



自然资源部第一海洋研究所
THE FIRST INSTITUTE OF OCEANOGRAPHY, MNR.



Improved ocean-related forecasting ability has been paving the way for providing decision-making actionable information

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**First Institute of Oceanography, MNR, China
29 Oct. 2024, PICES Annual Meeting, Hawaii**

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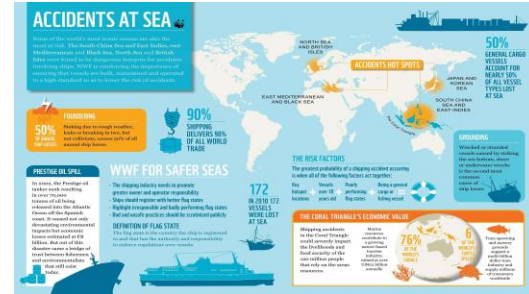
International cooperation

Significant Societal Needs for Ocean and Climate Prediction

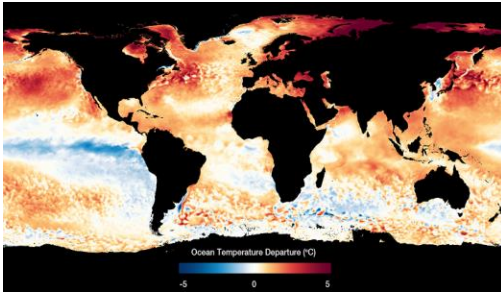


2005 Hurricane in New Orleans with 1836 death and over \$130B losses
2024 Hurricanes **Helene** and **Milton** with several hundreds death and over \$150B losses

Protect cities from being destroyed



Response to ocean accidents



Enhance resilience to extreme events

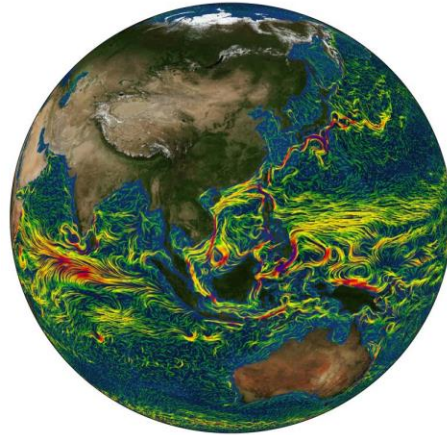


Guide energy conservation and emission reduction

What can we do?



Satellite and *in-situ*
observation data



Ocean & climate
prediction



Provide science-based
solutions

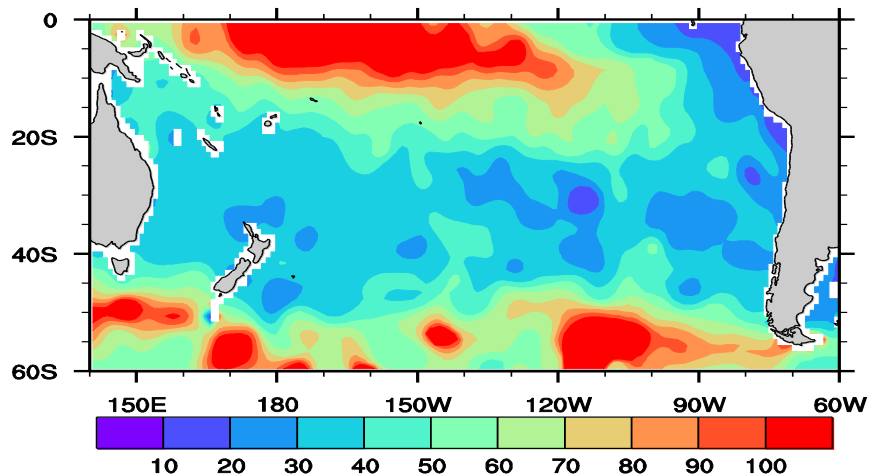
Long-lasting bottleneck problems for models

❑ **Importance** of numerical model: one of the ultimate purposes of marine science is to provide accurate forecast, and model represents the comprehensive level of a country's scientific research.

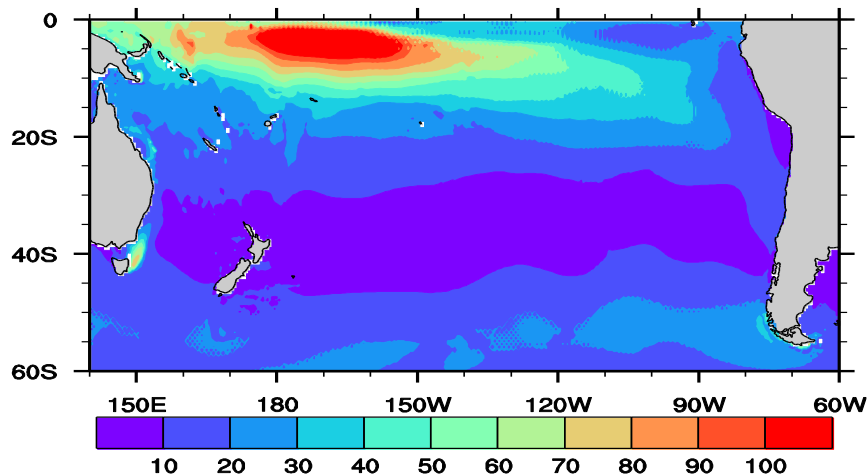
❑ **Developed** for half a century: 1967, the GFDL of US established the first numerical model of ocean circulation.

❑ **Huge common deviations (biases)** have long existed in ocean, typhoon and climate (Earth system) models, directly affecting the forecasting accuracy, making it hard to achieve accurate prediction, then provide science-based solutions.

Challenge 1: **Common** biases in OGCMs



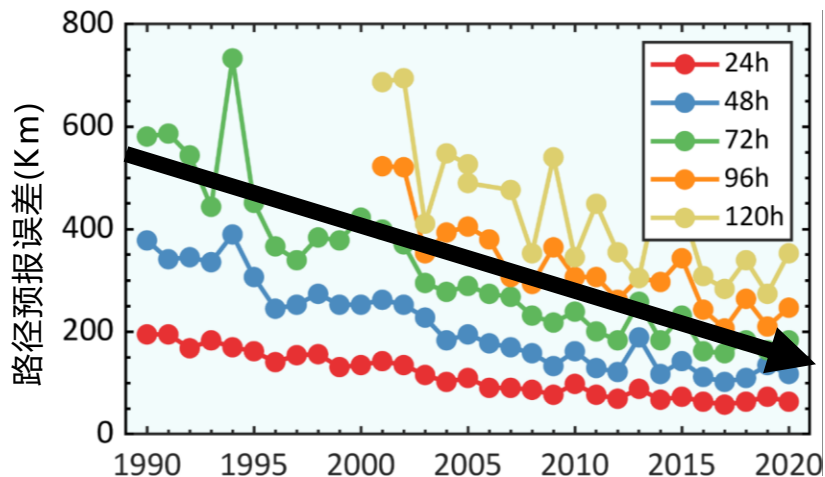
Observed MLD



Simulated MLD

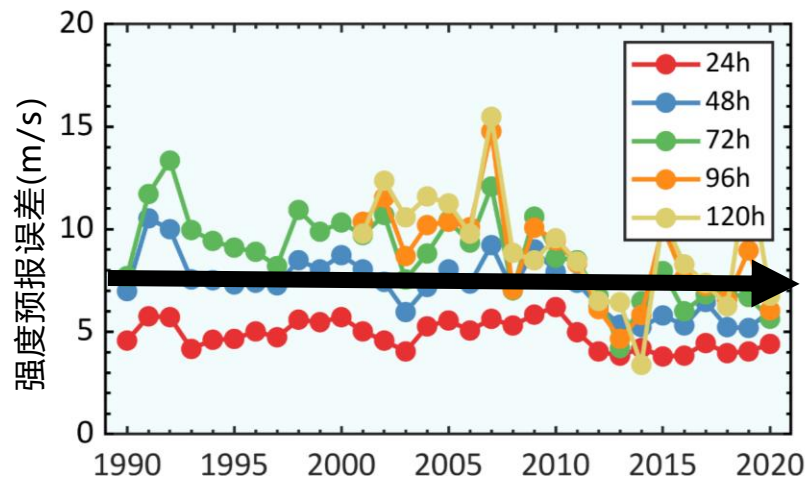
Challenge 2: Standstill in forecasting **Typhoon intensity**

