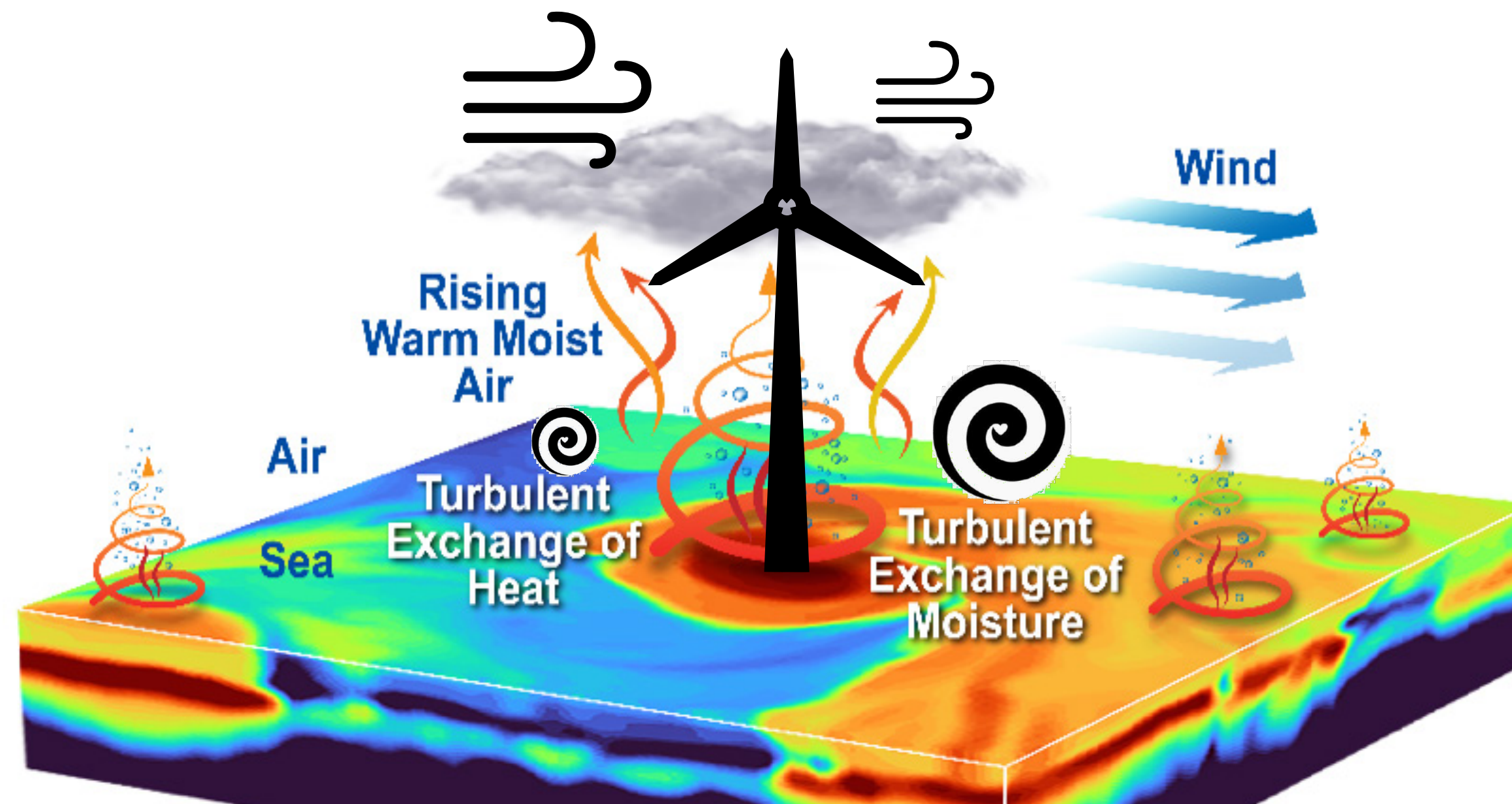
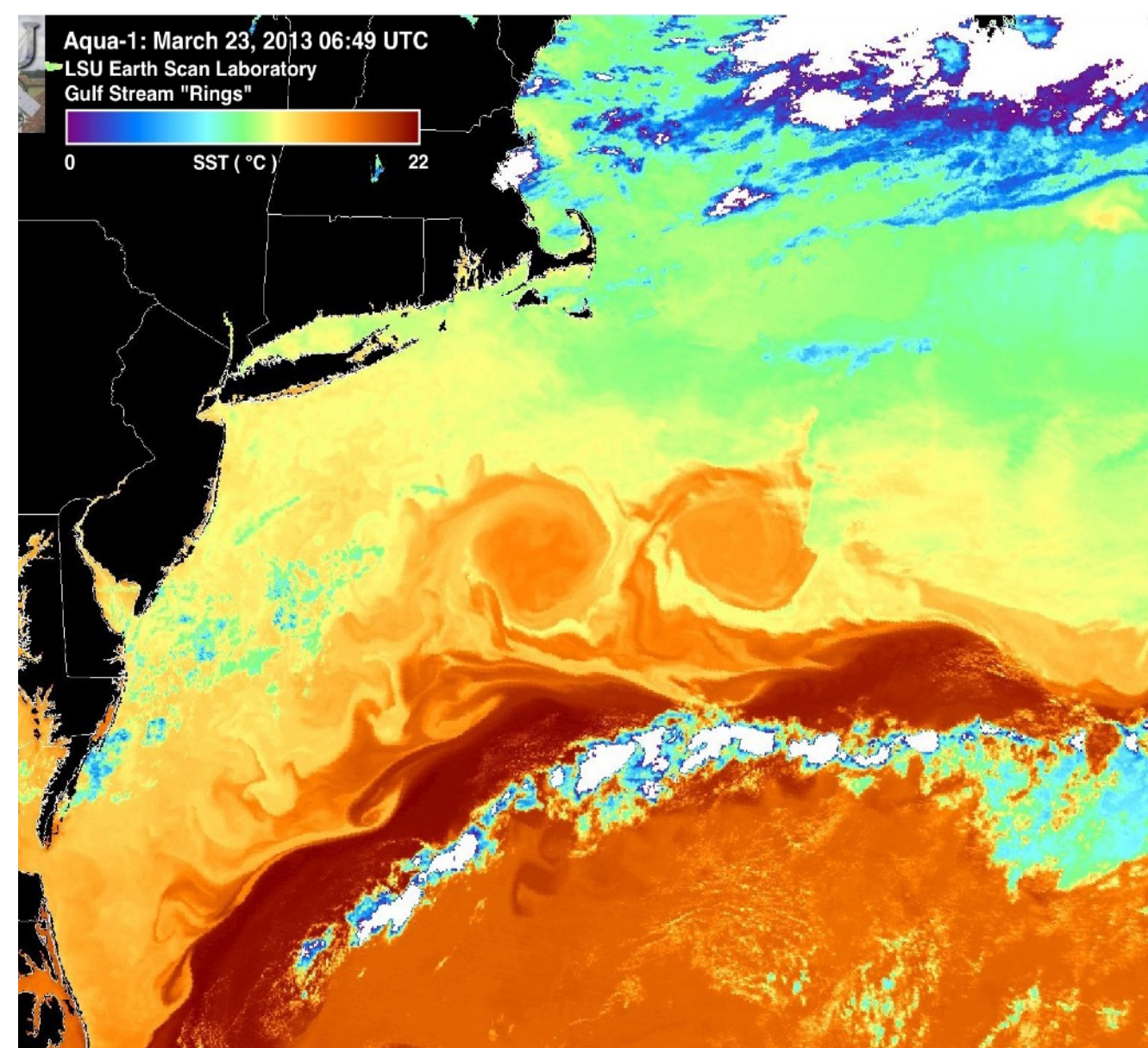


