



15th ODC Training Course

New generation ocean to climate coupled models and their applications

Fangli QIAO

First Institute of Oceanography, MNR, China

1st Sep, 2026 @ Qingdao of China

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Needs and challenges

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Science-based breakthroughs

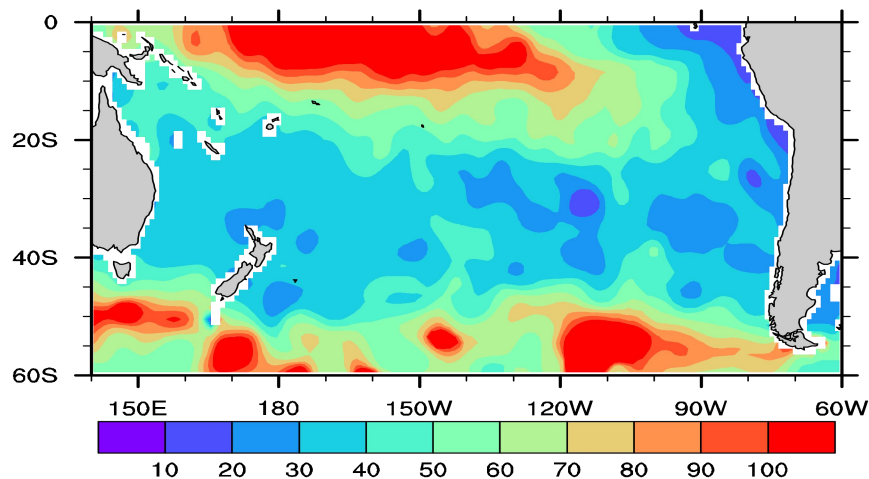
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New generation models

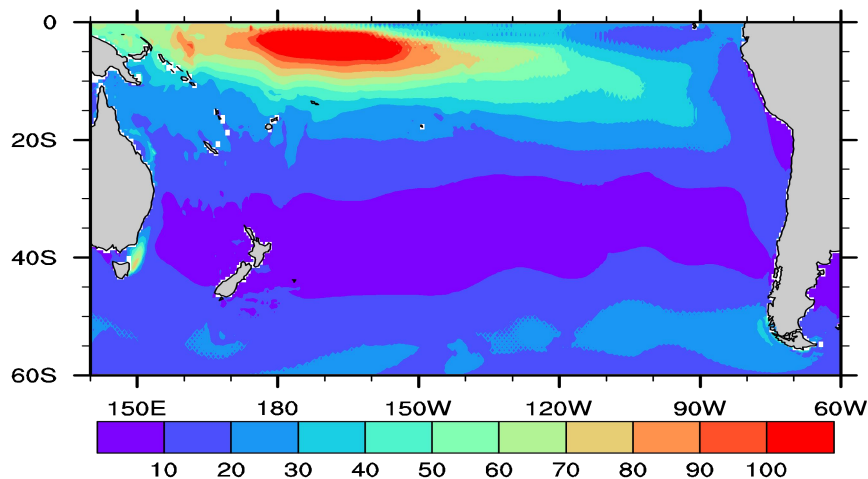
IV

Proving services for the world

Challenge 1: **Common** biases in OGCMs



Observed MLD

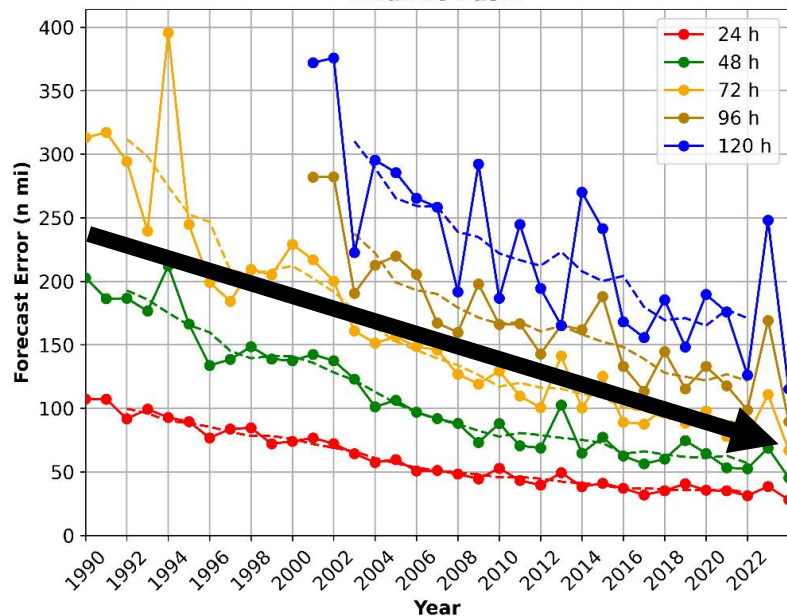


Simulated MLD

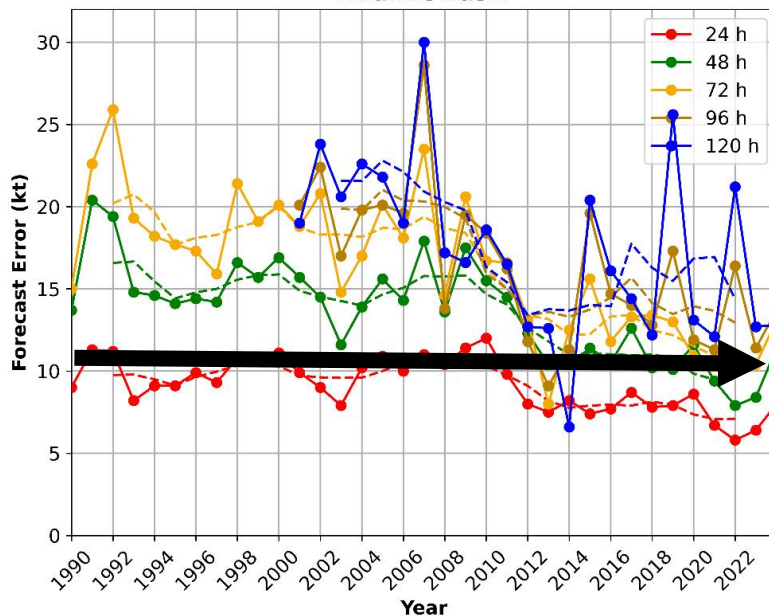
Qiao et al, 2010, 2016

Challenge 2: Standstill in forecasting **Typhoon intensity**

NHC Official Track Error Trend
Atlantic Basin



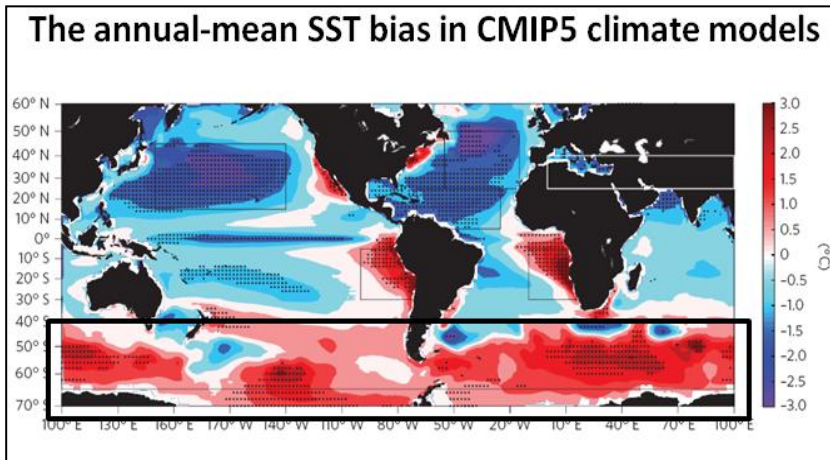
NHC Official Intensity Error Trend
Atlantic Basin



