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THE FIRST INSTITUTE OF OCEANOGRAPHY, MNR.

Ocean to climate Seamless Forecasting system

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

Prof. Dr. Fangli QIAO
First Institute of Oceanography, MNR, China
29 Oct. 2024, PICES Annual Meeting, Hawaii

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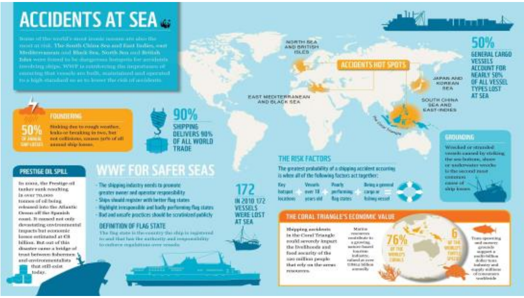
I Needs and challenges
II Science-based breakthroughs
III Ocean system models
IV International cooperation

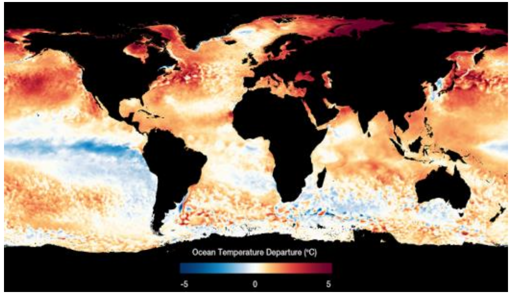
Significant Societal Needs for Ocean and Climate Prediction

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



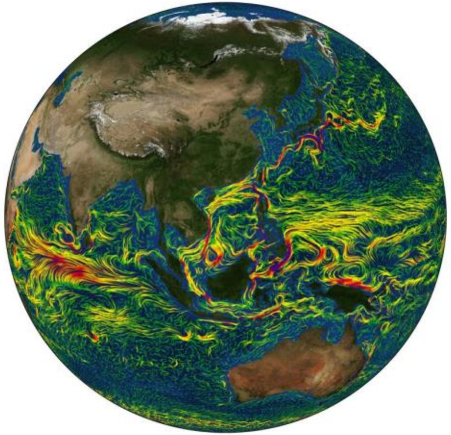
Response to ocean accidents



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

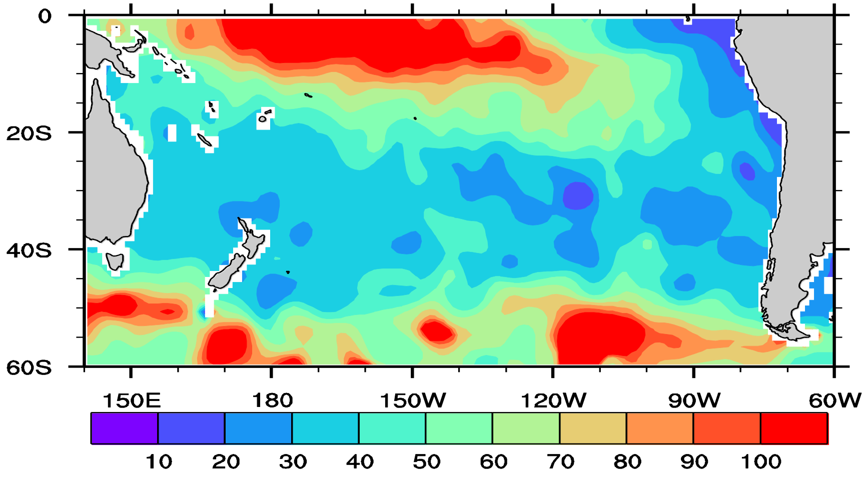
Long-lasting bottleneck problems for models

- 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.

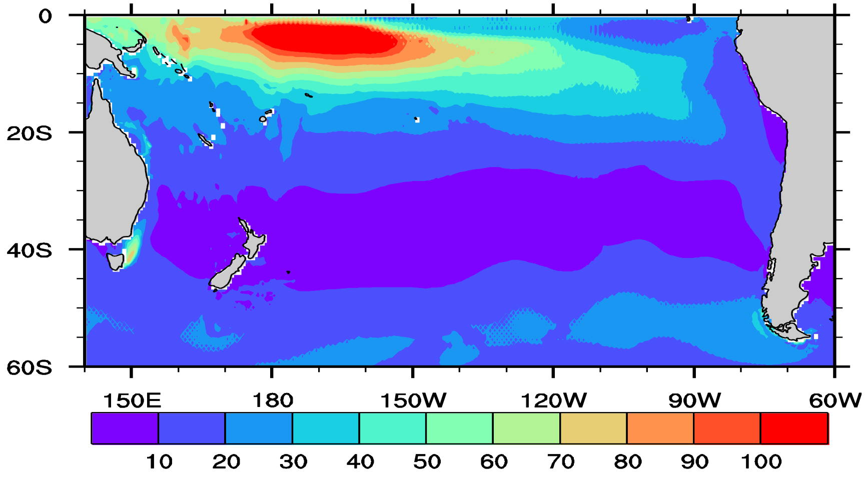
- Developed for half a century: 1967, the GFDL of US established the first numerical model of ocean circulation.

- 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

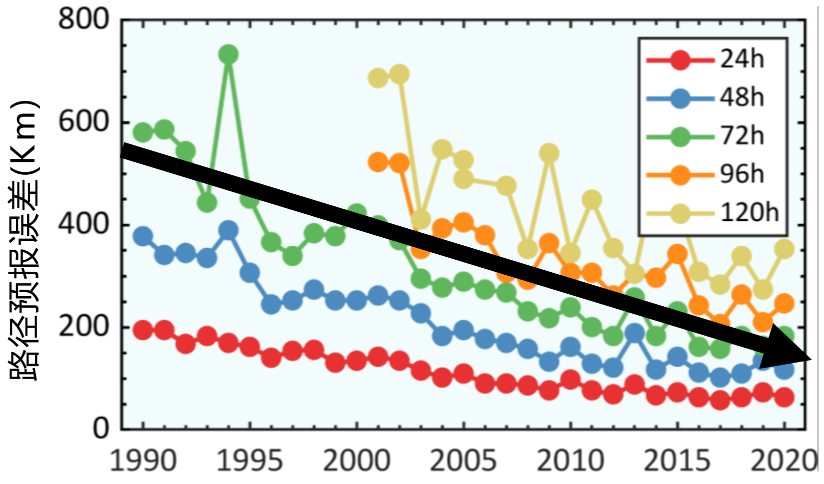


Simulated MLD

Qiao et al, 2010, 2016

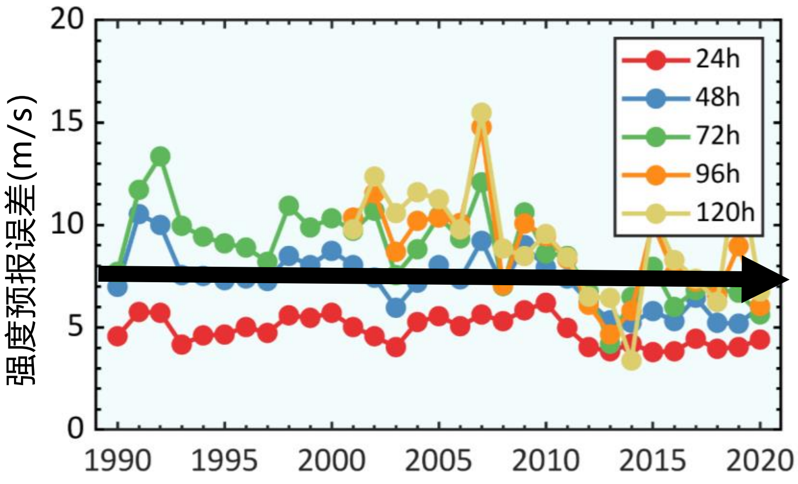
Challenge 2: Standstill in forecasting Typhoon intensity