Stratified Shelf Ocean and Fetch-Dependent Sea State Responses to Large-Scale Offshore Wind Farms on the US East Coast

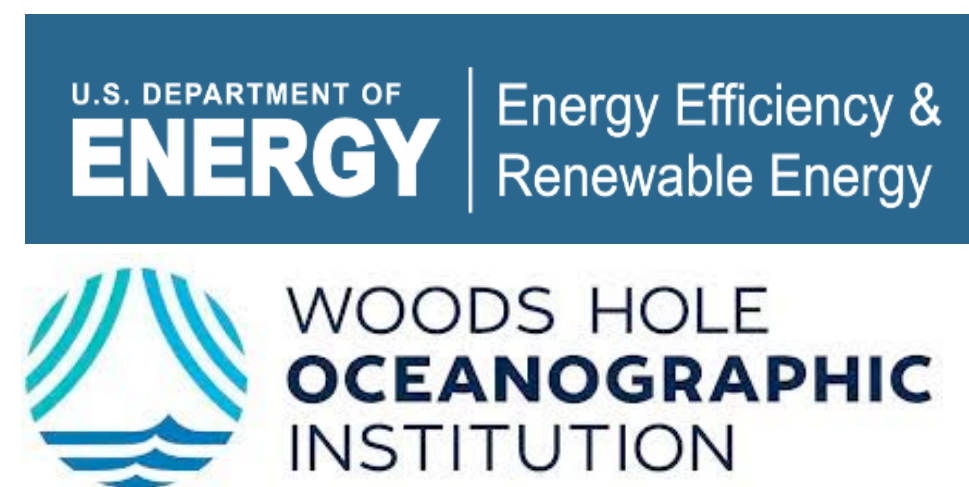


SNU Department Seminar
June 25, 2026

Hyodae Seo & César Sauvage, Christoph Renkl (UH),
Julie Lundquist (JHU/NREL),
Anthony Kirincich, Jim Edson, Carol Anne Clayson (WHOI)
& Seth Zippel (OSU)



UNIVERSITY
of HAWAII®
MĀNOA



Sea surface warming and ocean-to-atmosphere feedback driven by large-scale offshore wind farms under seasonally stratified conditions

[HYODAE SEO](#) , [CÉSAR SAUVAGE](#) , [CHRISTOPH RENKL](#) , [JULIE K. LUNDQUIST](#) , AND [ANTI](#)

JGR Oceans

Research Article

Fetch-Dependent Surface Wave Responses to Offshore Wind Farms in the Northeast U.S. Coast

[César Sauvage](#) , [Hyodae Seo](#), [Seth Zippel](#), [Carol Anne Clayson](#), [James B. Edson](#)

First published: 23 December 2025 | <https://doi.org/10.1029/2025JC023156> |

 VIEW METRICS

Accessibility issue? [Request accessibility update.](#)

Before and After: US Federal Government's Climate Action Plans

THE WHITE HOUSE



Administ

Find out how the Bipartisan Infrastructure Law can help your community supercharge the transition to clean energy, clean up