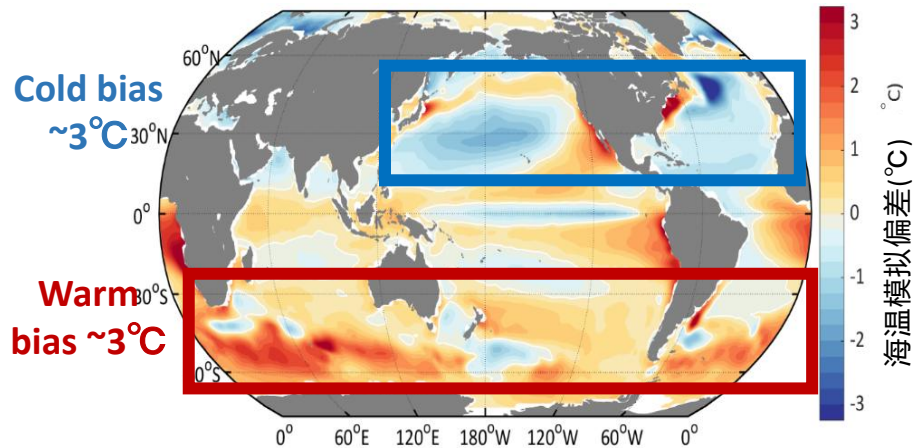
NHC Annual Report 2024

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

Challenge 3: **Common** biases in climate models



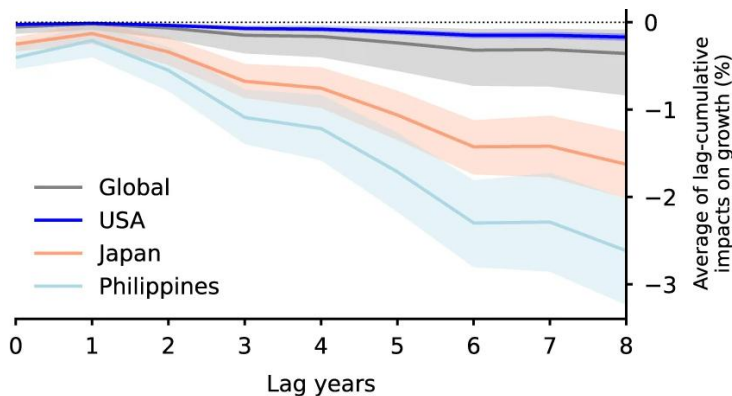
CMIP5



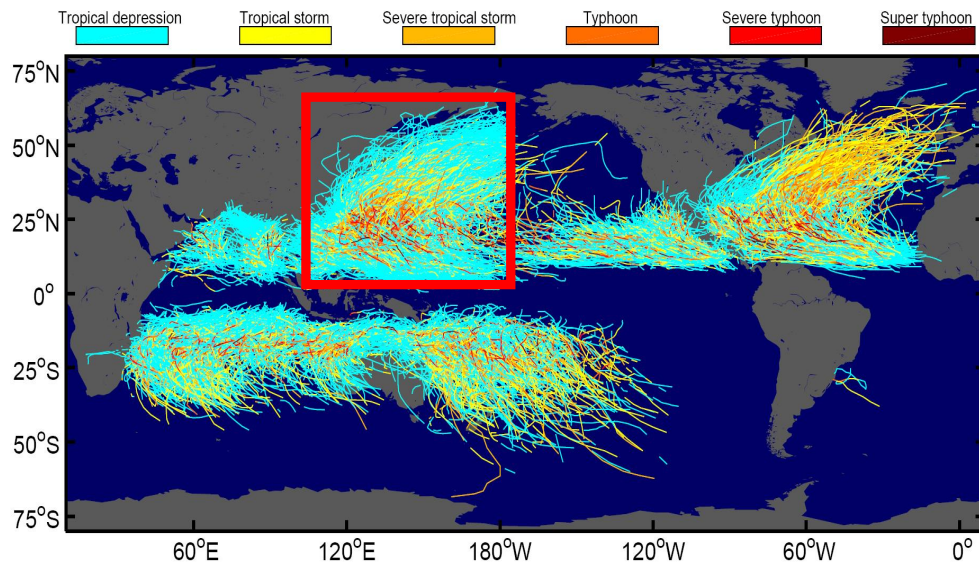
CMIP6

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

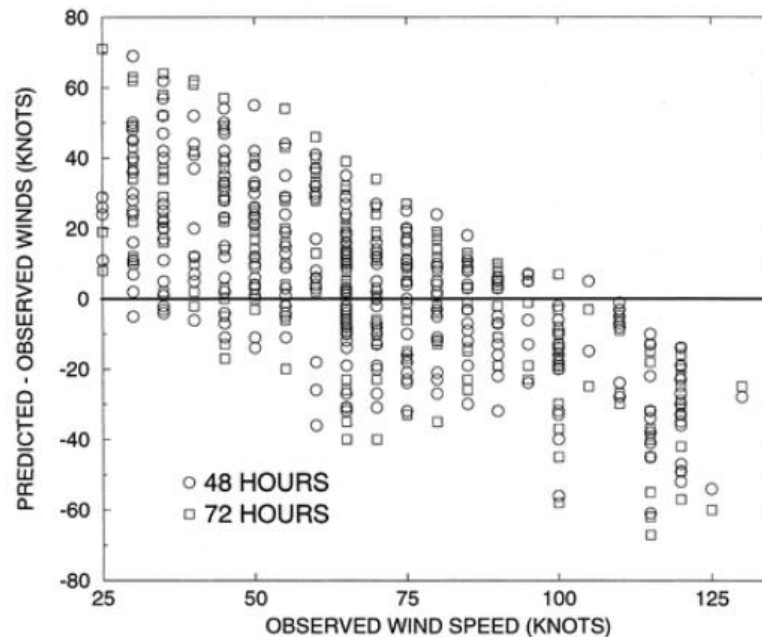
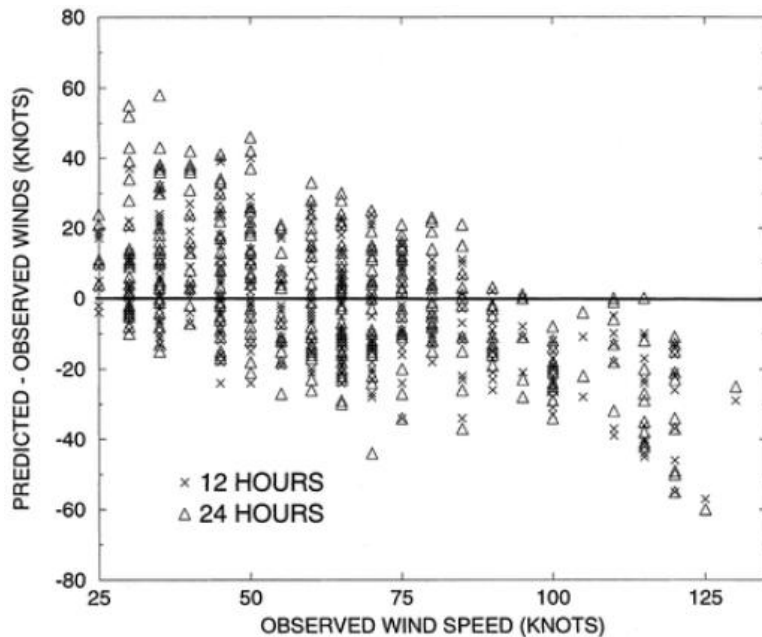


Retarded economic growth



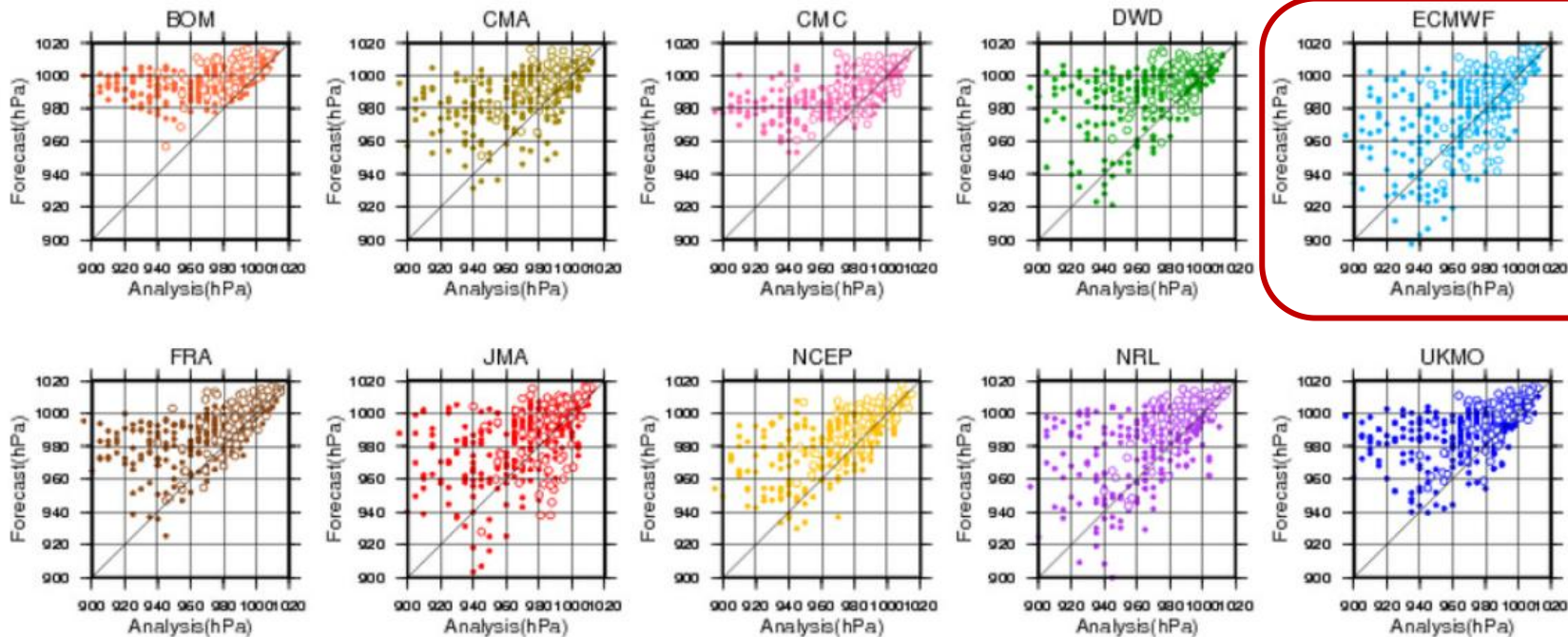
First generation TC model

GFDL WIND SPEED BIAS 1995 & 1996 ATLANTIC HURRICANE SEASON



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

Second generation TC model



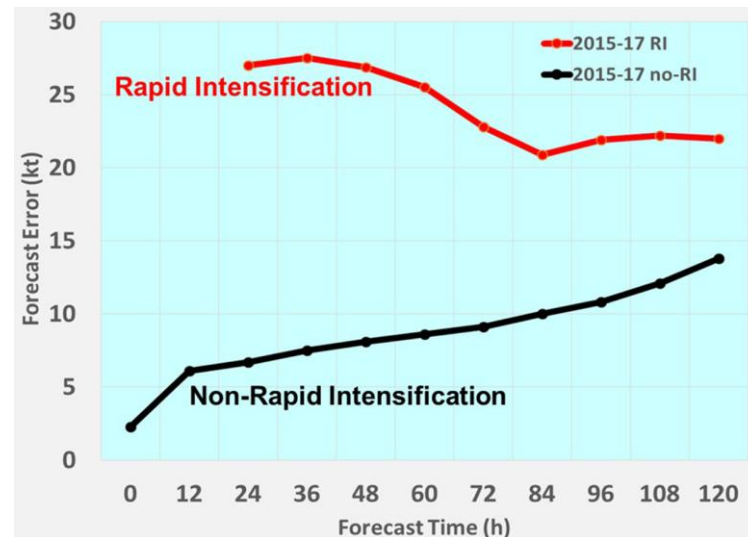
Yamaguchi, M., Ishida, J., Sato, H. & Nakagawa, M. 2017

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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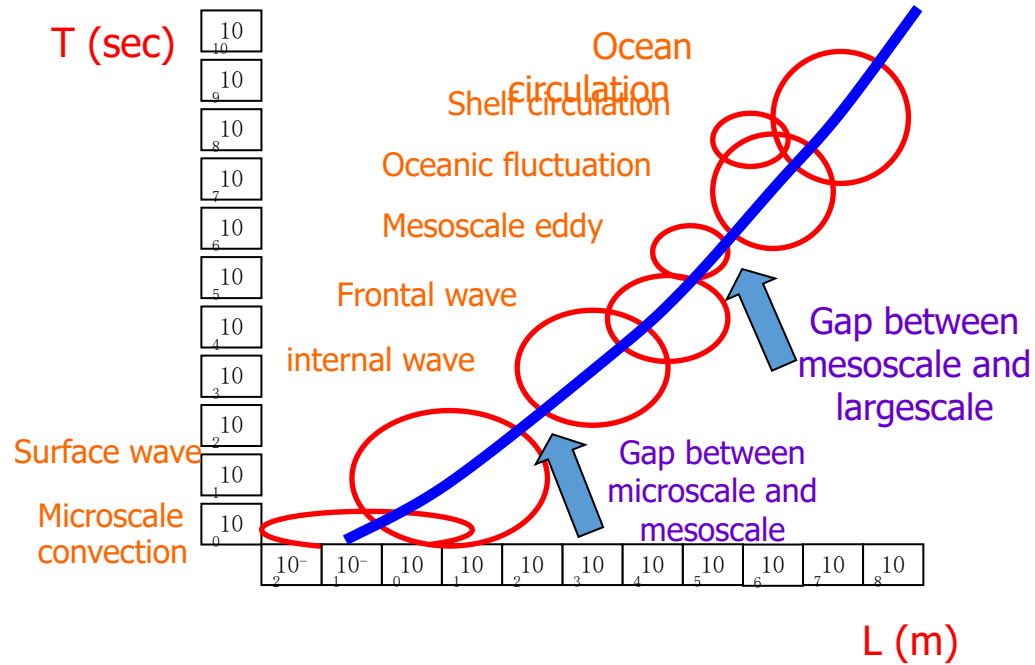
New generation models

IV

Proving services for the world

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

$$B_v = \alpha \iint E(\vec{k}) \exp\{2kz\} d\vec{k} \frac{\partial}{\partial z} \left(\iint \omega^2 E(\vec{k}) \exp\{2kz\} d\vec{k} \right)^{\frac{1}{2}} \quad (\text{Qiao et al, 2004, 2010})$$

- 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

4752

JOURNAL OF CLIMATE

VOLUME 27

Impacts of Parameterized Langmuir Turbulence and Nonbreaking Wave Mixing in Global Climate Simulations

YALIN FAN

Program in Atmospheric and Oceanic Sciences, Princeton University, and NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey

STEPHEN M. GRIFFIES

NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey

(Manuscript received 26 September 2013, in final form 24 February 2014)

ABSTRACT

The impacts of parameterized upper-ocean wave mixing on global climate simulations are assessed through modification to Large et al.'s K -profile ocean boundary layer parameterization (KPP) in a coupled atmosphere-ocean-wave global climate model. The authors consider three parameterizations and focus on impacts to high-latitude ocean mixed layer depths and related ocean diagnostics. The McWilliams and Sullivan parameterization (MS2000) adds a Langmuir turbulence enhancement to the nonlocal component of KPP. It is found that the

GFDL

AGU100
ADVANCING
EARTH AND
SPACE SCIENCE

JAMES | Journal of Advances in
Modeling Earth Systems

RESEARCH ARTICLE
10.1029/2018MS001494

Key Points

- Both rebreaking surface wave and shortwave penetration can enhance the temperature stratification of the upper ocean.
- Model improvement due to rebreaking wave is more considerable than shortwave penetration, especially in subtropical ocean.
- The regions where rebreaking wave generates stronger improvement are where large temperature bias exist.

Supporting Information:
• Supporting Information S1

Correspondence to:
Y. Fan
yfan@princeton.edu

Improving the Upper-Ocean Temperature in an Ocean Climate Model (FESOM 1.4): Shortwave Penetration Versus Mixing Induced by Nonbreaking Surface Waves

Shihua Wang^{1,2}, Qiang Wang¹, Qi Shu^{1,4,5}, Patrick Scholz¹, Gerrit Lohmann⁶, and Fangli Qiao^{2,4,5}

¹College of Oceanic and Atmospheric Sciences, Ocean University of China, Qingdao, China, ²First Institute of Oceanography, Ministry of Natural Resources, Qingdao, China, ³National Marine Science Museum, Beijing, China, ⁴Key Laboratory of Marine Science and Technology, Ministry of Natural Resources, Qingdao, China, ⁵Key Laboratory of Marine Science and Numerical Modeling, Ministry of Natural Resources, Qingdao, China

Abstract As the first mature global ocean general circulation model based on unstructured-mesh methods, the multiresolution Finite Element Sea-Ice-Ocean Model (FESOM) has shown great capability in reconstructing the ocean and sea ice in both standalone and coupled simulations at a relatively low computational cost. Parameterizations of some important processes, including the vertical mixing induced by surface waves, however, are still missing, contributing to temperature biases in the upper ocean. In this work we incorporate the vertical mixing induced by nonbreaking surface waves derived from a wave model into FESOM and compare its effect with that of shortwave penetration.

