PICES-Session 3

Improved prediction of tropical cyclone intensity by incorporating ocean waves: An example of a potential PICES science service

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First Institute of Oceanography, MNR, China

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I Needs and challenges

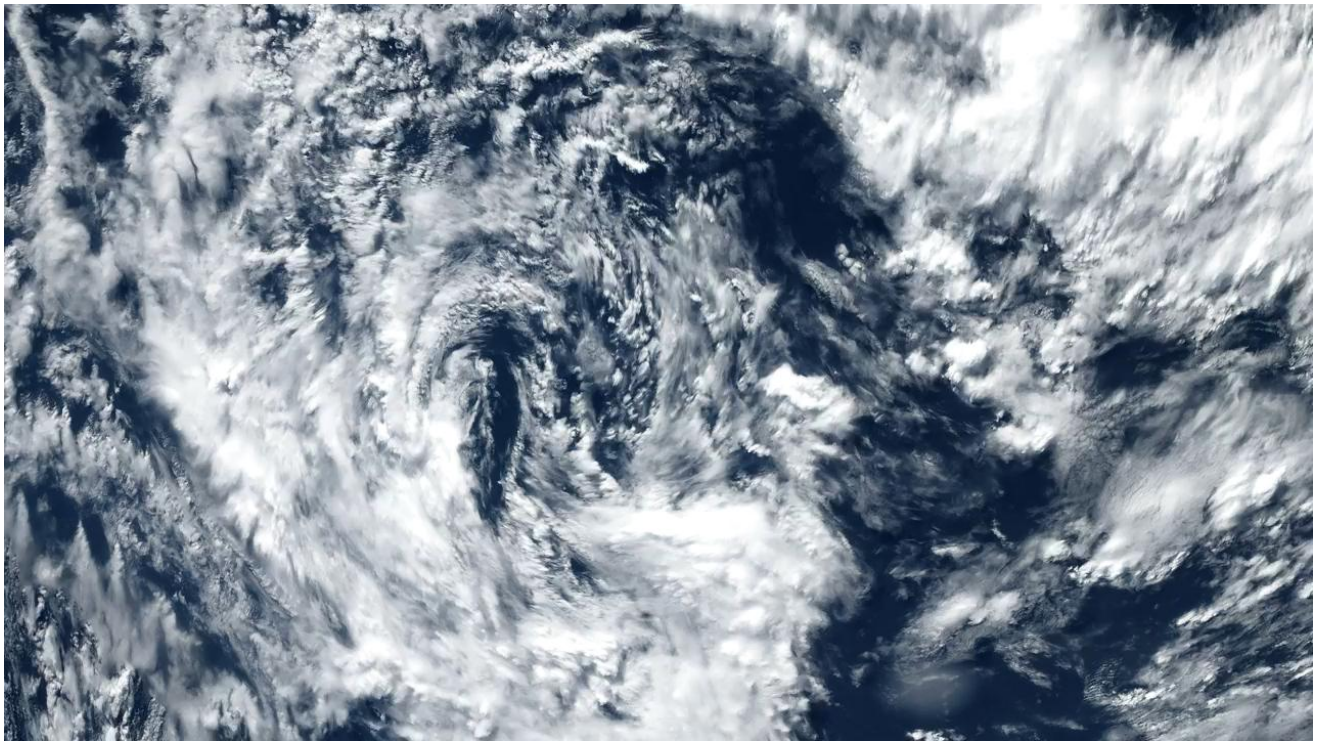
II Science-based breakthroughs

III Third generation TC model

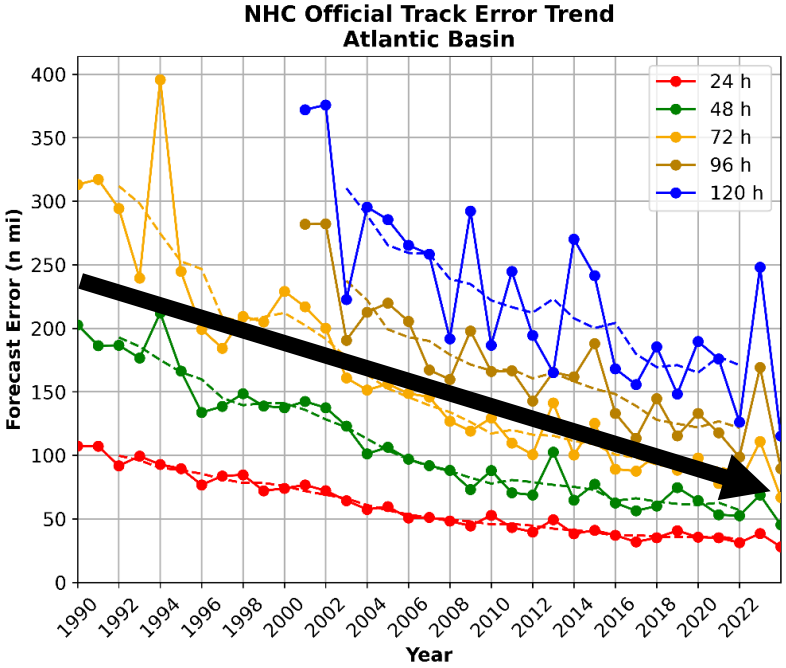
IV Observation and summary

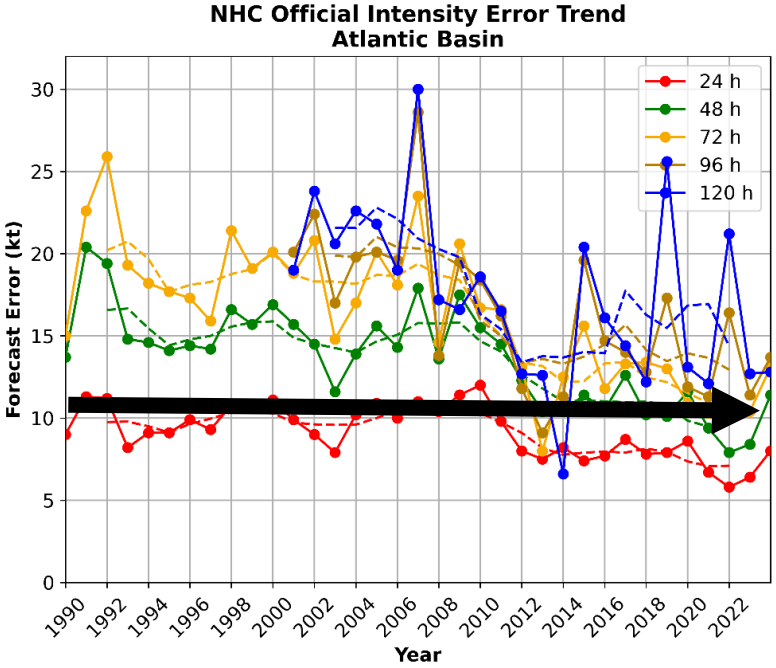
Huge impacts of TCs

- ~ 1B people exposed to TCs;
- ~2.6 M lost lives;
- ~ 130B UDS each year;
- From ocean;
- Under climate change.