Typhoon Track



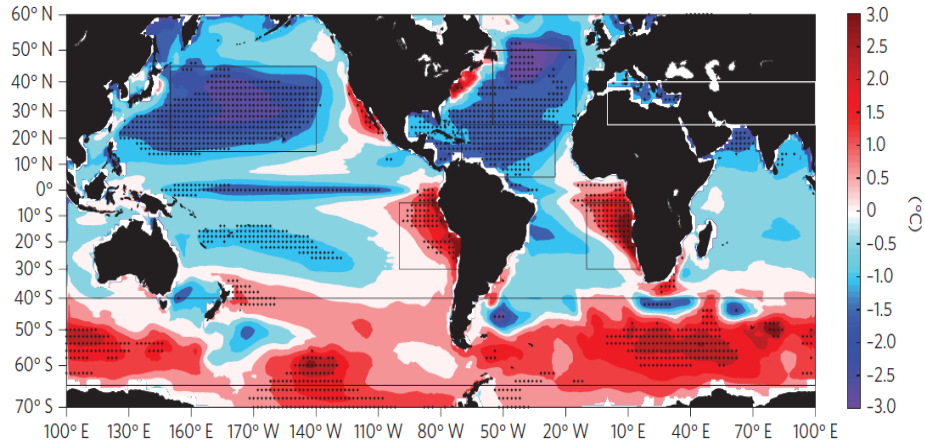
NHC Forecast Verification Report, 2020

Typhoon intensity



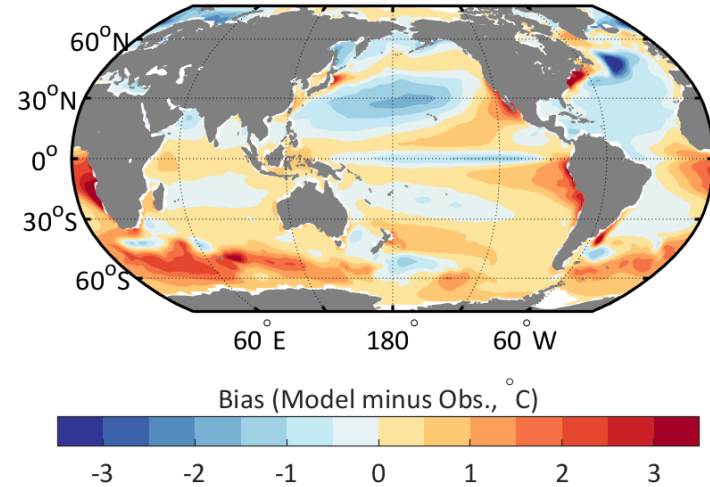
Controlled by air-sea heat fluxes

Challenge 3: Common biases in climate models



22 CMIP5 models results

(Wang et al., 2014)



CMIP6 results

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

Turbulence is to model what virus is to epidemic

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

—— Richard Feynman (Nobel Prize winner, 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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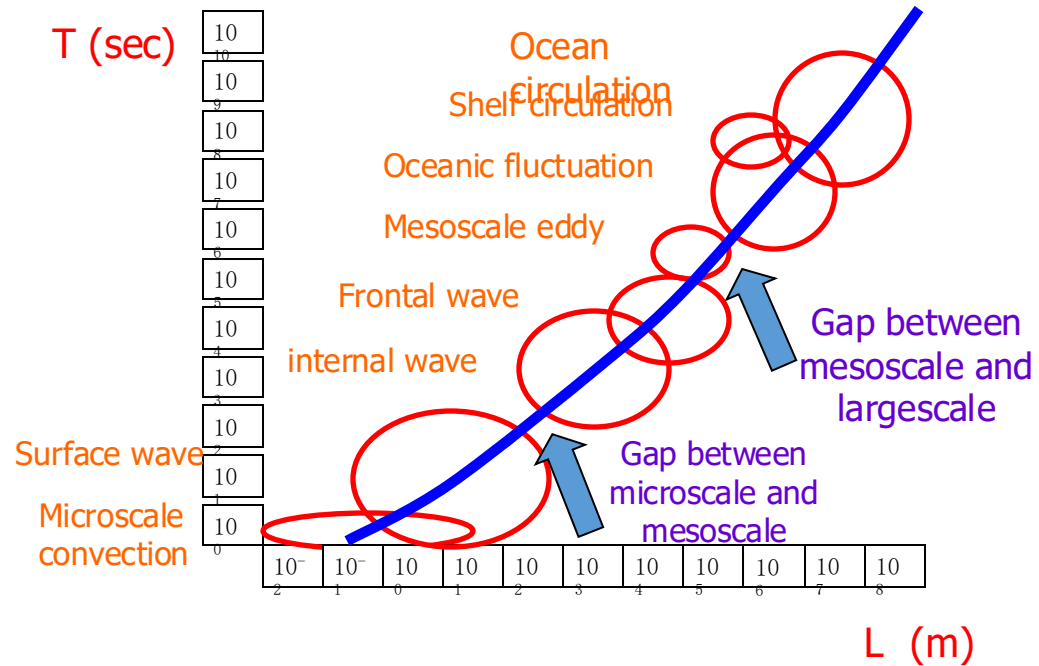
Ocean system models

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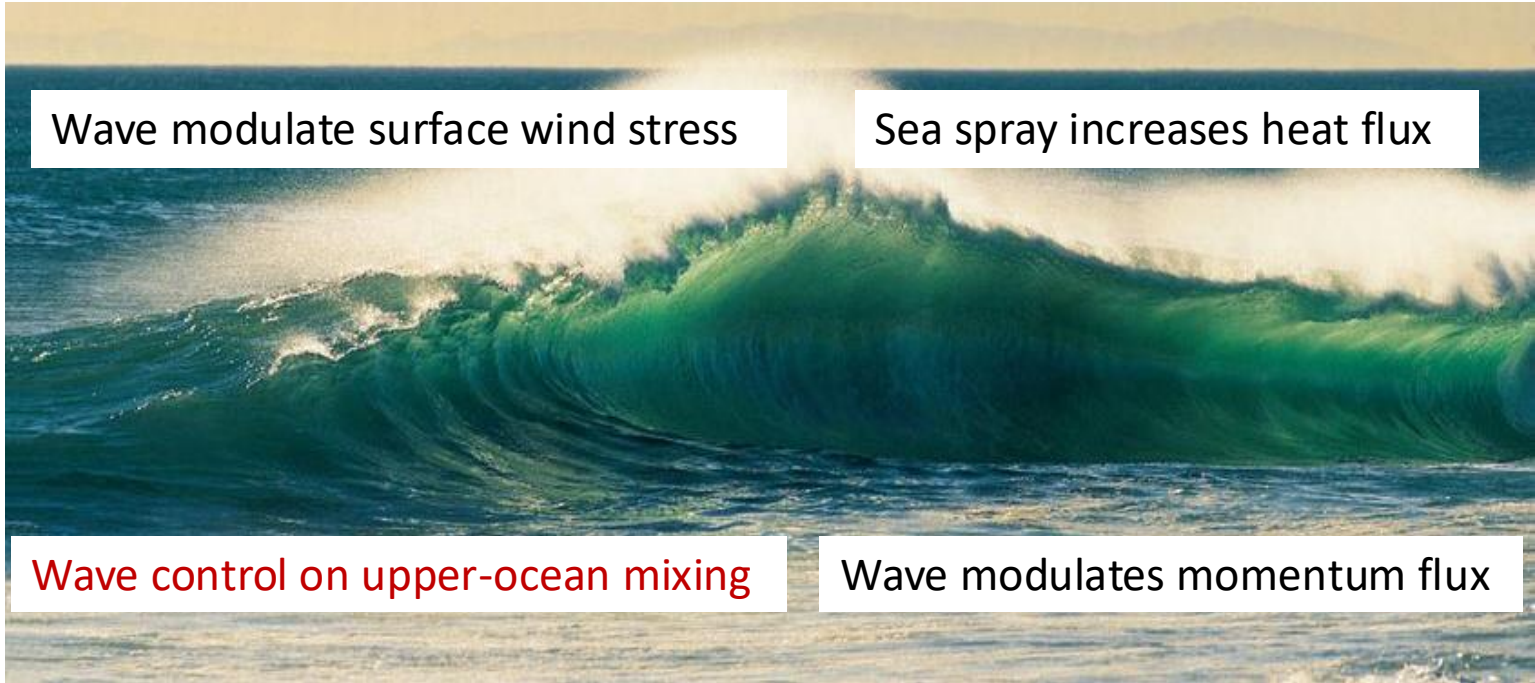
International cooperation

Ocean system science

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



Ocean impacts in shaping the climate system



Wave modulate surface wind stress

Sea spray increases heat flux

Wave control on upper-ocean mixing

Wave modulates momentum flux

Theory innovation 1: wave-induced mixing

- Wave is a major source of upper-ocean turbulence

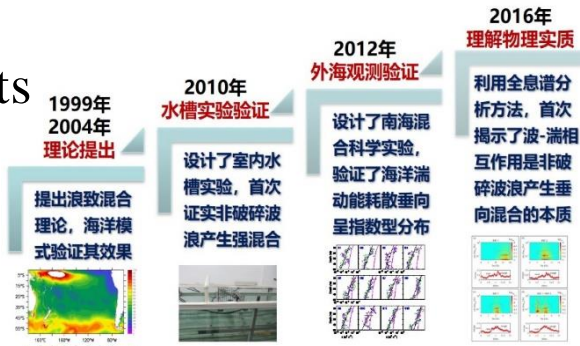
$$B_v = \alpha \iint E(\vec{k}) \exp\{2kz\} d\vec{k} \frac{\partial}{\partial z} \left(\iint \omega^2 E(\vec{k}) \exp\{2kz\} d\vec{k} \right)^{\frac{1}{2}} \quad (\text{Qiao et al, 2004, 2010})$$

- The key is that wave-turbulence interaction intensifies ocean turbulence (Qiao et al, 2016) ;