AWI-FESOM

NEMO
Community Ocean Model

Download & Install

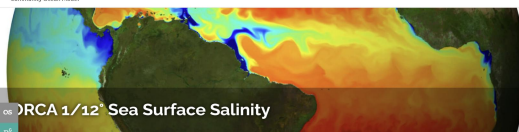
Documentation

Consortium

How To Cite

Community

Contact



Latest News

Announcement of 4.2.0 release - March 2022
NEMO at IUGG 2020 and NEMO Users meeting
Announcement of NEMO v4.2.0 release 4.0.1
NEMO 4.0.0 is out!
IUGG 2019 posters session

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About NEMO

NEMO standing for "Nucleus for European Modelling of the Ocean" is a state-of-the-art modelling framework for research activities and forecasting services in ocean and climate sciences, developed in a sustainable way by a European consortium.

NEMO is distributed under a GNU GPL compatible Free license

Overview

The NEMO ocean model has 3 major components:

- **HYDRO** module: the ocean thermodynamic and solves the adiabatic equations

NEMO

CROCO
Coastal and Regional Ocean Community model

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CROCO, Coastal and Regional Ocean Community model

CROCO is a new oceanic modeling system built upon ROMS, AGIB and the non-hydrostatic kernel of SHN (under testing), gradually including algorithms from MOCOS (sediments) and HYCOM (vertical coordinates). An important objective for CROCO is to resolve very fine scales (especially in the coastal area) and their interactions with larger scales. It is the oceanic component of a complex coupled system including various components, e.g., atmosphere, surface waves, marine sediments, biogeochemistry and ecosystems.

CROCO Version 1.2 official release is now available in the Download section. It includes new capabilities as non-hydrostatic kernel, ocean-wave-atmosphere coupling, sediment transport, new high-order numerical schemes for advection and mixing, a dedicated I/O server (IOSS), new online diagnostics, and new options for coastal configurations. A new version of CROCO-TOOLS accompany this release. CROCO will keep evolving and integrating new capabilities in the following years.

CROCO-TOOLS: version 1.2

CROCO-Sud

News

Two training sessions to CROCO model will be organized in October 2022. See [detailed page](#)

Releases

New intermediate release [CROCO v1.2.1](#)

New release [CROCO v1.2](#) is now available

Mailing list & Forum

We strongly encourage all users to join our mailing list (low traffic; announcements, updates, bug fixes)

croco-users@brr.fr

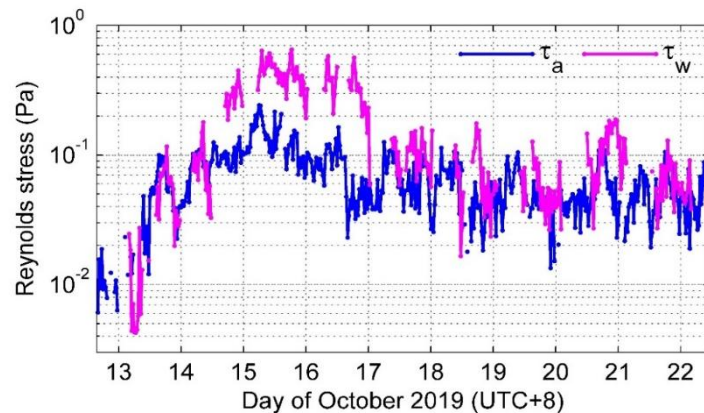
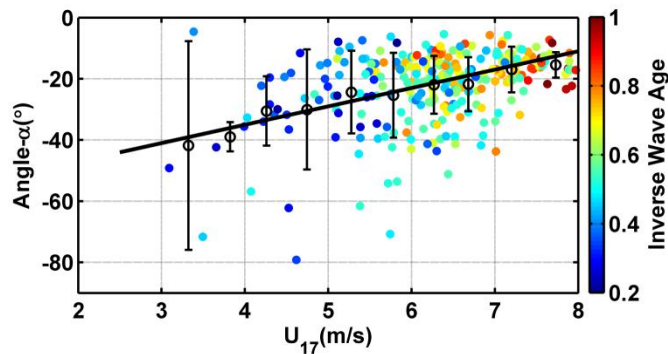
CROCO

Surface waves modulate wind stress



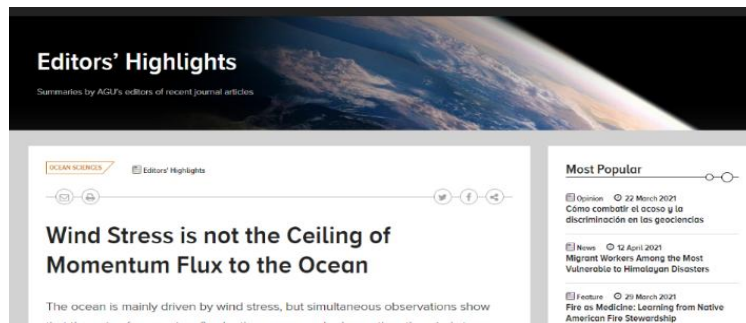
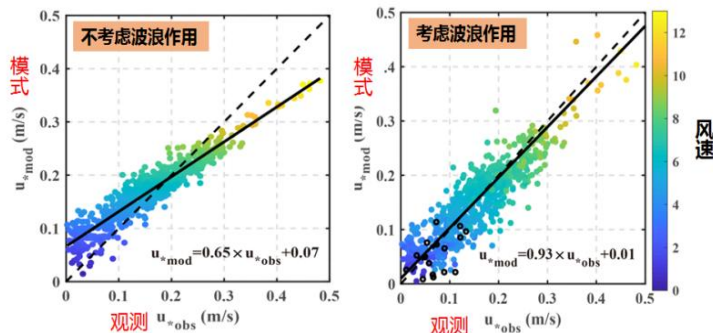
- ❑ The concept was proposed by many scientists, including Toba (1961), Stewart (1970), Wu (1975);
- ❑ Rieder & Smith (1994) reported: “Significant angles between the wind stress vector and the mean wind vector are seen” through FLIP in-situ observation ;
- ❑ Our group has long-term air-sea fluxes observation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

Theory innovation 2: wave modulates wind stress Cd

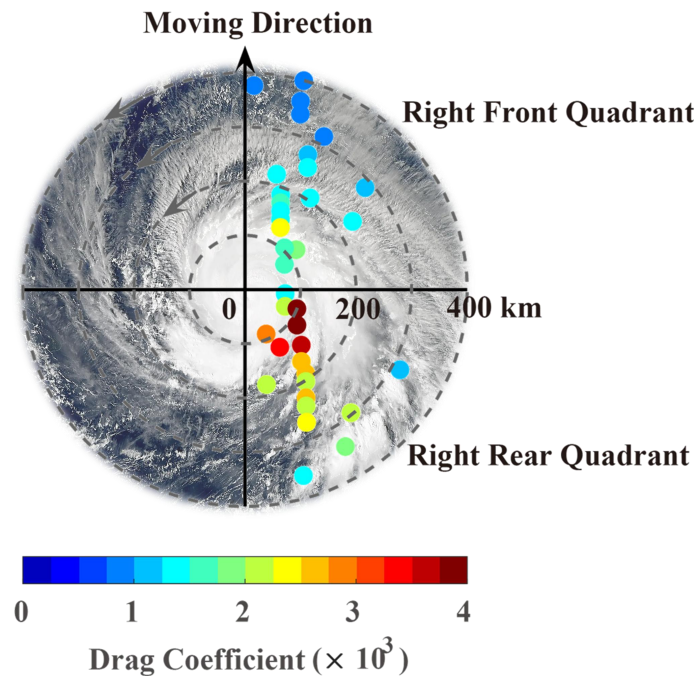
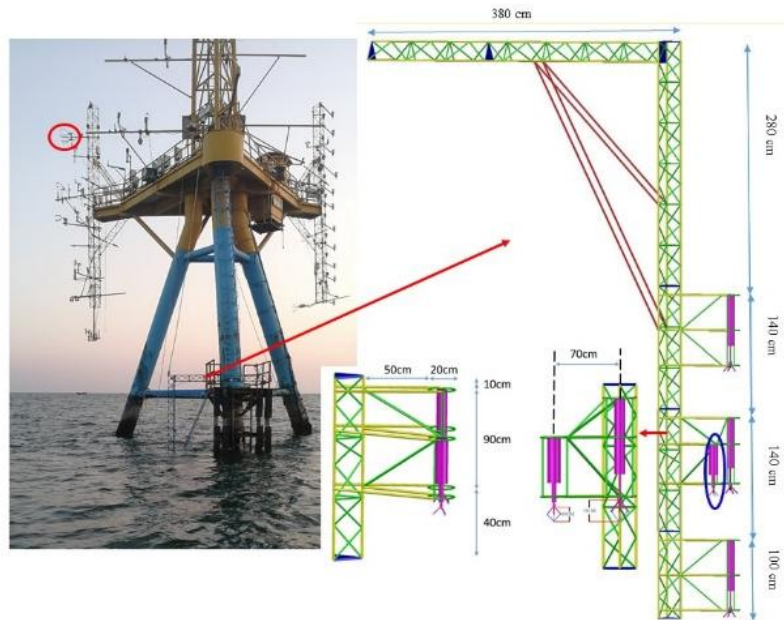


[Huang and Qiao, 2021, JGR]

Reverse the long-standing knowledge on ocean momentum flux

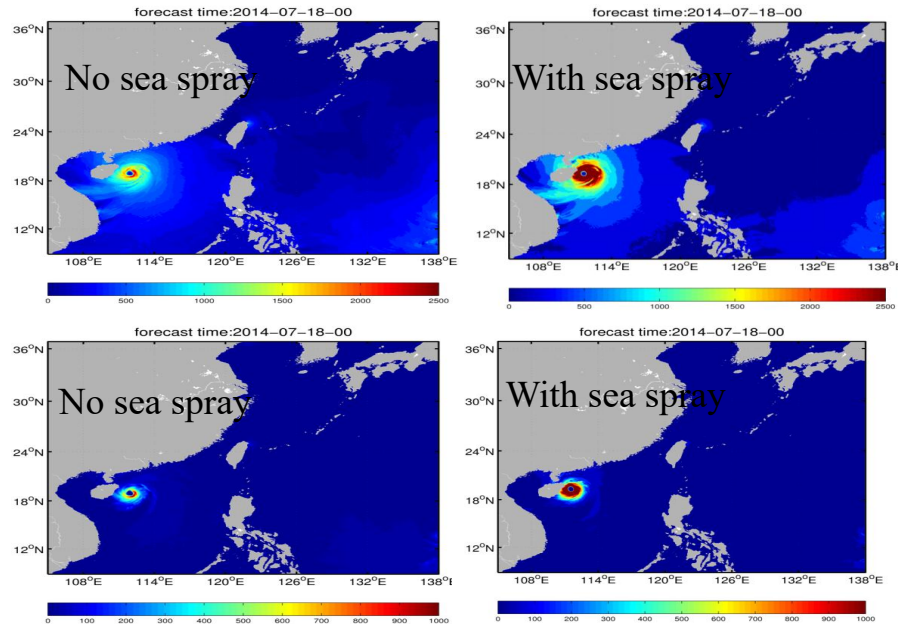


Asymmetry of Cd for TC



Theory innovation 3: sea spray increases heat flux

- Incorporate sea spray into typhoon and Earth system models



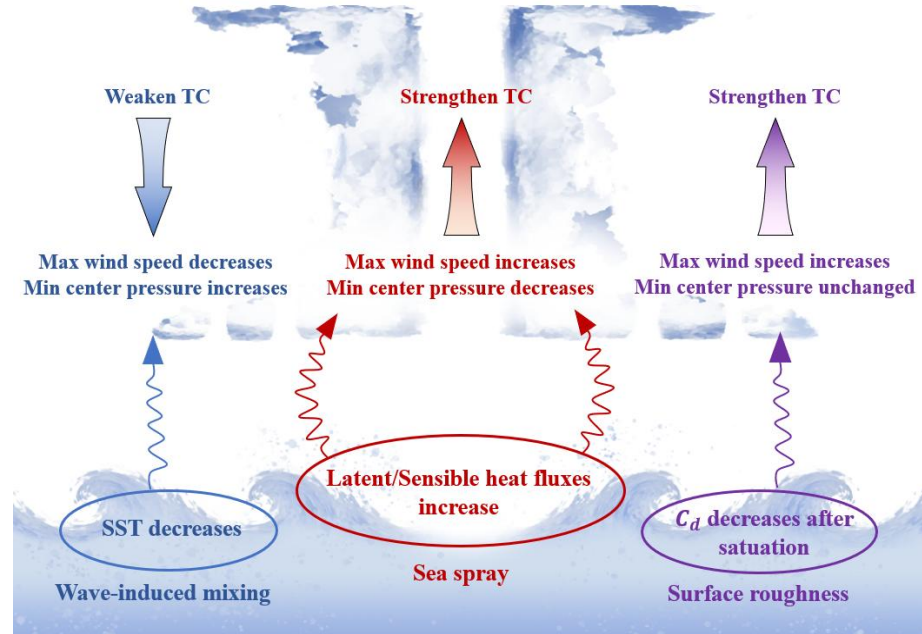
Latent heat
flux

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

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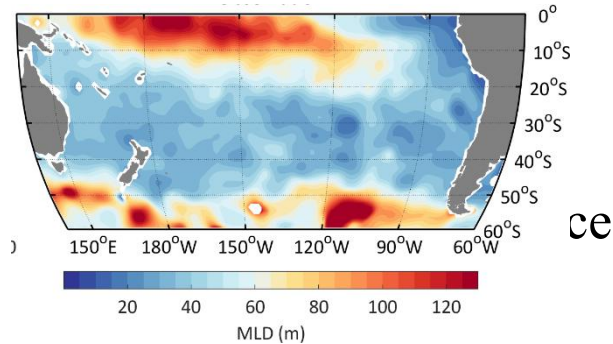
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Proving services for the world