Challenge: Standstill in forecasting Typhoon intensity



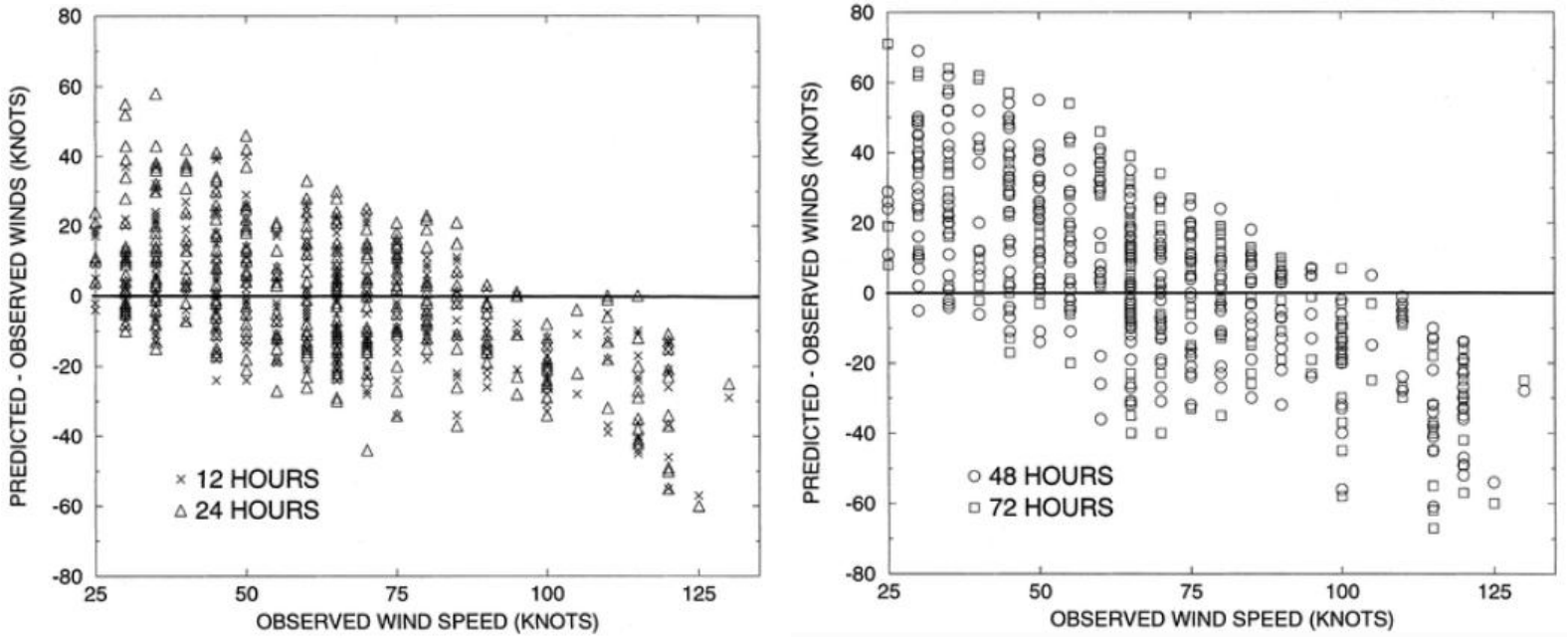


NHC Annual Report 2024

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

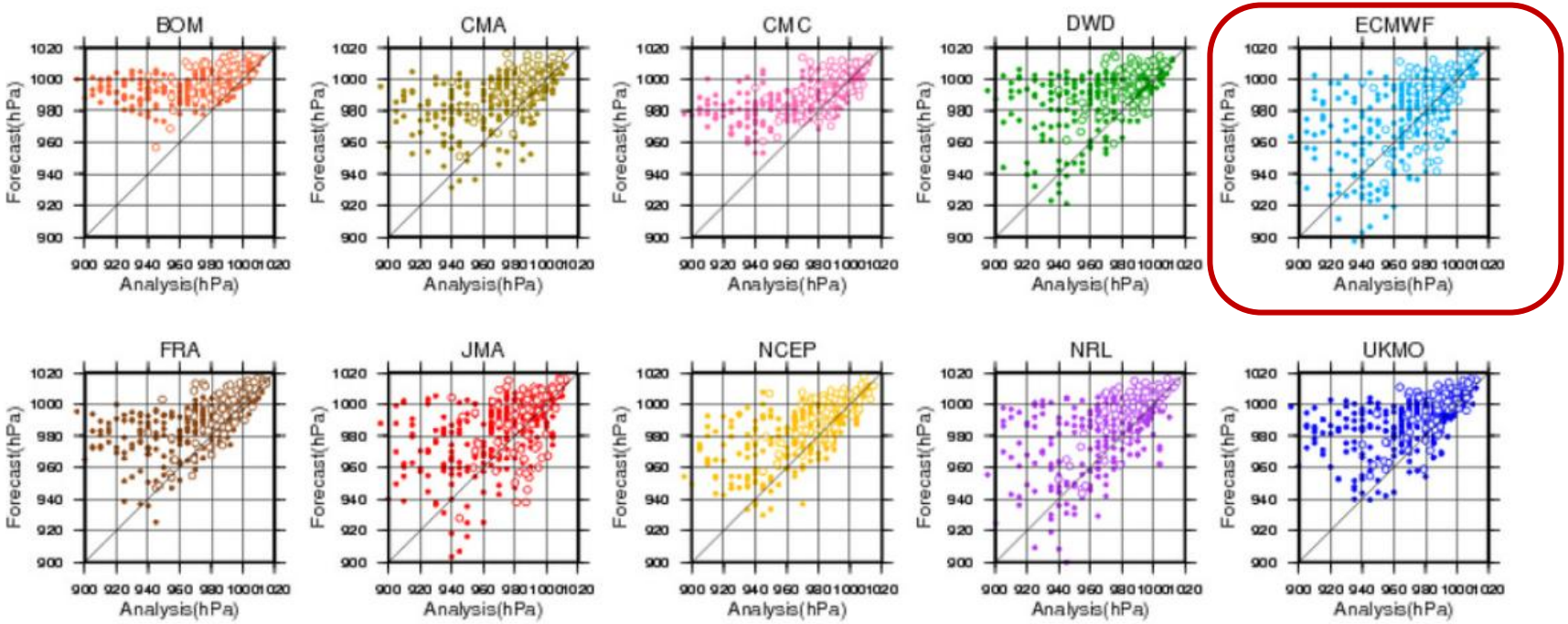
First generation TC model

GFDL WIND SPEED BIAS: 1995 & 1996 ATLANTIC HURRICANE SEASON



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

Second generation TC model



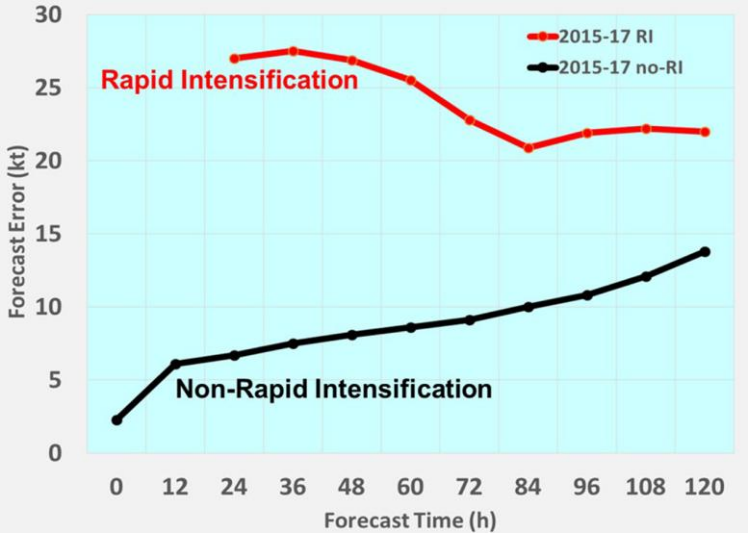
Yamaguchi, M., Ishida, J., Sato, H. & Nakagawa, M. 2017

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)

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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 of wave-turbulence interaction in intensifying ocean turbulence (Qiao et al, 2016);