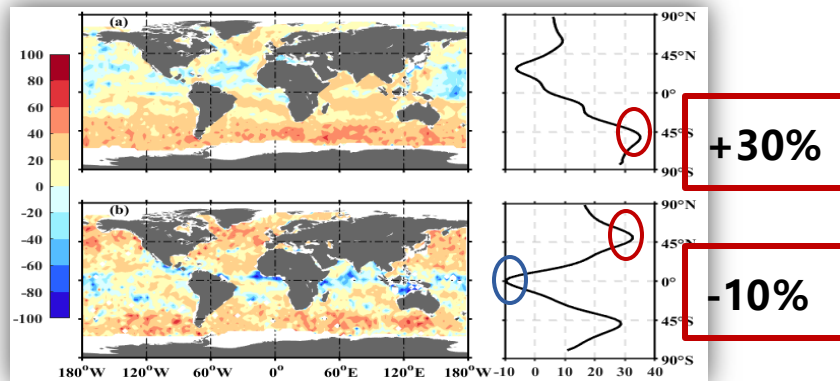
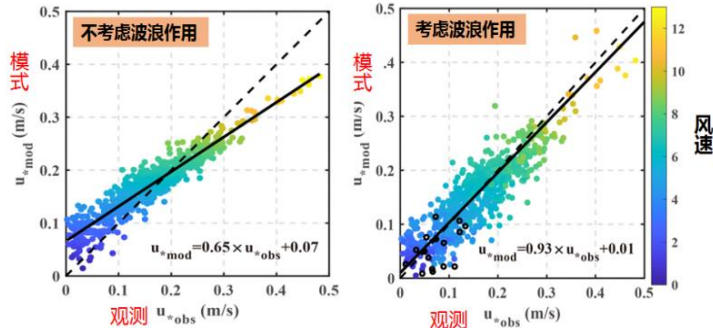
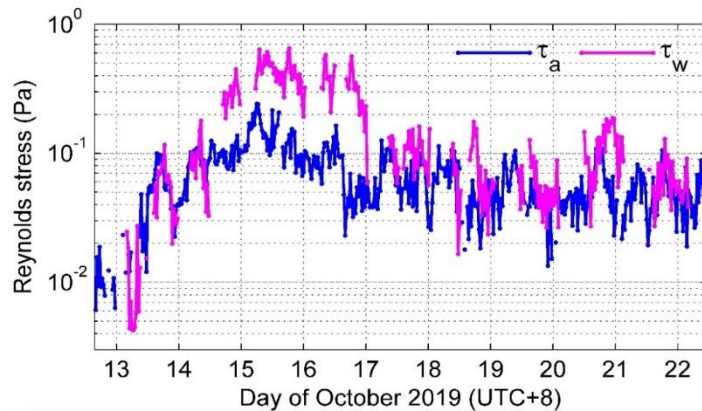
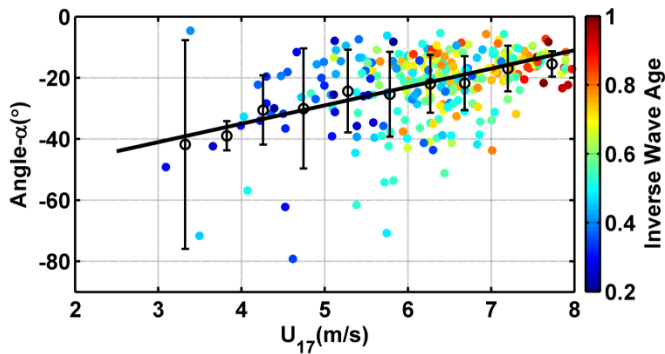
- Confirmed by following in-situ and Lab experiments

- Overturn the statement of J. Lumley (1983):

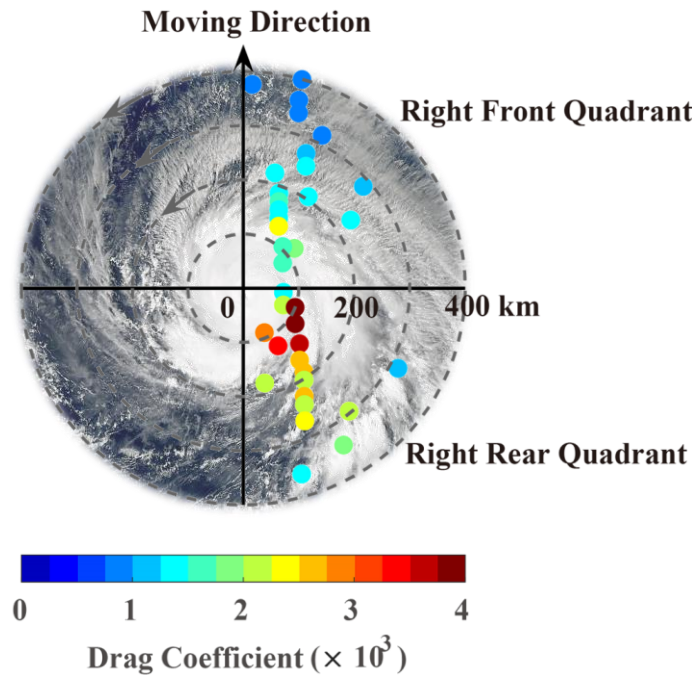
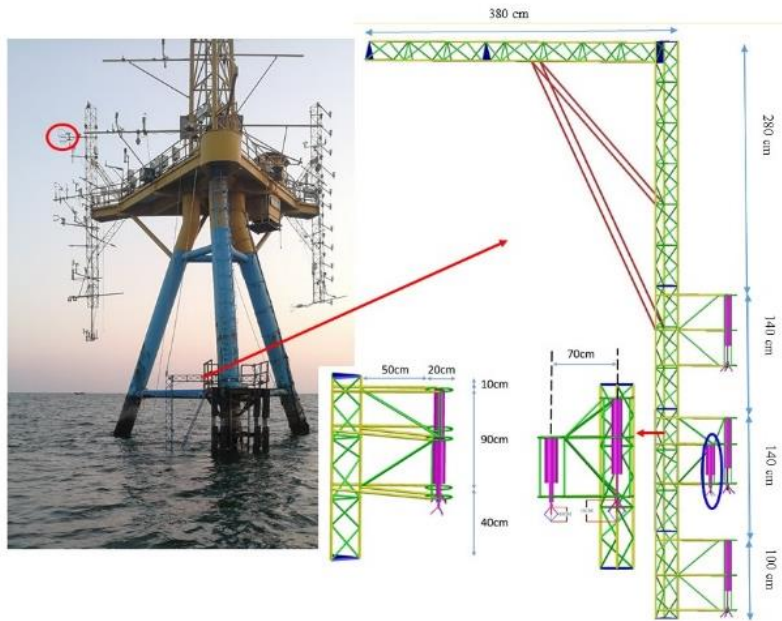
“non-breaking wave does not generate turbulence”



Theory innovation 2: wave modulates wind stress



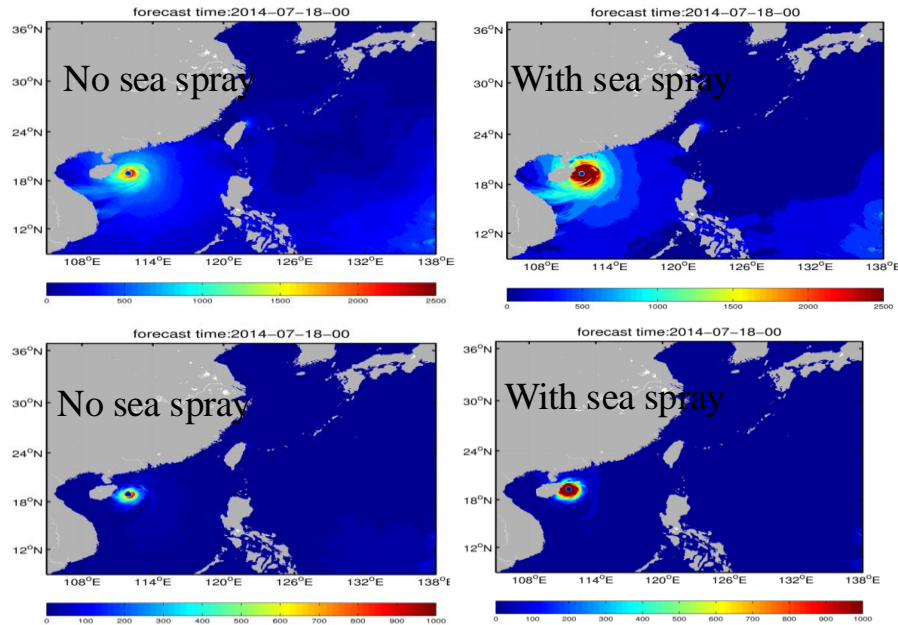
Asymmetry of Cd for TC



Chen et al., 2022, JGR-Oceans

Theory innovation 3: sea spray increases heat flux

- Incorporate sea spray into typhoon model and Earth system model

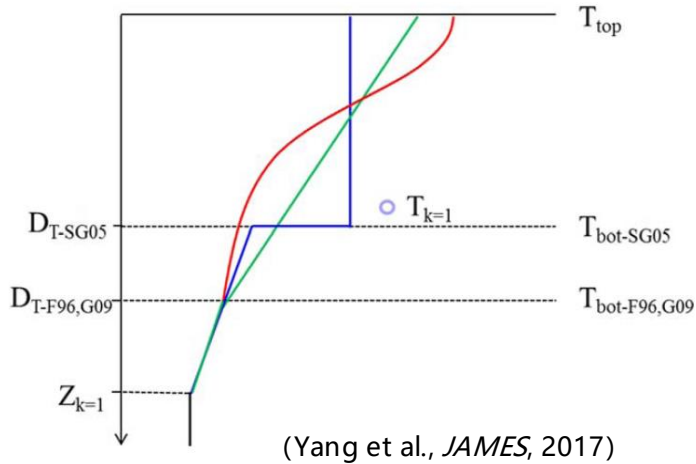


Latent heat
flux

Sensible
heat flux

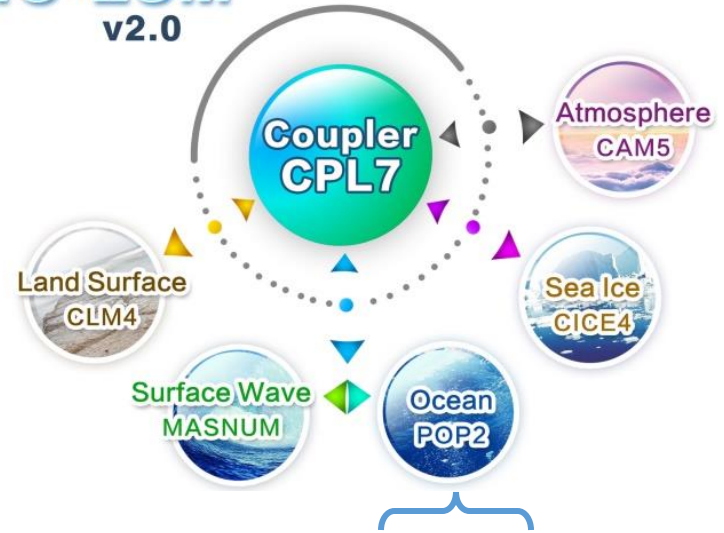
Zhao et al, 2017, JGR; Bao et al, 2020, JGR