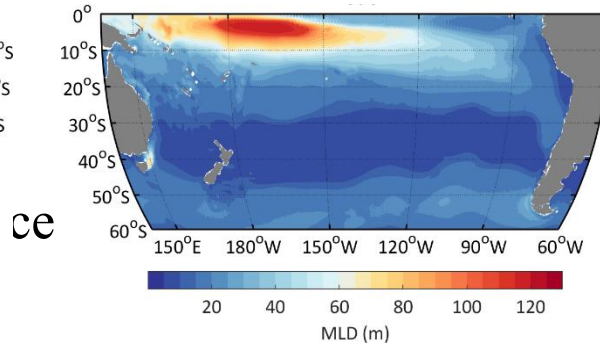
1. Wave-circulation coupled model

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

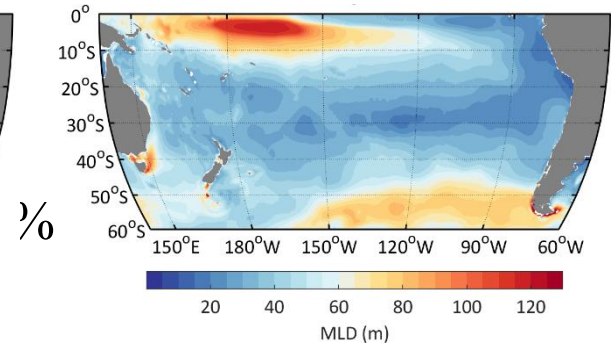
Observation data



Model without Bv



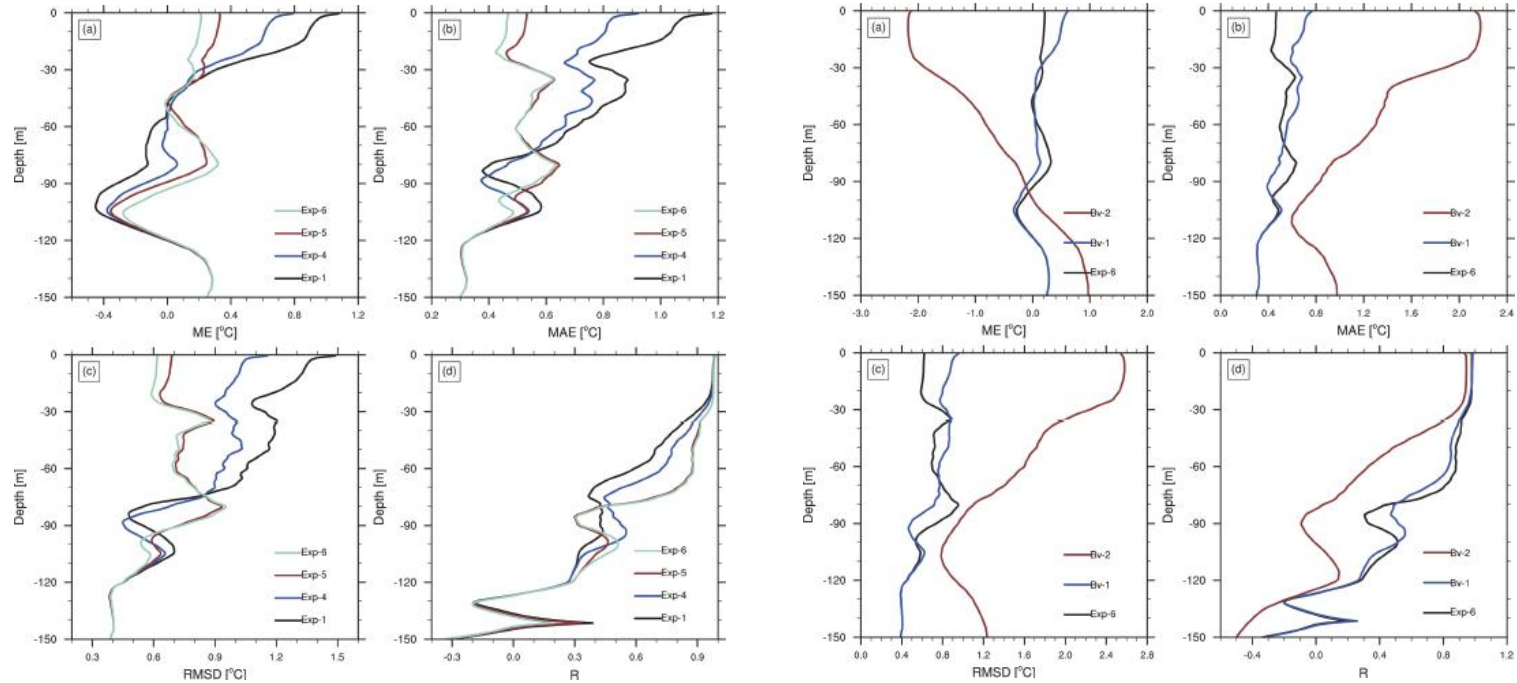
Model with Bv



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

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

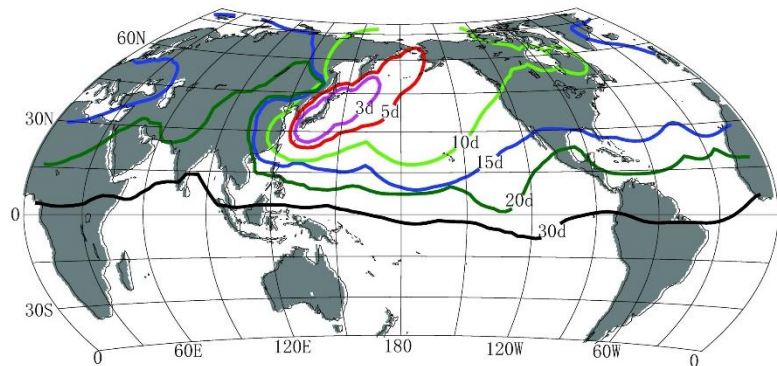
Wu L et al (2015, JGR) compared 7 parameterizations, Bv is most effective



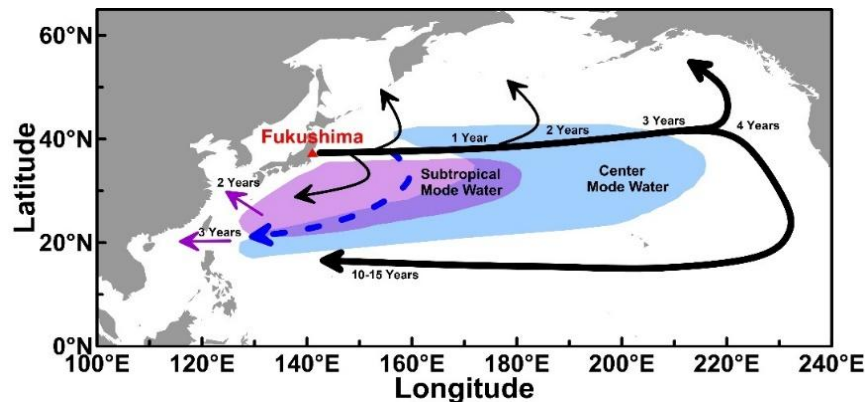
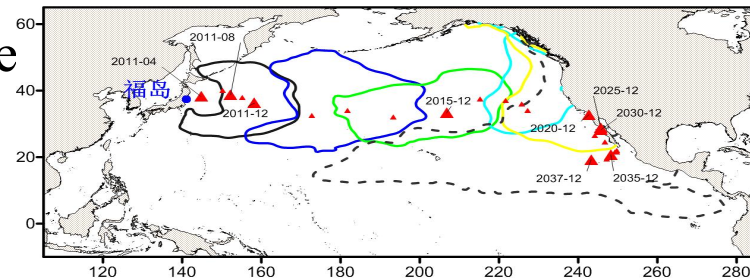
E1: none; E2: breaking; E3: CSF; E4: LC; **E5: NB**; E6: E2+E3+E4+E5

Application: simulation of nuclear discharge

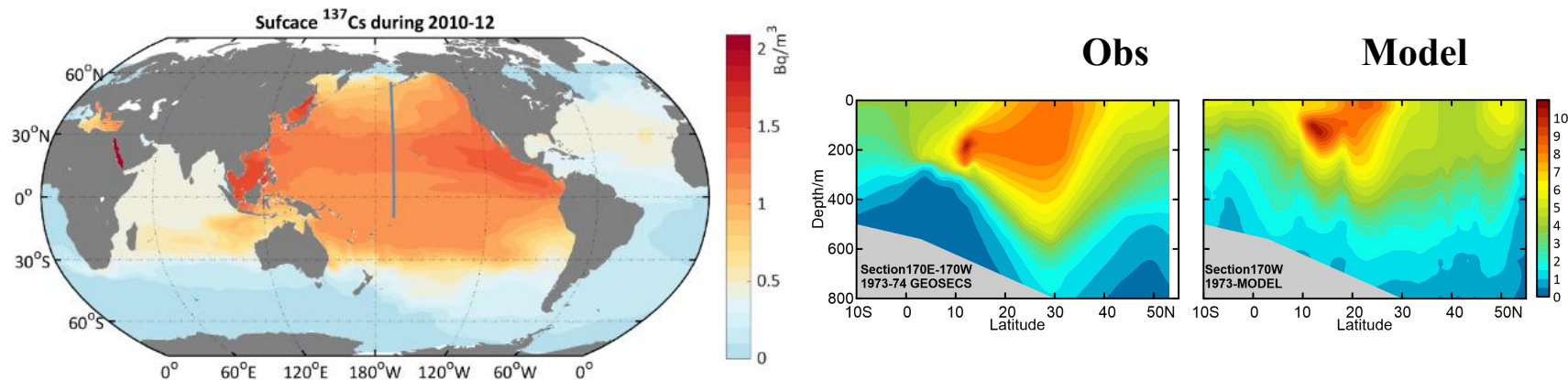
- The first simulation and warning system for predicting the nuclear matters in the ocean and atmosphere nuclear matter.