- Overturn the statement of J. Lumley (1983): "wave does not generate turbulence before breaking"



Surface waves modulate wind stress

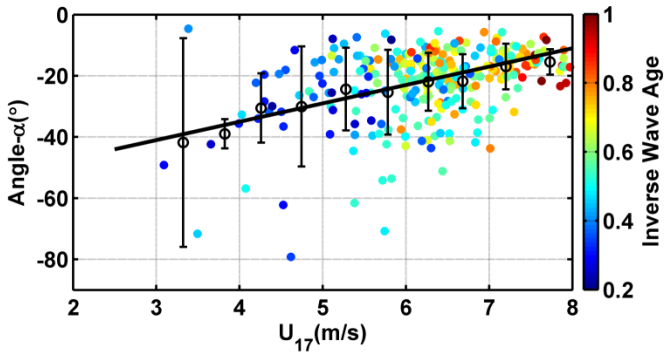


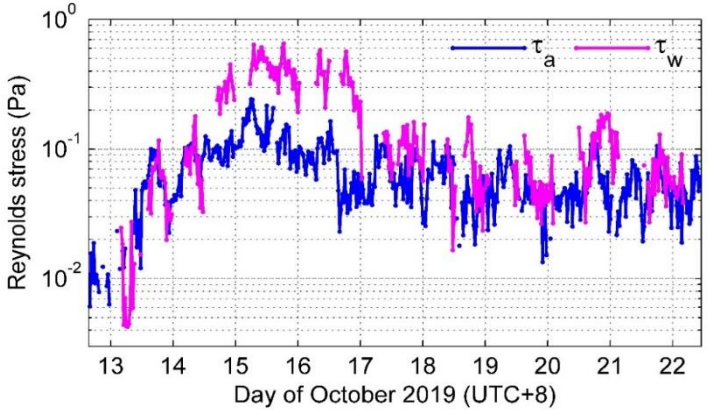




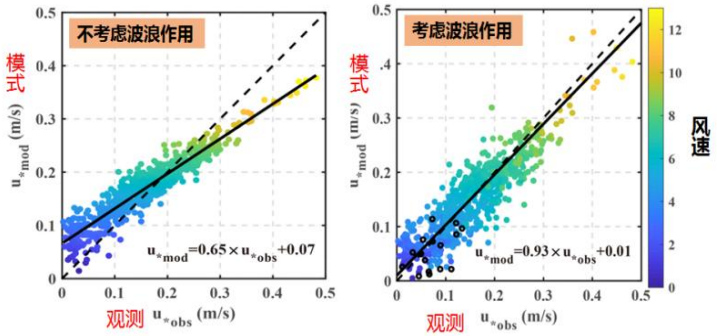
- **The concept was proposed by many scientists, including Toba (1961), Stewart (1970), Wu (1975);**
- **Rieder & Smith (1994) reported: "Significant angles between the wind stress vector and the mean wind vector are seen" through FLIP in-situ observation ;**
- **Our group has long-term air-sea fluxes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