President Biden's Actions to Tackle the Climate Crisis

President Biden campaigned on a bold vision of tackling the climate crisis with the urgency that science demands, by building a clean energy economy that benefits all Americans—with lower costs for families, good-paying jobs for workers, and healthier air and cleaner water for communities. As part of that vision, the President set groundbreaking goals:

- Reducing U.S. greenhouse gas emissions 50-52% below 2005 levels in 2030
- Reaching 100% carbon pollution-free electricity by 2035
- Achieving a net-zero emissions economy by 2050
- Delivering 40% of the benefits from federal investments in climate and clean energy to disadvantaged communities

- 30 GW of offshore wind energy by 2030 (2.5K wind turbines)
- 3000 GW by 2050 (250K)

<https://www.whitehouse.gov/climate/#:~:text=Reducing U.S. greenhouse gas emissions,zero emissions economy by 2050>

The WHITE HOUSE



PRESIDENTIAL ACTIONS

Temporary Withdrawal of All Areas on the Outer Continental Shelf from Offshore Wind Leasing and Review of the Federal Government's Leasing and Permitting Practices for Wind Projects

The White House | January 20, 2025

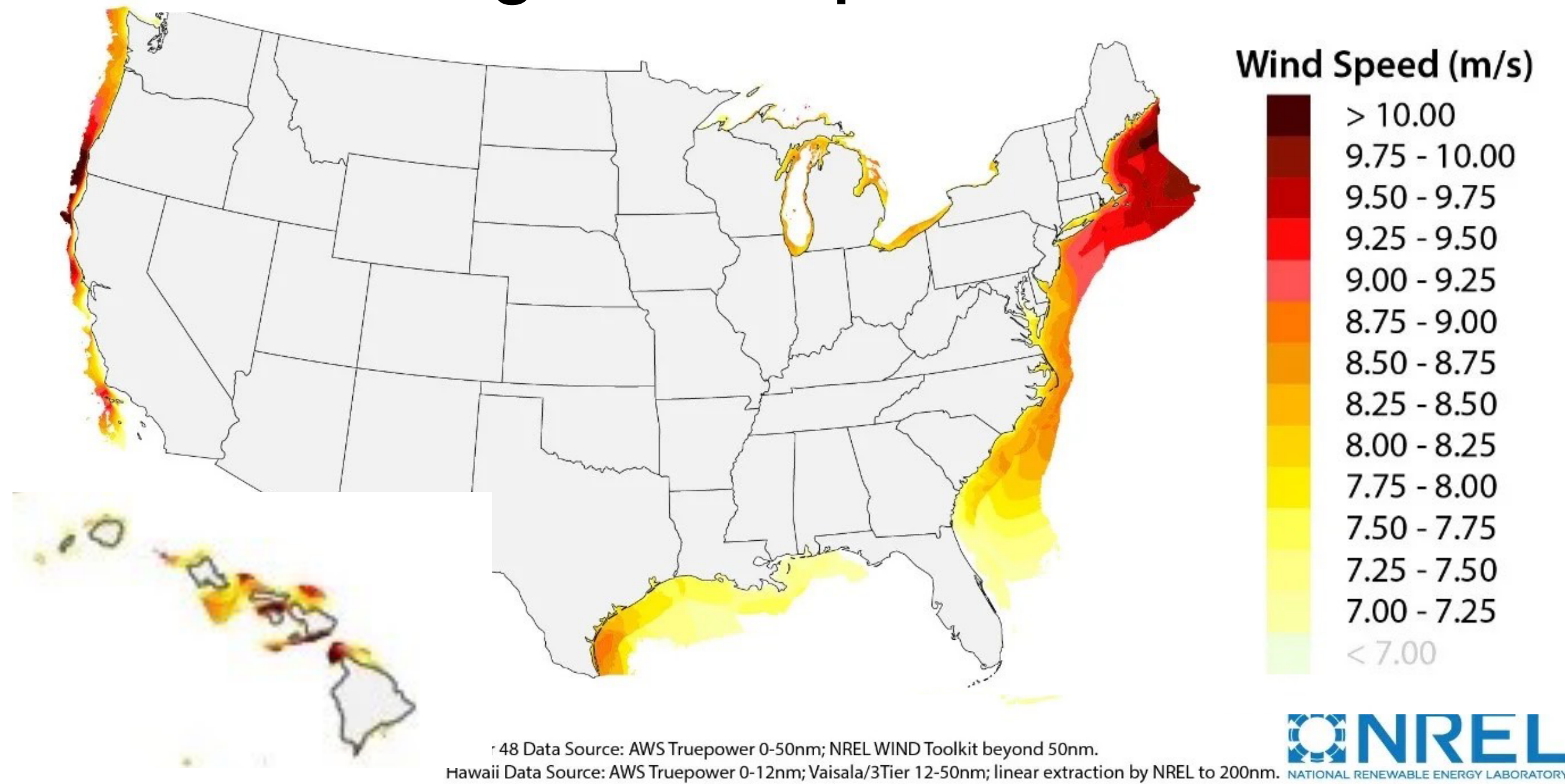
<https://www.whitehouse.gov/presidential-actions/2025/01/temporary-withdrawal-of-all-areas-on-the-outer-continental-shelf-from-offshore-wind-leasing-and-review-of-the-federal-governments-leasing-and-permitting-practices-for-wind-projects/>

Big Picture Questions

- 1. Why offshore wind?**
- 2. Why does air-sea interaction matters for wind energy production?**
- 3. What are the environmental impacts of wind energy production?**