Theory innovation 4: Diurnal SST cycle in ESM



Diurnal SST parameterization scheme

FIO-ESM v2.0



Diurnal SST

(Bao et al., 2020, JGR)

Theory adopted by different model groups

4752

JOURNAL OF CLIMATE

VOLUME 27

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

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(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
10.1029/2013MS001494

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

Supporting Information:
• Supporting Information S1

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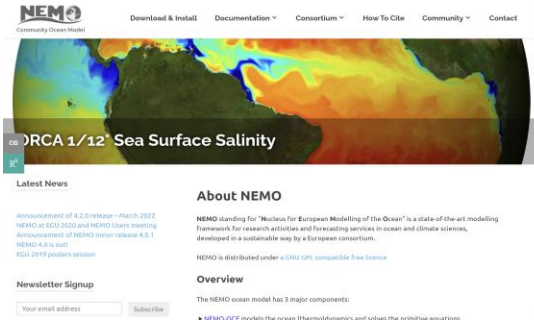
Improving the Upper-Ocean Temperature in an Ocean Climate Model (FESOM 1.4): Shortwave Penetration Versus Mixing Induced by Nonbreaking Surface Waves

Shizha Wang^{1,2}, Qiang Wang¹, Qi Shi^{1,2,3}, Patrick Scholz⁴, Gerrit Lohmann⁵, and Fangli Qiao^{1,2,4}

¹College of Oceanic and Atmospheric Sciences, Ocean University of China, Qingdao, China, ²First Institute of Oceanography, Ministry of Natural Resources, Qingdao, China, ³Nielsen-Wegener Institute Helmholtz Center for Polar and Marine Research (AWI), Bremerhaven, Germany, ⁴Laboratory for Regional Oceanography and Numerical Modeling, Qingdao National Laboratory for Marine Science and Technology, Qingdao, China, ⁵Toy 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 stand-alone 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

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ORCA 1/12' Sea Surface Salinity

Latest News

About NEMO

Announcement of 4.2.0 release – March 2012
NEMO at OGI 2010 and NEMO Users Meeting
Announcement of NEMO major release 4.0.1
NEMO 4.0.1 code
DOI: 10.1016/j.jos.2010.08.008

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Overview

The NEMO ocean model has 3 major components:

- NEMO/OSY includes the ocean thermohaline and solves the circulation structure.

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, AGRI and the non-hydrostatic kernel of SHN (under testing), gradually including algorithms from MARCO (Indonesia) and IFMOM (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 (KIO), new online diagnostics, and new options for coastal configurations. A new version of CROCO/TOOLS accompanying this release. CROCO will keep evolving and integrating new capabilities in the following years.

CROCO project version 1.2

CROCO-Sud

News

Two training sessions to CROCO model will be organized in October 2012. See [didactical guide](#).

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@inra.fr

CROCO

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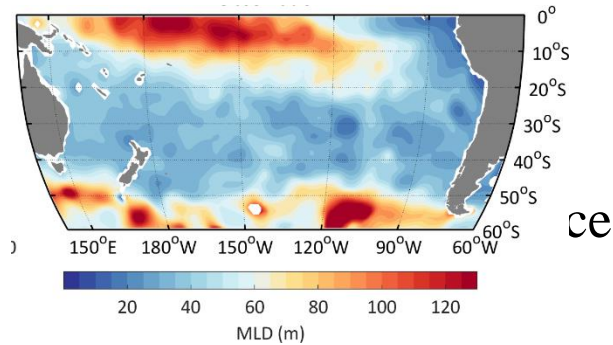
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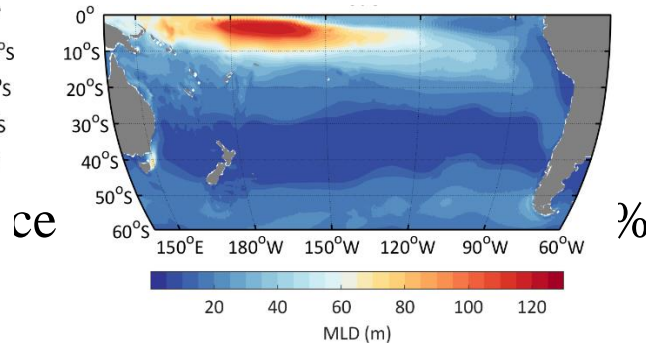
1. Wave-circulation coupled model

$$B_V = \alpha \iint_k E(\mathbf{k}^V) \exp(2kz) dk^V \frac{\partial}{\partial z} \left[\iint_k \omega^2 E(\mathbf{k}^V) \exp(2kz) dk^V \right]^{\frac{1}{2}}$$