Zhao et al, 2021, MPB



Long-term simulation validation against observation



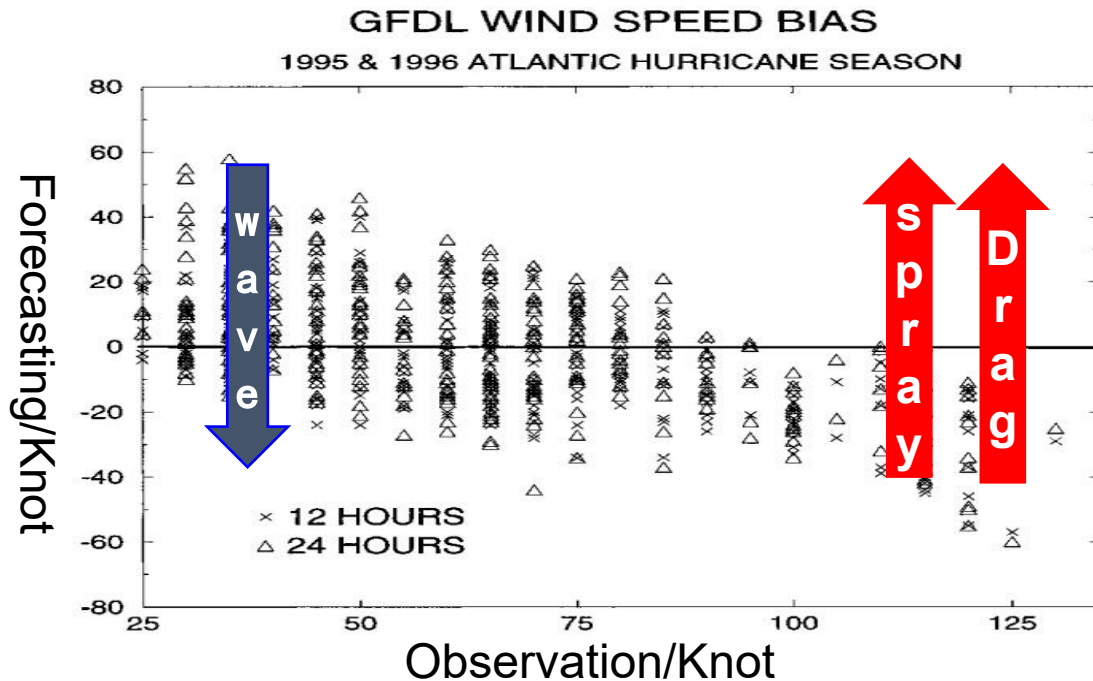
2. Third generation TC model

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

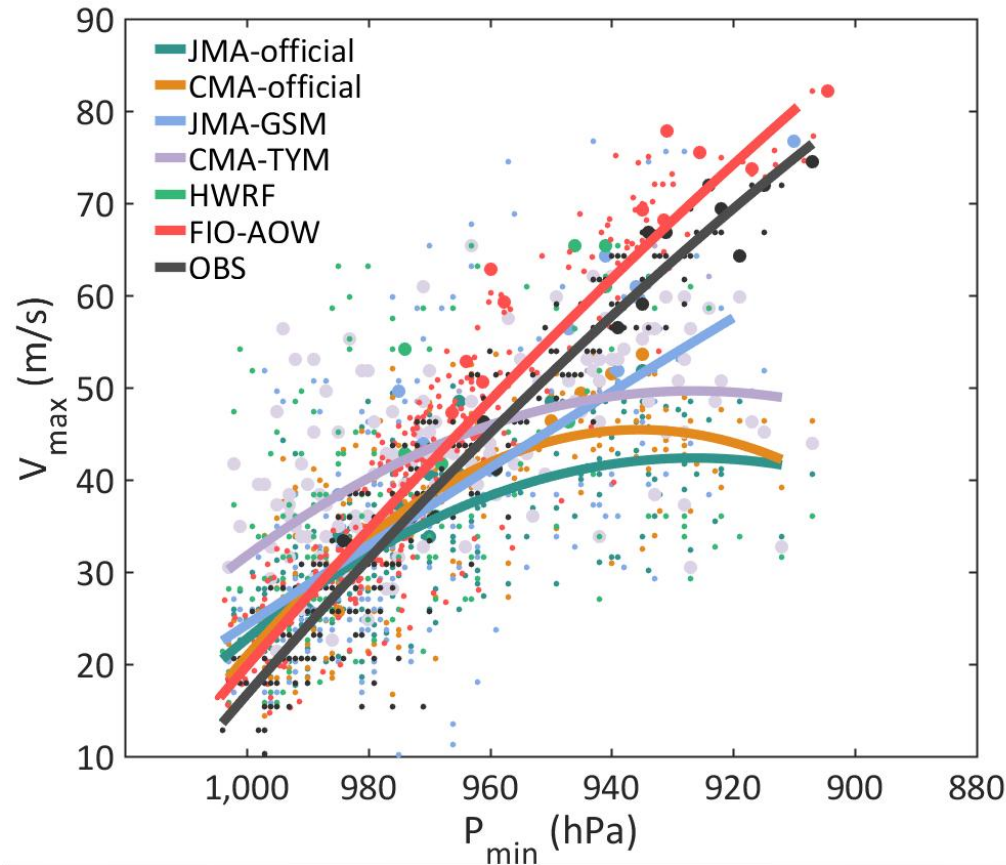
Bv: Qiao et al, 2004

Spray: Andreas et al, 2015

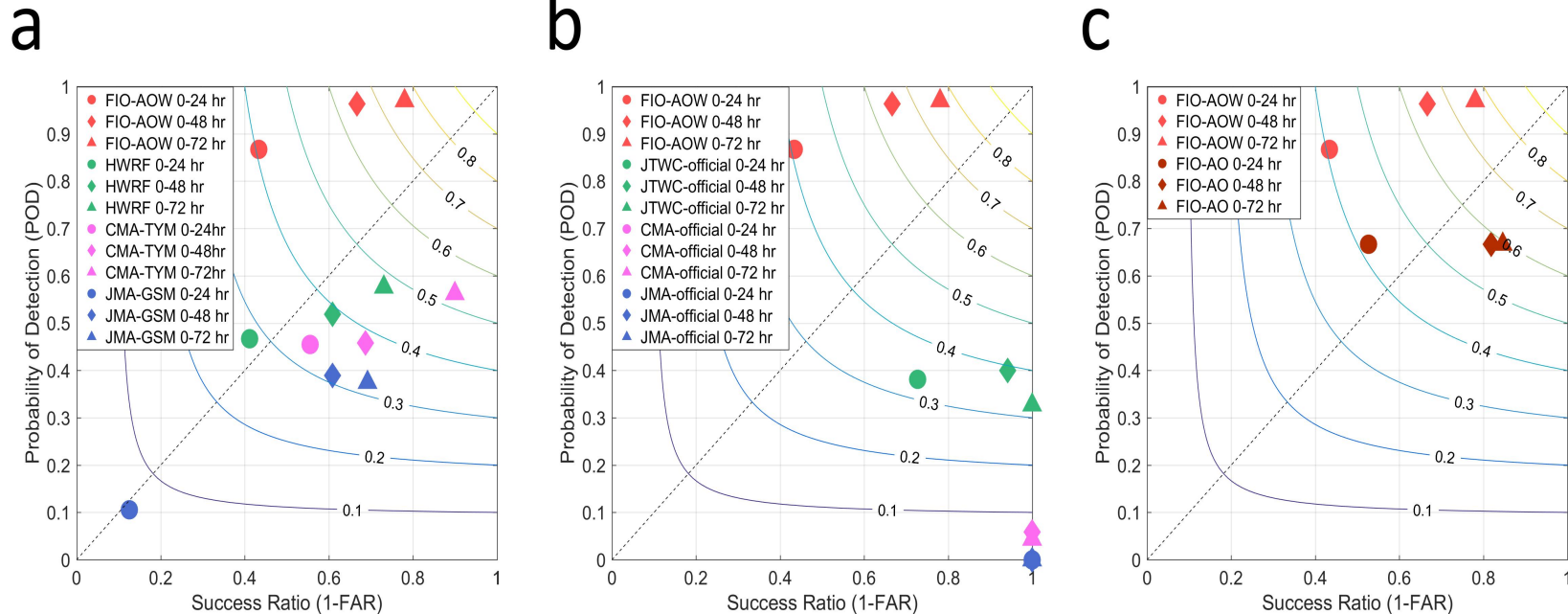
Cd: Zhao et al, 2024



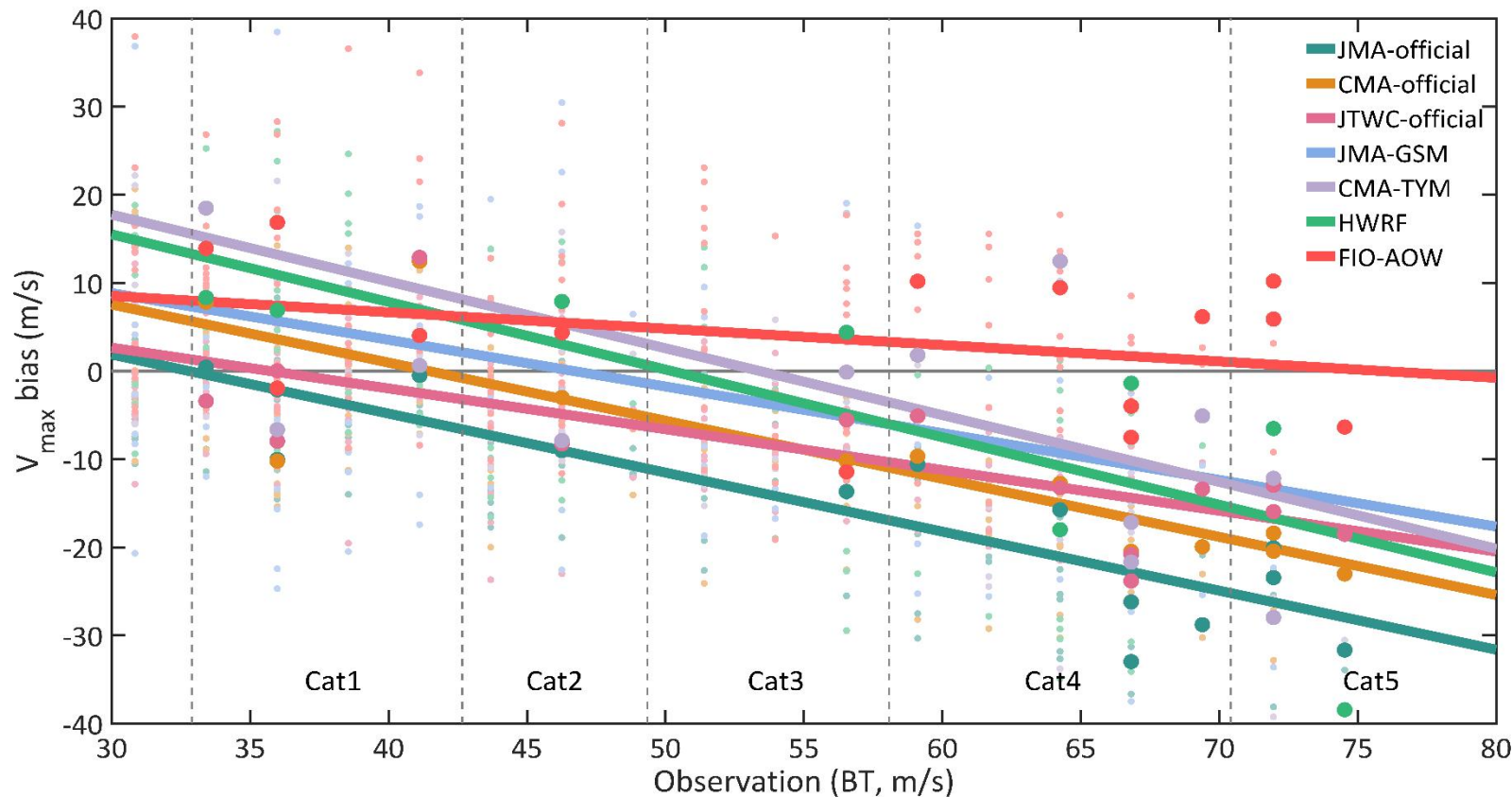
(1) Comparison of wind-pressure relation in 2024