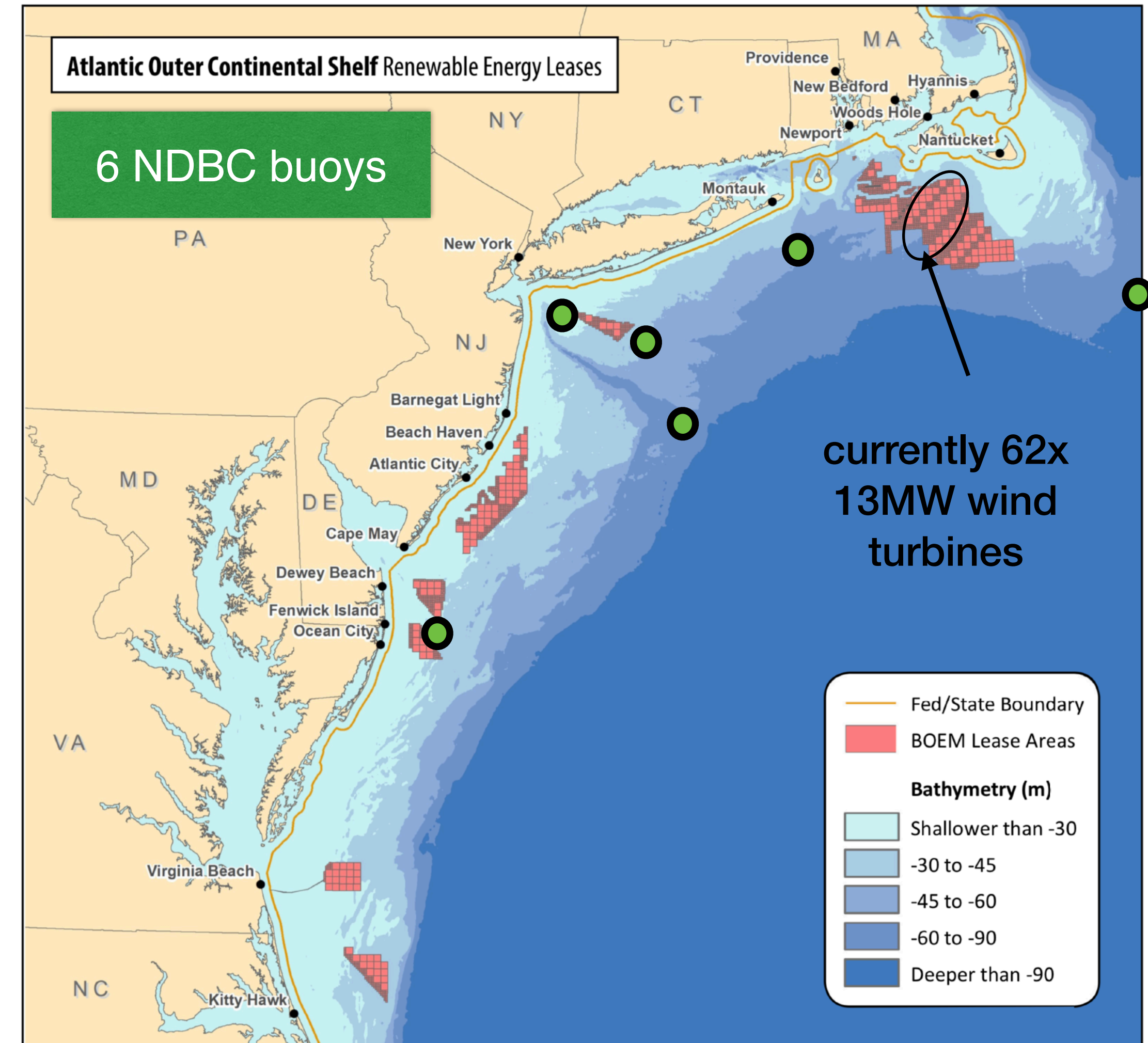
Why offshore wind?

hub height wind speeds



- Winds are stronger and steadier offshore
- Supply is higher offshore, closer to cities with high electricity demand
- Less conflict with local communities
- Previous Federal Gov. Climate Action Plan: 30 GW by 2030 & 3000 GW by 2050
- Protecting biodiversity & promoting ocean co-use
- Huge changes in the way we use coastal/shelf oceans

US Northeast Lease/call areas (NREL 2022)



