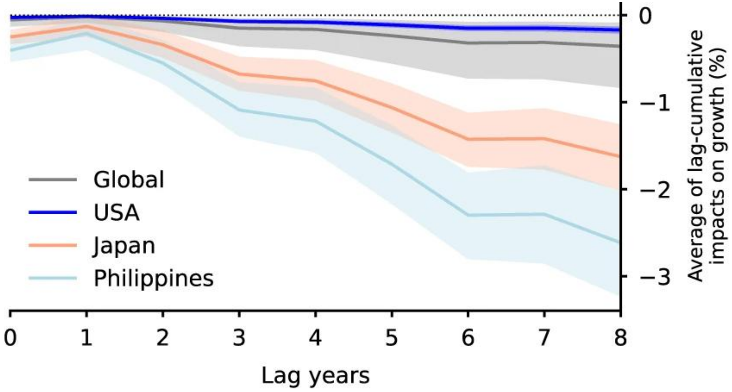

CMIP5



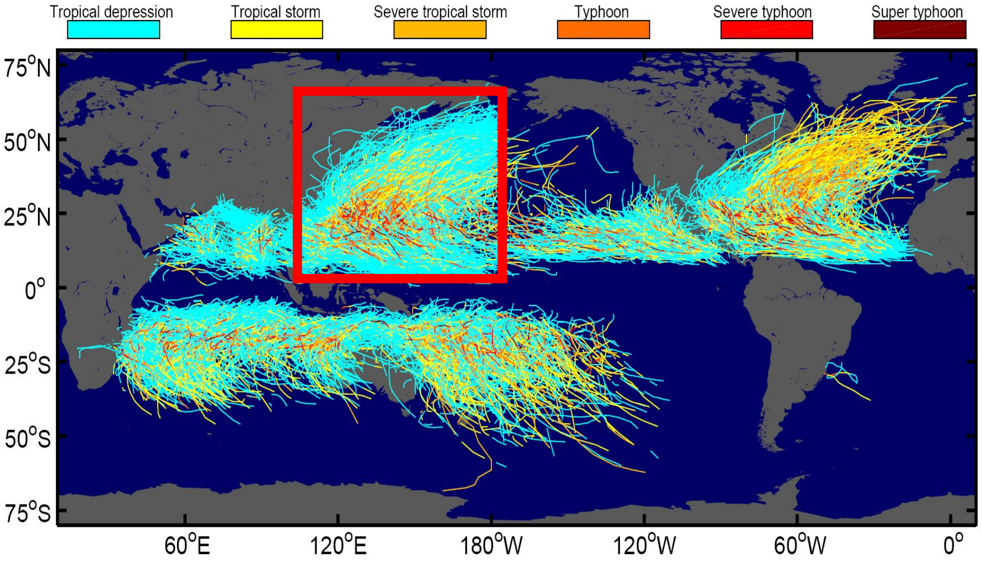

CMIP6

# Focus on TC

- Up to 1 B people exposed, and ~2.6 M lost lives since 19th century
- Recent global economic losses: ~ 700 B$,  >50% uninsured;
- China, ~200B$ since 2000

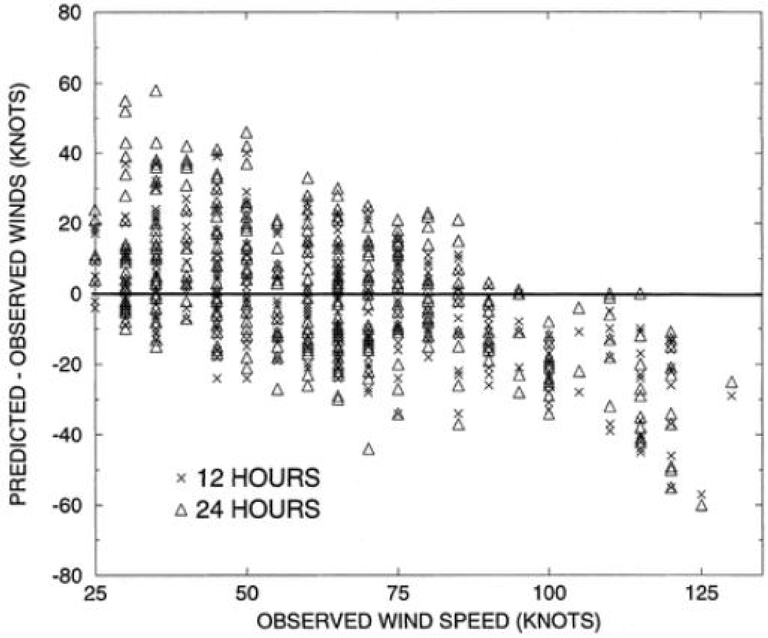


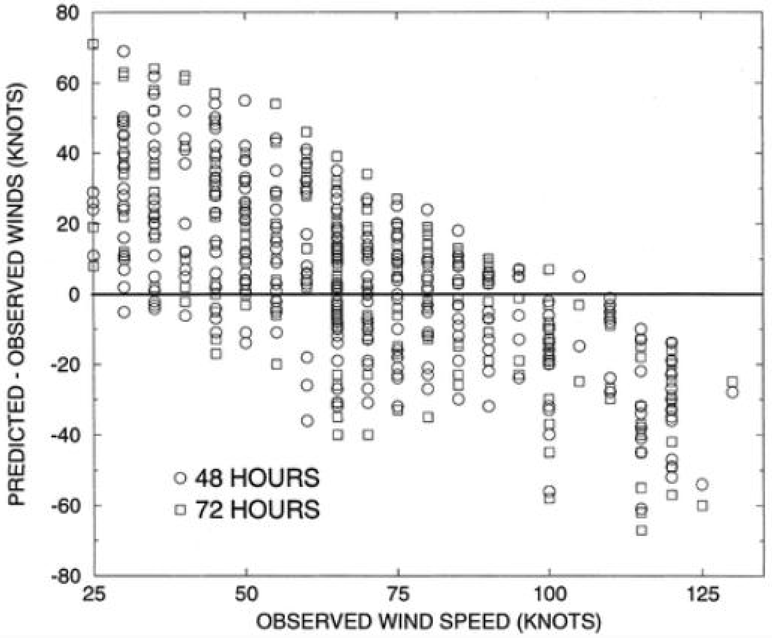

Retarded economic growth



# First generation TC model

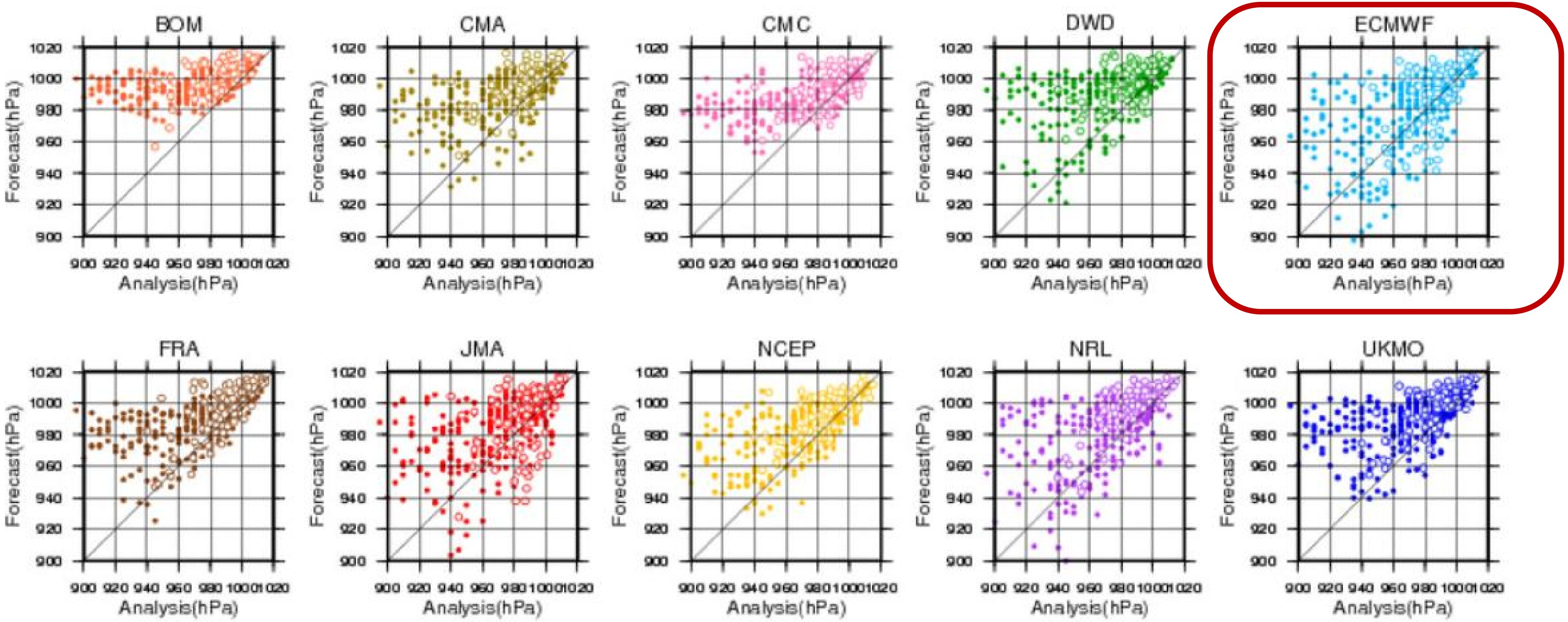
GFDL WIND SPEED BIAS
1995 & 1996 ATLANTIC HURRICANE SEASON




*Bender, M. A. & Ginis, I. 2000*

# Second generation TC model



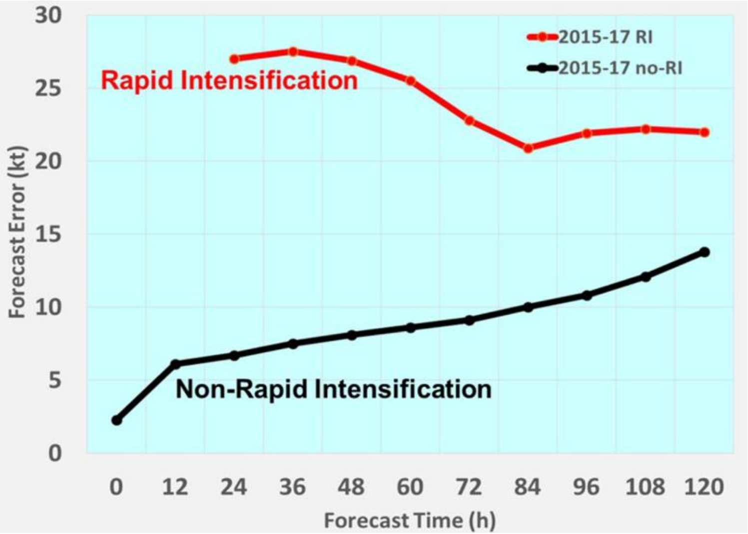

*Yamaguchi, M., Ishida, J., Sato, H. & Nakagawa, M. 2017*

# Rapid Intensification is the key

**TCs forecasting AME during 1989-2018 in North Atl**

| | 12 h | 24 h | 36 h | 48 h |
|---|---|---|---|---|
| AME with RI and sample No. | 15.78 [763] | 21.56 [847] | 29.57 [473] | 33.37 [404] |
| AME with and no RI and sample No. | 6.17 [8403] | 9.58 [847] | 12.05 [473] | 14.21 [404] |
| AME no RI and sample No. | 5.21 [7640] | 8.06 [6718] | 10. 73 [6294] | 12.83 [5598] |