Typhoon Track



NHC Forecast Verification Report, 2020

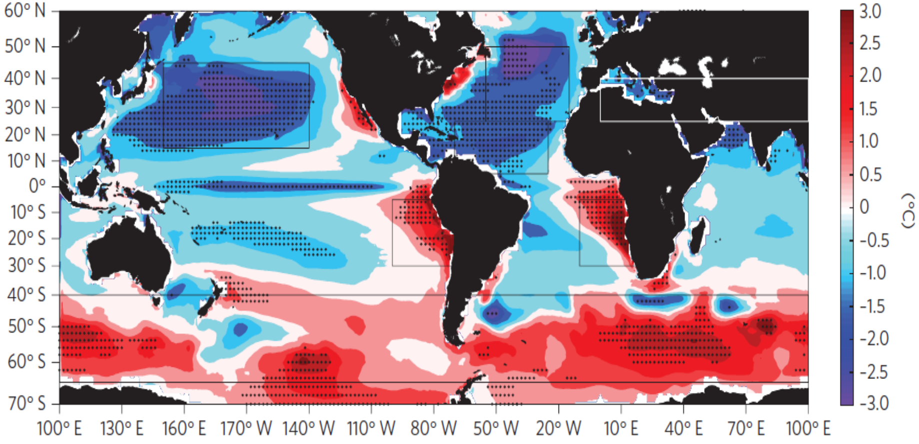
Typhoon intensity



Controlled by air-sea heat fluxes

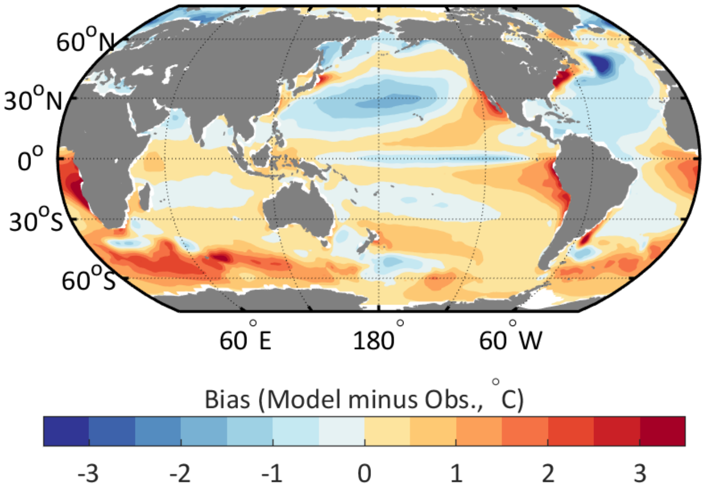
NHC https://www.nhc.noaa.gov/data/tcr/

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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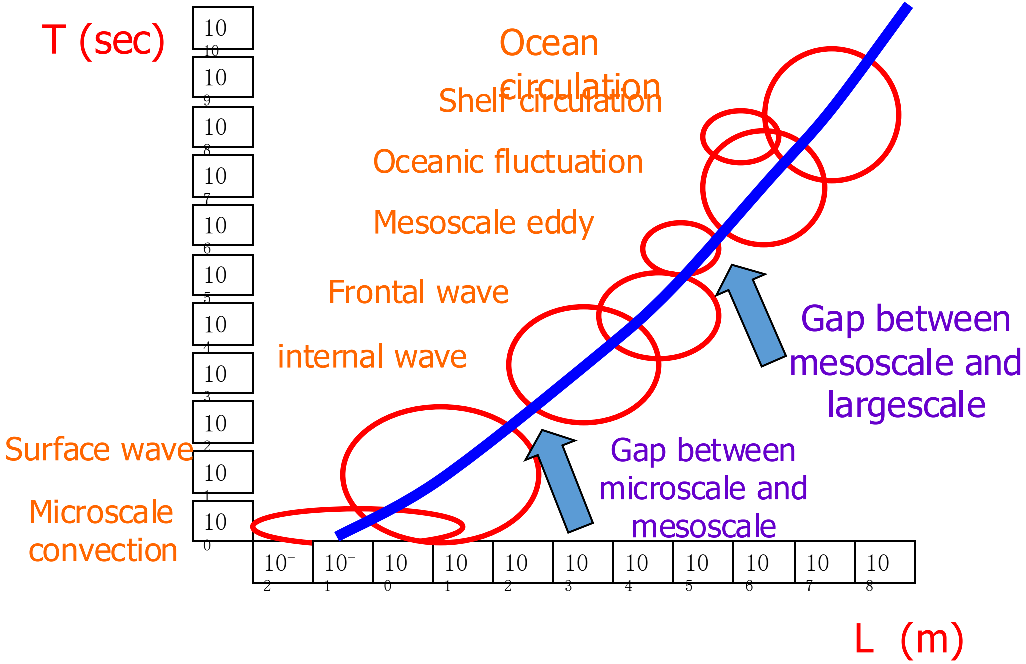
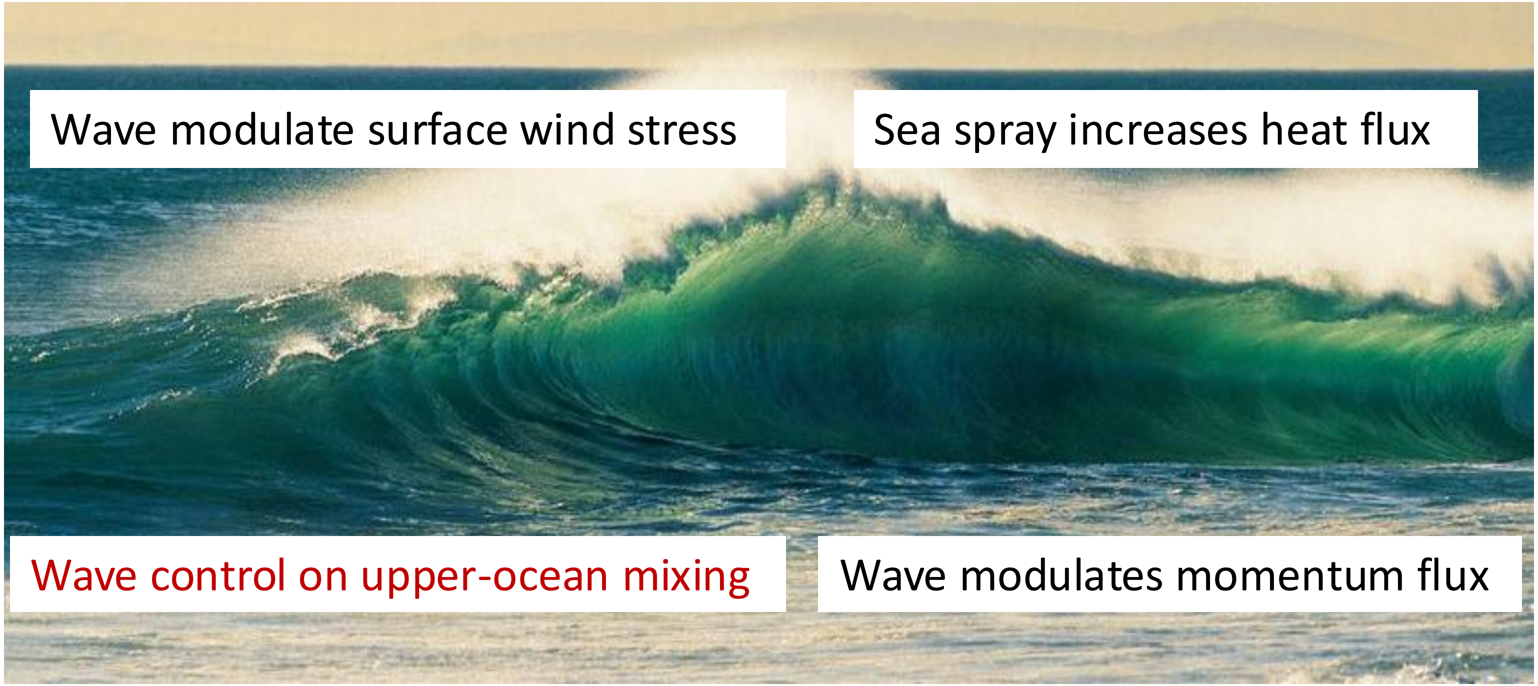
Ocean system science

- 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



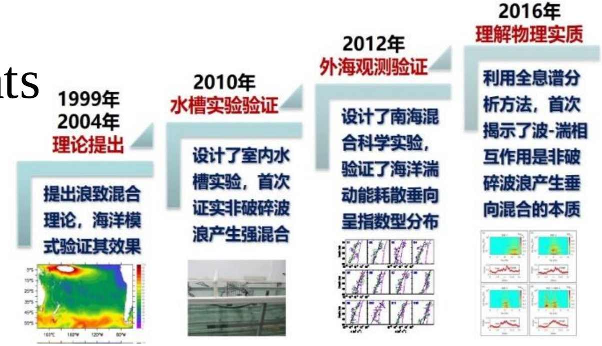
Theory innovation 1: wave-induced mixing

- Wave is a major source of upper-ocean turbulence

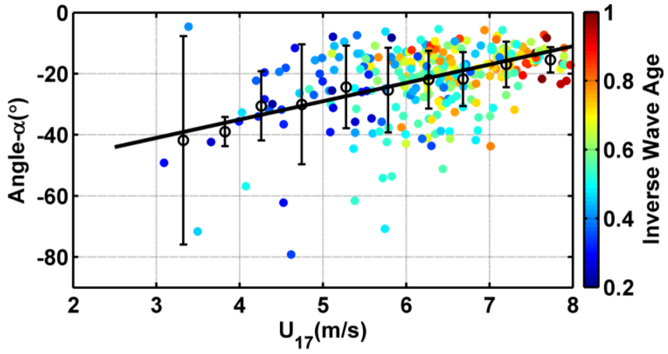
$$B_v = \alpha \iint E(\vec{k}) \exp\{2kz\} \mathrm{d}\vec{k} \frac{\partial}{\partial z} \left(\iint_{\vec{k}} \omega^2 E(\vec{k}) \exp\{2kz\} \mathrm{d}\vec{k} \right)^{\frac{1}{2}}$$

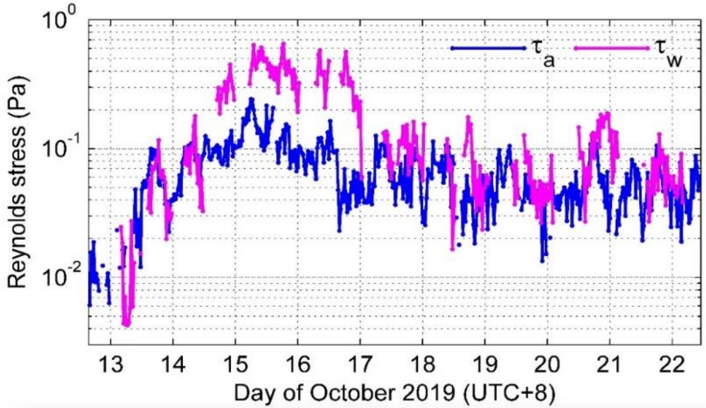
(Qiao et al, 2004，2010)