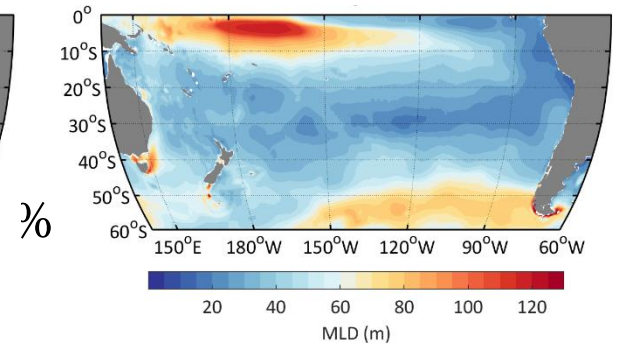
Observation data



Model without B_V

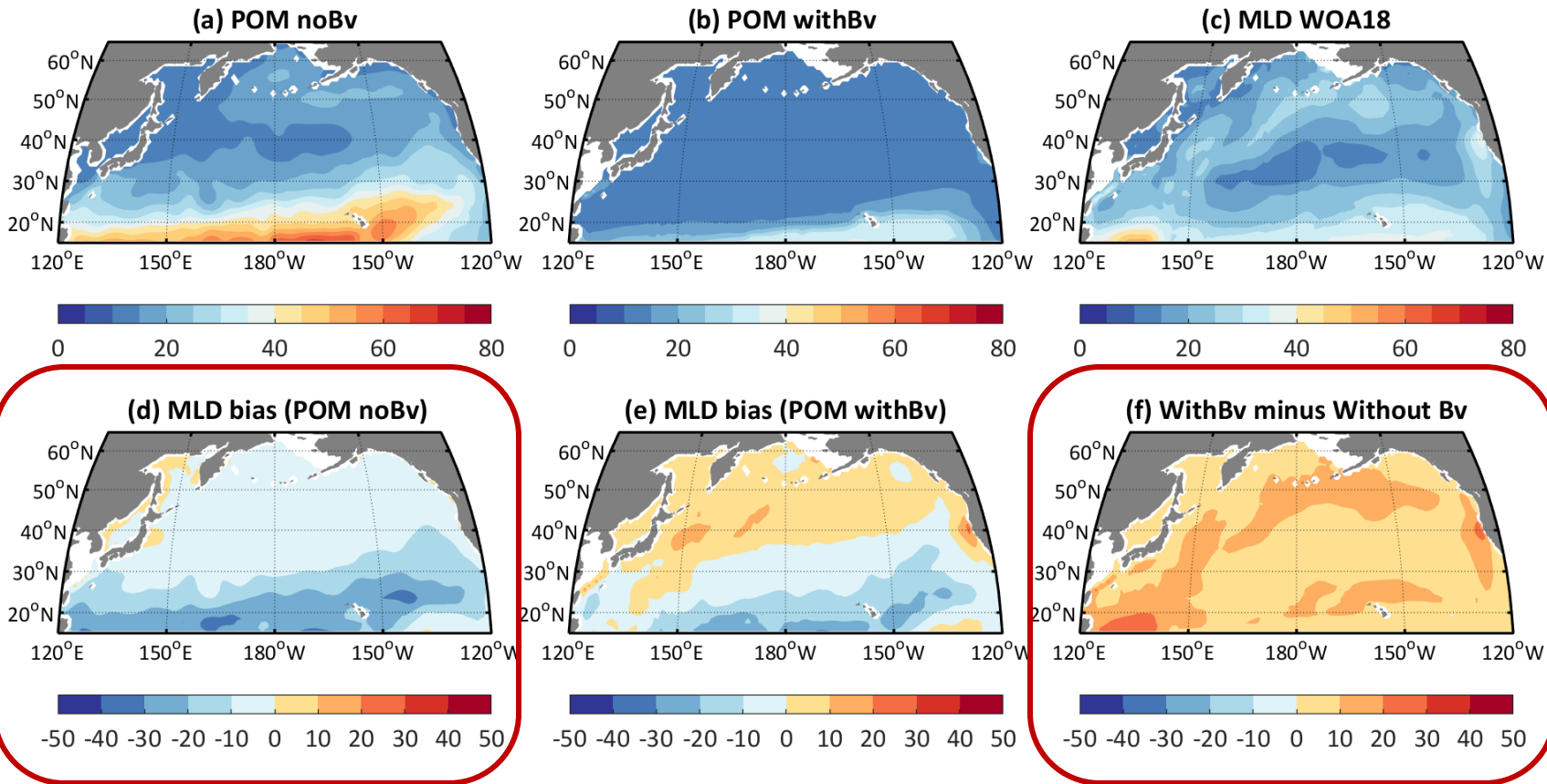


Model with B_V

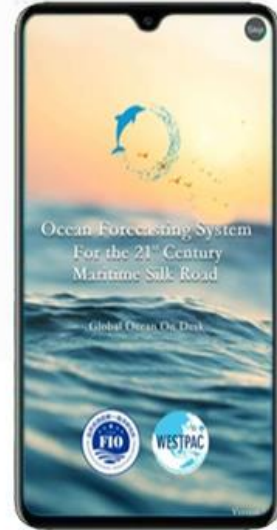
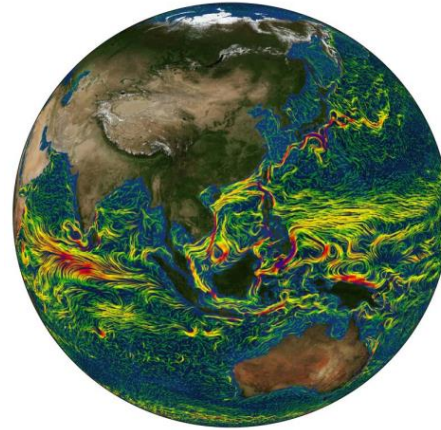
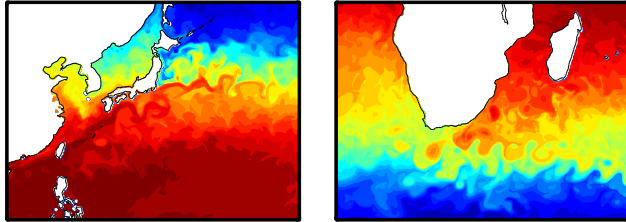
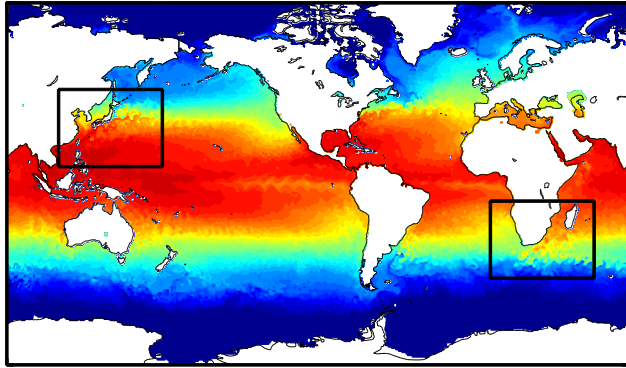


Qiao et al, 2004, GRL; 2010, OD; 2016, RS

Wave-circulation coupled model

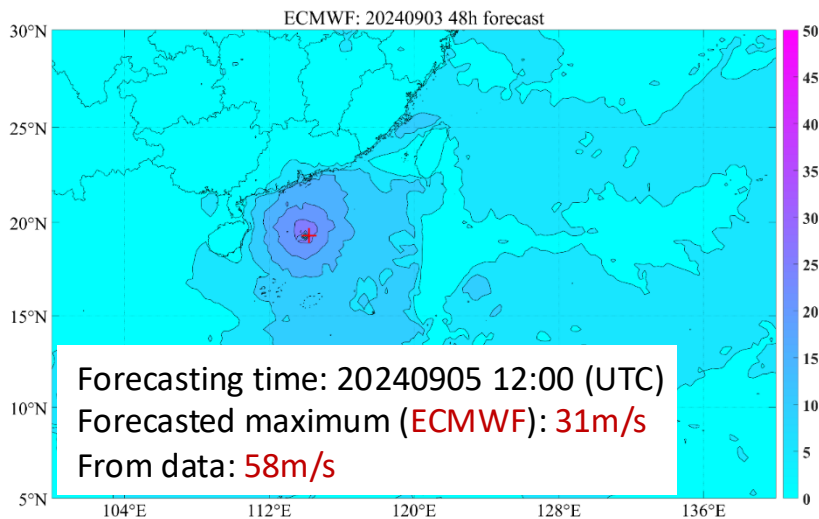
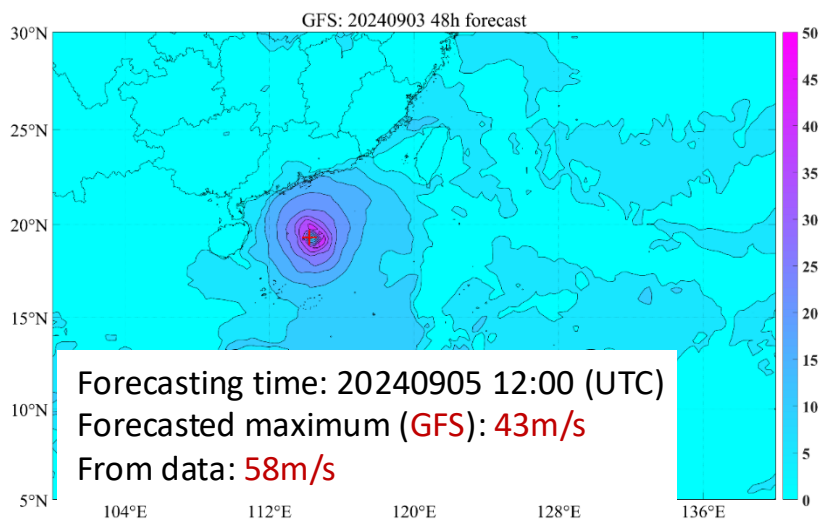
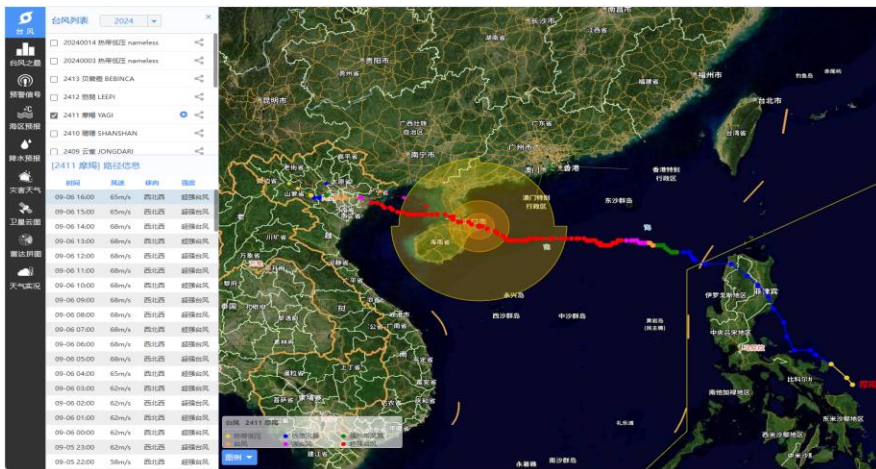