*Trabing, B. C. & Bell, M. M. (2020)*




Rogers, R. F. (2021)

## Breaking Point：cognition on turbulence (mixing and air-sea fluxes)

**Turbulence to model is what virus to epidemic**

“turbulence is *the most important unsolved problem of classical physics."*

—— Richard Feynman (Nobel Prize, 1965)

Werner Heisenberg (Nobel Prize, 1932) was asked what he would ask God, given the opportunity. His reply was: *"When I meet God, I am going to ask him two questions: Why relativity? And why turbulence? I really believe he will have an answer for the first."*

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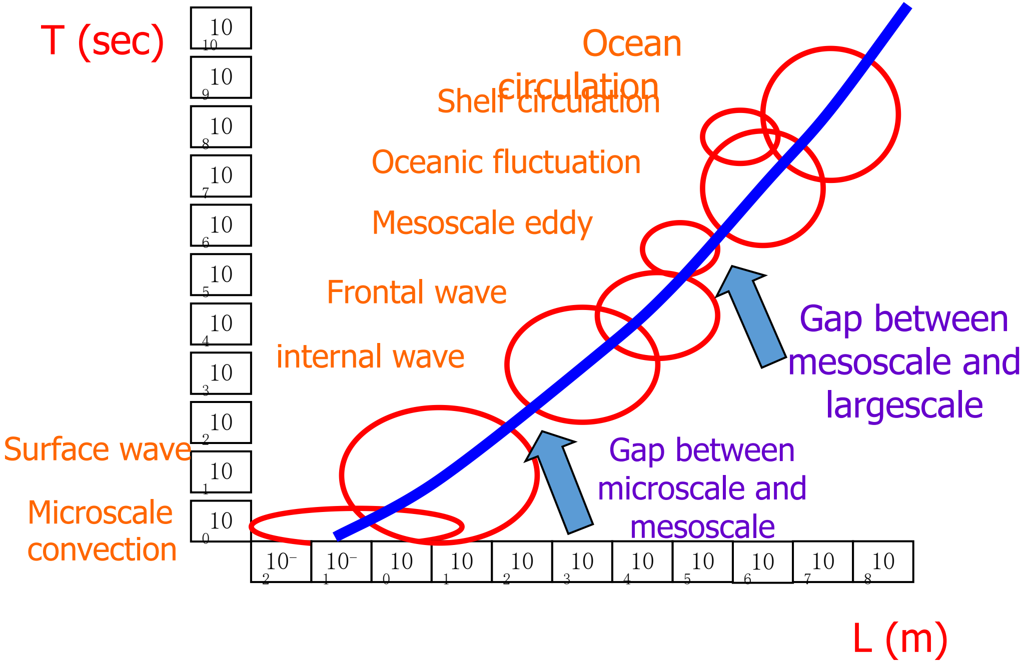
# Ocean system

- Simple system: surface wave/internal wave/tide/ocean circulation: parameterization
- Complex system: all processes combined into one: interaction



# Theory innovation 1: wave-induced mixing

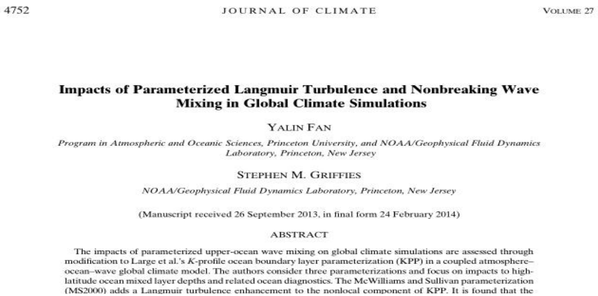
- Wave is a major source of upper-ocean turbulence

$$B_v = \alpha \iint E\left(\vec{k}\right)\exp\{2kz\}\mathrm{d}\vec{k}\,\frac{\partial}{\partial z}\left(\iint_{\vec{k}} \omega^2 E\left(\vec{k}\right)\exp\{2kz\}\mathrm{d}\vec{k}\right)^{\frac{1}{2}}$$

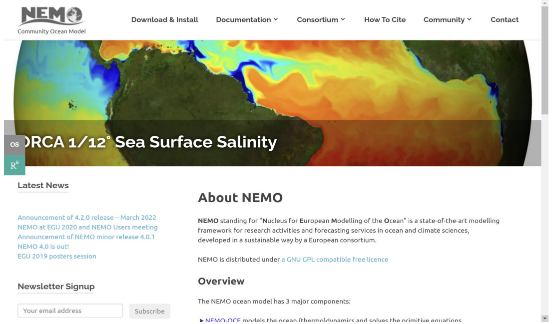
（Qiao et al, 2004， 2010）

- The key of wave-turbulence interaction in intensifying ocean turbulence （Qiao et al, 2016）；
- Reviewed by D'Asaro
- Overturn the statement of J. Lumley (1983): "wave does not generate turbulence"

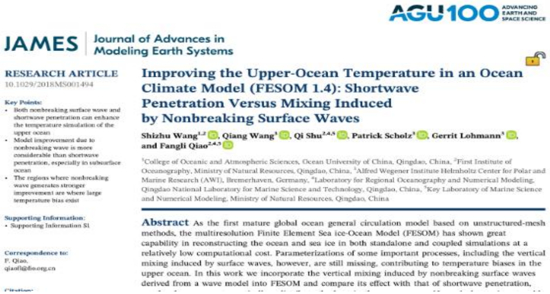
# Theory adopted by leading model development groups



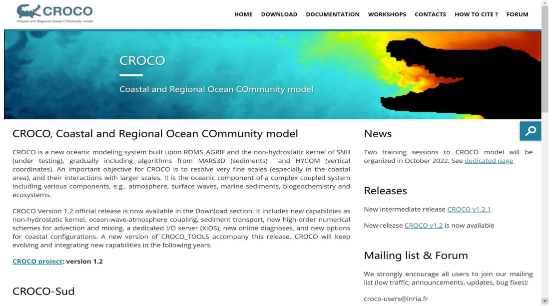

GFDL




NEMO

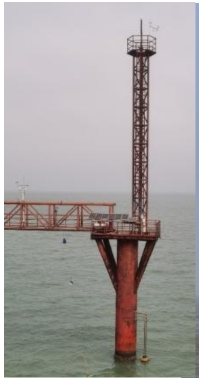



AWI-FESOM



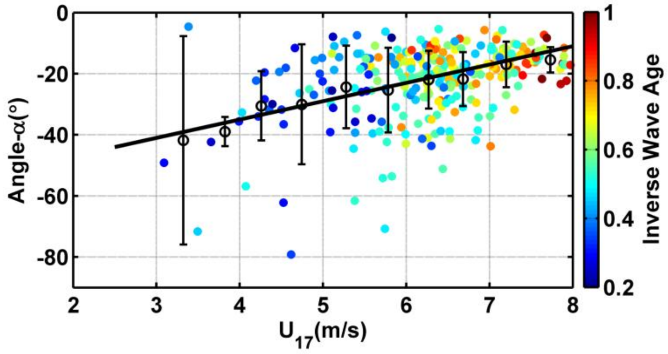

CROCO

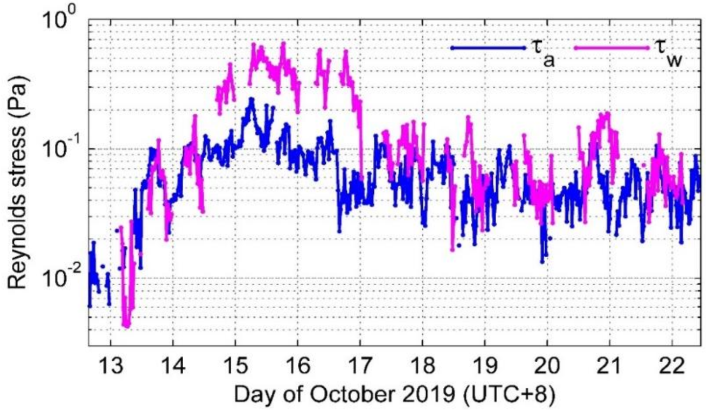
# Surface waves modulate wind stress



- **The concept was proposed by many scientists, including Toba (1961), Stewart (1970), Wu (1975);**
- **Rieder & Smith (1994) reported: "Significant angles between the wind stress vector and the mean wind vector are seen" through FLIP in-situ observation ;**
- **Our group has long-term air-sea fluxes observation at offshore towers for several years to quantify the wave effects in air-sea fluxes**

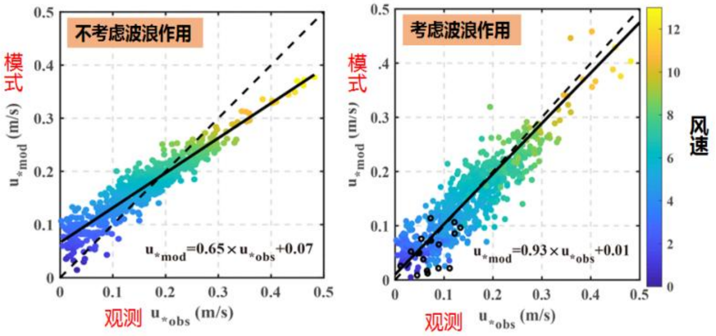
# Theory innovation 2: wave modulates wind stress Cd