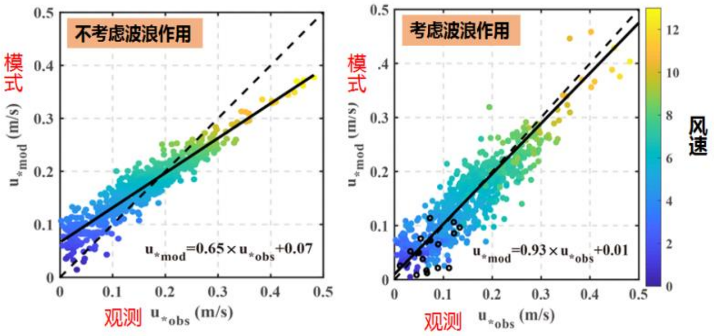
- The key is that wave-turbulence interaction intensifies ocean turbulence（Qiao et al, 2016）；
- Confirmed by following in-situ and Lab experiments
- Overturn the statement of J. Lumley (1983): “non-breaking wave does not generate turbulence”

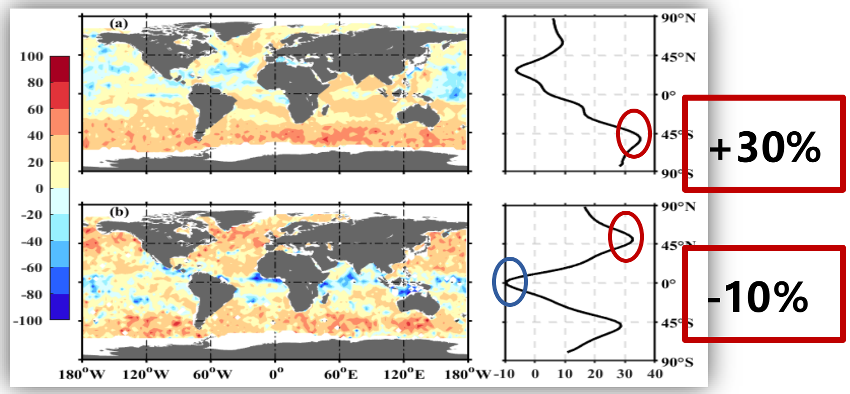


Theory innovation 2: wave modulates wind stress



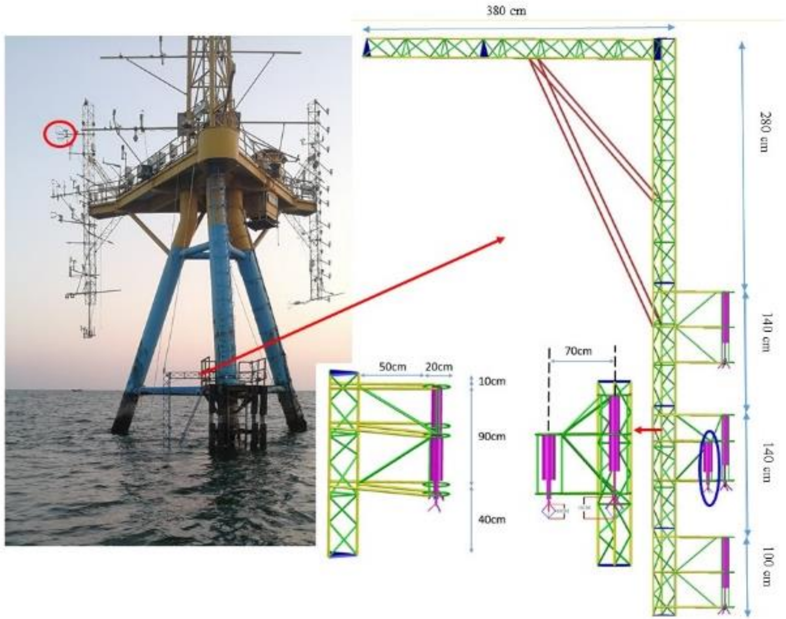


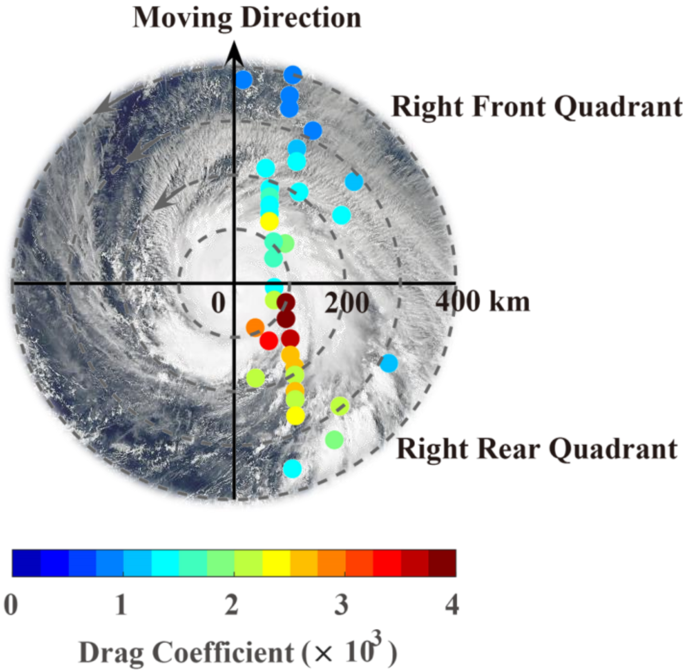




Chen et al, 2018; Huang and Qiao, 2021, JGR)

Asymmetry of Cd for TC

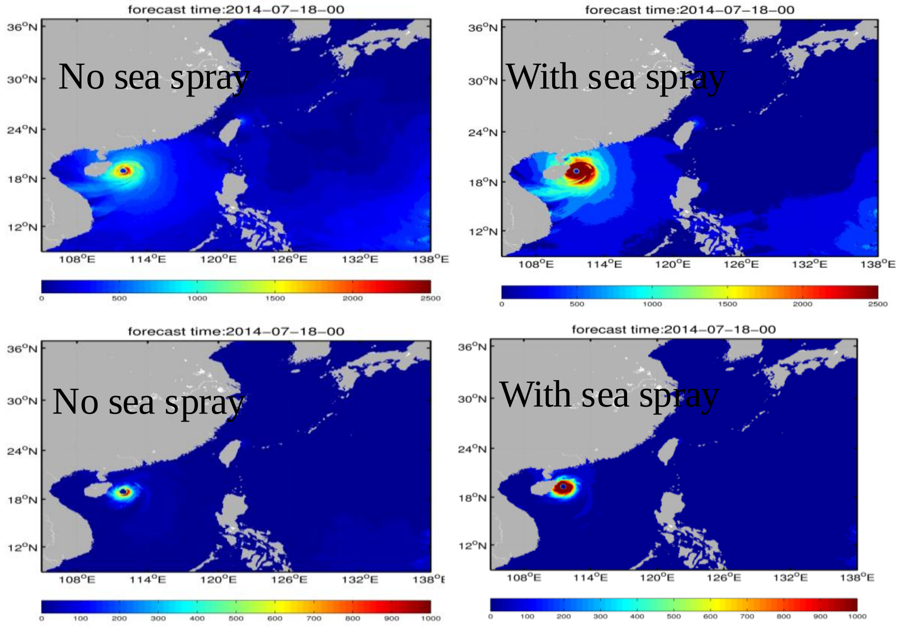




Chen et al., 2022, JGR-Oceans

Theory innovation 3: sea spray increases heat flux

- Incorporate sea spray into typhoon model and Earth system model

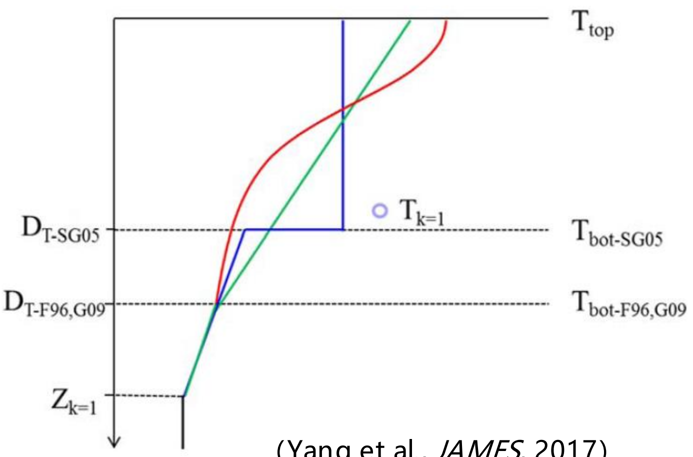


Latent heat flux

Sensible heat flux

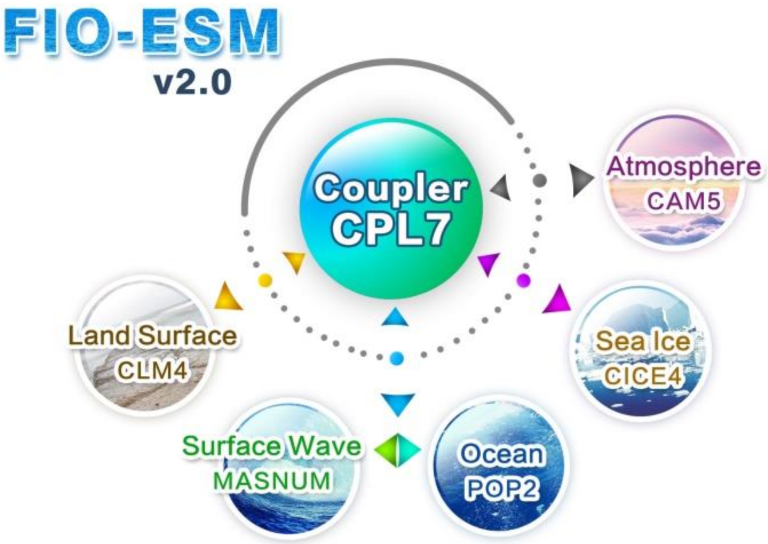
Zhao et al, 2017, JGR; Bao et al, 2020, JGR