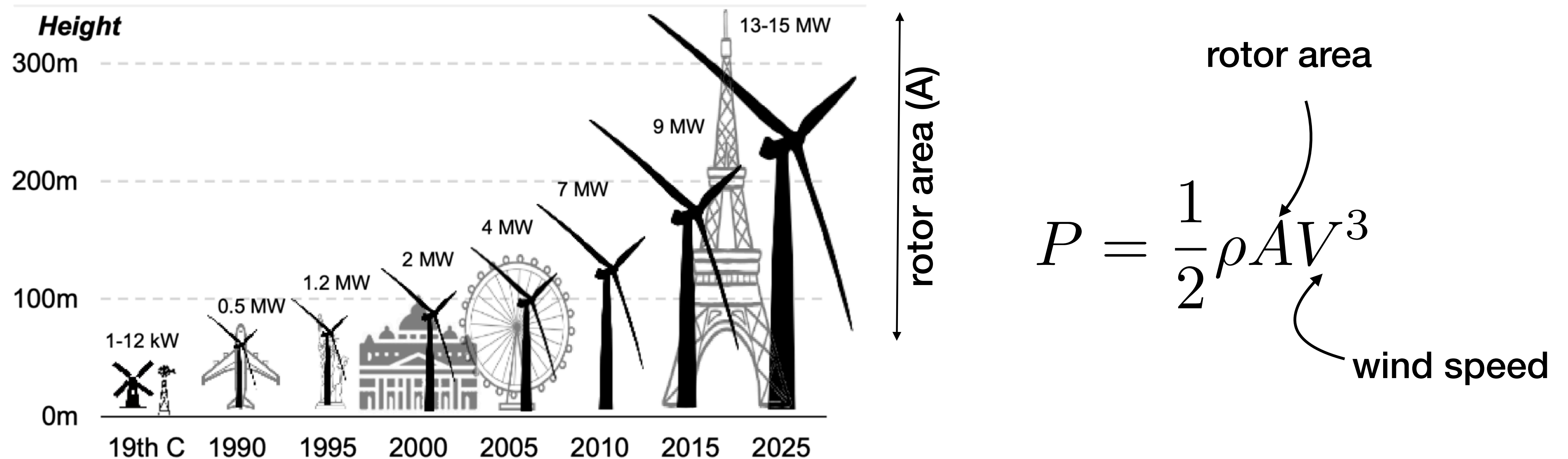
Big Picture Questions

1. Why offshore wind energy?

2. Why does air-sea interaction matters?

3. What are the environmental impacts of wind energy production?

Wind turbines are huge and getting bigger



Source: IEA (2019) Offshore Wind Outlook 2019

- Big turbines drive cost down / MW.
- Engineering challenges in transportation, installation, construction, and maintenance
- Greater environmental impacts



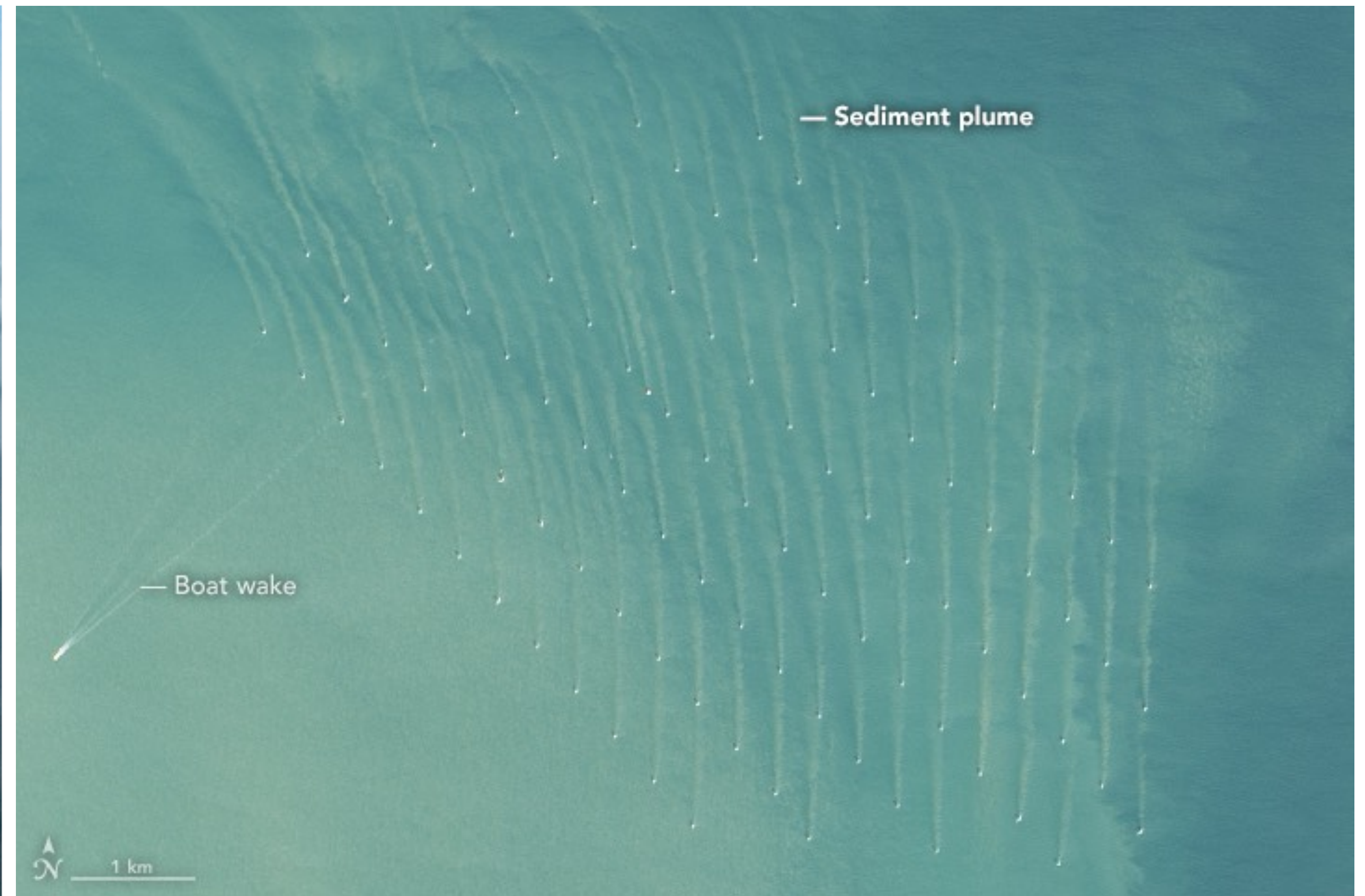
Wind Wakes

Wind turbines extract kinetic energy from the atmosphere to generate electricity. This reduces wind speed and increases turbulence downstream.