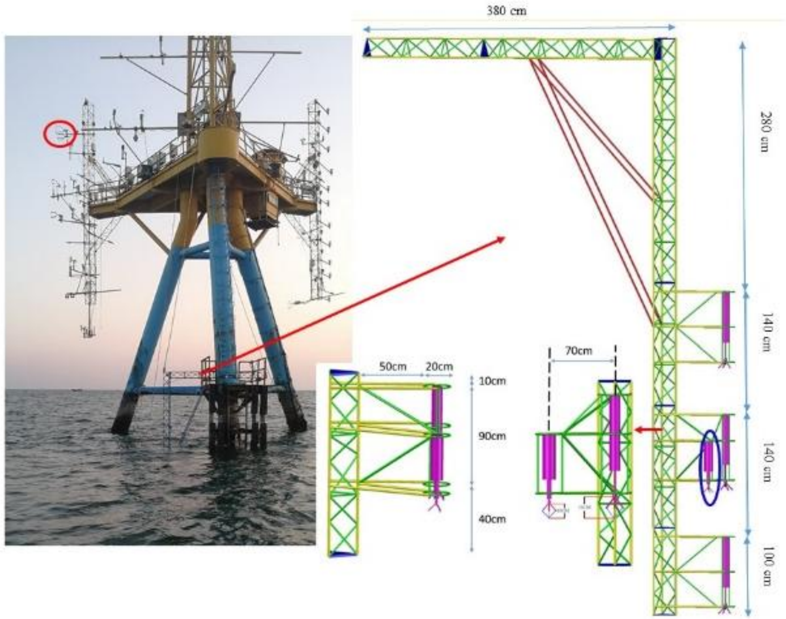



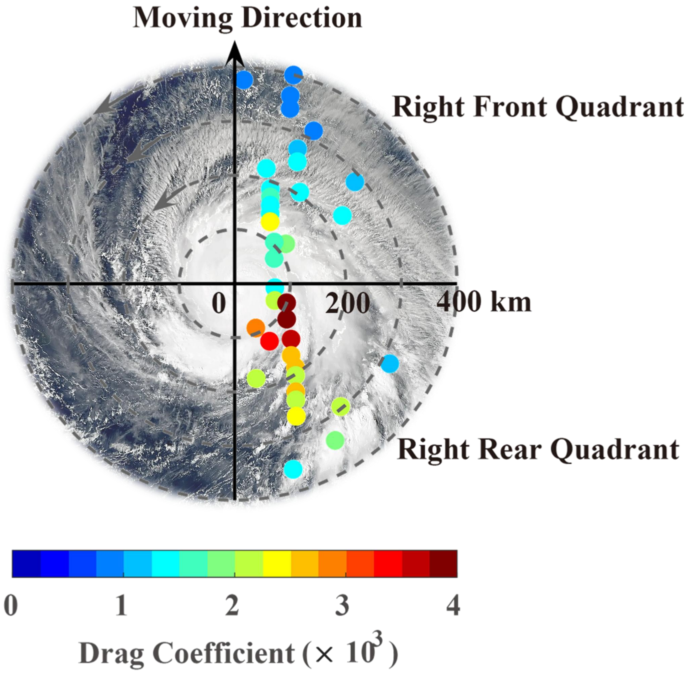

*[Huang and Qiao, 2021, JGR]*

**Reverse the long-standing knowledge on ocean momentum flux**




# Asymmetry of Cd for TC

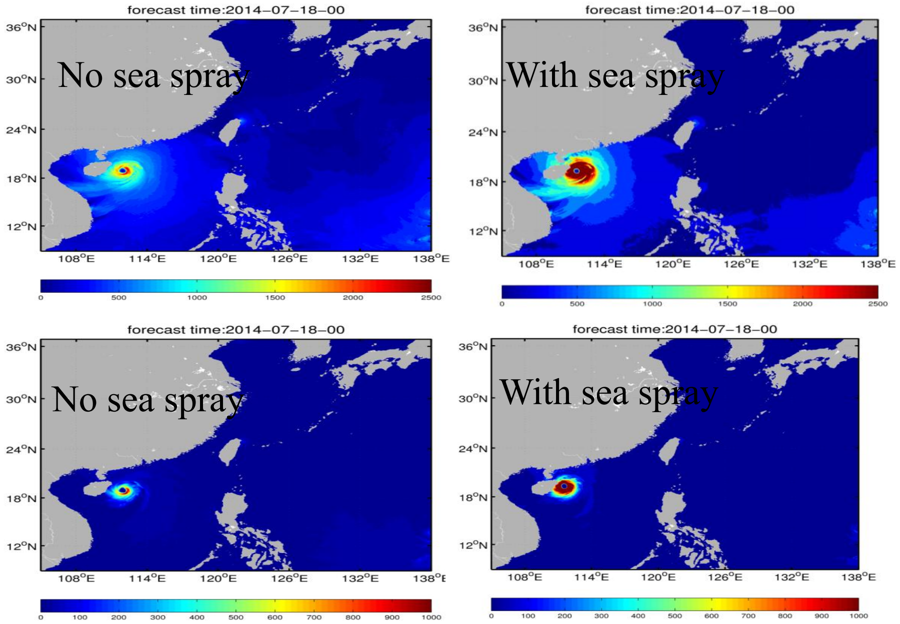



Chen et al., 2022, JGR-Oceans

# Theory innovation 3: sea spray increases heat flux

- Incorporate sea spray into typhoon and Earth system models



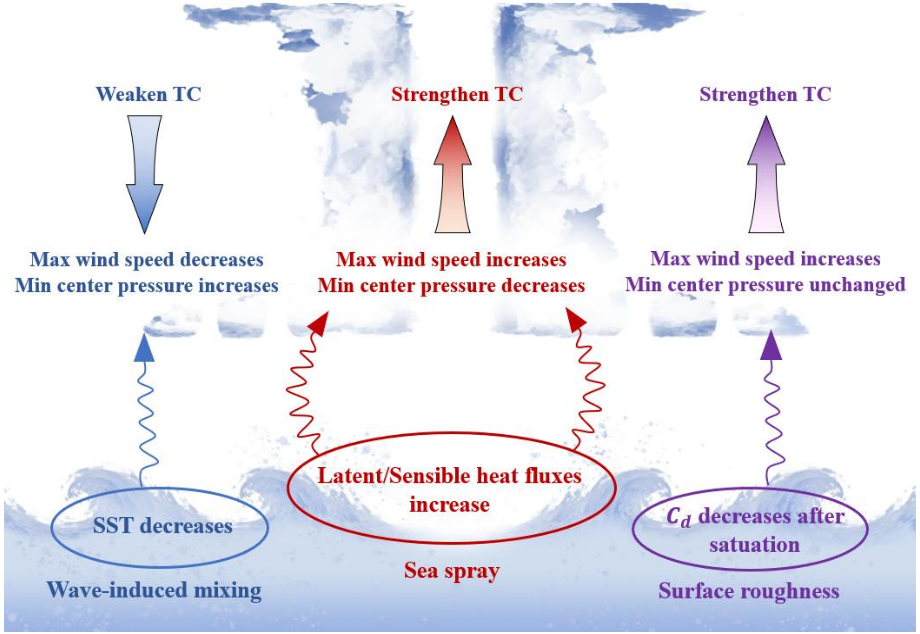

Latent heat flux

Sensible heat flux

Zhao et al, 2017, JGR; Bao et al, 2020, JGR

## From surface wave to climate system

Although as early as 1991, Klaus Hasselmann, the Nobel Prize winner of 2021, suggested that surface waves may play a key role in the climate system， …… Qiao and his team elaborated the way for such coupling, through turbulent processes at both sides of the ocean interface， ……bring the modeling into a new era.




(Babanin, 2023, JGR)

# Model for extreme conditions from BAMS

Current state-of-the-art modeling systems, like the Coupled Ocean–Atmosphere–Wave–Sediment Transport Modeling System (COAWST; Warner et al. 2010), still overlook crucial components such as non–breaking wave-induced ocean mixing and breaking-wave-induced sea spray effects on air–sea fluxes which are important for realistically capturing the major TCs (Zhao et al. 2022). Such missing representation of the wave processes may contribute to larger uncertainty alongside the spatial resolution effects on uncertainties. There is a pressing need to deploy fully integrated models that can realistically represent TC and ETC characteristics by considering all critical interactions at high spatial and temporal resolutions, requiring high-performance computing resources like those available at the national laboratories.

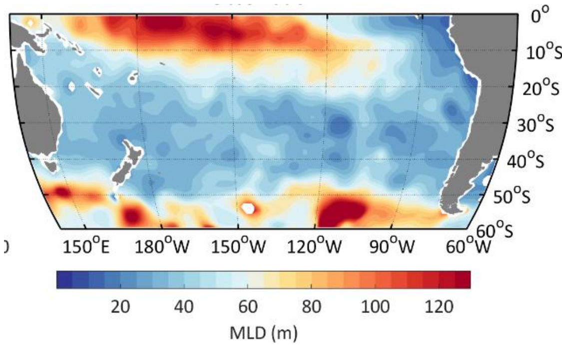
Jiali Wang, Georgios Deskos, William J. Pringle, Sue Ellen Haupt, Sha Feng, Larry K. Berg, Matt Churchfield, Mrinal Biswas, Walter Musial, Paytsar Muradyan, Eric Hendricks, Rao Kotamarthi, Pengfei Xue, Christopher M. Rozoff, and George Bryan, 2024, BAMS

# CONTENTS

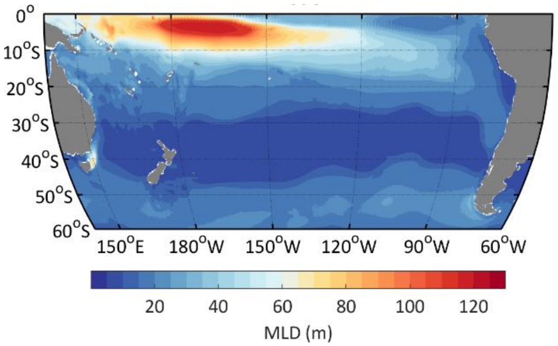
# 1. Wave-circulation coupled model

$$B_V = \alpha \iint_{\vec{k}} E(\vec{k}) \exp(2kz)\, d\vec{k}\, \frac{\partial}{\partial z}\left[\iint_{\vec{k}} \omega^2 E(\vec{k}) \exp(2kz)\, d\vec{k}\right]^{\frac{1}{2}}$$

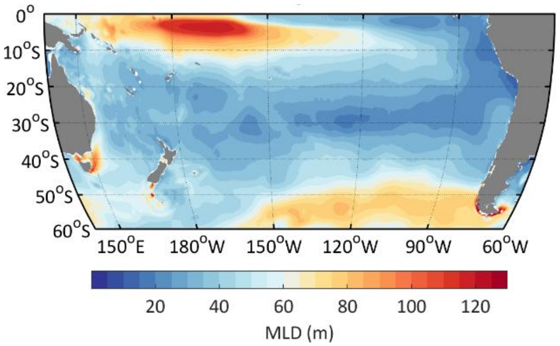
Observation data




Model without Bv



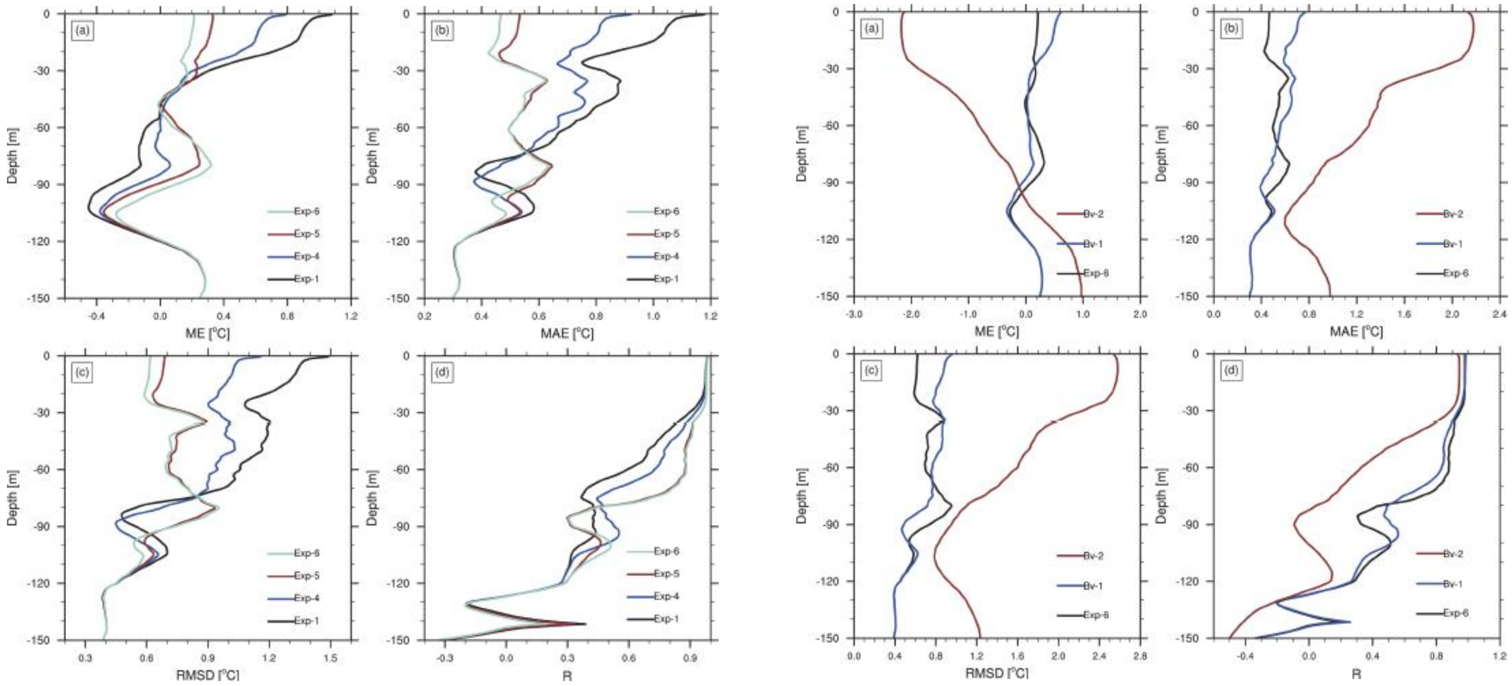

Model with Bv




- ☐ MLD biases reduce from 10.8 m to 1.5 m (86% improvement)