Theory innovation 4: Diurnal SST cycle in ESM



(Yang et al., *JAMES*, 2017)

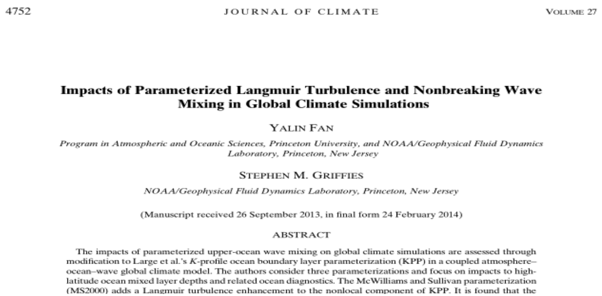
Diurnal SST parameterization scheme



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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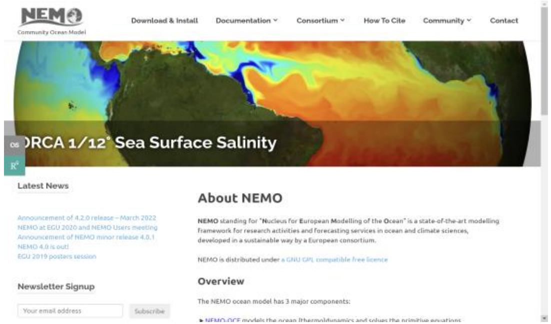
NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey

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

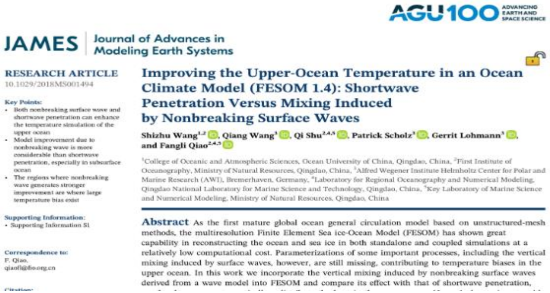
ABSTRACT

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



NEMO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JAMES | Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE
10.1029/2018MS001494

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

Shizhu Wang[1,2], Qiang Wang[3], Qi Shu[2,4,5], Patrick Scholz[3], Gerrit Lohmann[3], and Fangli Qiao[2,4,5]

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

CROCO

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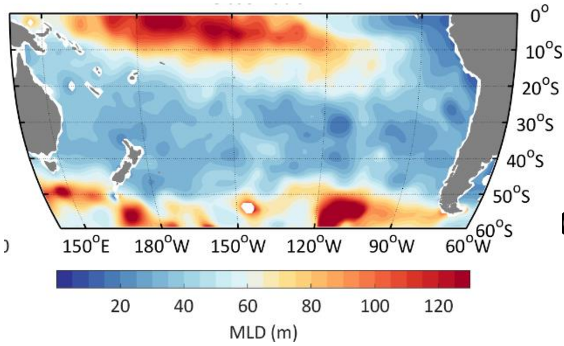
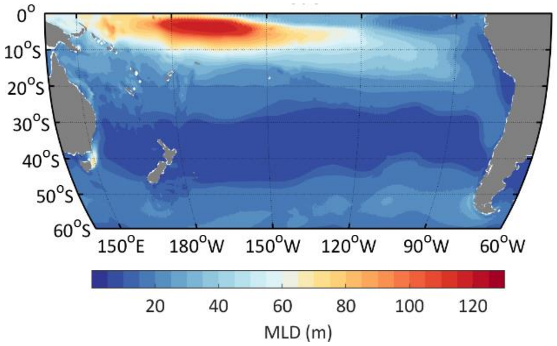
1. Wave-circulation coupled model

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

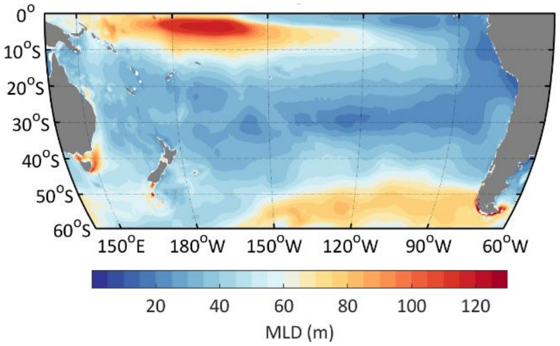
Observation data



Model without Bv

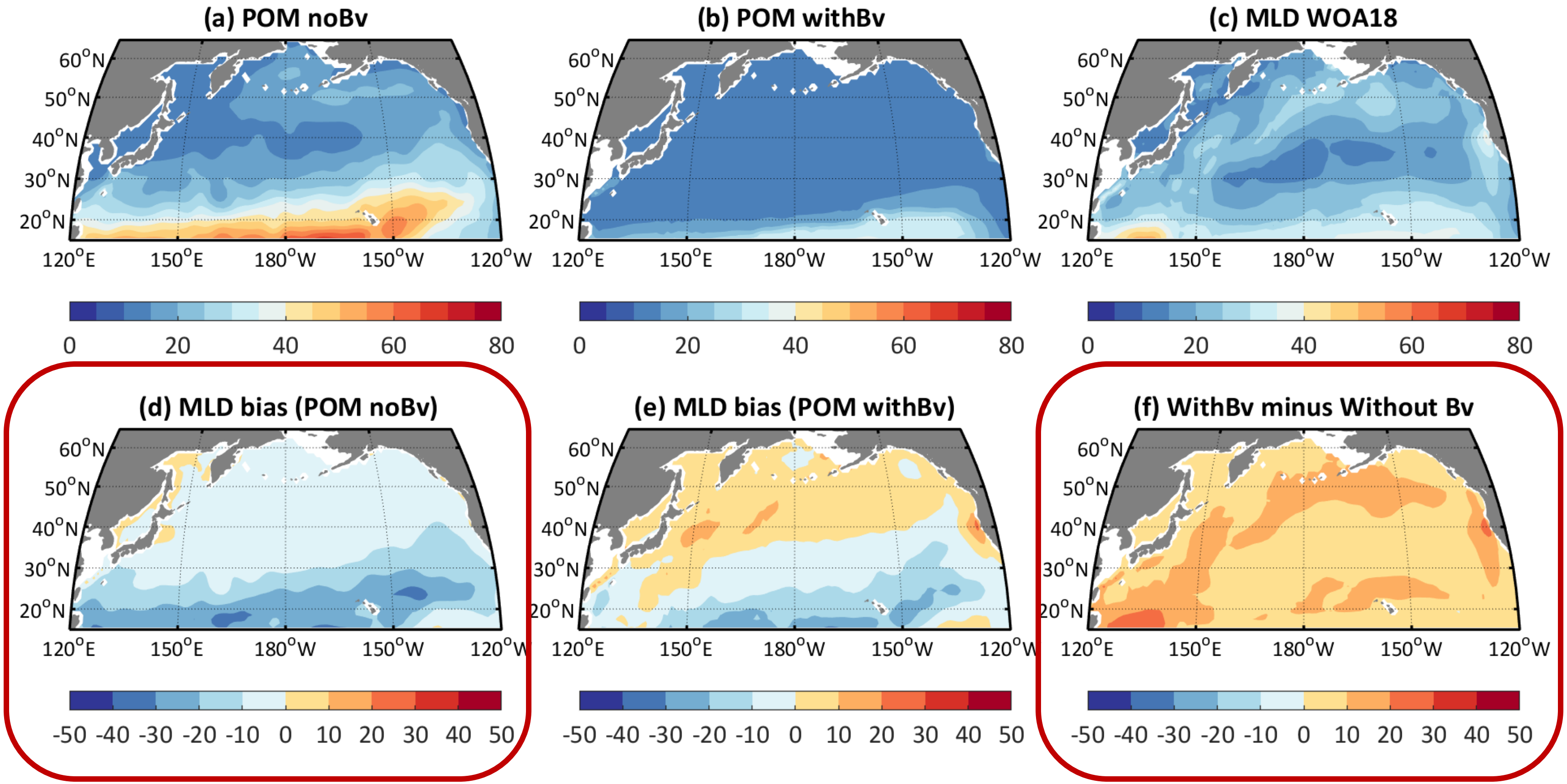


Model with Bv

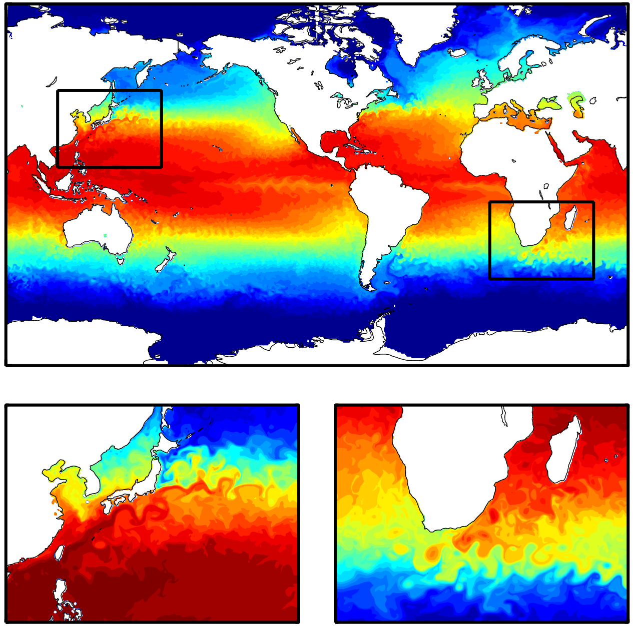


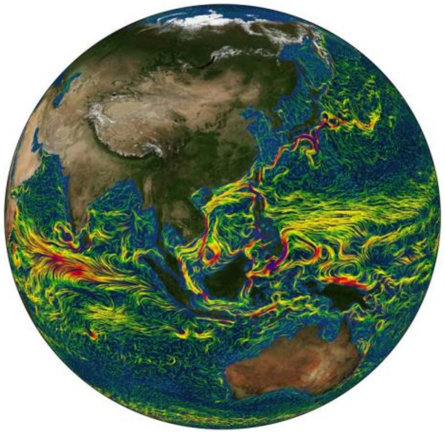
Qiao et al,2004, GRL; 2010, OD; 2016, RS