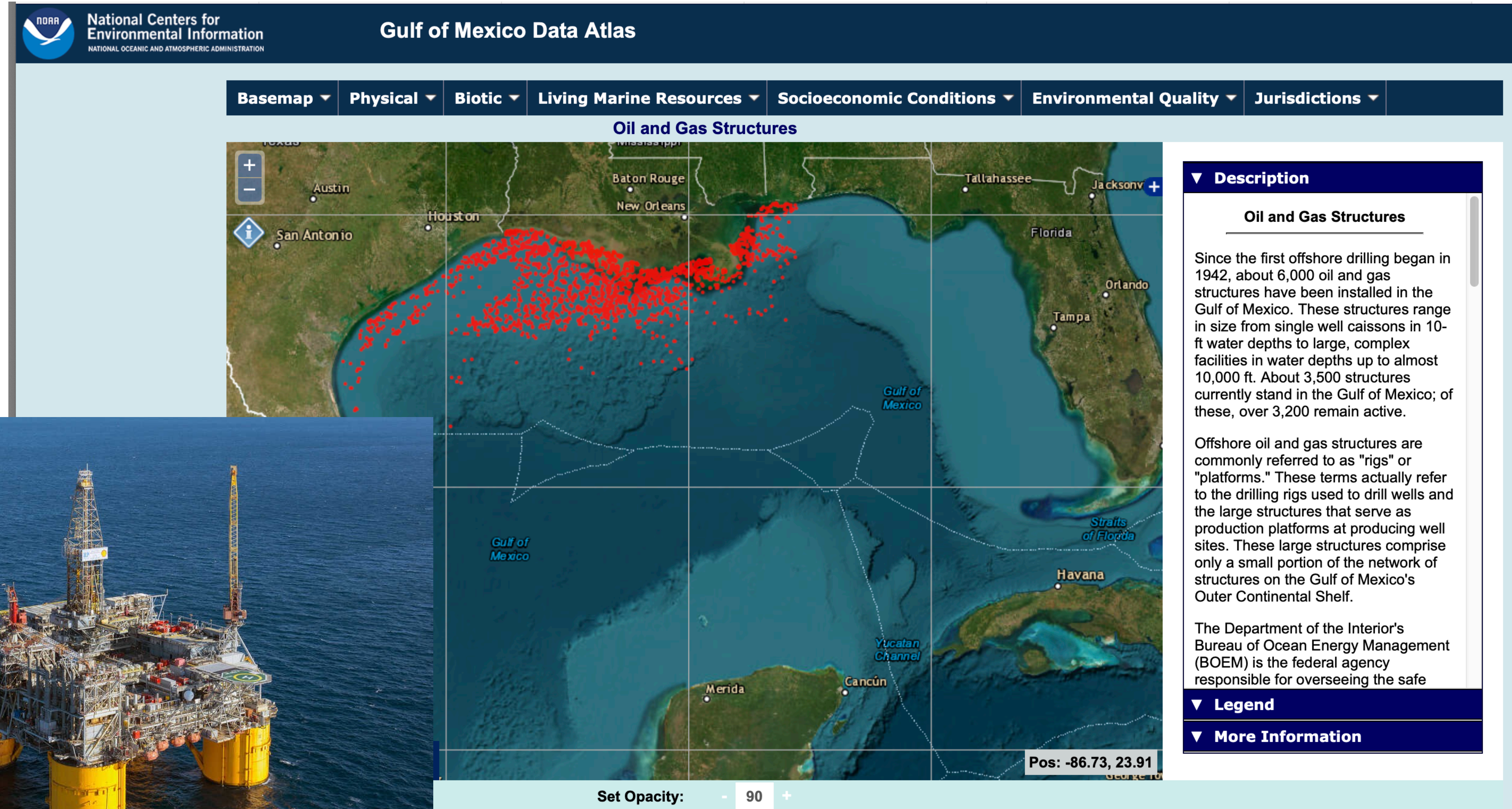
Wind Wakes



Ocean Wakes



High-density offshore structures



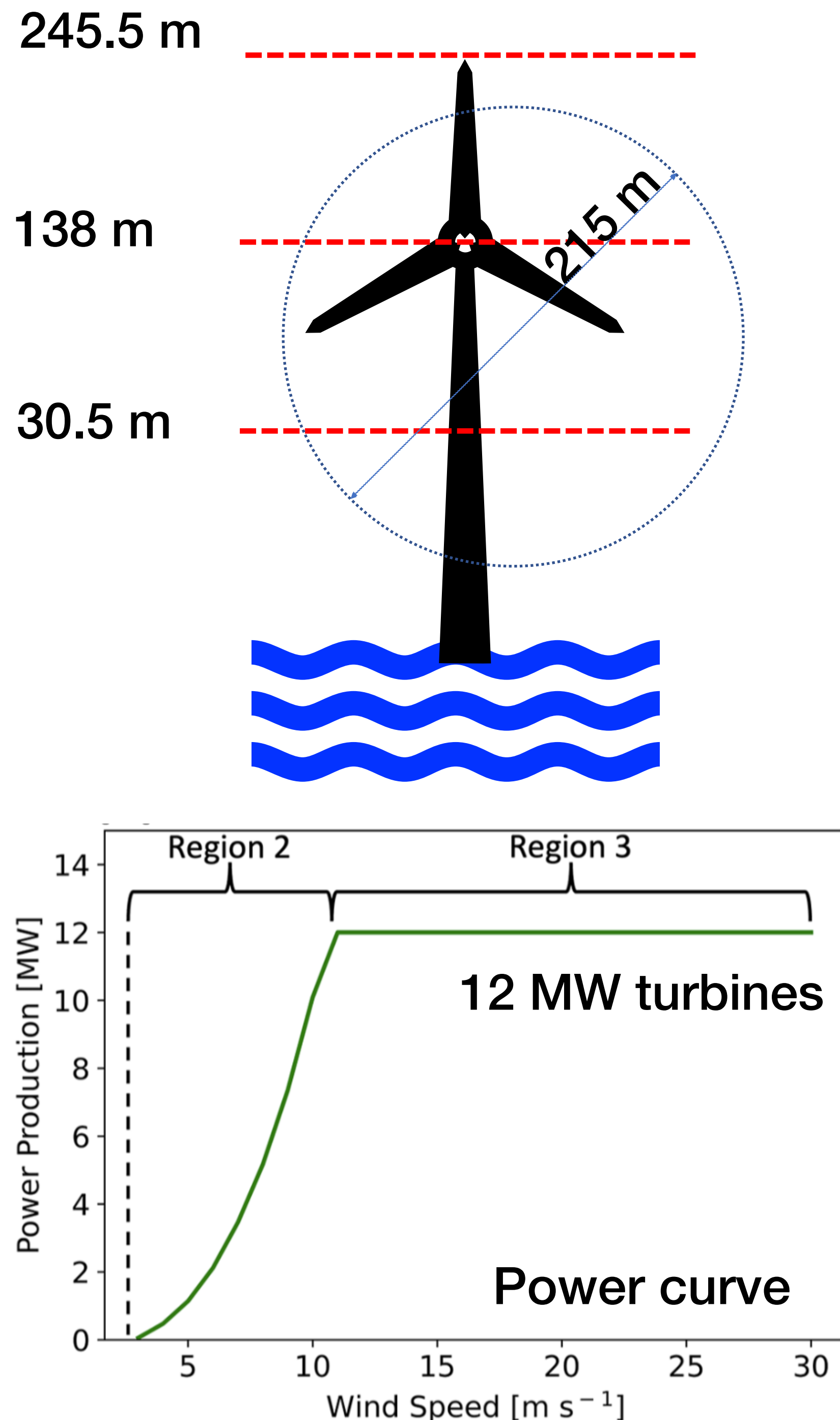
Currently, there are ~3,200 active oil rigs in the Gulf of Mexico.

However, unlike wind farms, they do not generate significant structural wind wake impacts.