Qiao et al,2004, GRL; 2010, OD; 2016, RS

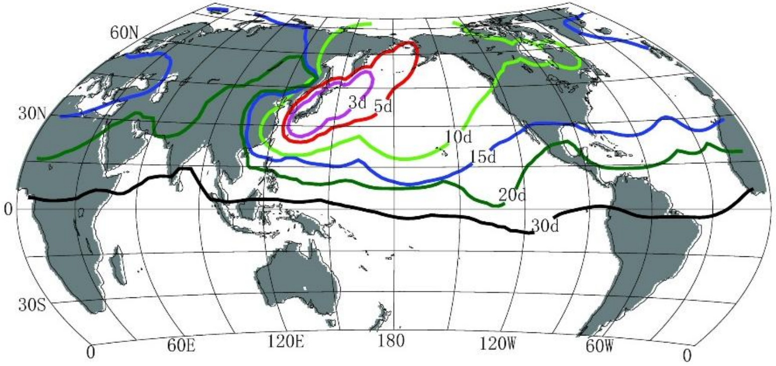
# Wu L et al (2015, JGR) compared 7 parameterizations, Bv is most effective

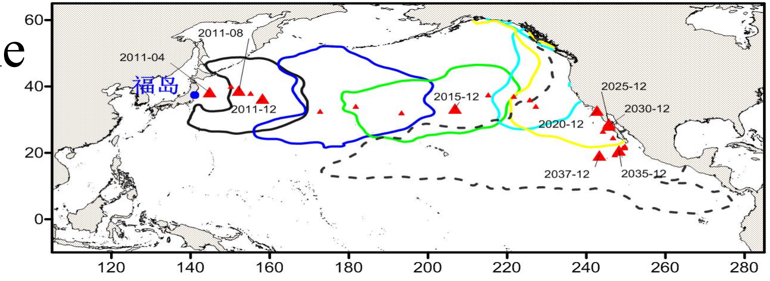


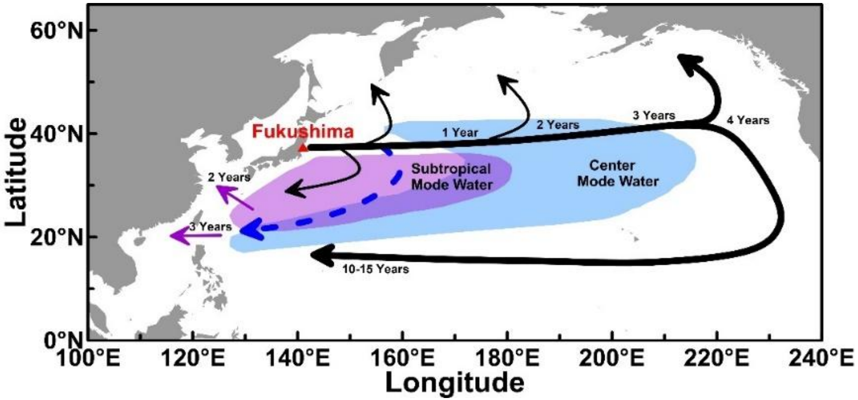

E1: none; E2: breaking; E3: CSF; E4: LC; E5: NB; E6: E2+E3+E4+E5

# Application: simulation of nuclear discharge

- The first simulation and warning system for predicting the nuclear matters in the ocean and atmosphere nuclear matter.