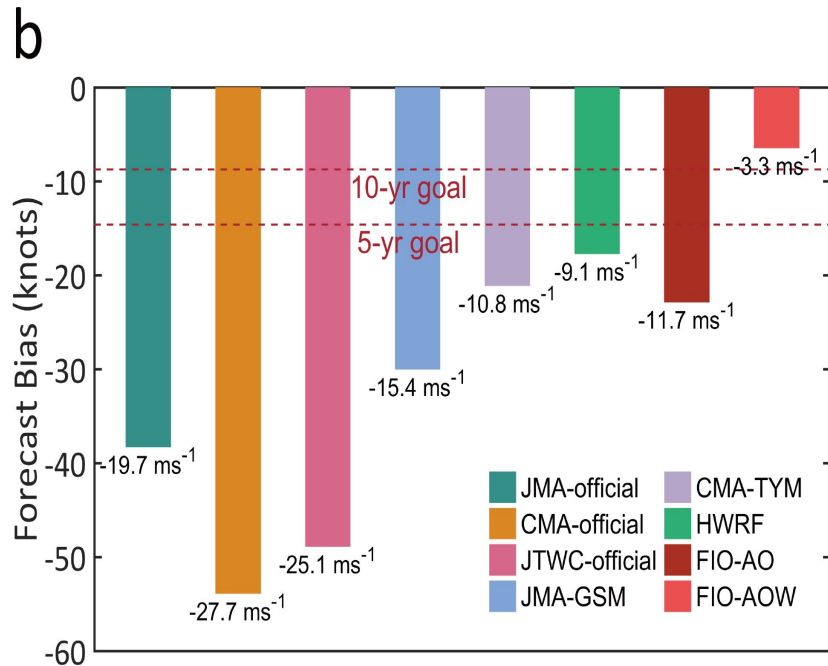
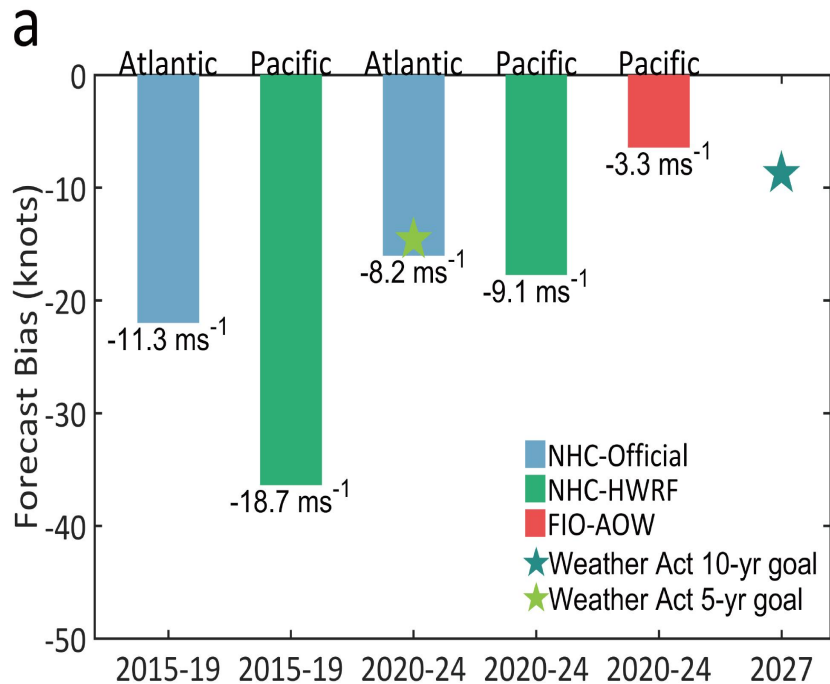
For all RI in 2024 in the Northwest Pacific



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

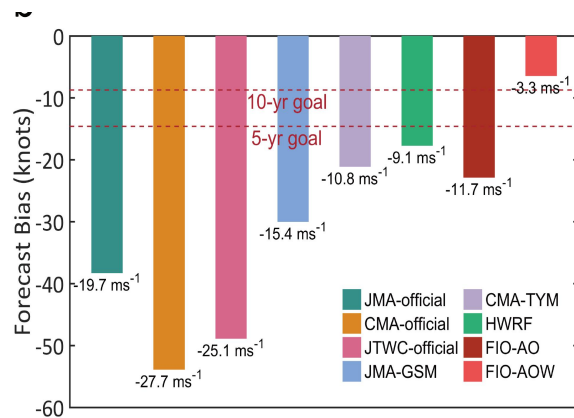


(2) For all 37 RIs during 2020-2024



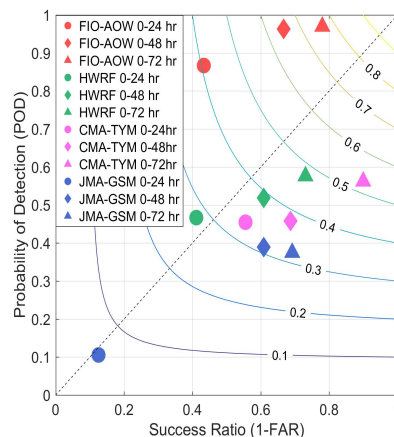
For 3 bottleneck challenges

Big intensity bias



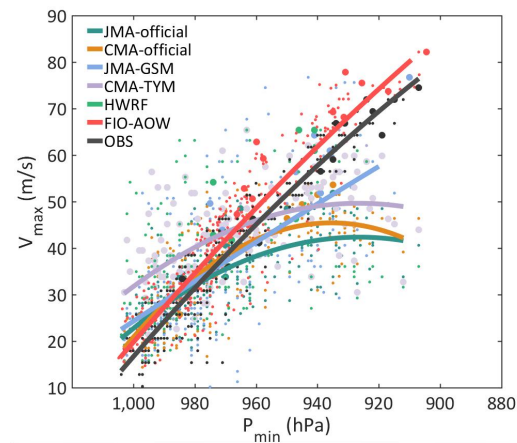
Over “weather Act”