Wave-circulation coupled model



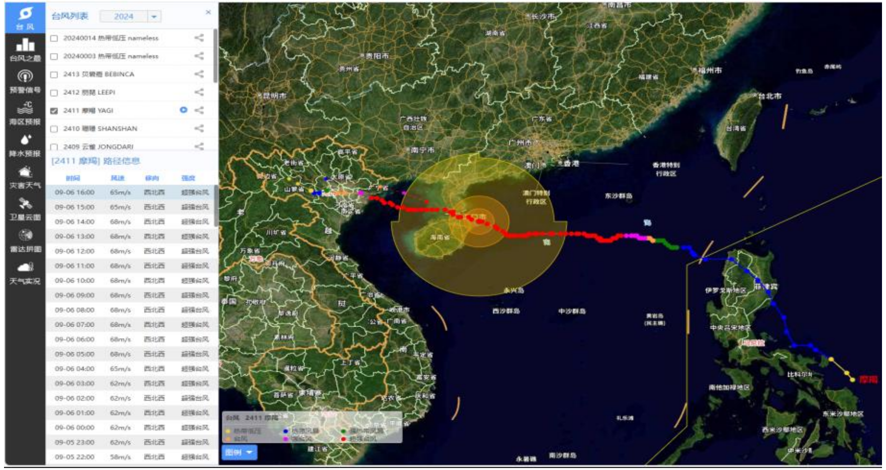
Global surface-wave–tide–circulation coupled ocean model

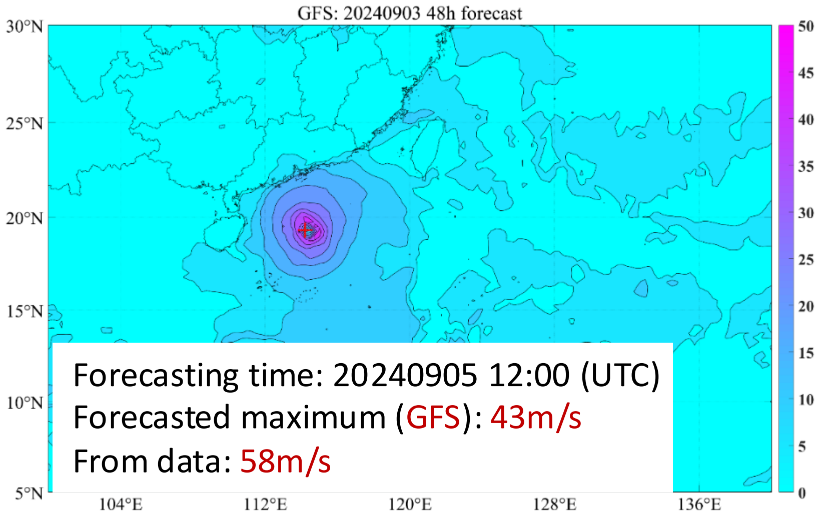


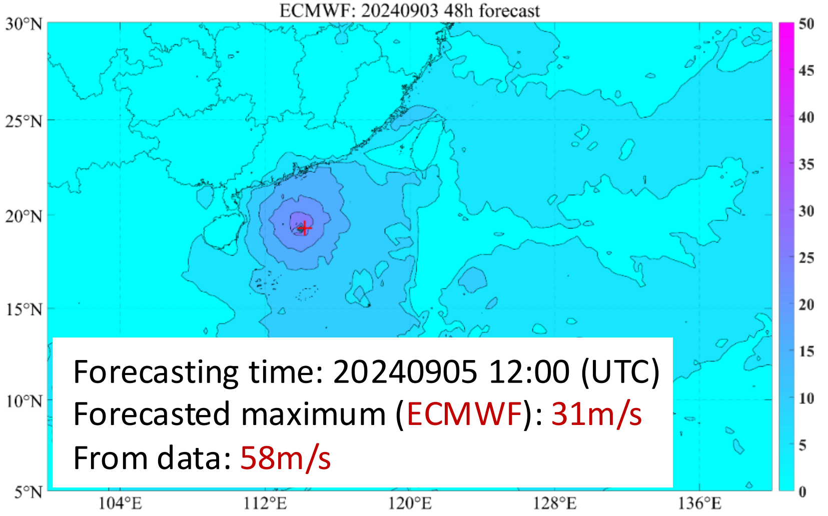


2. Typhoon model

Take super Typhoon Yagi in early Sep 2024 as an example

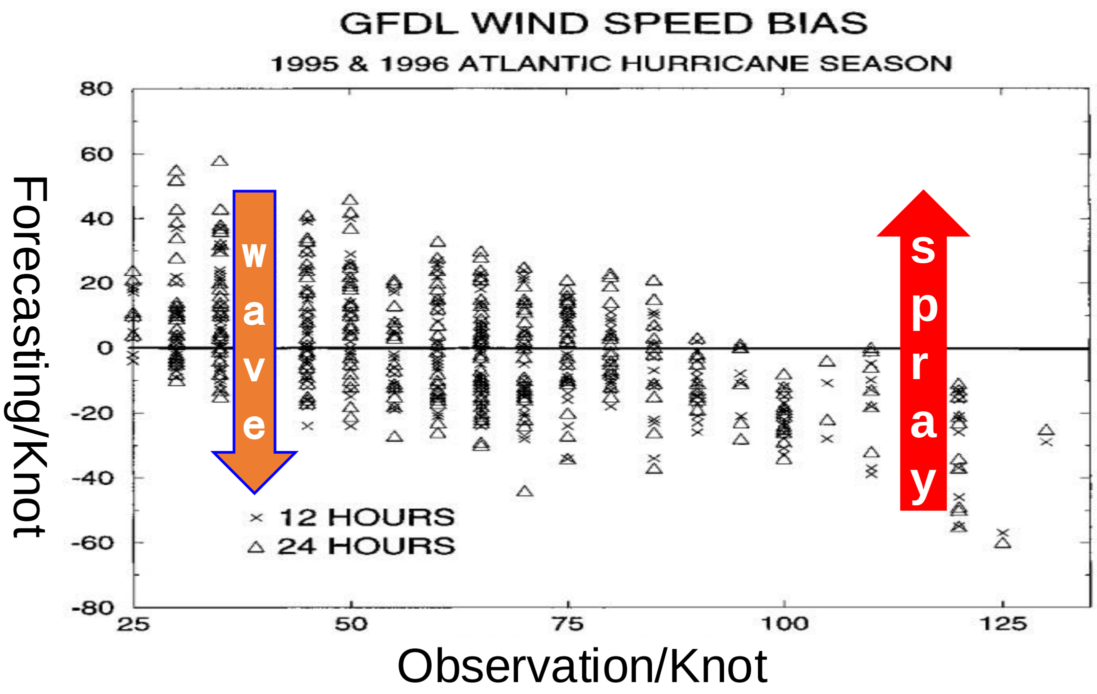




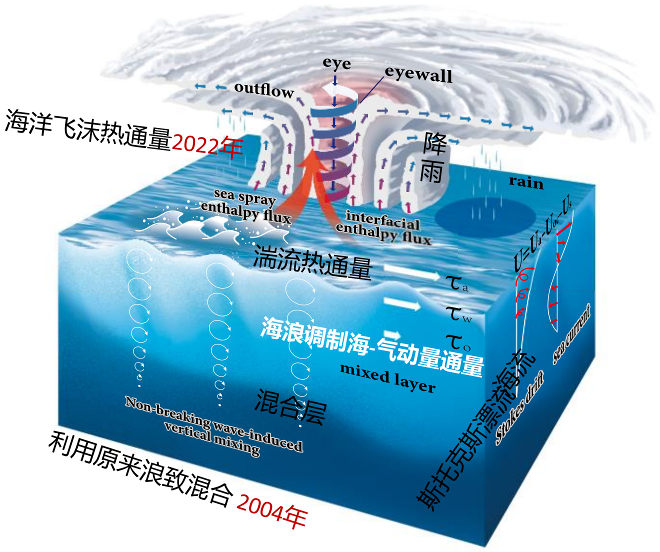


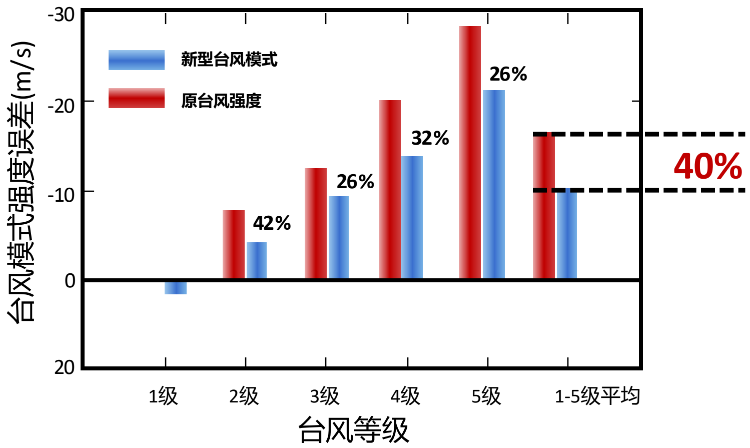
New Typhoon model

Sea spray (intensify) + wave (weaken)