Global surface-wave-tide-circulation coupled ocean model



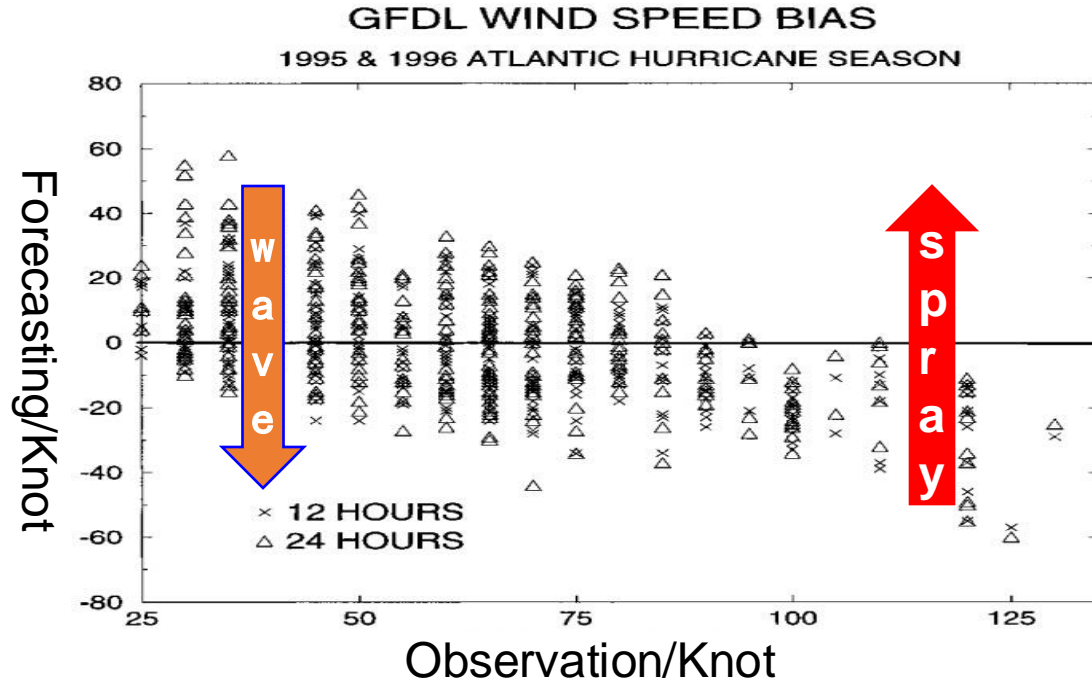
2. Typhoon model

Take super Typhoon Yagi in early Sep 2024 as an example

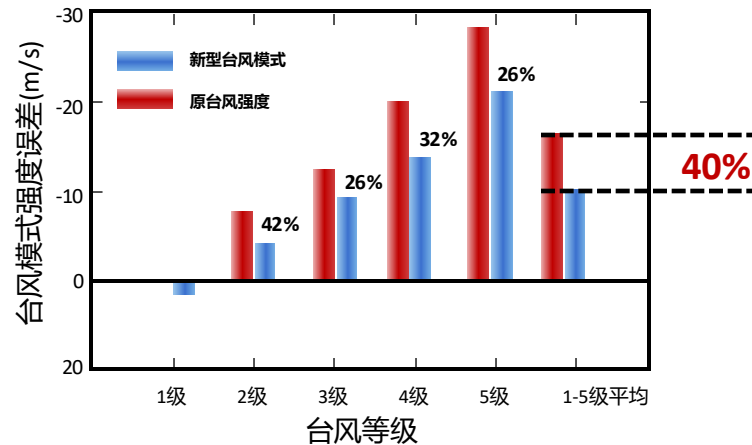
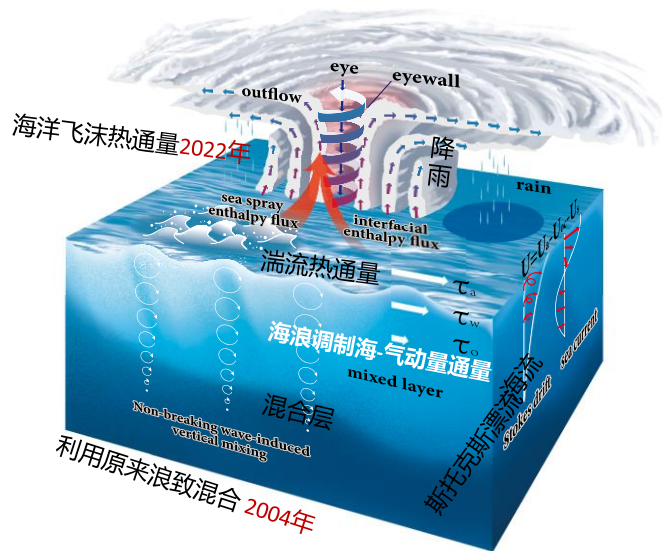


New Typhoon model

Sea spray (intensify) + wave (weaken)



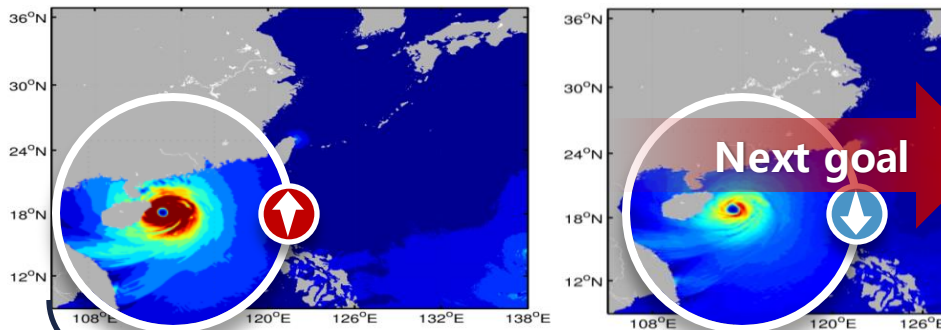
New Typhoon or Tropical Cyclone model



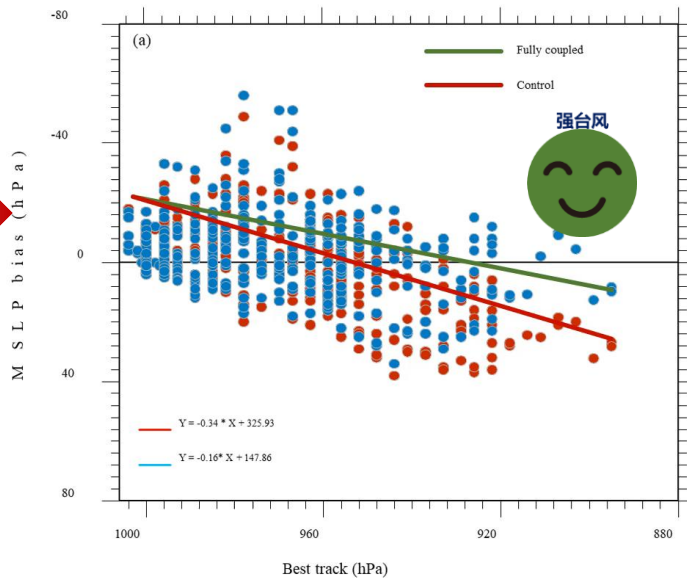
The new theory can reduce the forecasting error of TC intensity by 40% (30 years challenge)

The hindcast of Typhoon intensity is improved

Sea spray—**Increase** Heat flux Bv—**decrease** heat flu

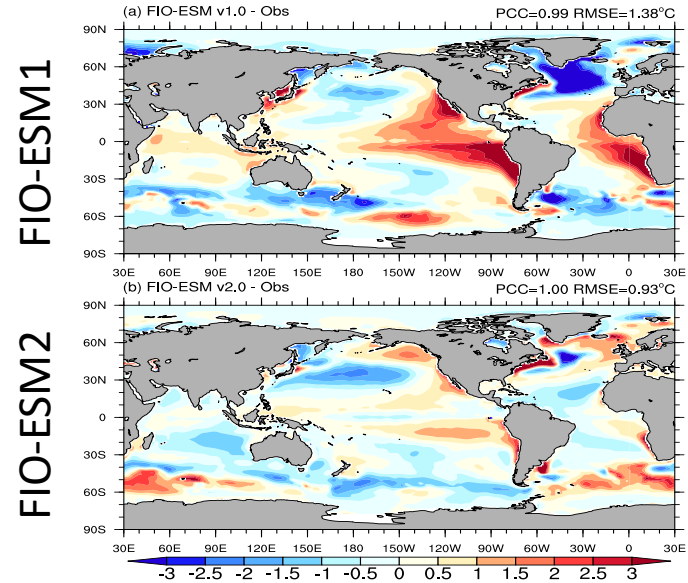
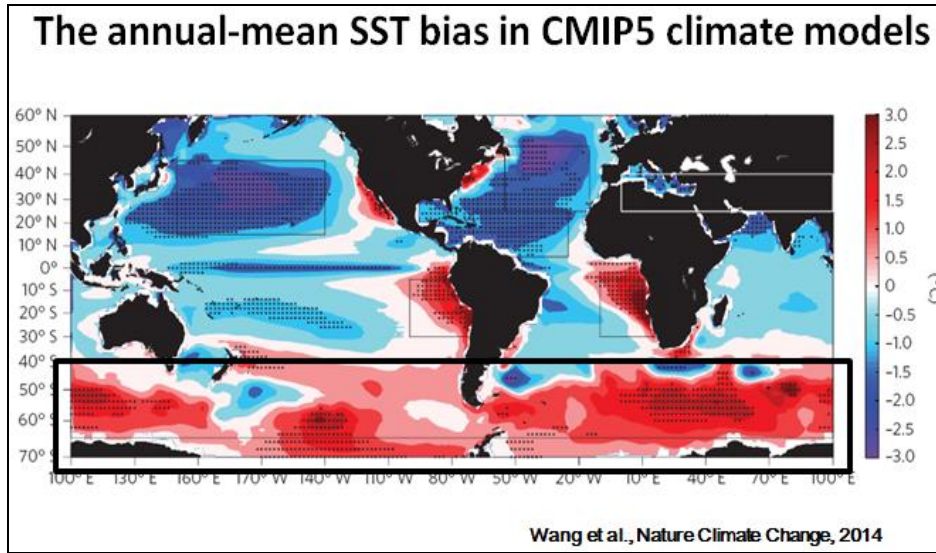


Bv theory + **New heat flux**



3. Two-generation of Earth system model FIO-ESM

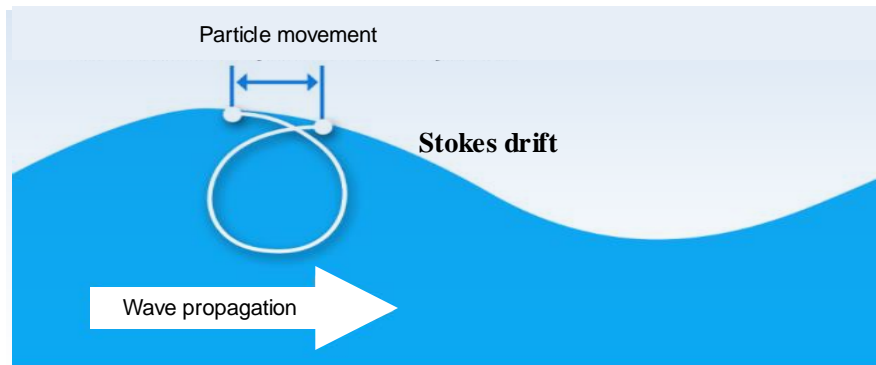
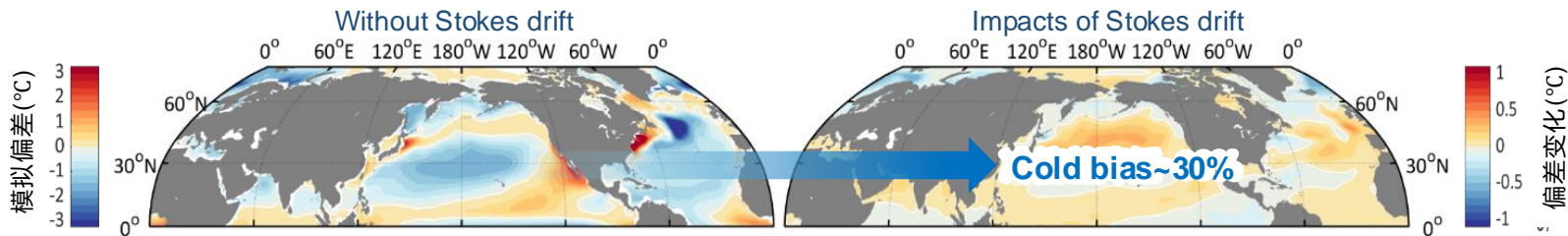
First ESM with wave incorporated, reducing half of the original biases