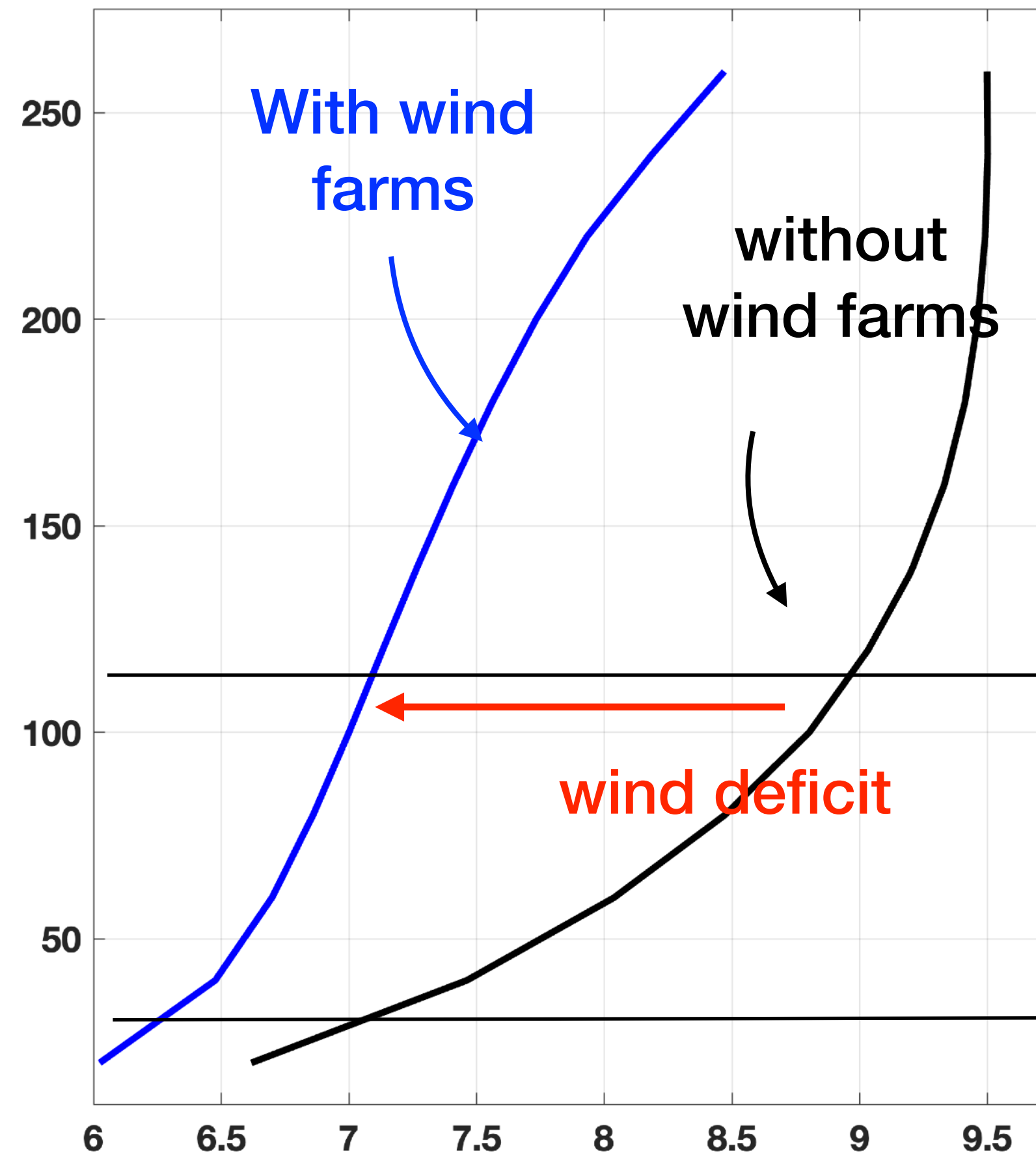
Big Picture Questions

1. Why offshore wind energy?
2. Why does air-sea interaction matters for wind energy production?