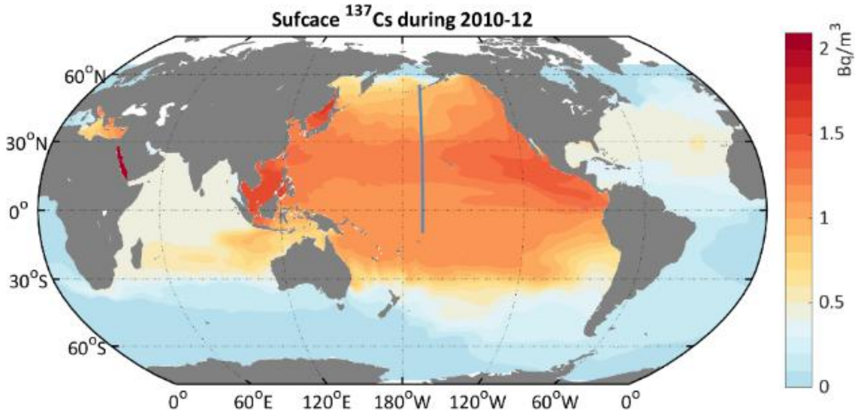


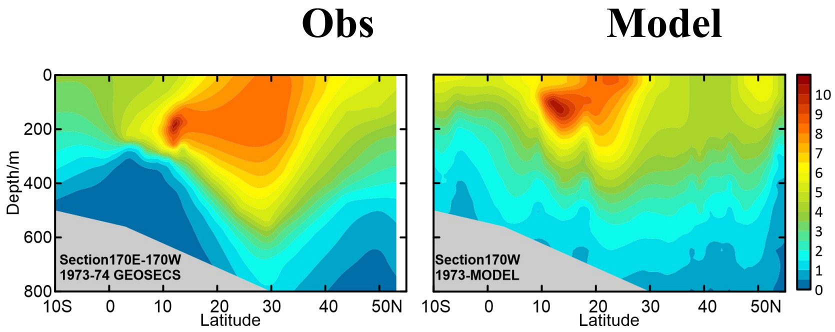




Zhao et al, 2021, MPB

# Long-term simulation validation against observation



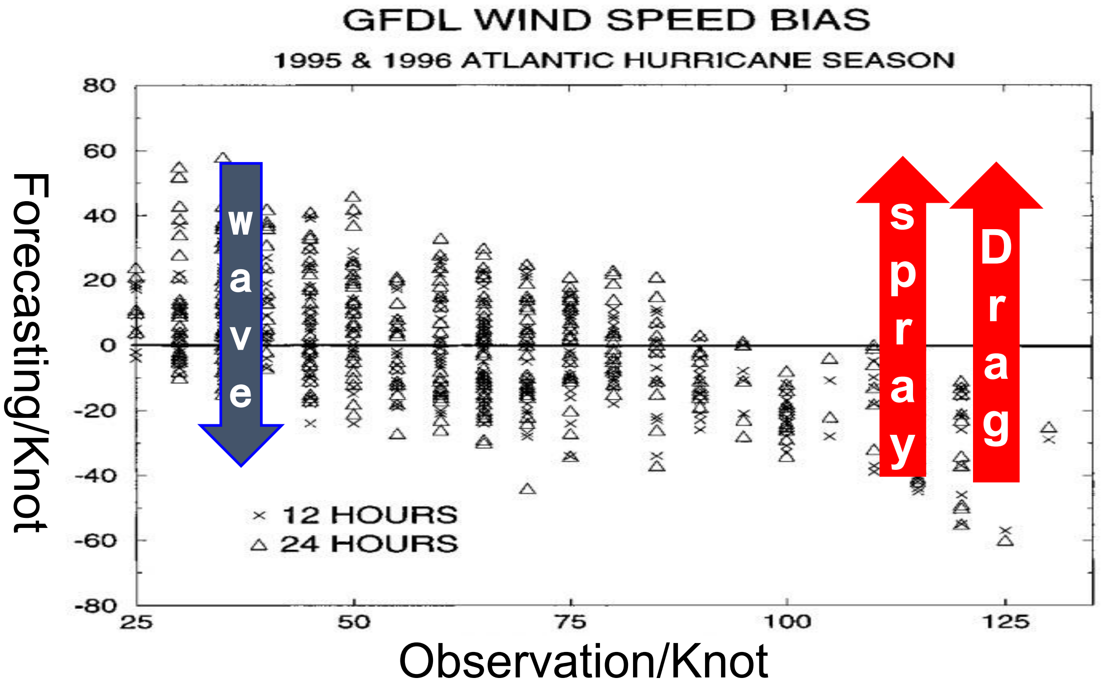
# 2. Third generation TC model

## Bv mixing (weaken)+ Sea spray + Cd(intensify)

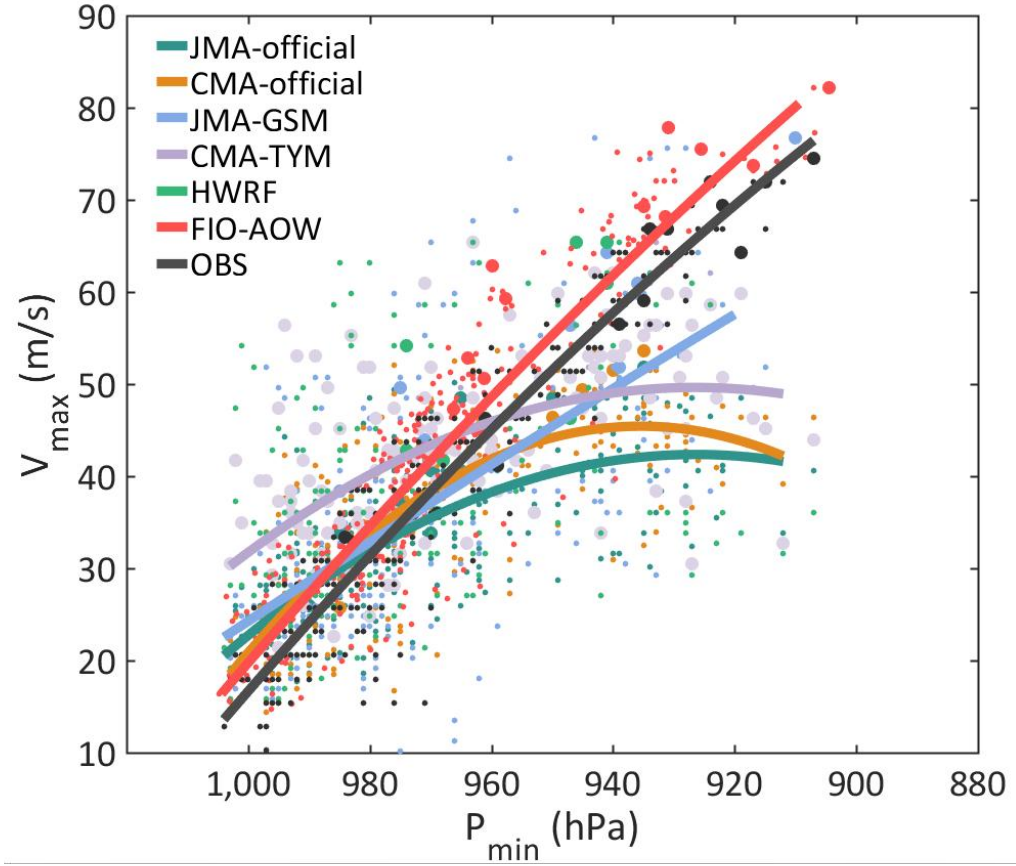
Bv: Qiao et al, 2004

Spray: Andreas et al, 2015

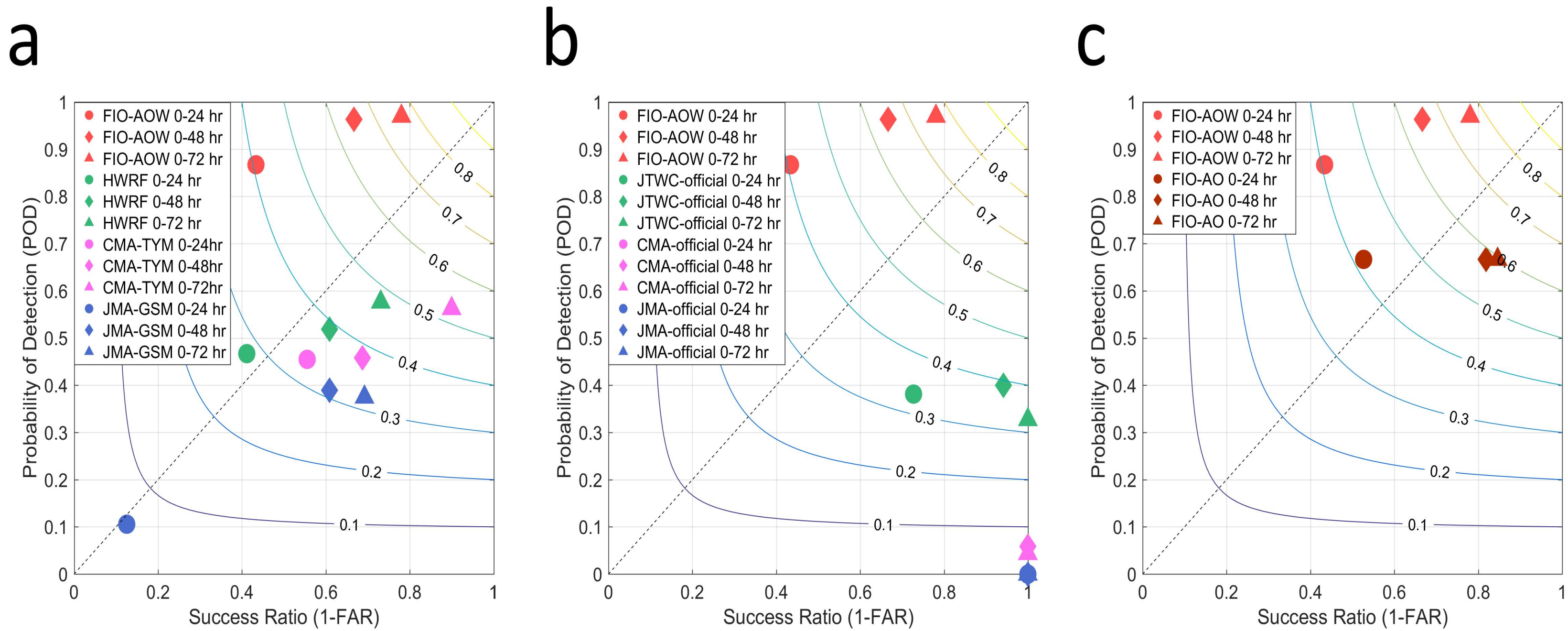
Cd: Zhao et al, 2024



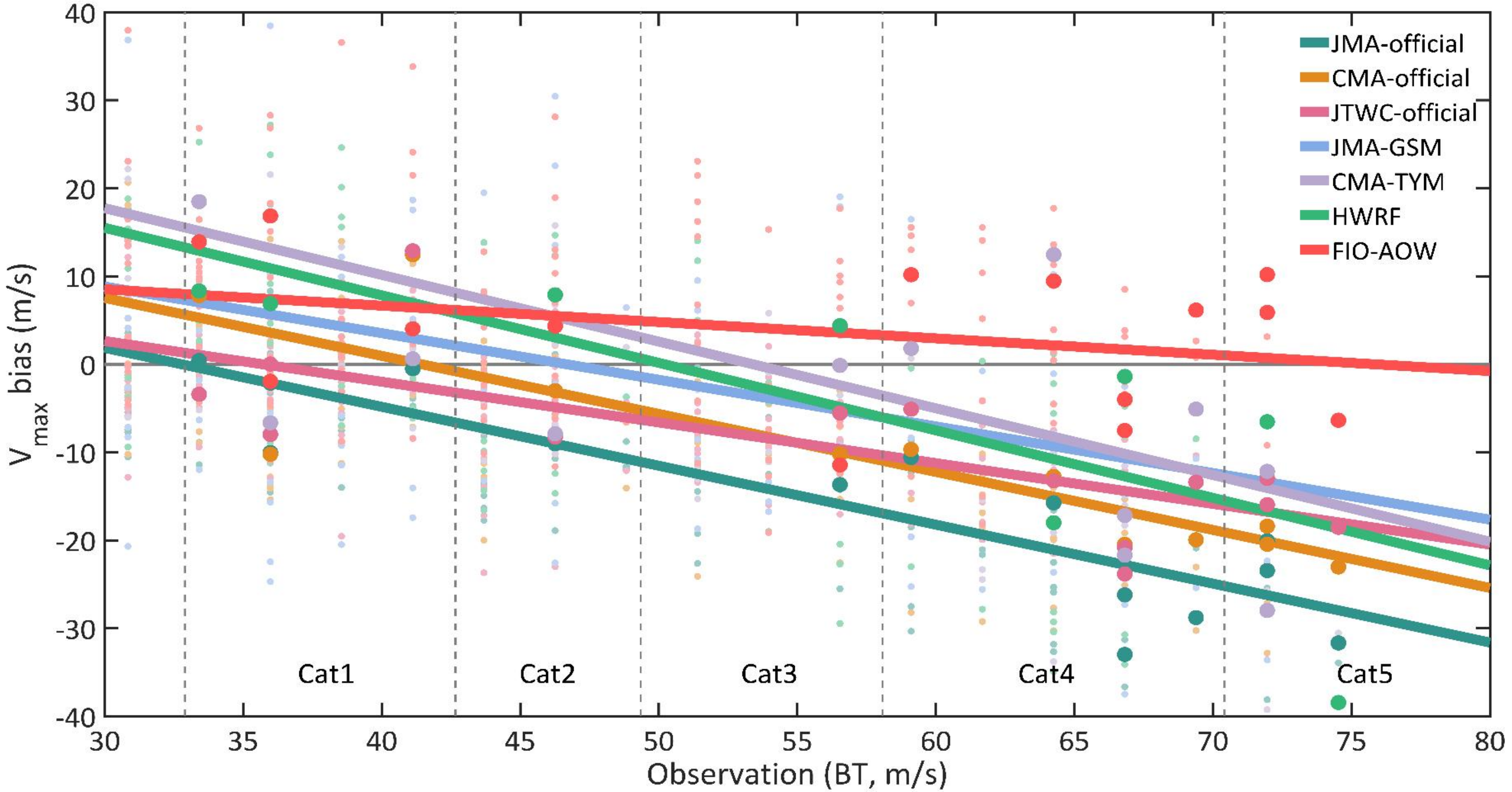
# (1) Comparison of wind-pressure relation in 2024



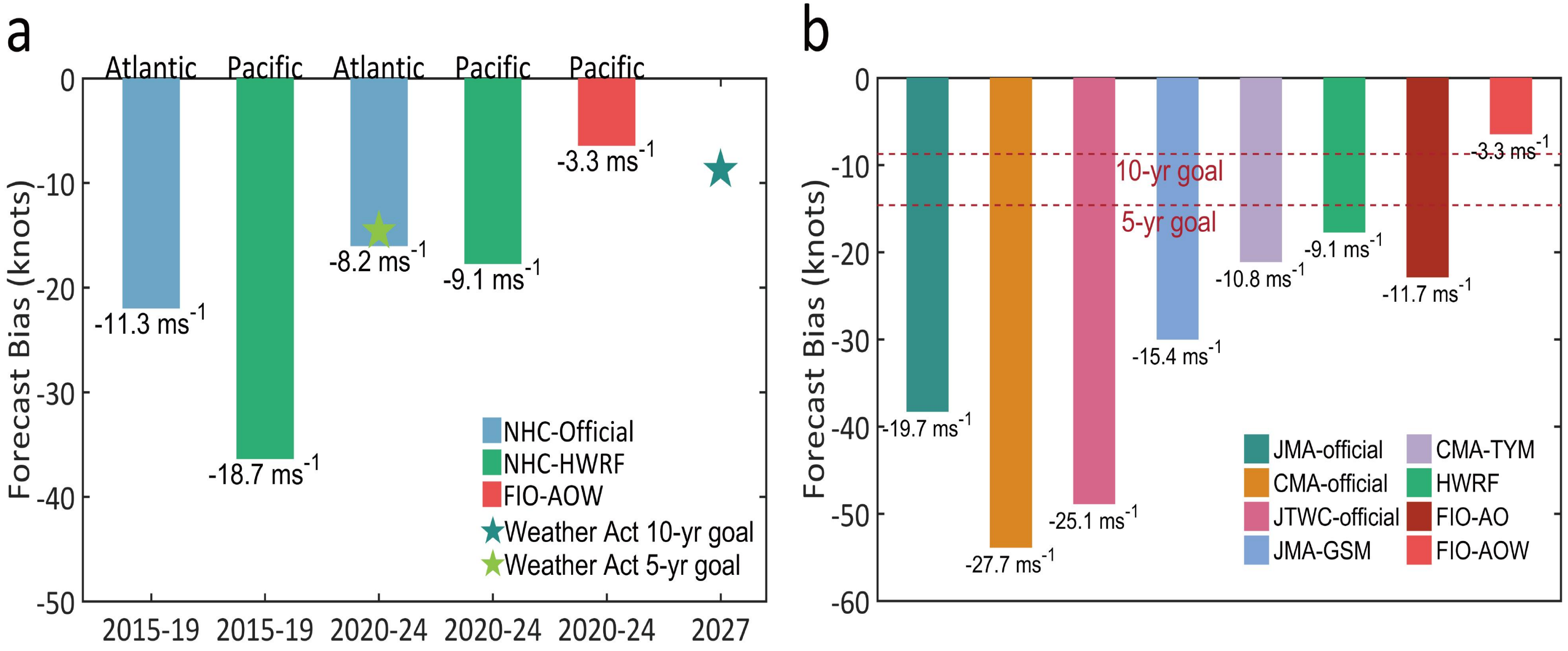
# For all RI in 2024 in the Northwest Pacific