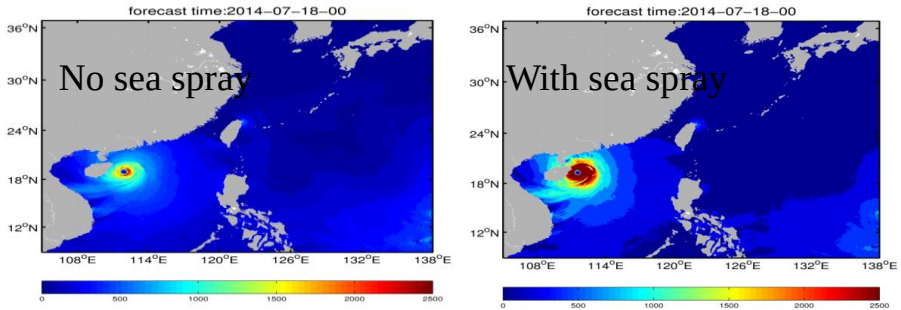


Reverse the long-standing knowledge on ocean momentum flux



Theory innovation 3: sea spray increases heat flux

- Incorporate sea spray into typhoon and Earth system models



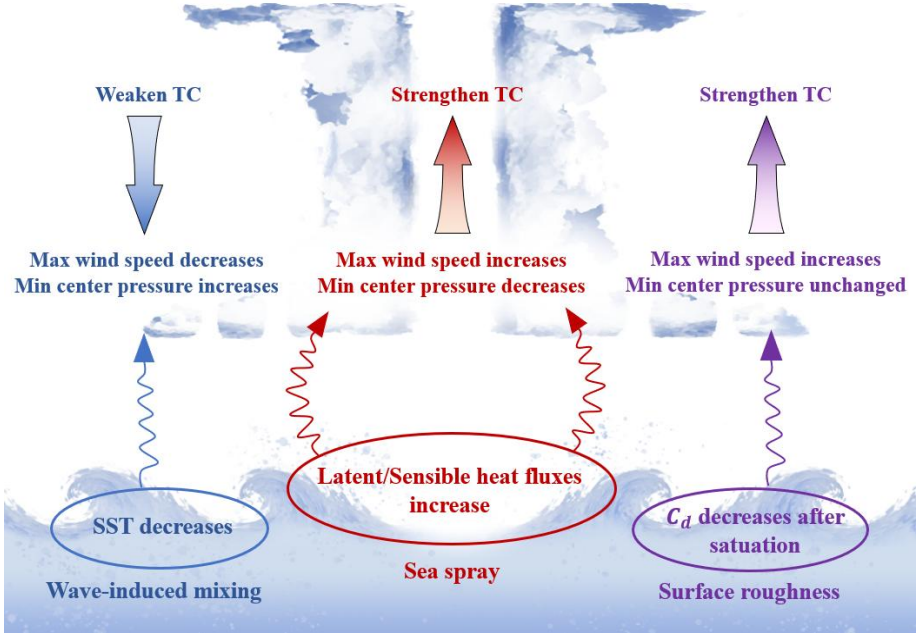
Latent heat flux

Sensible heat flux

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

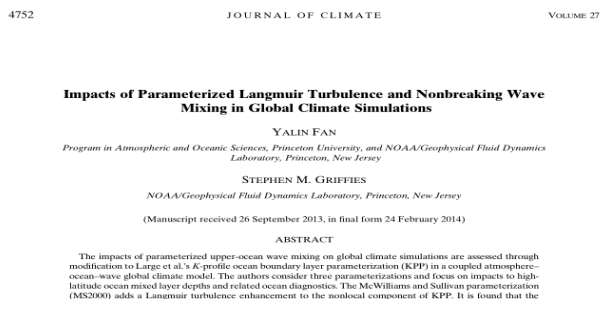
From surface wave to climate system

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)

Theory adopted by leading model development groups



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

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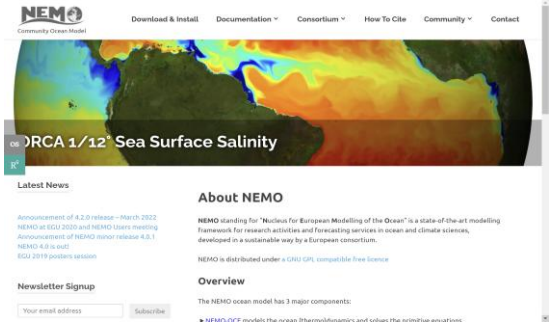
(Manuscript received 26 September 2013, in final form 24 February 2014)

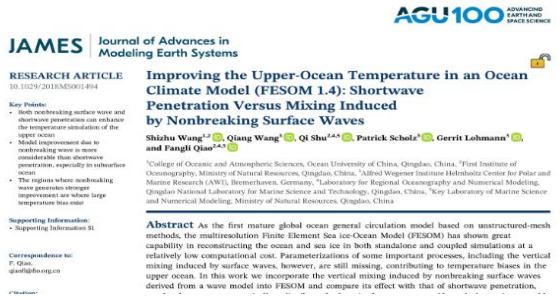
ABSTRACT

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



NEMO



AGU100 ADVANCING EARTH AND SPACE SCIENCE

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, Qiang Wang, Qi Shu, Patrick Scholz, Gerrit Lohmann, and Fangli Qiao

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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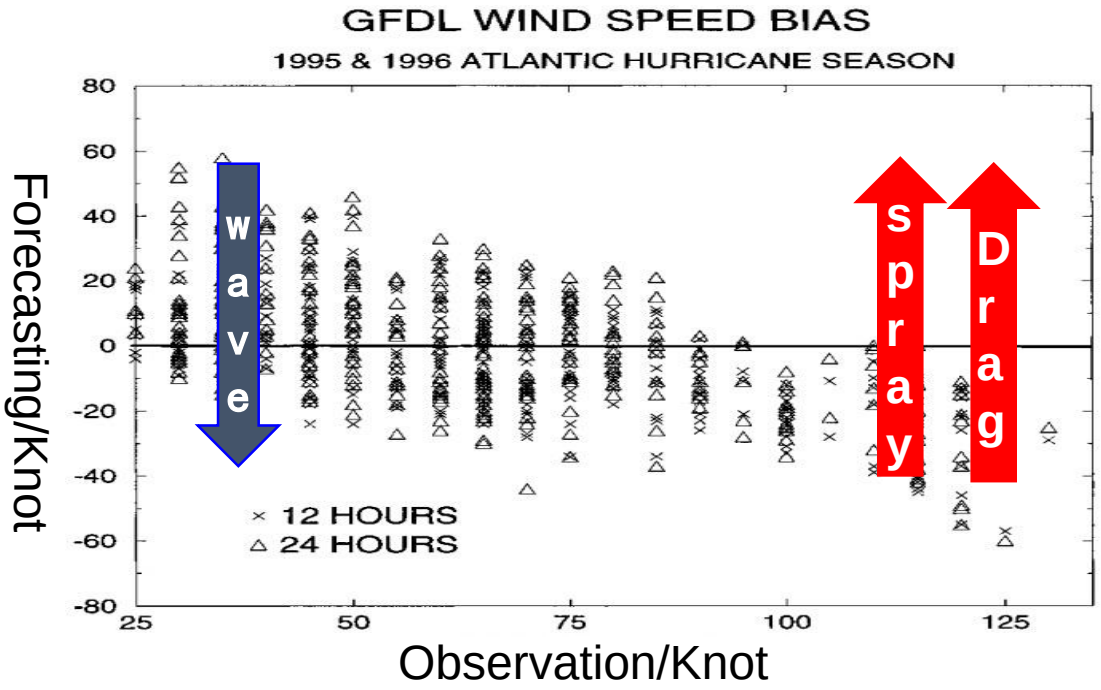
Third generation TC model