Predict RI



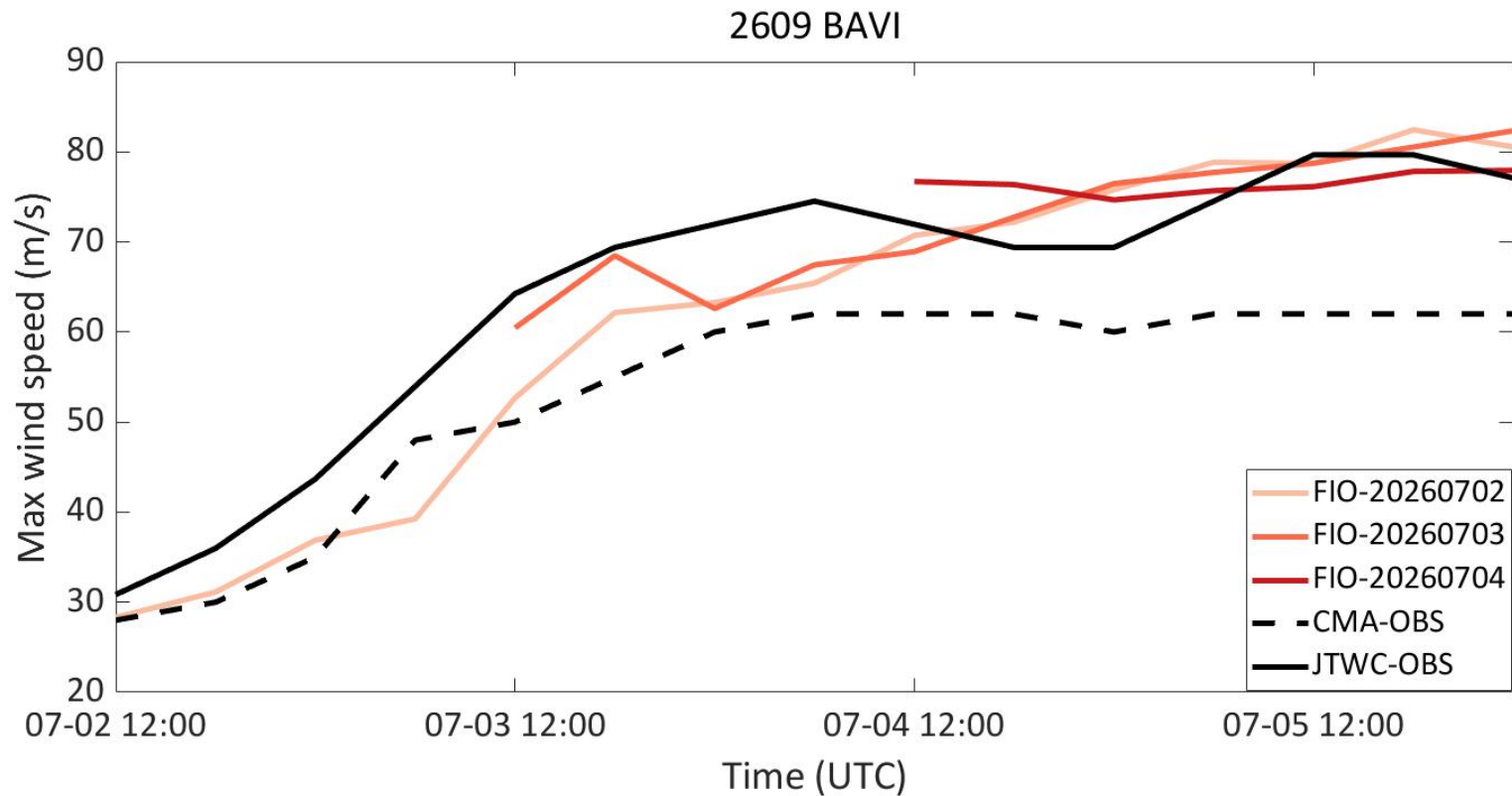
RI 90%+

Wind-press rela

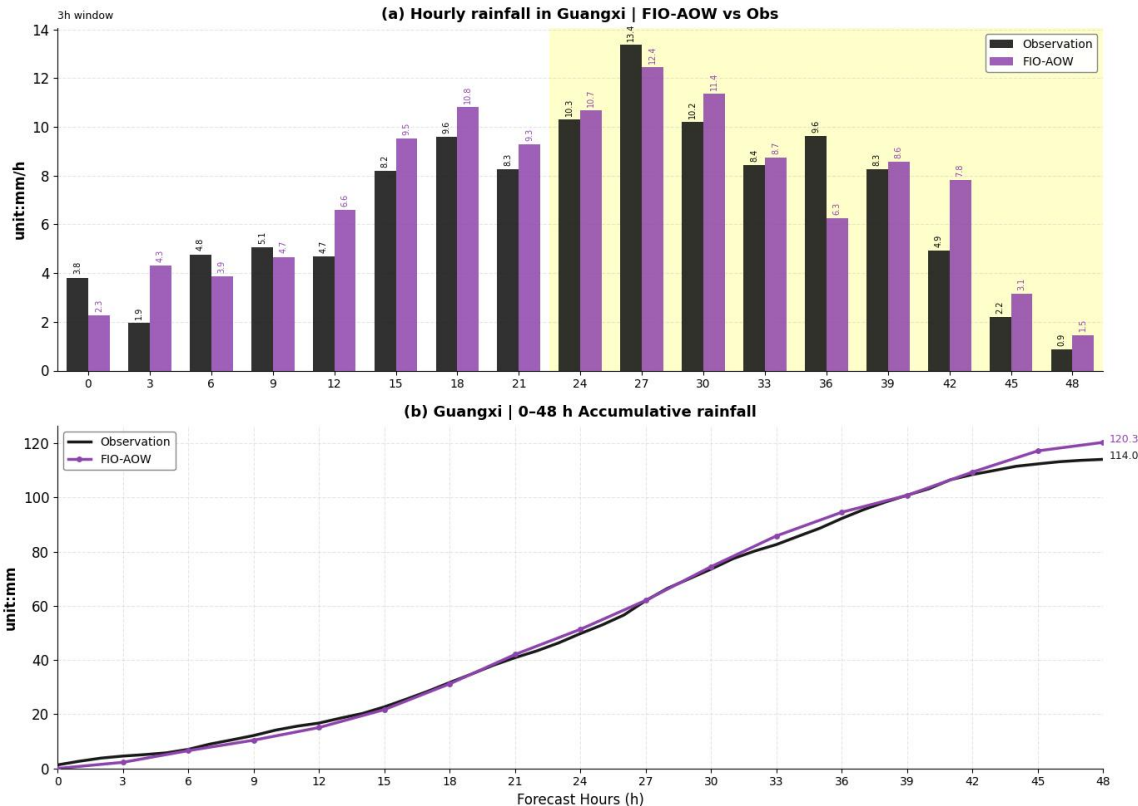


Good relationship

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

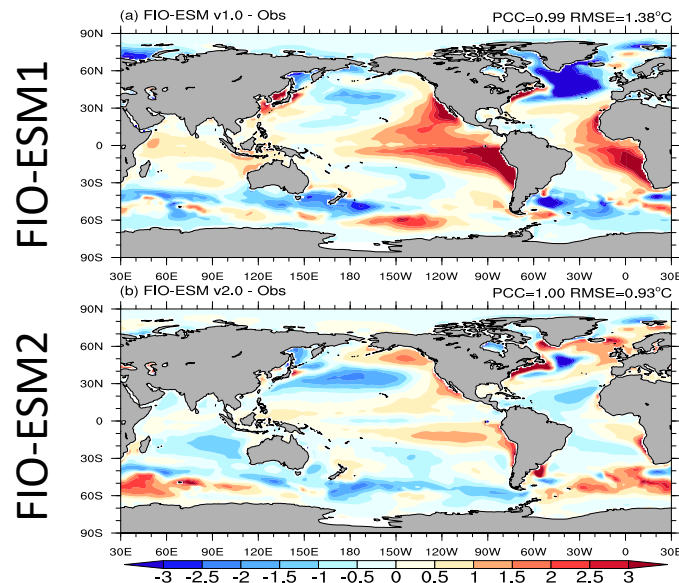
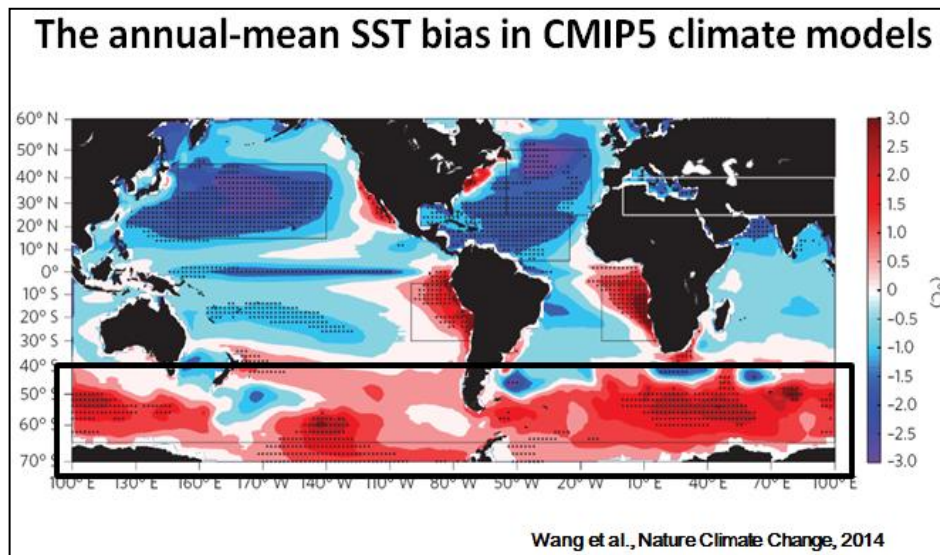


Heavy precipitation in Guangxi from Severe Tropical Storm Maysak



3. Two-generation of FIO-ESMs

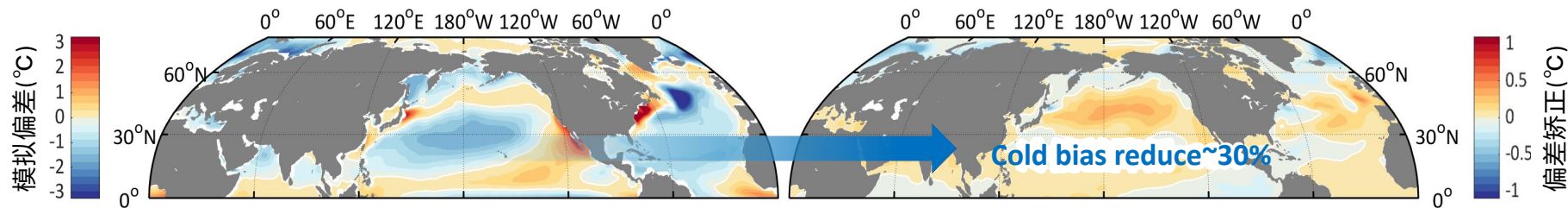
First ESM with wave incorporated, reducing half of the original biases



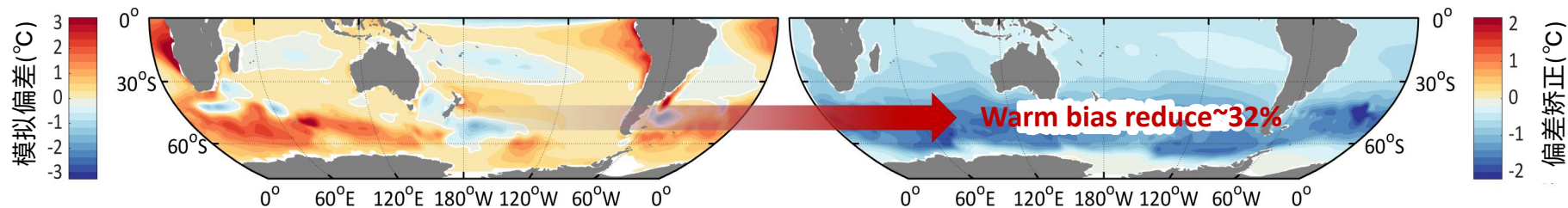
Qiao et al, 2013, JGR; Bao et al. 2021, JGR

Wave effects in climate system

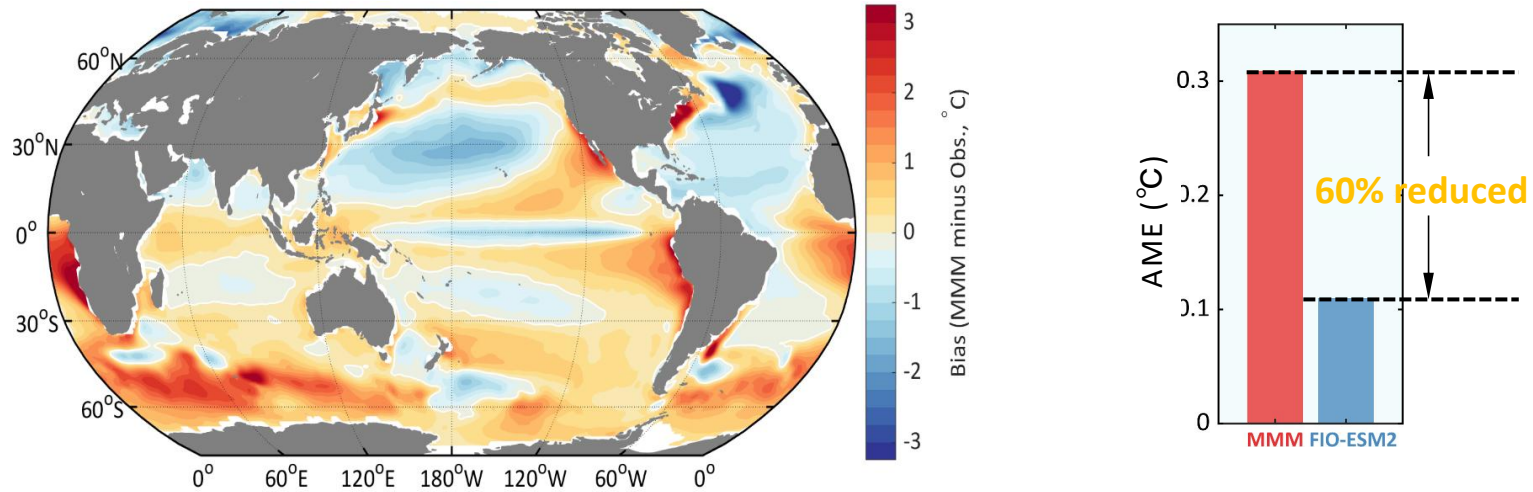
Stokes Drift



Sea Spray



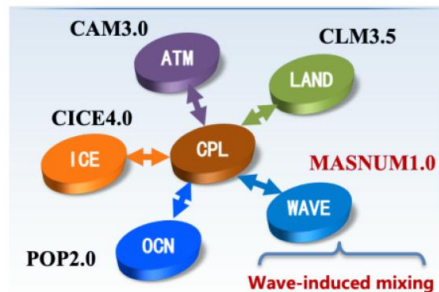
Climate prediction challenge and solution



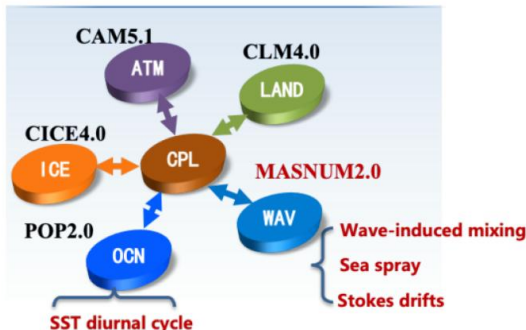
The Bv theory can **reduce the prediction error of climate by about 60%**, which is a long-standing scientific challenge in the world for all climate models.

ENSO comparison in the past 100 years

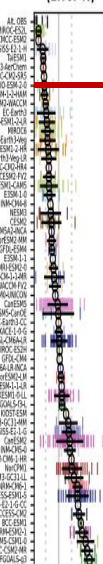
FIO-ESM v1.0



FIO-ESM v2.0



**(j) ENSO_asymmetry
(Error %)**



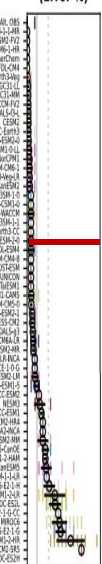
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**(e) ENSO_amplitude
(Error %)**



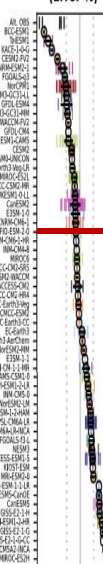
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**(f) ENSO_duration
(Error %)**



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**(g) ENSO_seasonality
(Error %)**



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**(h) ENSO_diversity
(Error %)**



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[Lee, 2021, GRL]

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III

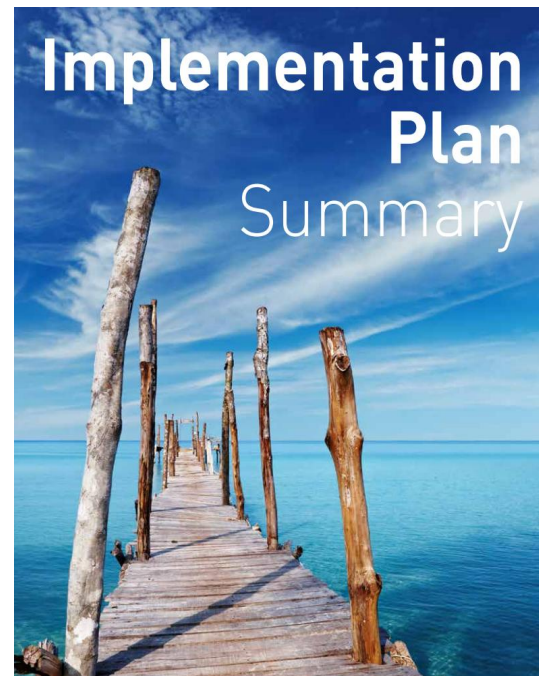
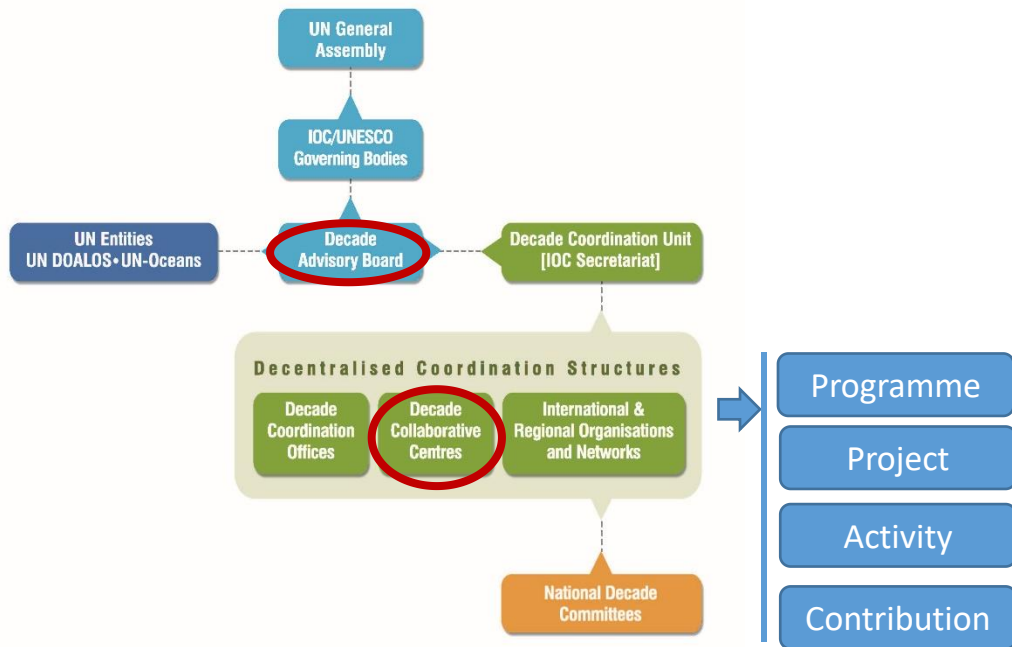
New generation models