# For the maximum wind speed of all TCs in 2024: 72h



# (2) For all 37 RIs during 2020-2024

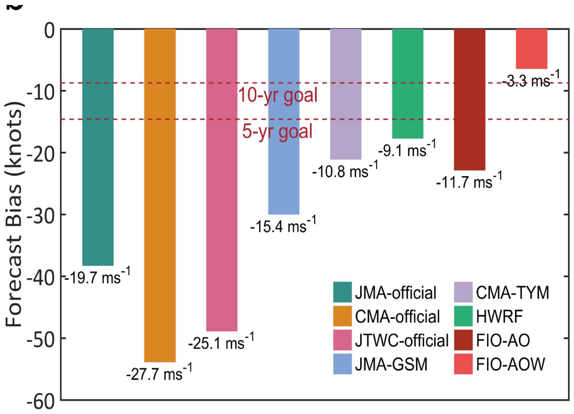


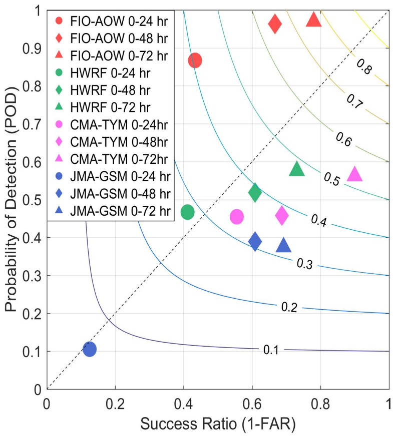
# For 3 bottleneck challenges

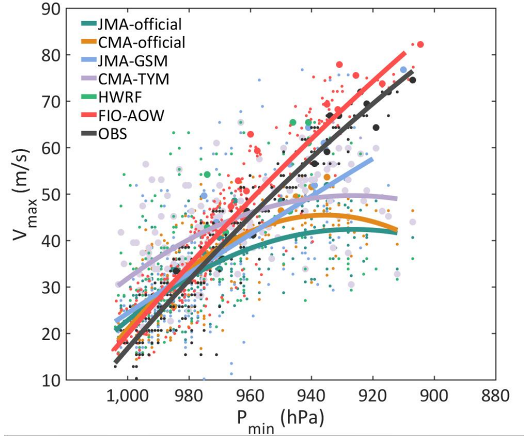
Big intensity bias

Predict RI

Wind-press rela



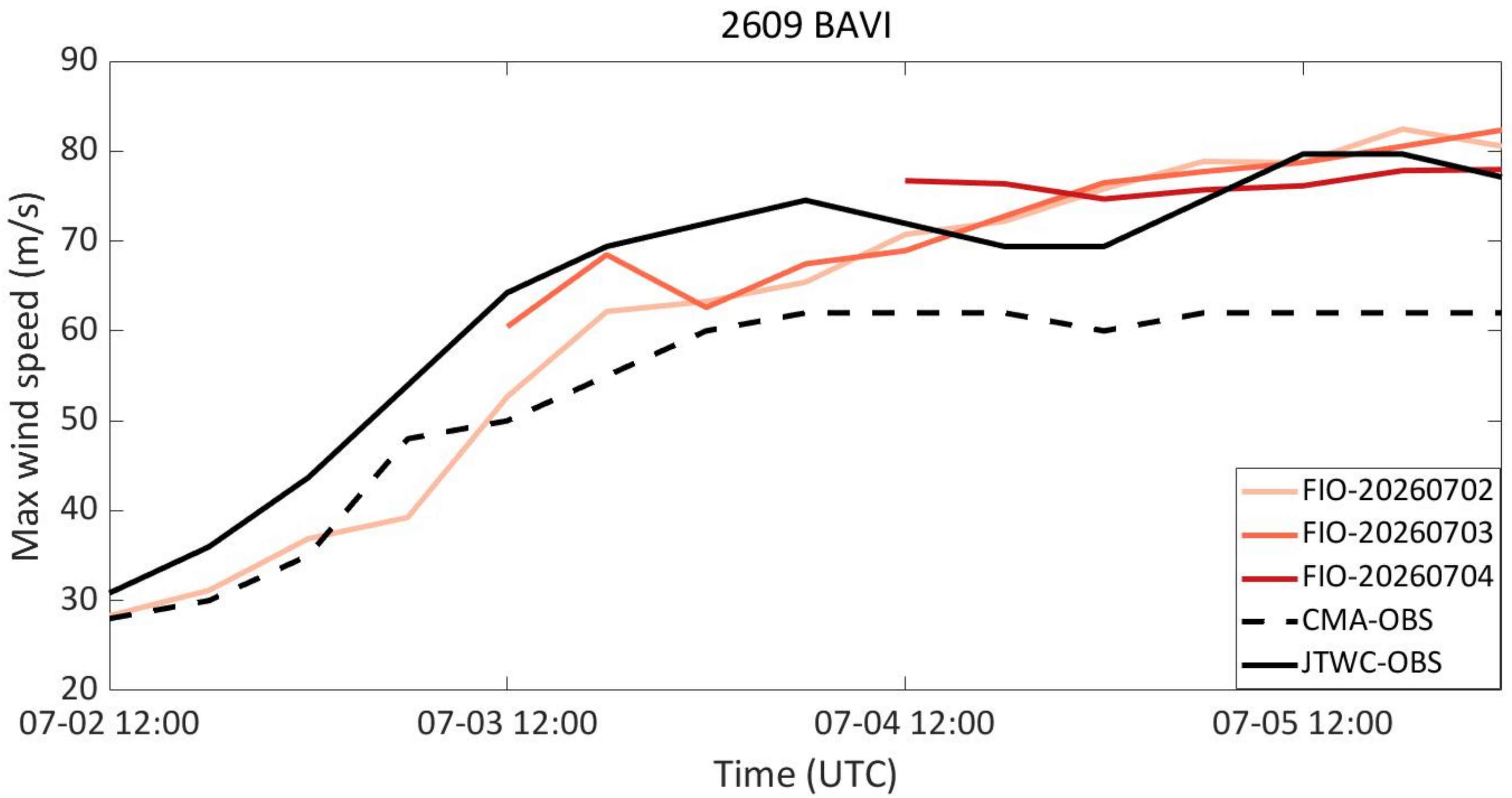




Over “weather Act”

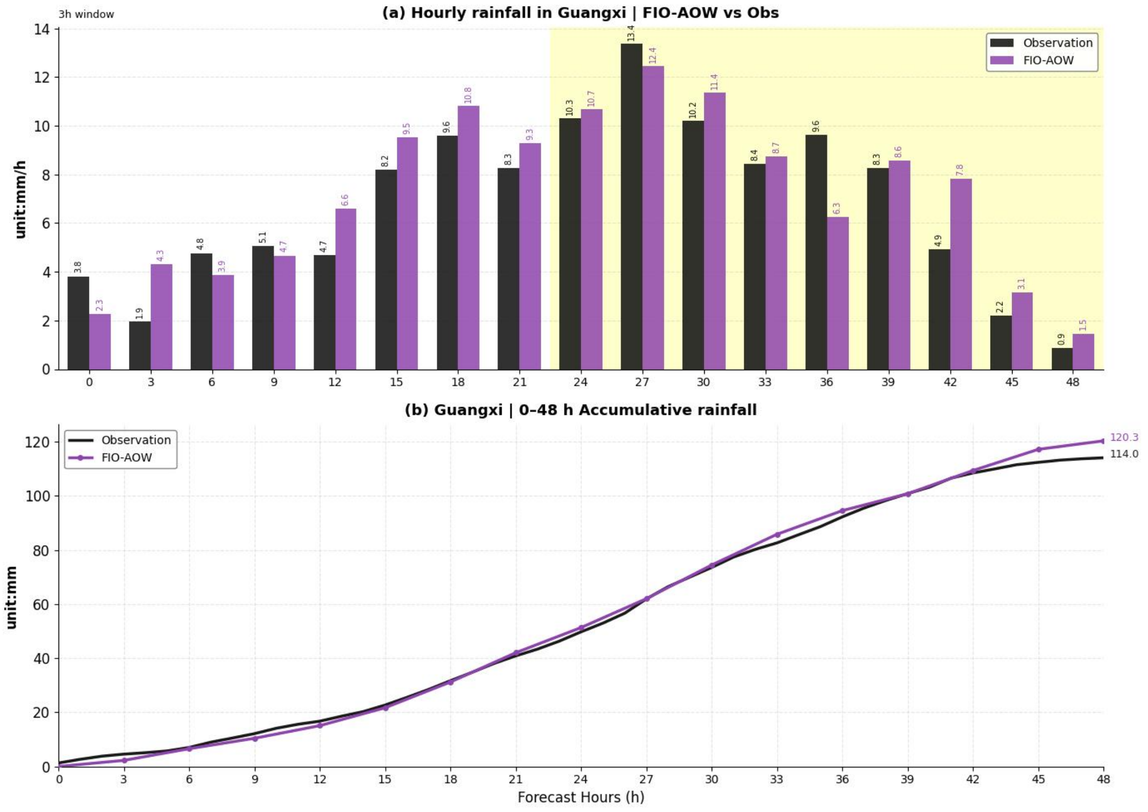
RI 90%+

Good relationship

# For strong Typhoon *Bavi* started on July 2, 2026

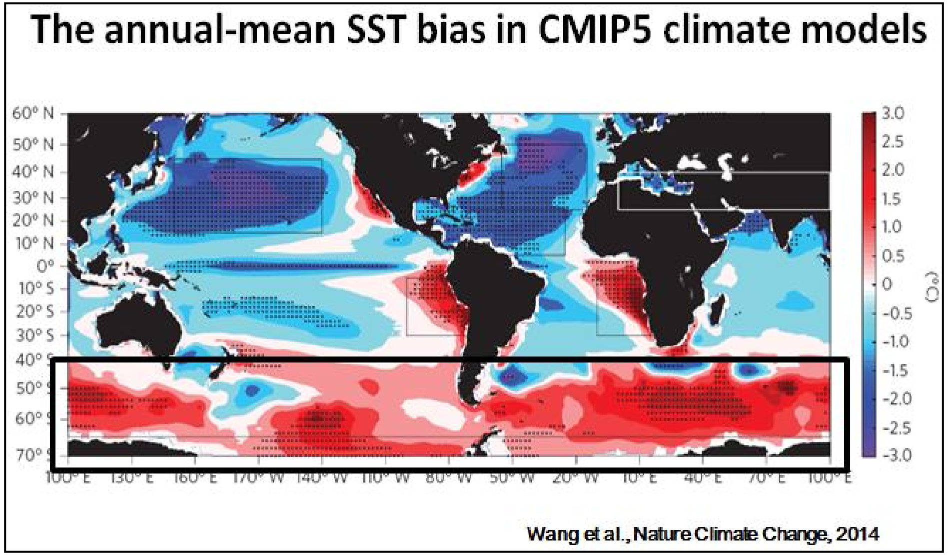


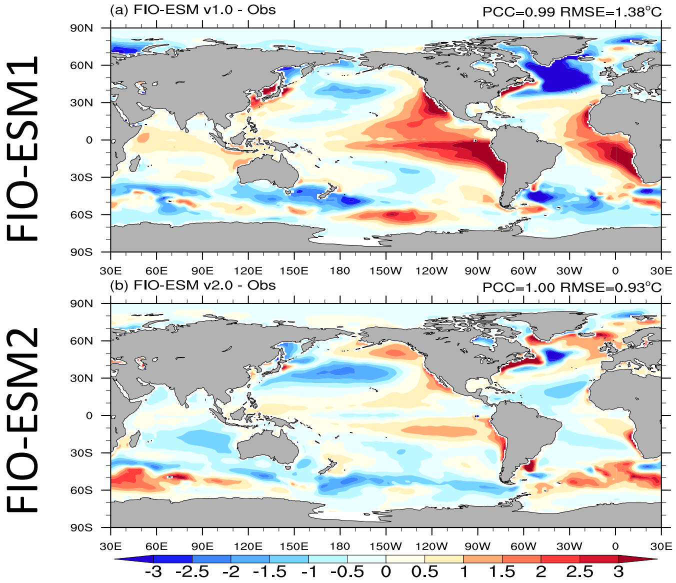
# Heavy precipitation in Guangxi from Severe Tropical Storm Maysak