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

Surface wave Stokes drift on air-sea fluxes

Stokes drift changes the heat flux and improve PICES area



$$\text{Air-sea fluxes: } \vec{\tau} = \rho_A |\Delta \vec{V}| C_d \Delta \vec{V}$$

$$\Delta \vec{V} = \vec{V}_A - \vec{V}_O \rightarrow \Delta \vec{V} = \vec{V}_A - \vec{V}_O - \vec{V}_{S0}$$

Wind speed Surface current Stokes drift

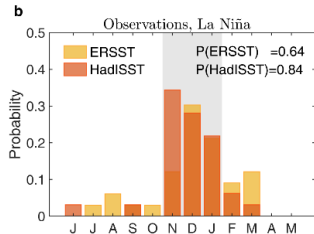
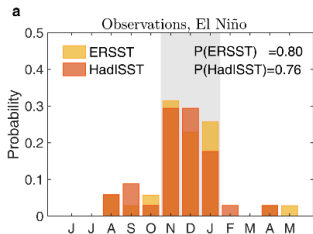
Diurnal cycle on ENSO phase-locking

El Niño

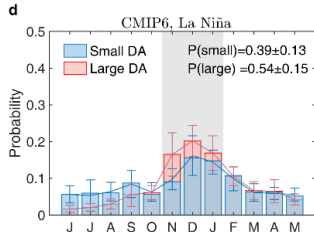
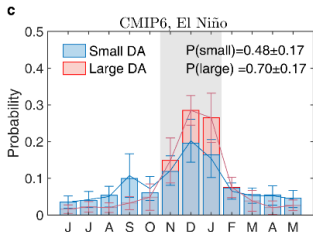
La Niña

Niño 3.4 SSTA tendencies

OBS



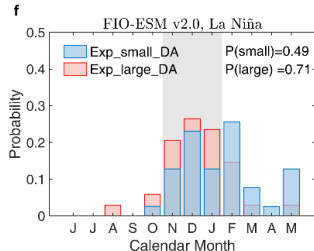
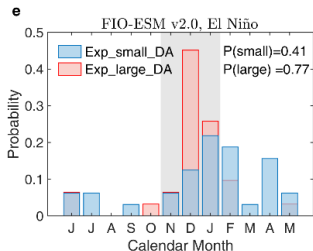
CMIP6



Small DA

Large DA

FIO-ESMv2.0



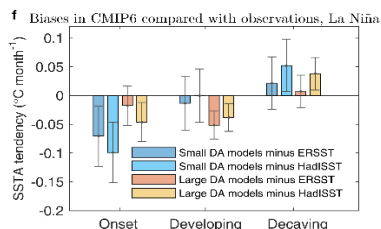
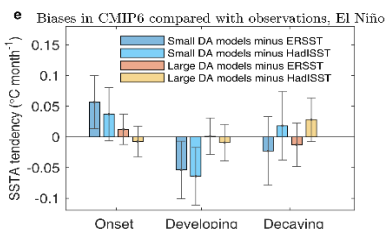
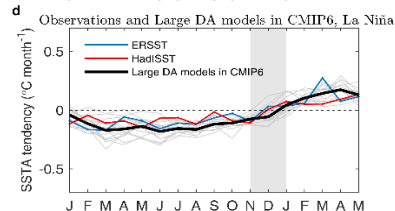
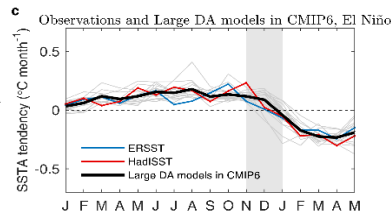
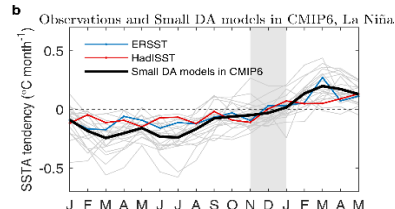
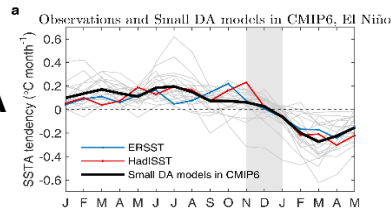
Bias

blue: small DSST

red: large DSST

El Niño

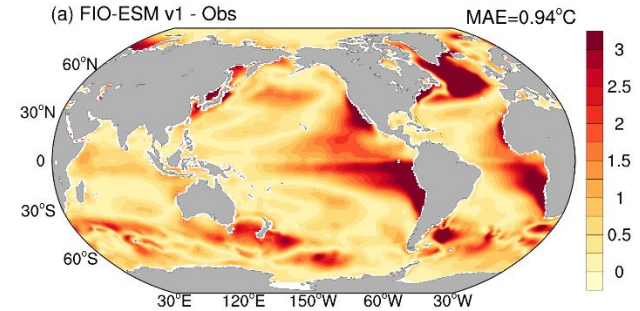
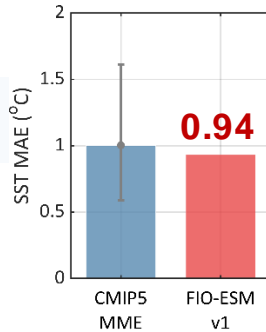
La Niña



New climate model FIO-ESM v1.0 & 2.0

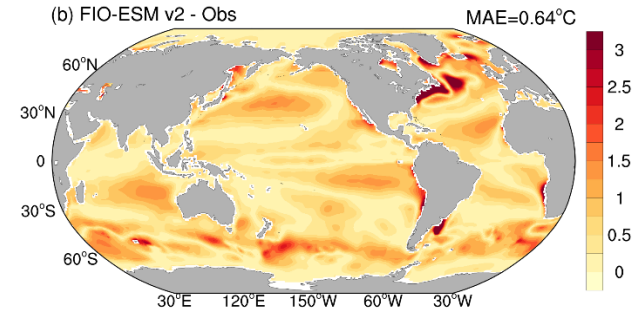
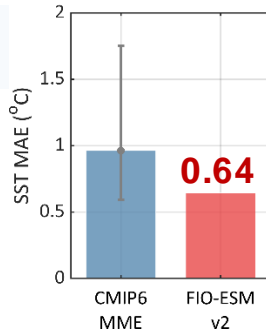
FIO-ESM v1

- Bv



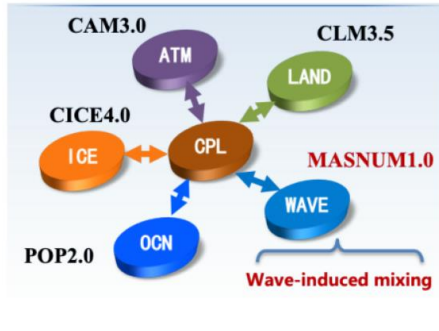
FIO-ESM v2

- Bv
- Stokes drift
- Sea spray

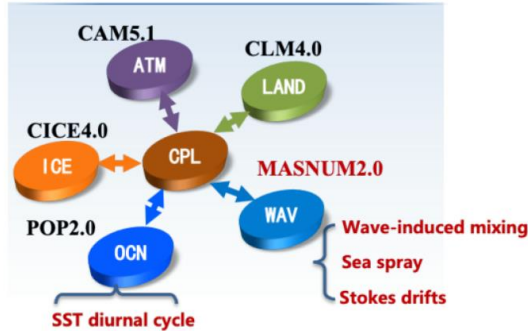


ENSO comparison in the past 100 years

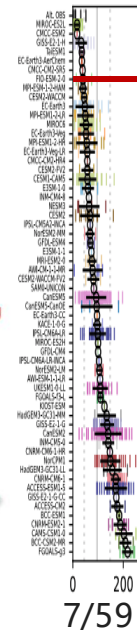
FIO-ESM v1.0



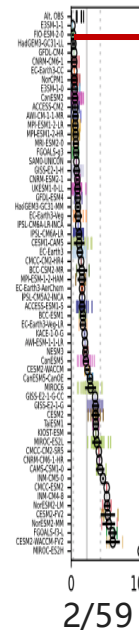
FIO-ESM v2.0



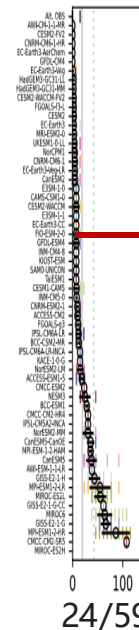
(j) ENSO_asymmetry (Error %)



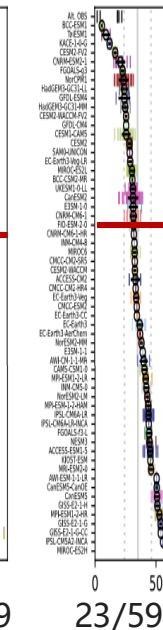
(e) ENSO_amplitude (Error %)



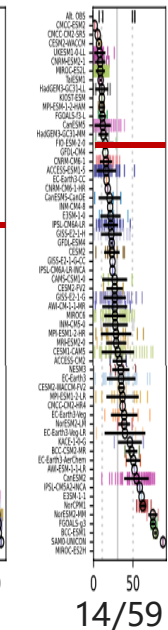
(f) ENSO_duration (Error %)