New Typhoon or Tropical Cyclone model



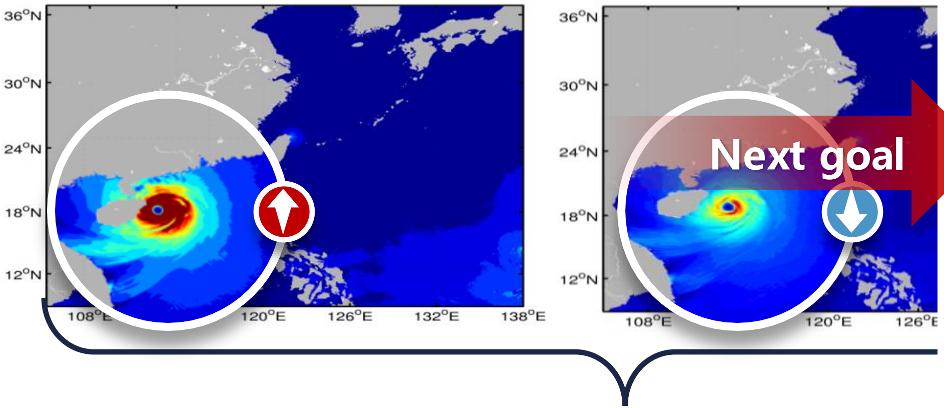


The new theory can reduce the forecasting error of TC intensity by 40% (30 years challenge)

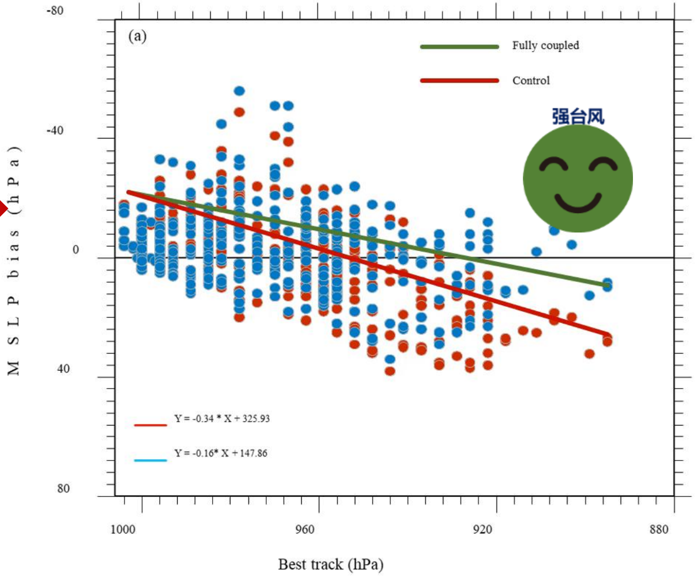
Zhao et al., 2022, JGR

The hindcast of Typhoon intensity is improved

Sea spray—Increase Heat flux   Bv—decrease heat flu

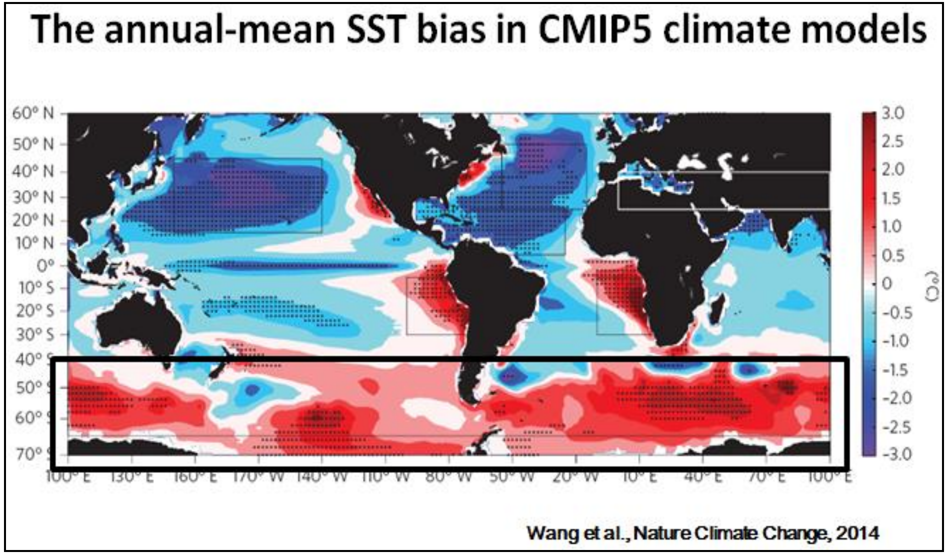


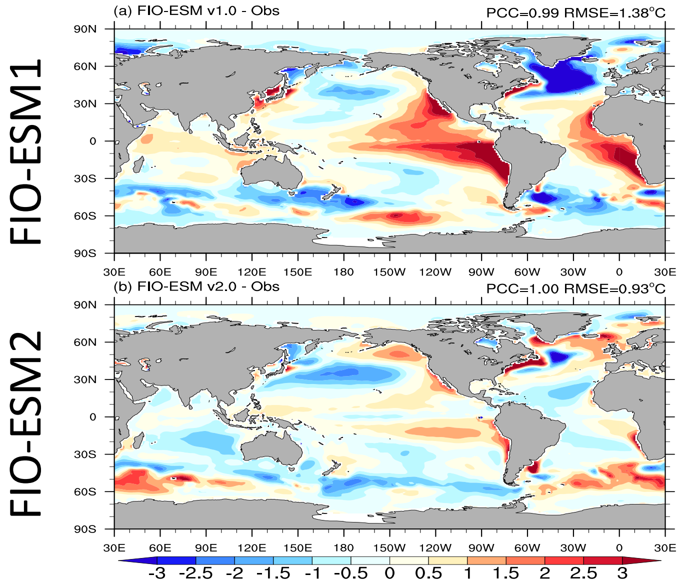
Bv theory + New heat flux



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

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

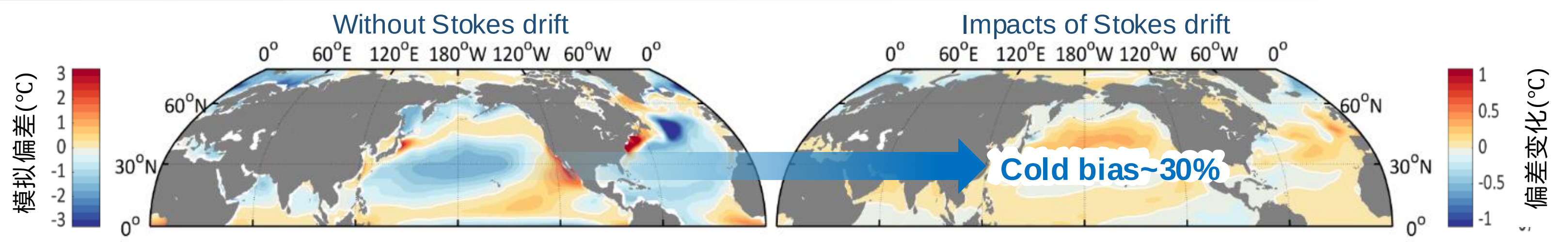


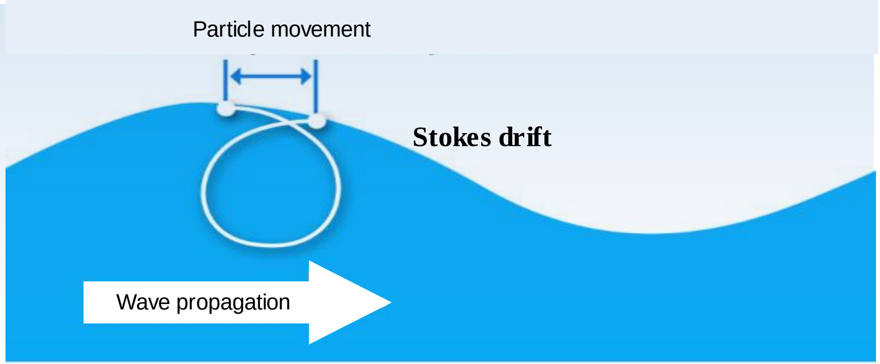


Qiao et al, 2013, JGR; Bao et al. 2021, JGR

Surface wave Stokes drift on air-sea fluxes

■ Stokes drift changes the heat flux and improve PICES area





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

$\Delta\vec{V} = \vec{V}_A - \vec{V}_O$ → $\Delta\vec{V} = \vec{V}_A - \vec{V}_O - \vec{V}_{SO}$

Wind speed ($\vec{V}_A$) Surface current ($\vec{V}_O$) Stokes drift ($\vec{V}_{SO}$)