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

Bv: Qiao et al, 2004

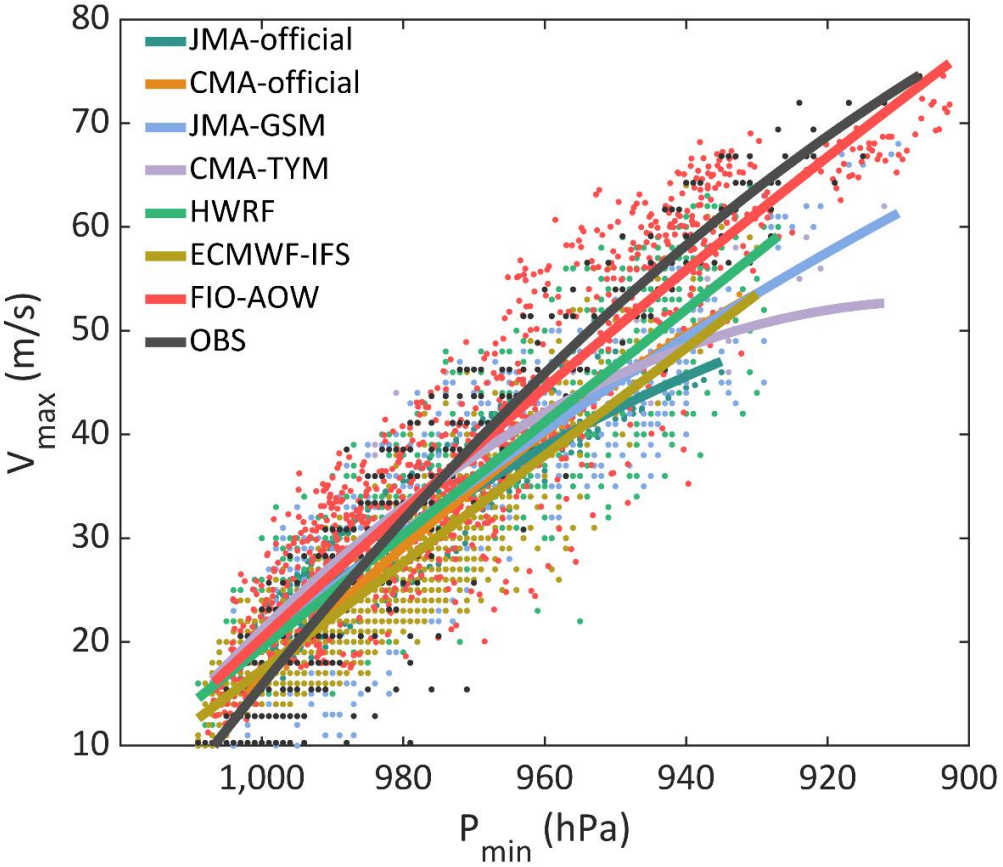
Spray: Andreas et al, 2015

Cd: Zhao et al, 2024



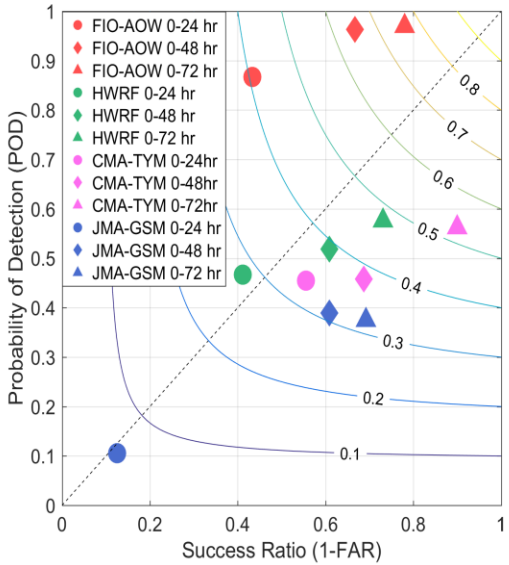
Li Songlin, Biao Zhao, Qi Shu, Vladimir Ryabinin, Dong Ji, Guomin Chen, Fangli Qiao* and Ka-Kit Tung*, 2026. Forecasts of strong tropical cyclones improved by incorporating ocean waves at air–sea interface. Communications earth & environment, 7(1):751, doi: https://doi.org/10.1038/s43247-026-03754-y