IV

Proving services for the world

DCC-OCC of UN Ocean Decade

□ 2018-2020: **EPG** 2021-2023: **DAB**



The United Nations
Decade of Ocean Science
for Sustainable Development
(2021-2030)

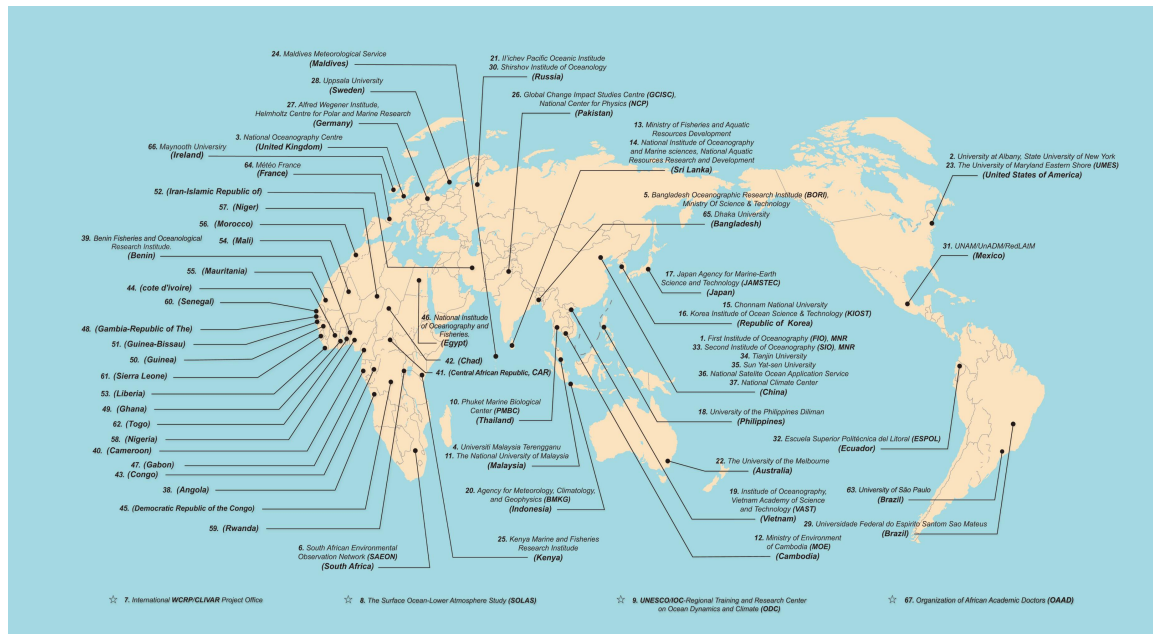


Ocean to climate seamless forecasting system (OSF)

80+
Institutes

50+
Countries

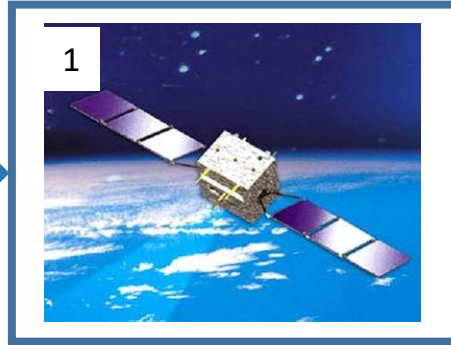
5
International
organizations



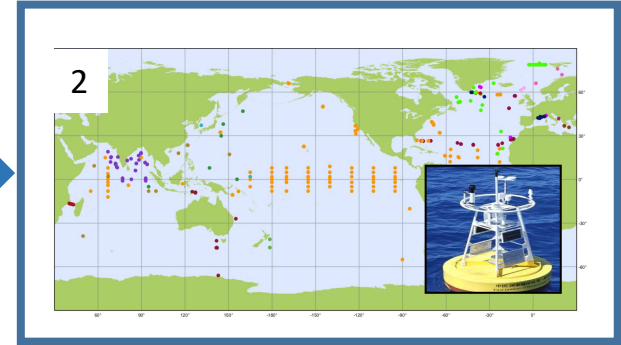
Technical innovation for observation: ~5% cost



English Challenger, 1872-76



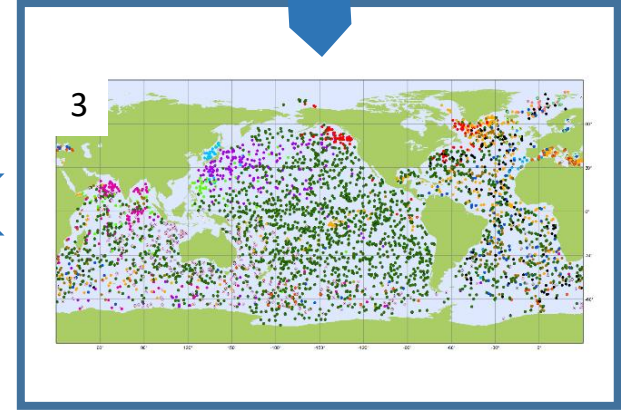
SeaSat-A, 1978



ENSO Buoy, 1980s

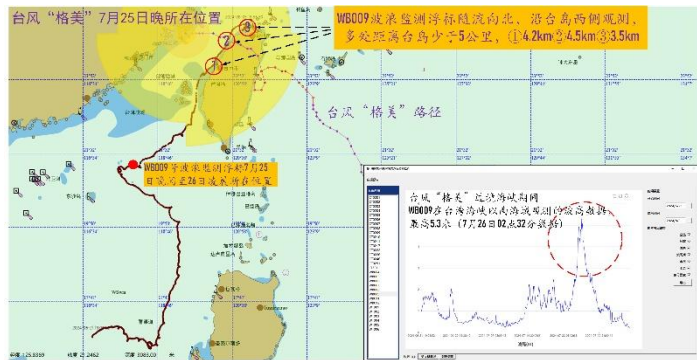


GNSS new buoy: high precision and low cost



ARGO, 2000s

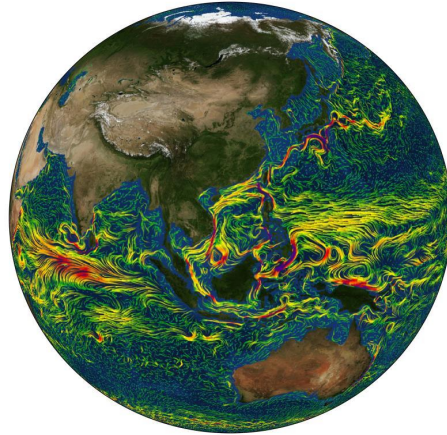
The buoy has been tested more than 100 times



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

Ocean Forecasting
system

Typhoon
forecasting system

Climate prediction:
SLR, climate heat
wave and
drought/flood

Marine search and
rescue; oil spill
tracking

Maritime Navigation Safety

Maritime Silk
Road forecasting

Polar shipping risk
assessment

Optimal route
planning

Customi
forecasting s

Coastal Ecosystem Health

Coral reef
bleaching
monitoring and
forecasting

Pollution tracing
and trajectory
prediction

Marine
aquaculture

Integrated Coastal Management

ICM Code

MPA planning

Estuarial pollution

Blue Economy Development

Ocean renewable
energy
development

Blue carbon
storage estimation

Assessment on
marine
environment
effects

an tourism
index

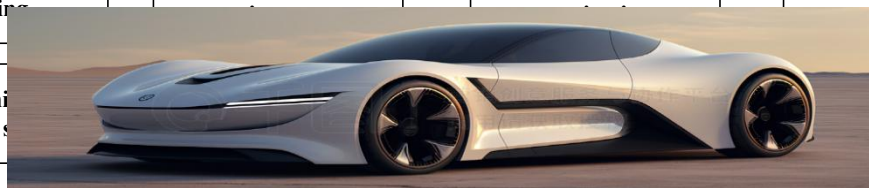
Ocean Literacy and Capacity Building

Ocean Literacy
Alliance for
Primary and
Middle Schools

Marine Museums
Alliance

Marine knowledge
outreach

Best practice on
human-ocean
harmony



FUEL

Data support

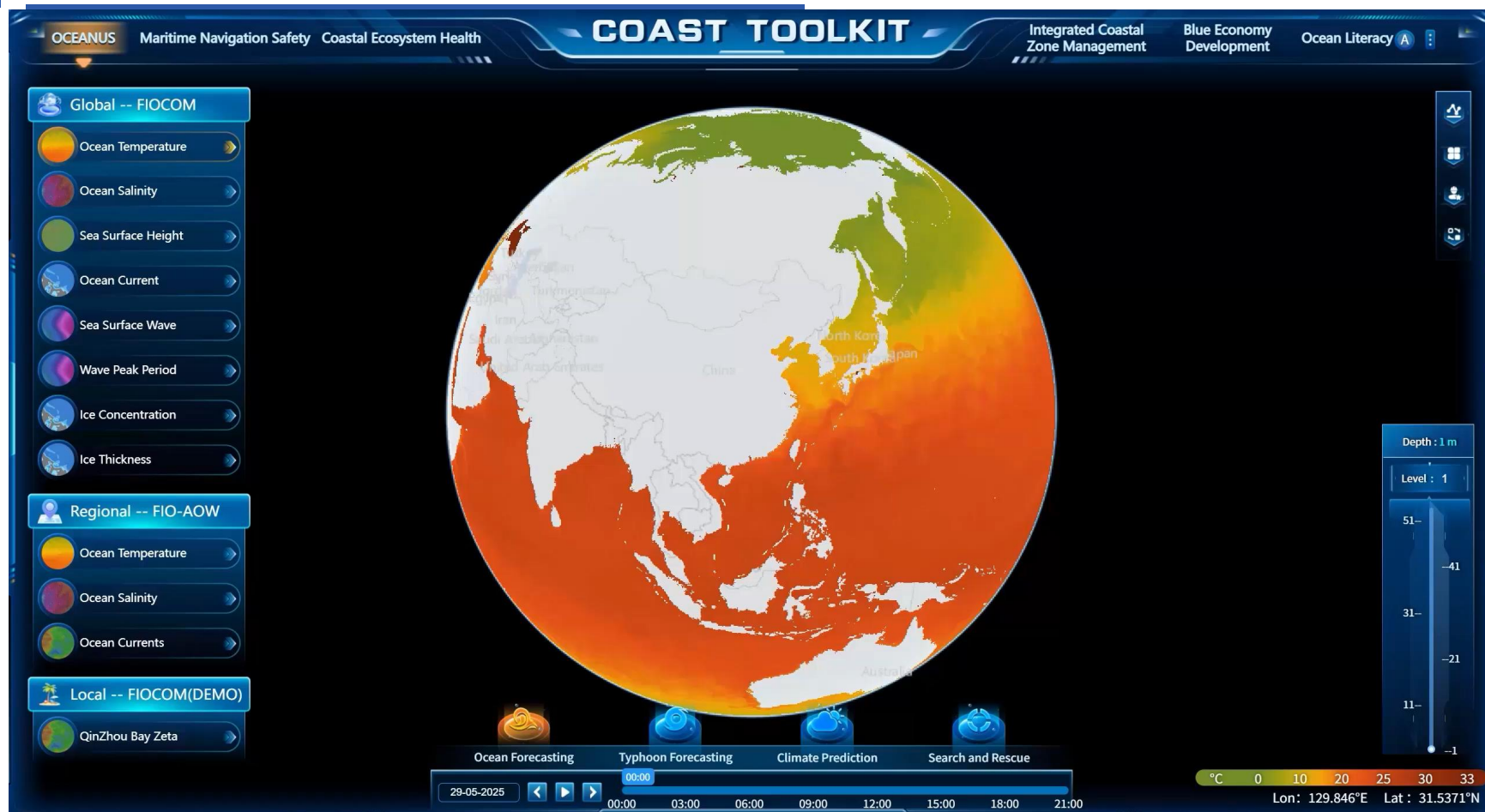
State-of-the-art model + AI

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.**

A full-page photograph of a sailboat on the ocean during sunset. The sun is low on the horizon, creating a bright, golden glow that reflects on the water's surface. A large, light-colored sail is partially visible, billowing in the wind. A person is seen on the deck of the boat, which is moving through the water, leaving a wake. The overall mood is peaceful and serene.

Thanks

qiaofl@fio.org.cn