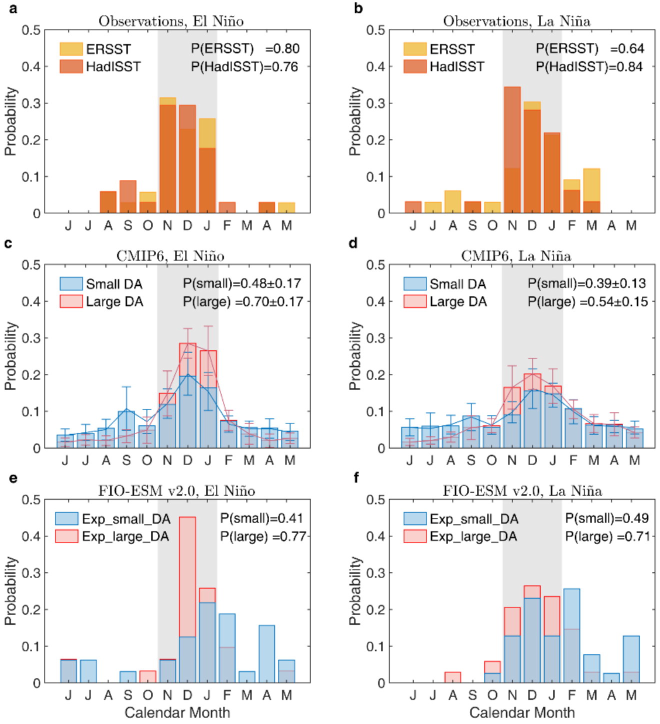
Diurnal cycle on ENSO phase-locking

El Niño   La Niña

OBS

CMIP6

FIO-ESMv2.0



blue: small DSST   **red: large DSST**

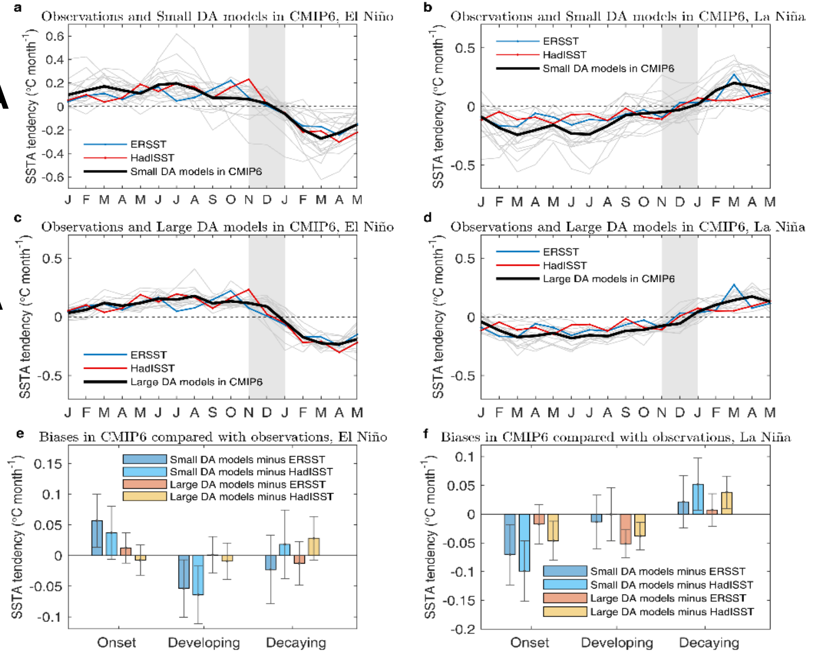
Niño 3.4 SSTA tendencies

El Niño   La Niña

Small DA

Large DA

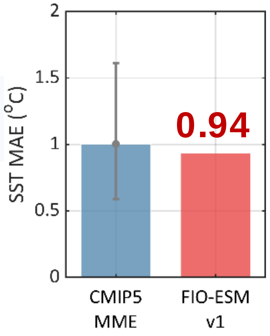
Bias

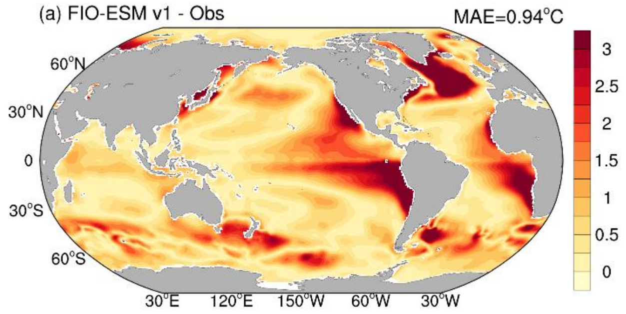


New climate model FIO-ESM v1.0 & 2.0

FIO-ESM v1

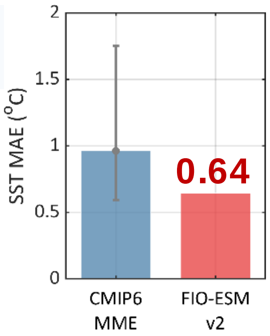
- Bv

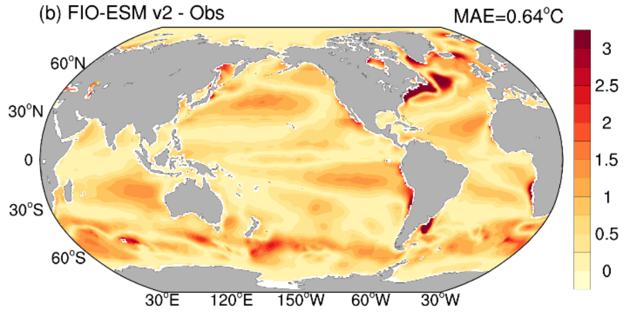




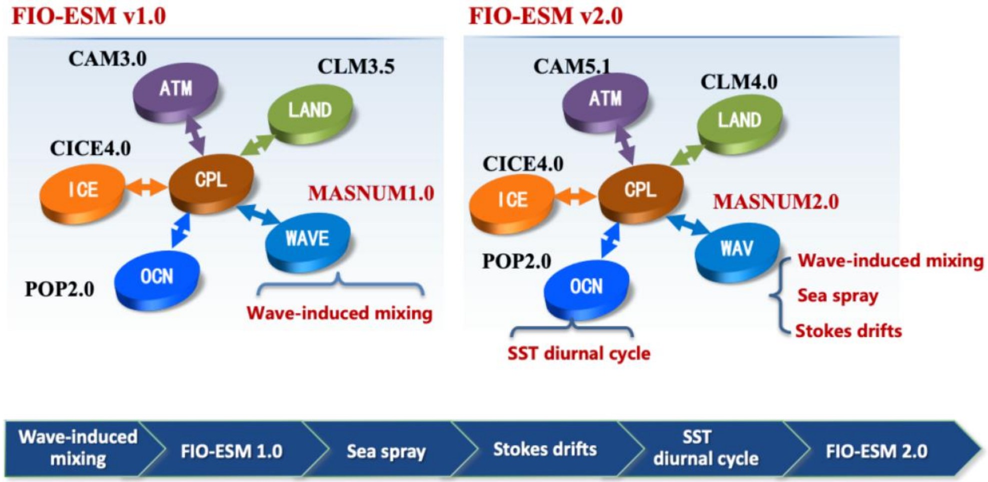
FIO-ESM v2

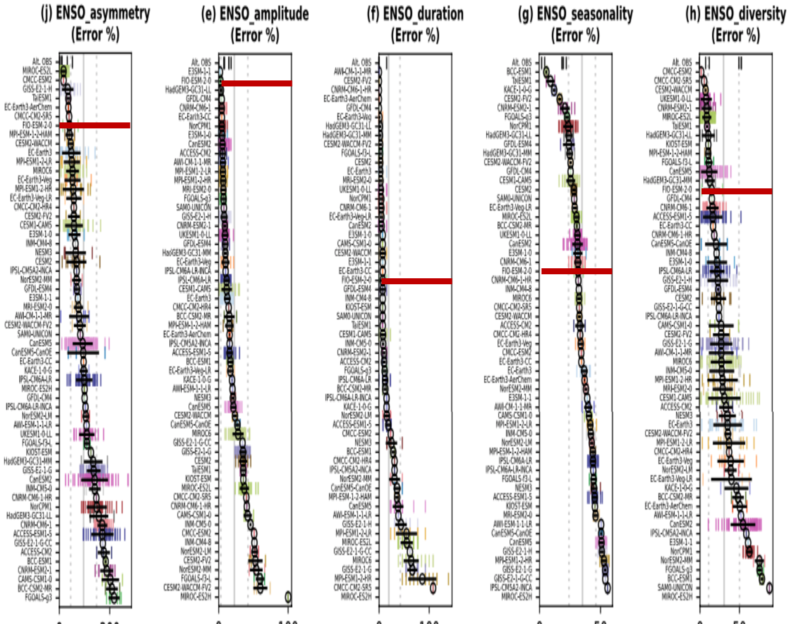
- Bv
- Stokes drift
- Sea spray





ENSO comparison in the past 100 years





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[Lee, 2021, GRL]