Comparison of wind-pressure relation in 2024



For all RI in 2024 in the Northwest Pacific

a



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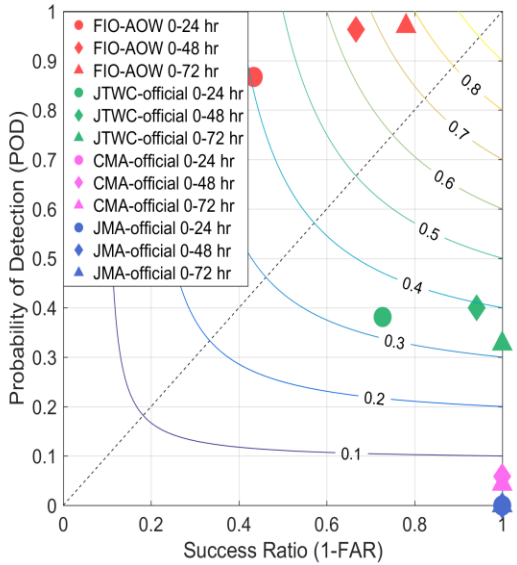
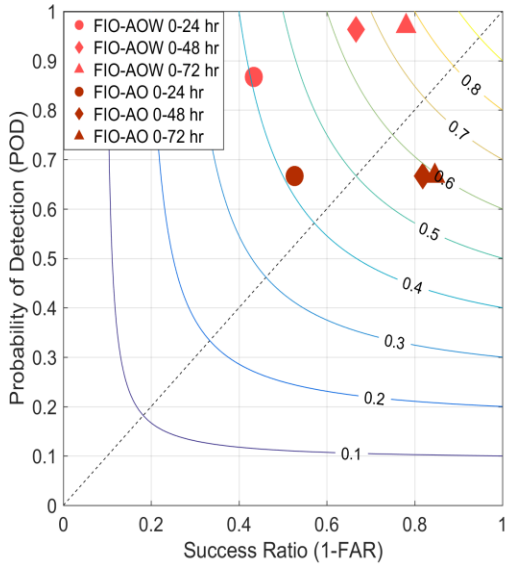
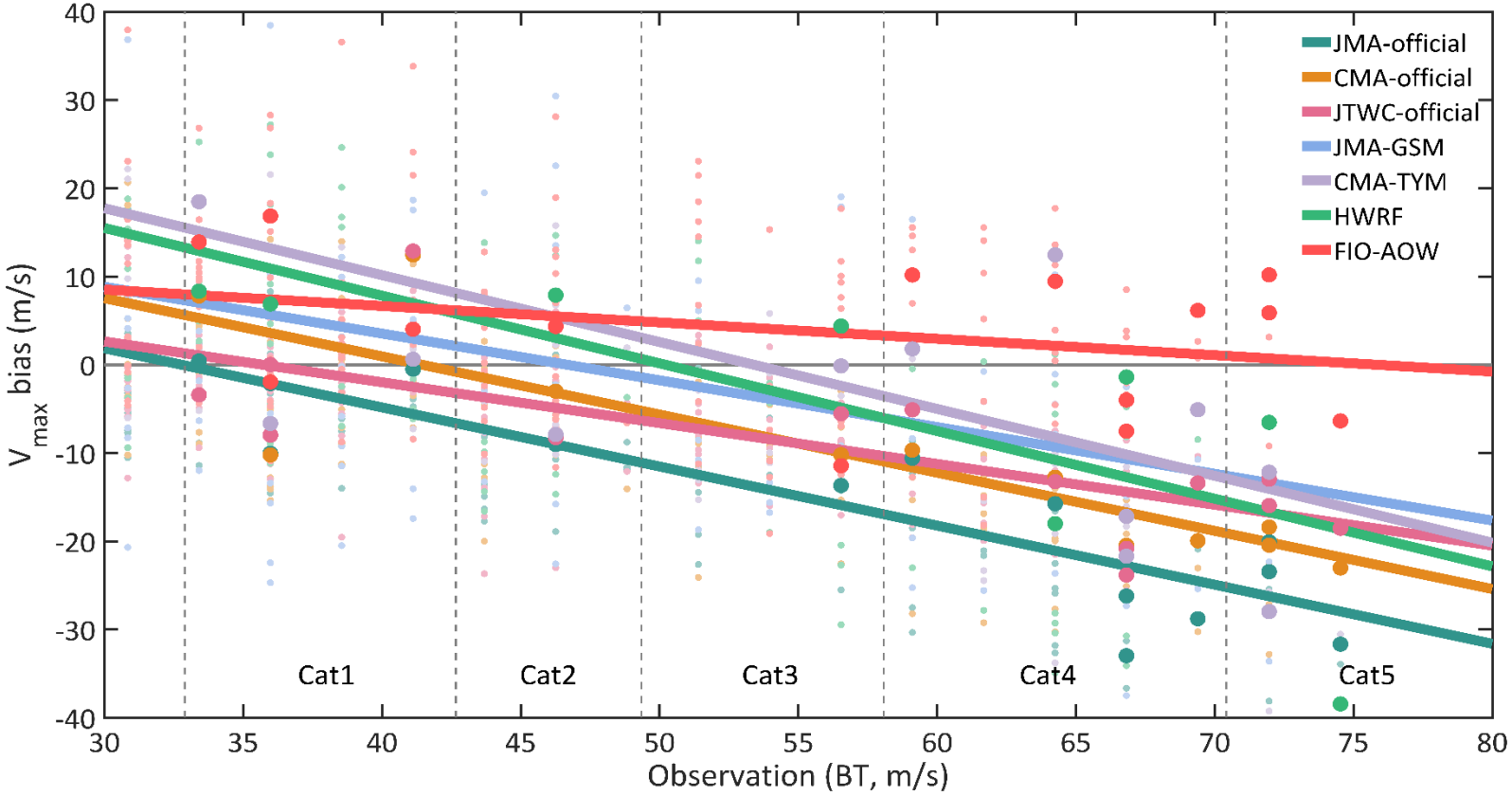