# 3. Two-generation of FIO-ESMs

First ESM with wave incorporated, reducing half of the original biases

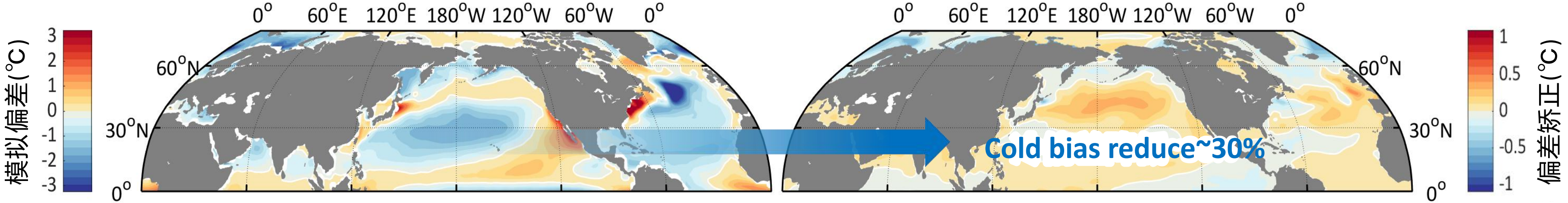


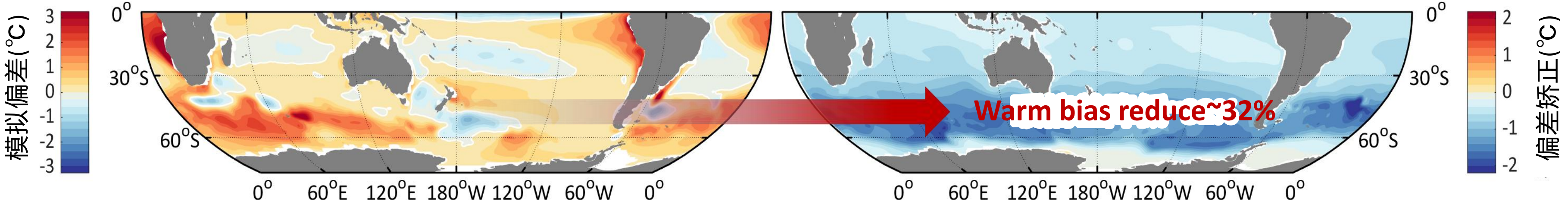

Qiao et al, 2013, JGR; Bao et al. 2021, JGR

# Wave effects in climate system

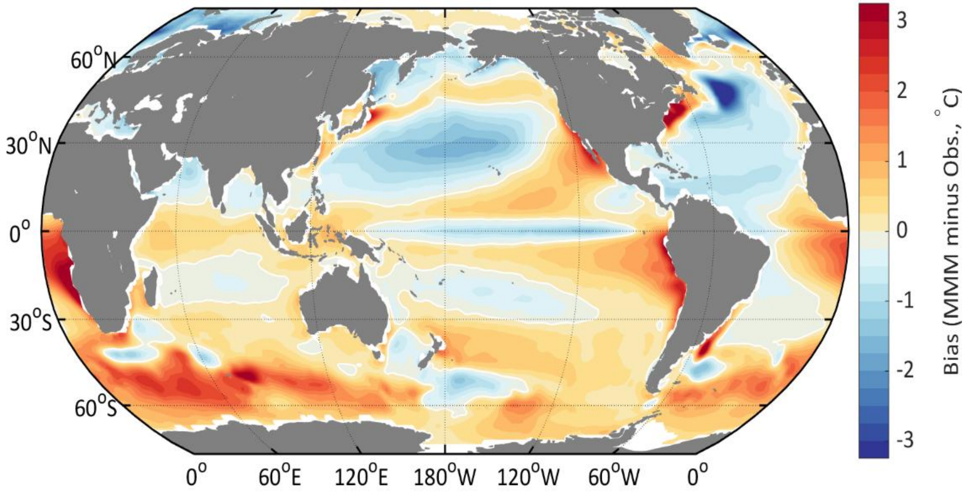
## Stokes Drift

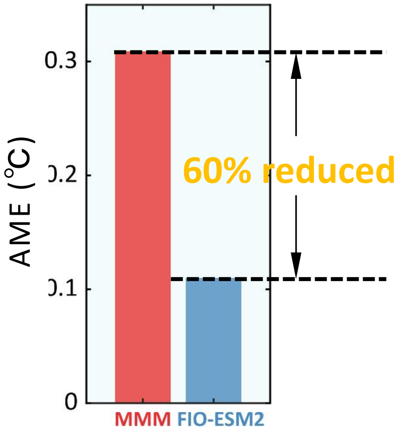



## Sea Spray



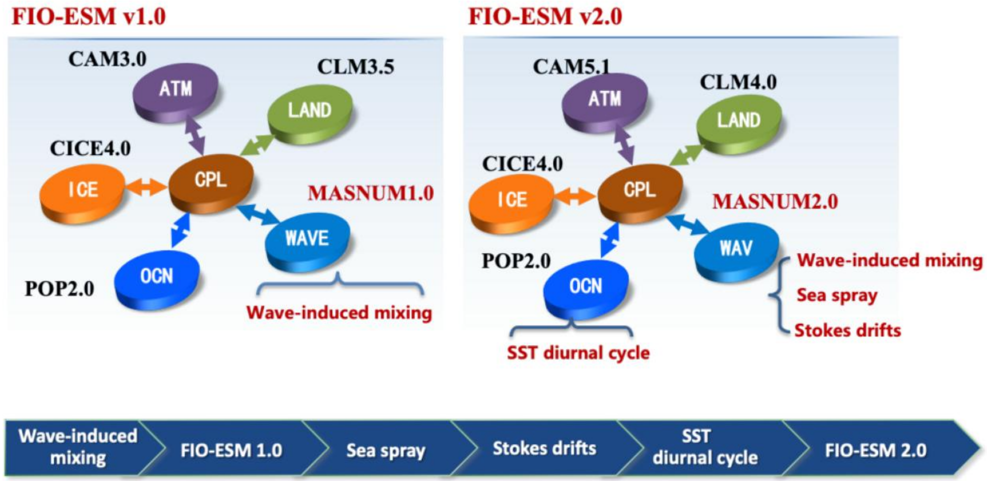
# Climate prediction challenge and solution

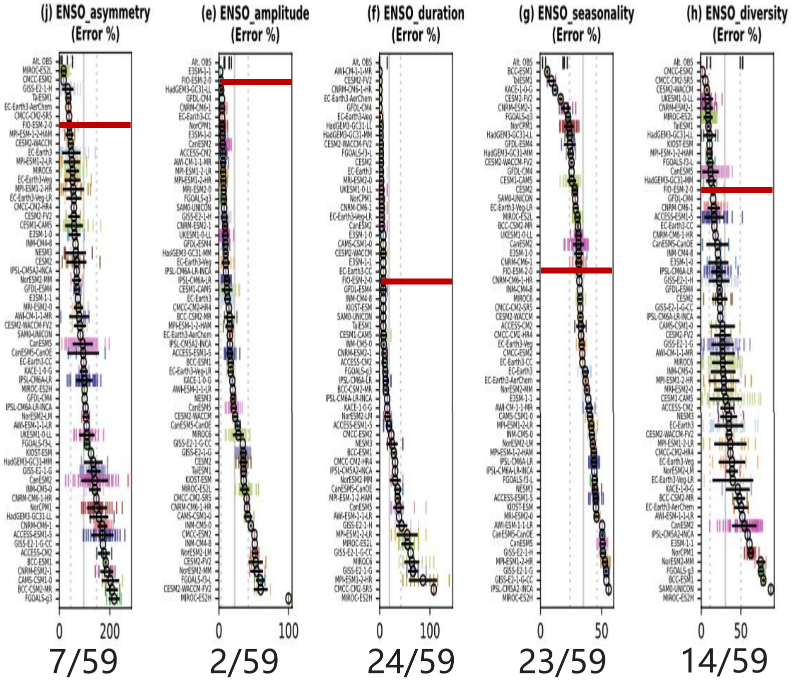



The Bv theory can reduce the prediction error of climate by about 60%, which is a long-standing scientific challenge in the world for all climate models.

# ENSO comparison in the past 100 years




*[Lee, 2021, GRL]*

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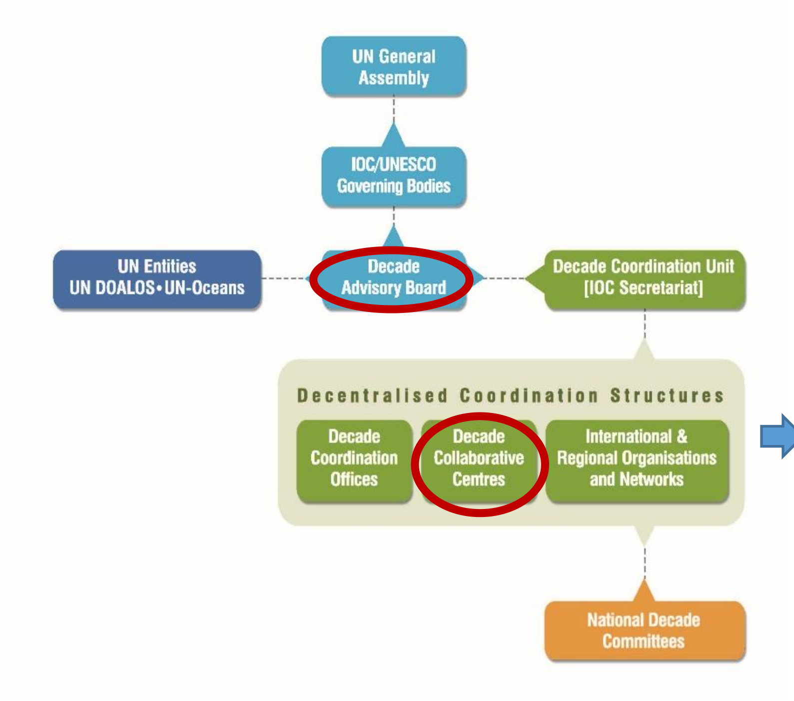
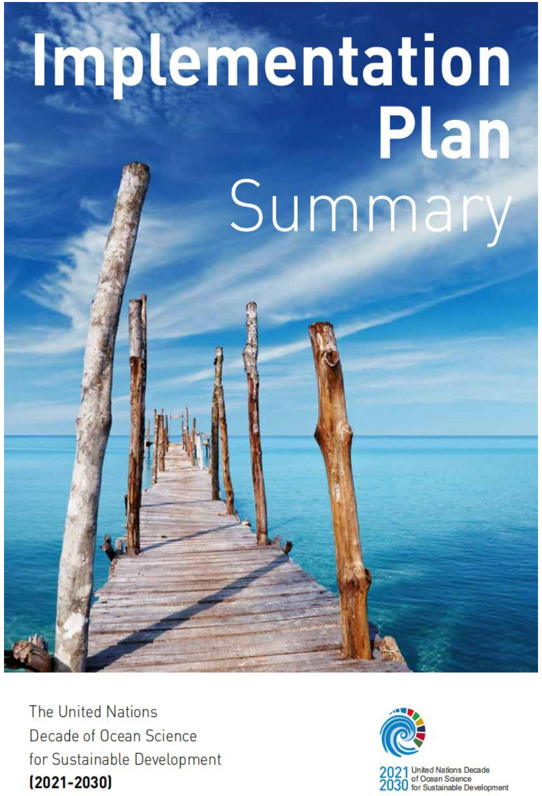
# DCC-OCC of UN Ocean Decade