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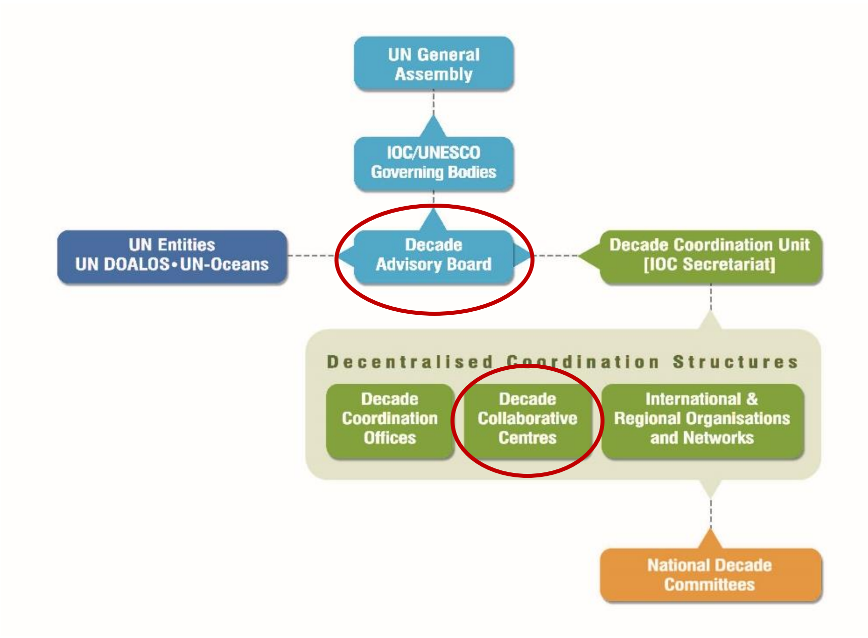
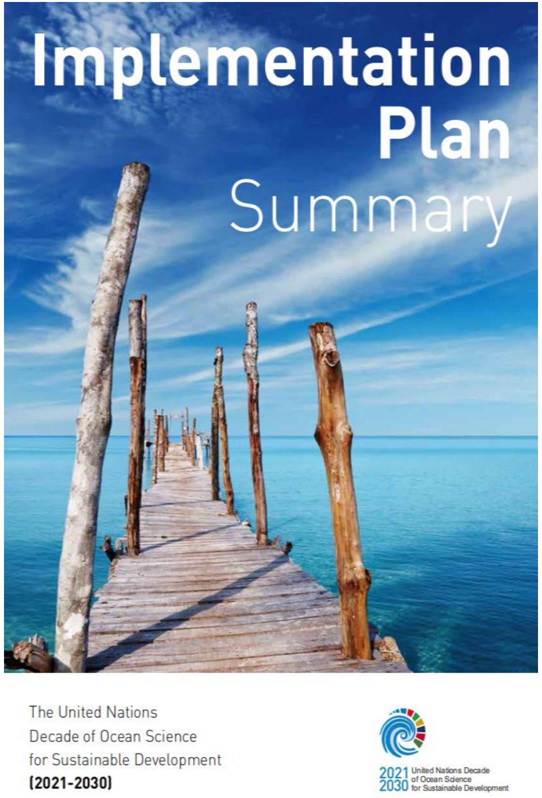
Deep involvement of UN Ocean Decade

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



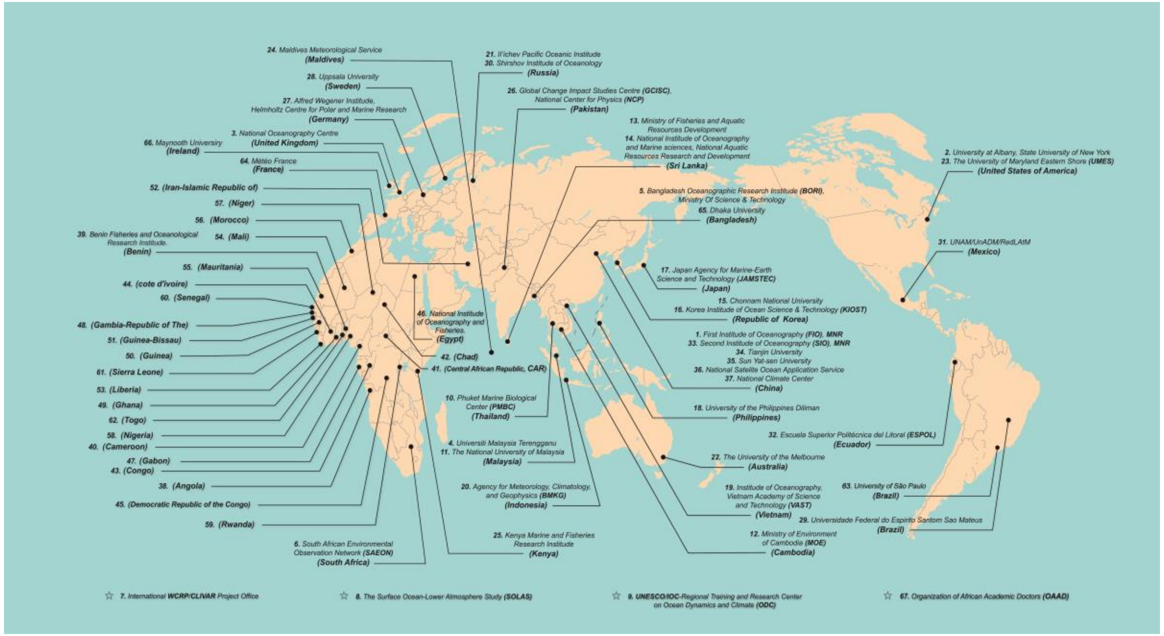


Ocean to climate seamless forecasting system (OSF)

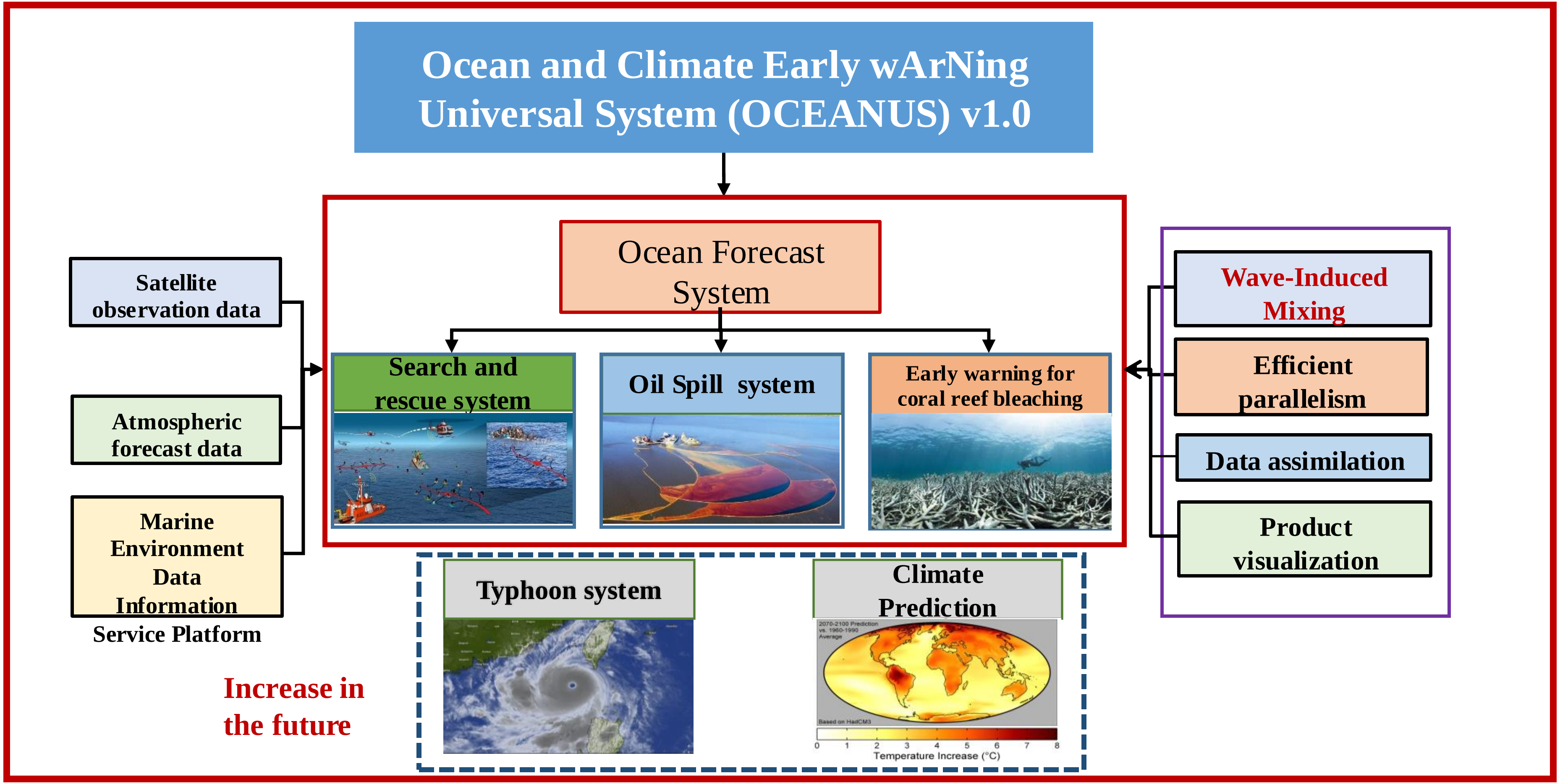
70+
Institutes

50+
Countries

5
International organizations



Scientific tools for decision-making



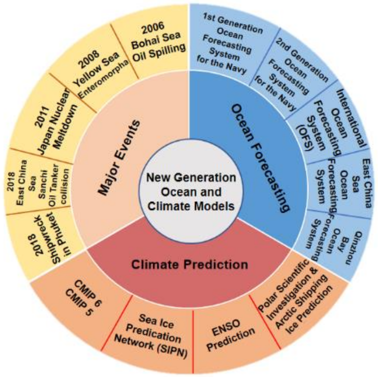
Conclusions

- 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



New Generation Ocean and Climate Models
Ocean Forecasting
Major Events
Climate Prediction
1st Generation Ocean Forecasting System for the Navy
2nd Generation Ocean Forecasting System for the Navy
International Ocean Forecasting System (OFS)
East China Sea Ocean Forecasting System
Qinzhou Bay Ocean Forecasting System
Polar Scientific Investigation & Arctic Shipping Ice Prediction
ENSO Prediction
Sea Ice Predication Network (SIPN)
CMIP 6
CMIP 5
2018 Shipwreck in Phuket
2018 East China Sea Sanchi Oil Tanker collision
2011 Japan Nuclear Meltdown
2008 Yellow Sea Enteromorpha
2006 Bohai Sea Oil Spilling