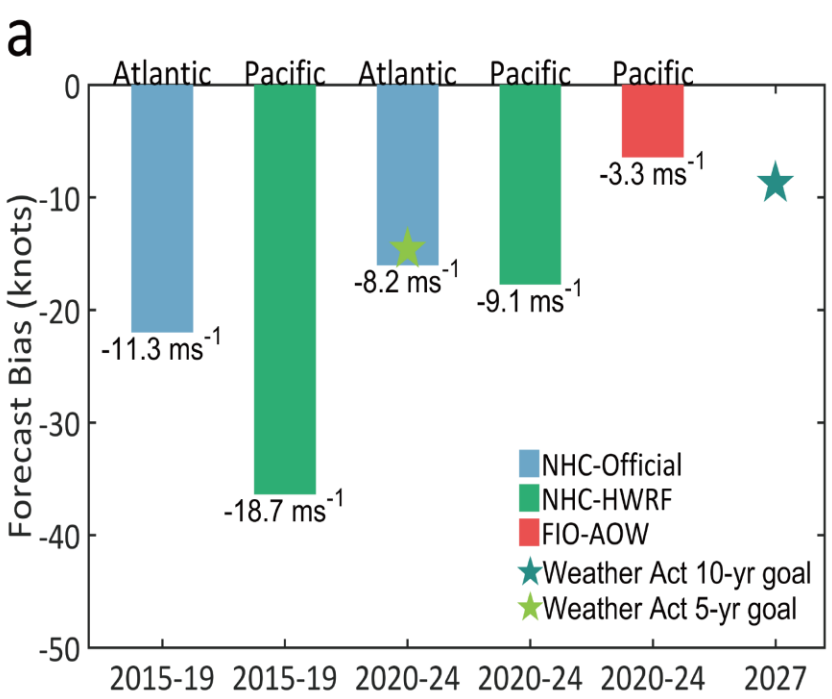
c

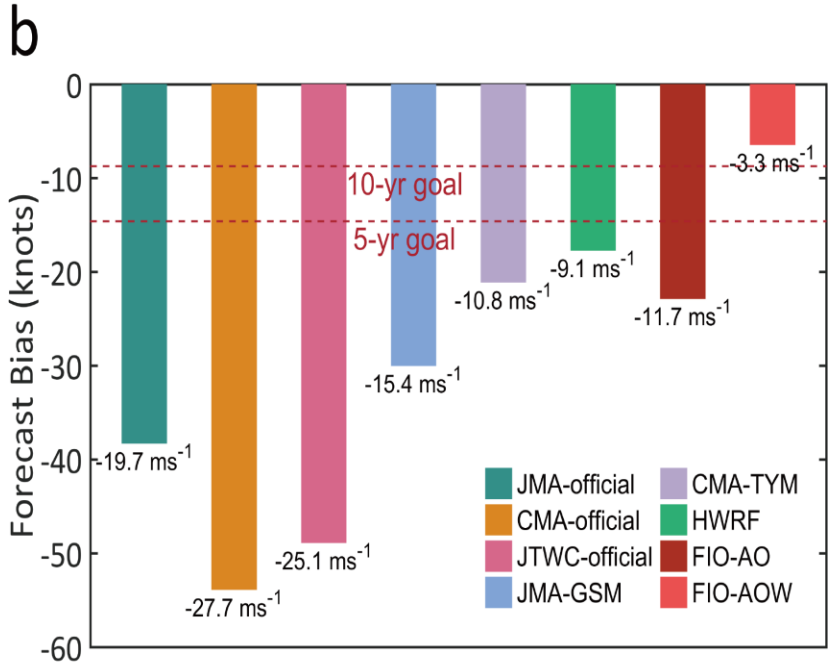


For the maximum wind speed of all TCs in 2024: 72h



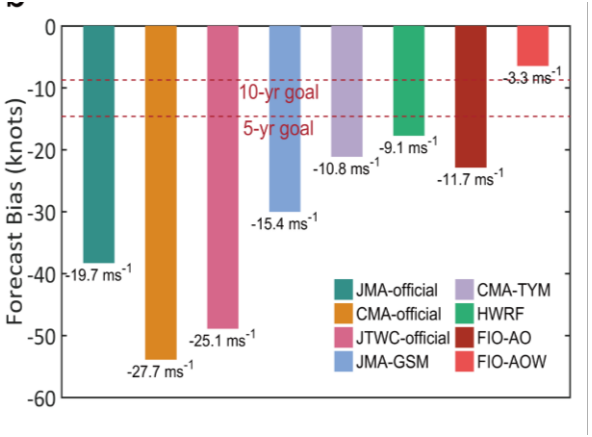
For all 37 RIs during 2020-2024



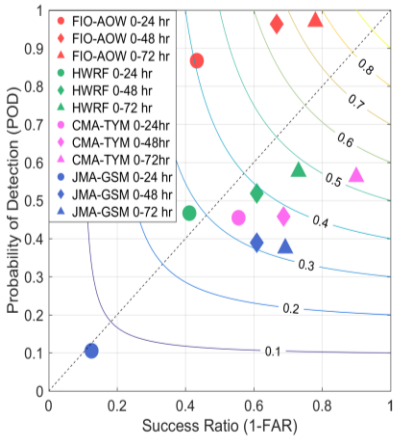


For 3 bottleneck challenges

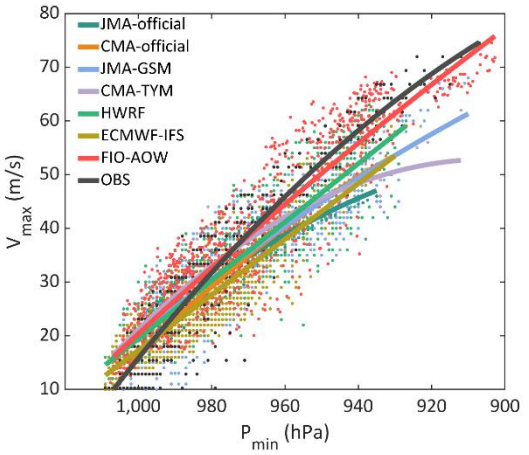
Big intensity bias



Predict RI



Wind-press rela

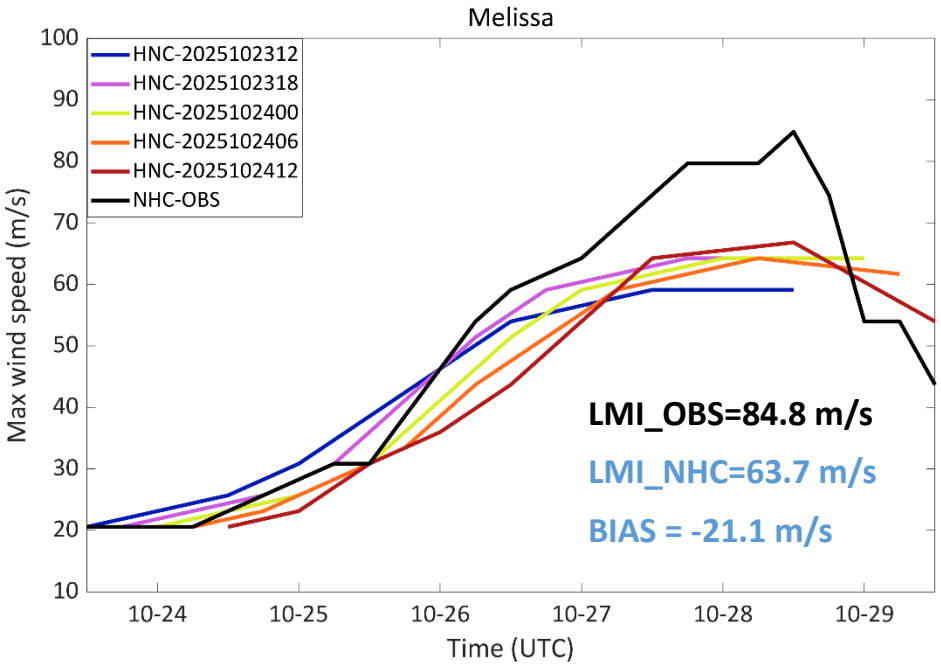


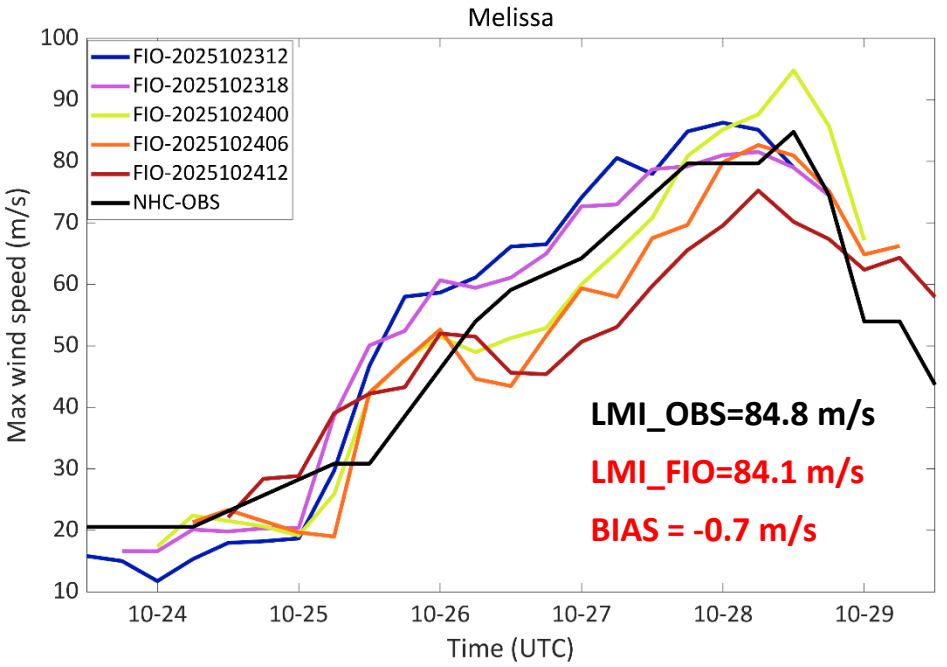
Over “weather Act”

RI 90%+

Good relationship

The strongest Hurricanes in 2026 in Atlantic: Melissa





Mean negative bias of lifetime maximum intensity (LMI) was reduced by 97%