(g) ENSO_seasonality (Error %)



(h) ENSO_diversity (Error %)



[Lee, 2021, GRL]

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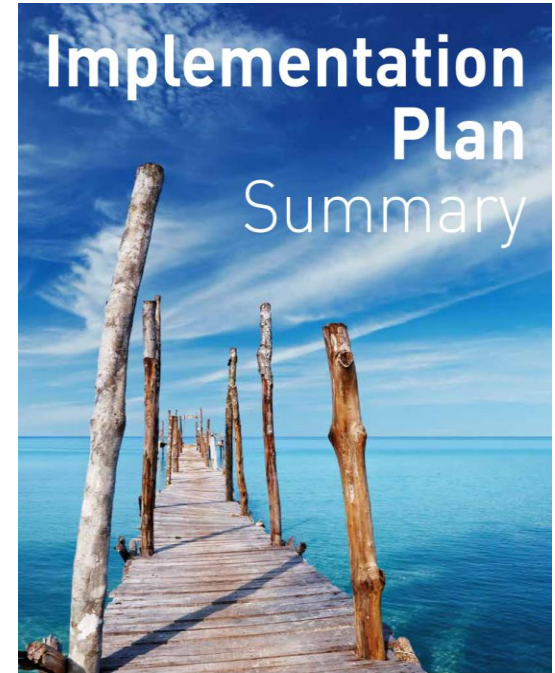
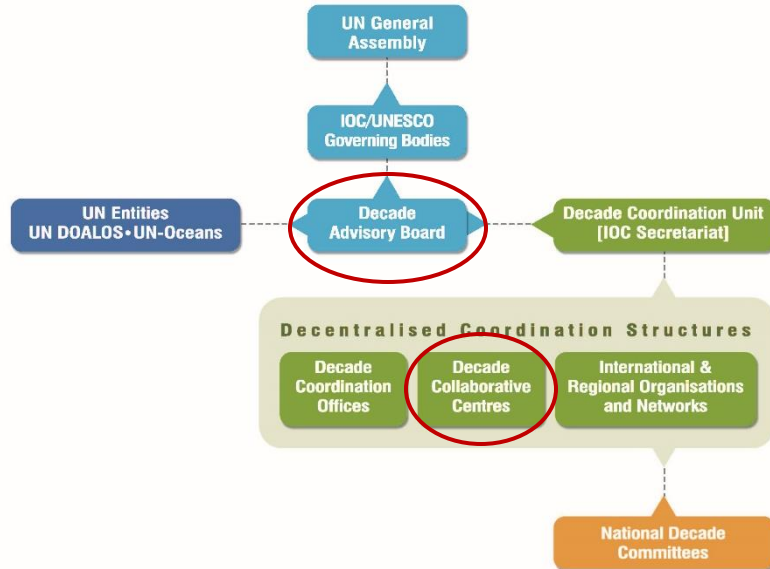
Ocean system models

IV

International cooperation

Deep involvement of UN Ocean Decade

- ❑ 2018-2020: member of **EPG**
- ❑ 2021-2023: member of **DAB**



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

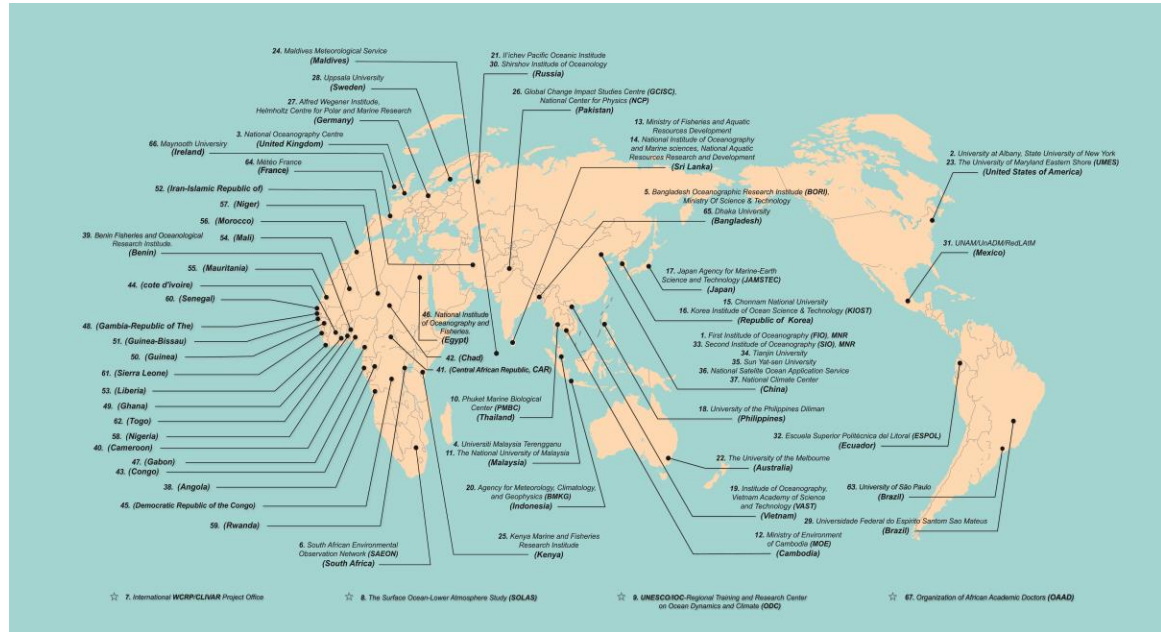


Ocean to climate seamless forecasting system (OSF)

70+
Institutes

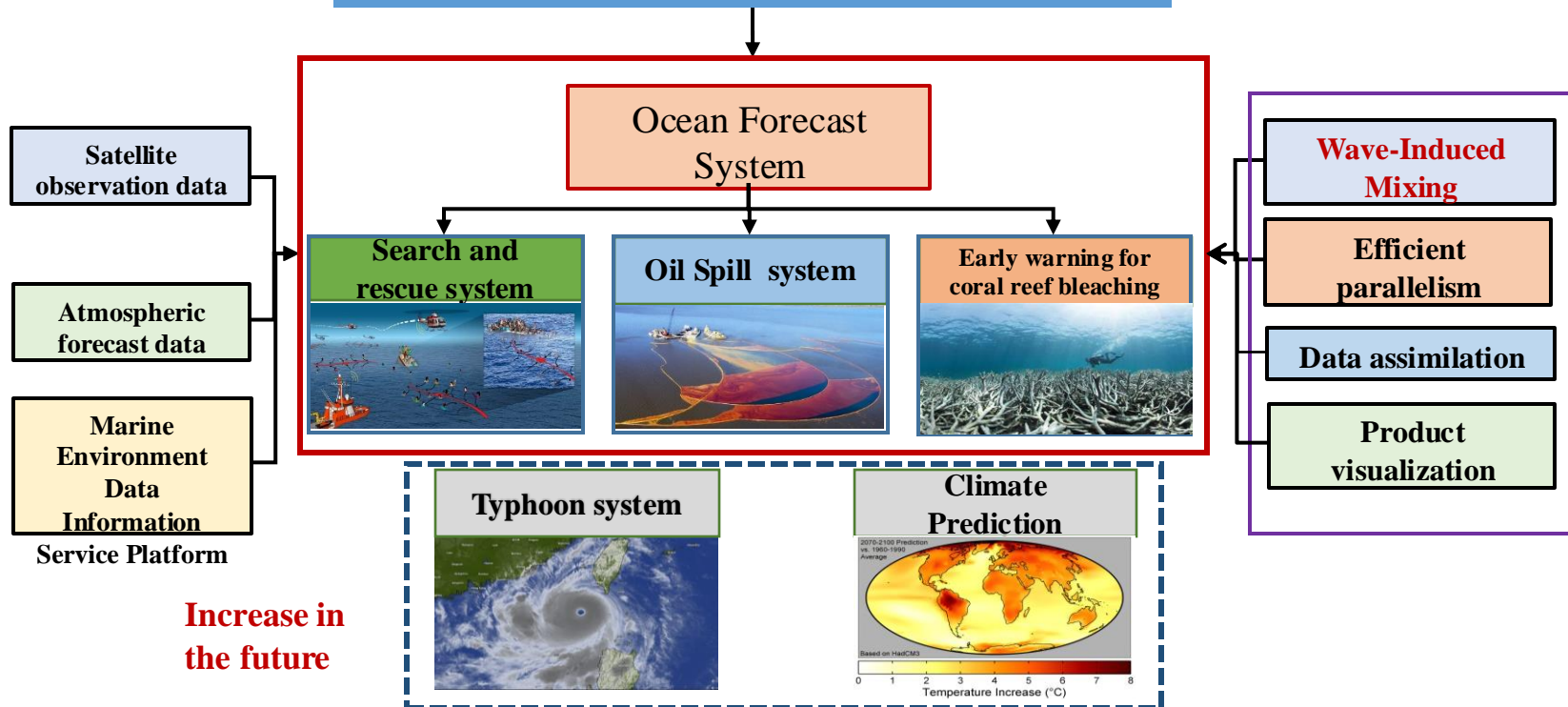
50+
Countries

5
International
organizations



Scientific tools for decision-making

Ocean and Climate Early wArNing Universal System (OCEANUS) v1.0



Conclusions

- **New ocean mixing and air-sea flux theory are developed;**
- **New wave-tide-circulation coupled model, Typhoon model and Earth system model are set up and validated;**
- **Through joint efforts, we could provide decision-making actionable information. OCEANUS is a first try.**

Hope you find this system helpful

<http://144.123.38.62:2024/#/>

Thanks