- 2018-2020: EPG 2021-2023: DAB




- Programme
- Project
- Activity
- Contribution

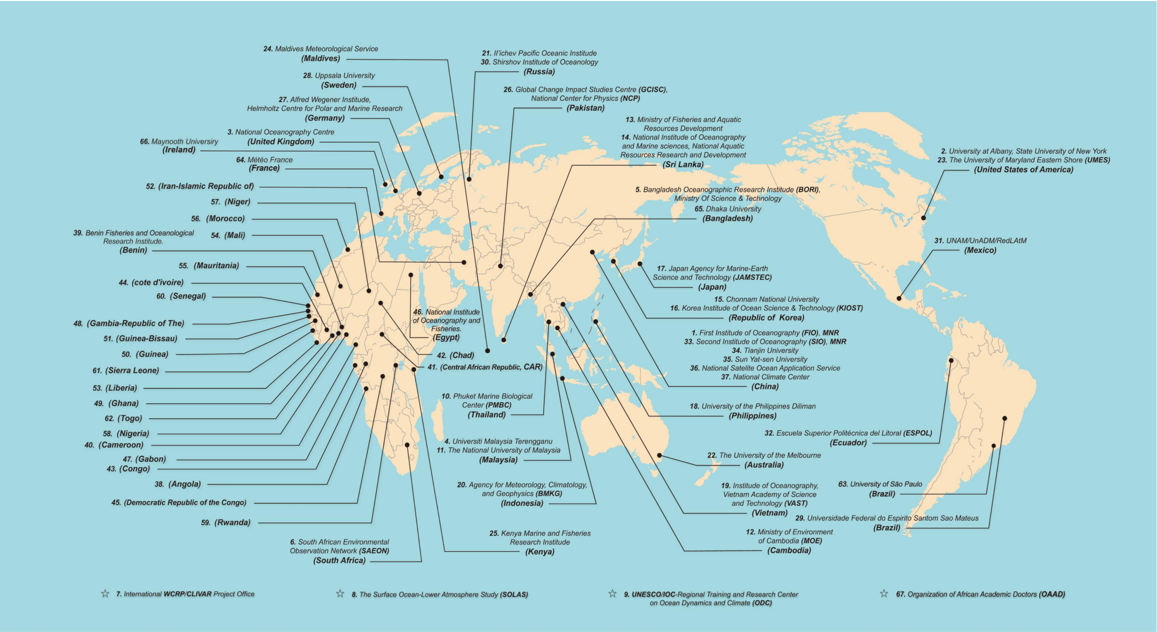


# Ocean to climate seamless forecasting system (OSF)

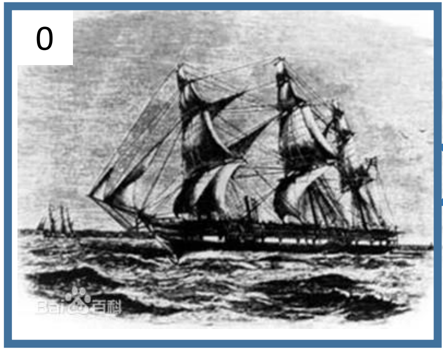
**80+**
Institutes

**50+**
Countries

**5**
International organizations

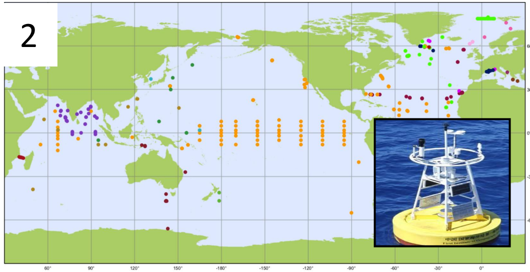


# Technical innovation for observation: ~5% cost

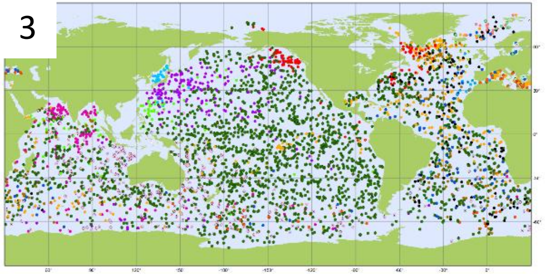



English Challenger, 1872-76


SeaSat-A, 1978



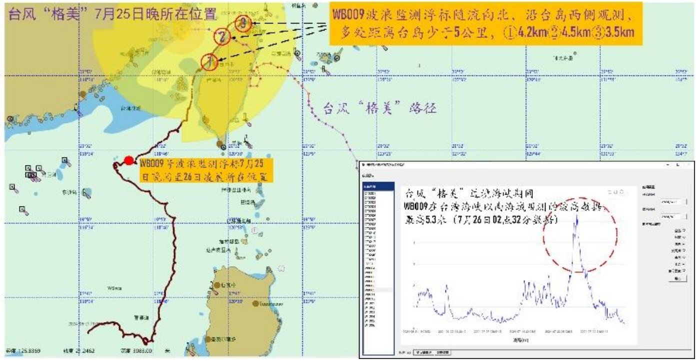

ENSO Buoy, 1980s




ARGO, 2000s

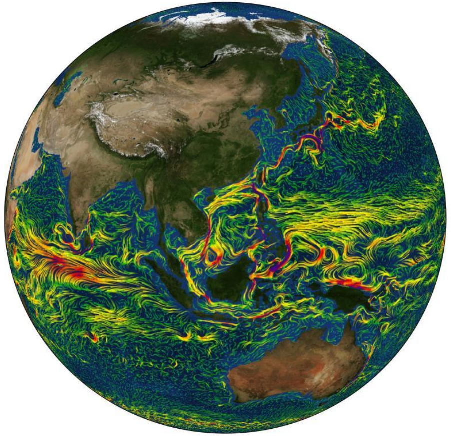

**GNSS new buoy: high precision and low cost**

# The buoy has been tested more than 100 times




# What can we do for the global public? Solution


Satellite and *in-situ* observation data

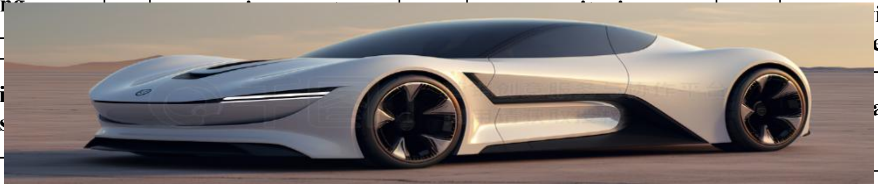


Ocean & climate prediction

Provide science-based solutions

# Coastal city Ocean-bAsed Solution Toolkit for sustainable development (COAST)

| Ocean & Climate Early wArNing Universal System | Maritime Navigation Safety | Coastal Ecosystem Health | Integrated Coastal Management | Blue Economy Development | Ocean Literacy and Capacity Building |
|---|---|---|---|---|---|
| Ocean Forecasting system | Maritime Silk Road forecasting | Coral reef bleaching monitoring and forecasting | ICM Code | Ocean renewable energy development | Ocean Literacy Alliance for Primary and Middle Schools |
| Typhoon forecasting system | Polar shipping risk assessment | Pollution tracing and trajectory prediction | MPA planning | Blue carbon storage estimation | Marine Museums Alliance |
| Climate prediction: SLR, climate heat wave and drought/flood | Optimal route plannin | Marine aquaculture | Estuarial pollution | Assessment on marine ironment effects | Marine knowledge outreach |
| Marine search and rescue; oil spill tracking | Customi forecasting s | | | an tourism index | Best practice on human-ocean harmony |



FUEL

Data support

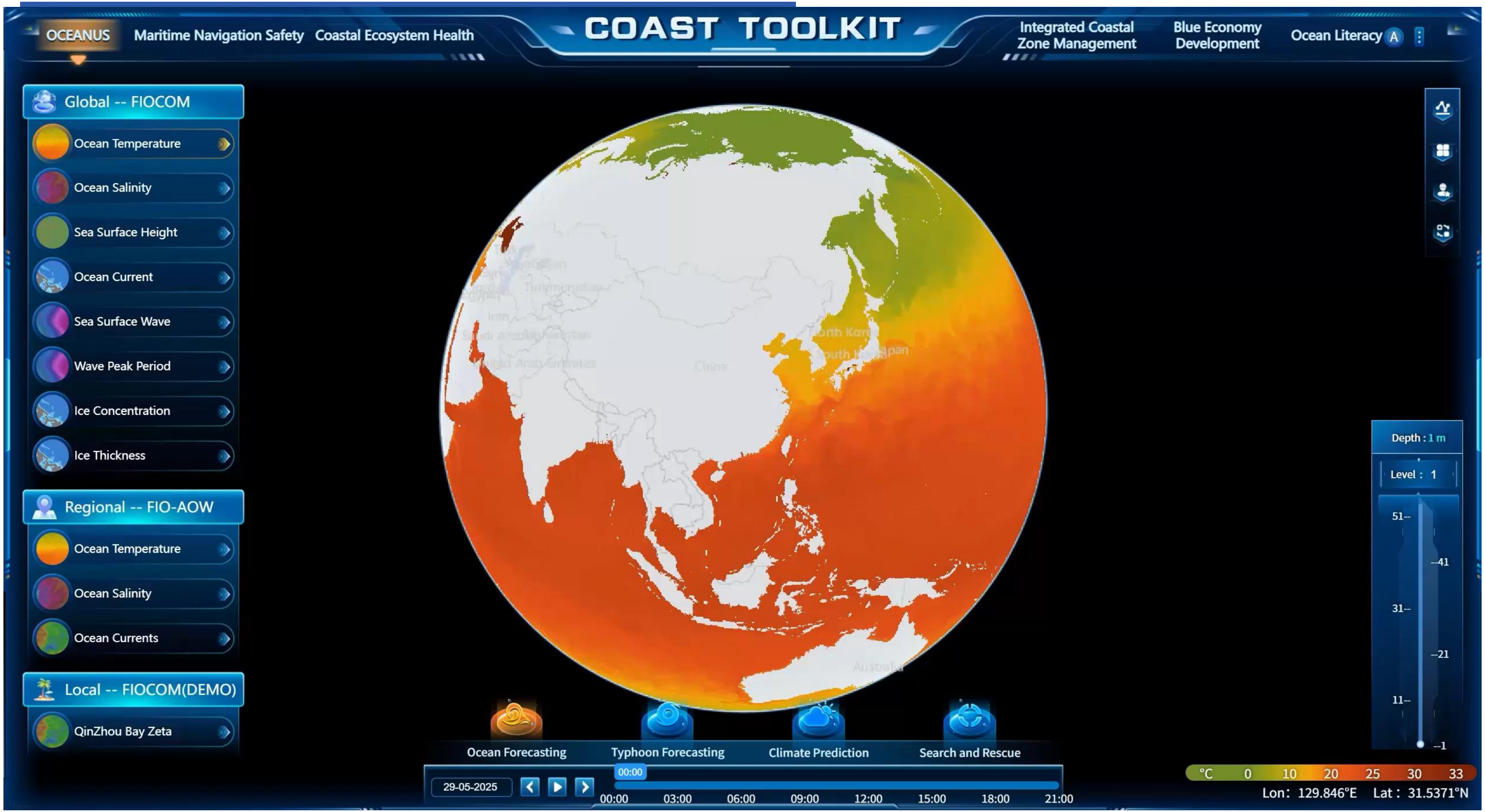
**State-of-the-art model + AI**

DRIVER LICENSE

Capacity building

# COAST TOOLKIT

http://toolkit.dcc-occ.cn



# Take home message: novel research to management

- □ **Scientific breakthrough: New understanding of surface wave on air-sea flux;**
- □ **Technical innovation: super low cost, high precision, AI-tech buoy of "Jingwei" for new generation GOOS;**
- □ **A predicted ocean: new generation ocean, TC and climate models with amazing prediction ability;**
- □ **Disaster management: COAST Toolkit for decision-makers and world public.**


Thanks
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