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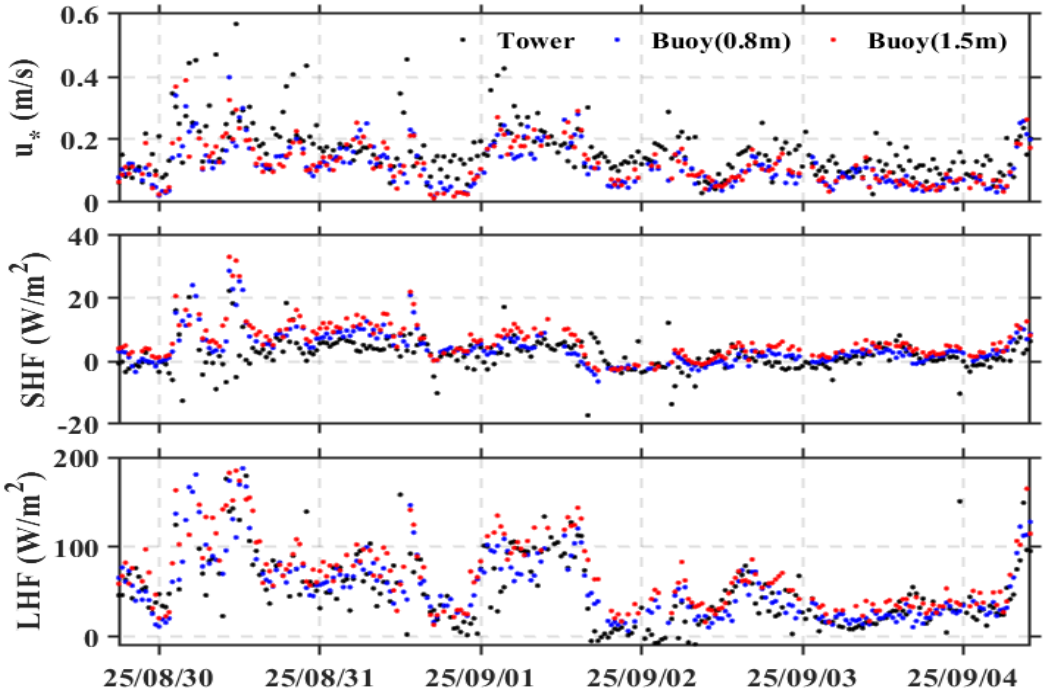
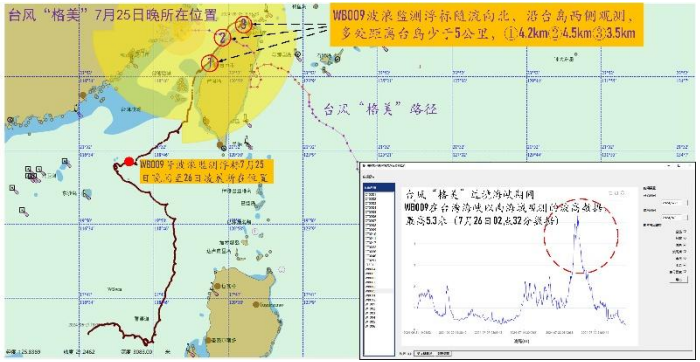
Jingwei Buoy: air-sea heat and momentum fluxes





The buoy has been tested more than 100 times







Take home message

- **Scientific breakthrough: New understanding of surface wave on air-sea flux;**
- **Technical innovation: super low cost, high precision, AI-tech buoy for direct observation of air-sea fluxes;**
- **A predicted ocean: third generation TC model with amazing prediction ability;**
- **PICES actionable information: could we start from ocean and climate extremes, especially Typhoon forecasting?**


Thanks
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