3. What are the ocean impacts of wind energy production?

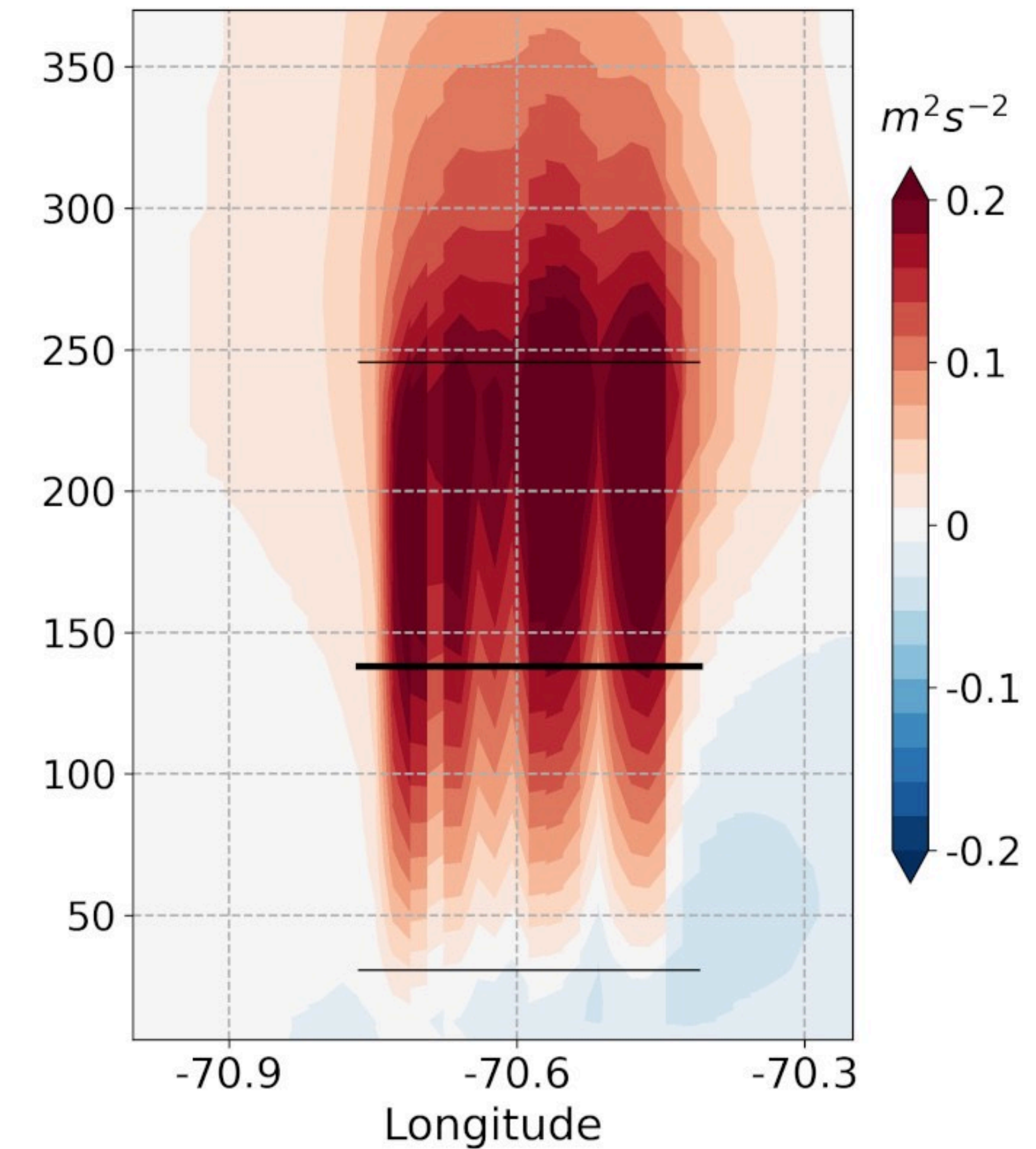
Wind farm wakes in mesoscale models



Wind Speed Changes



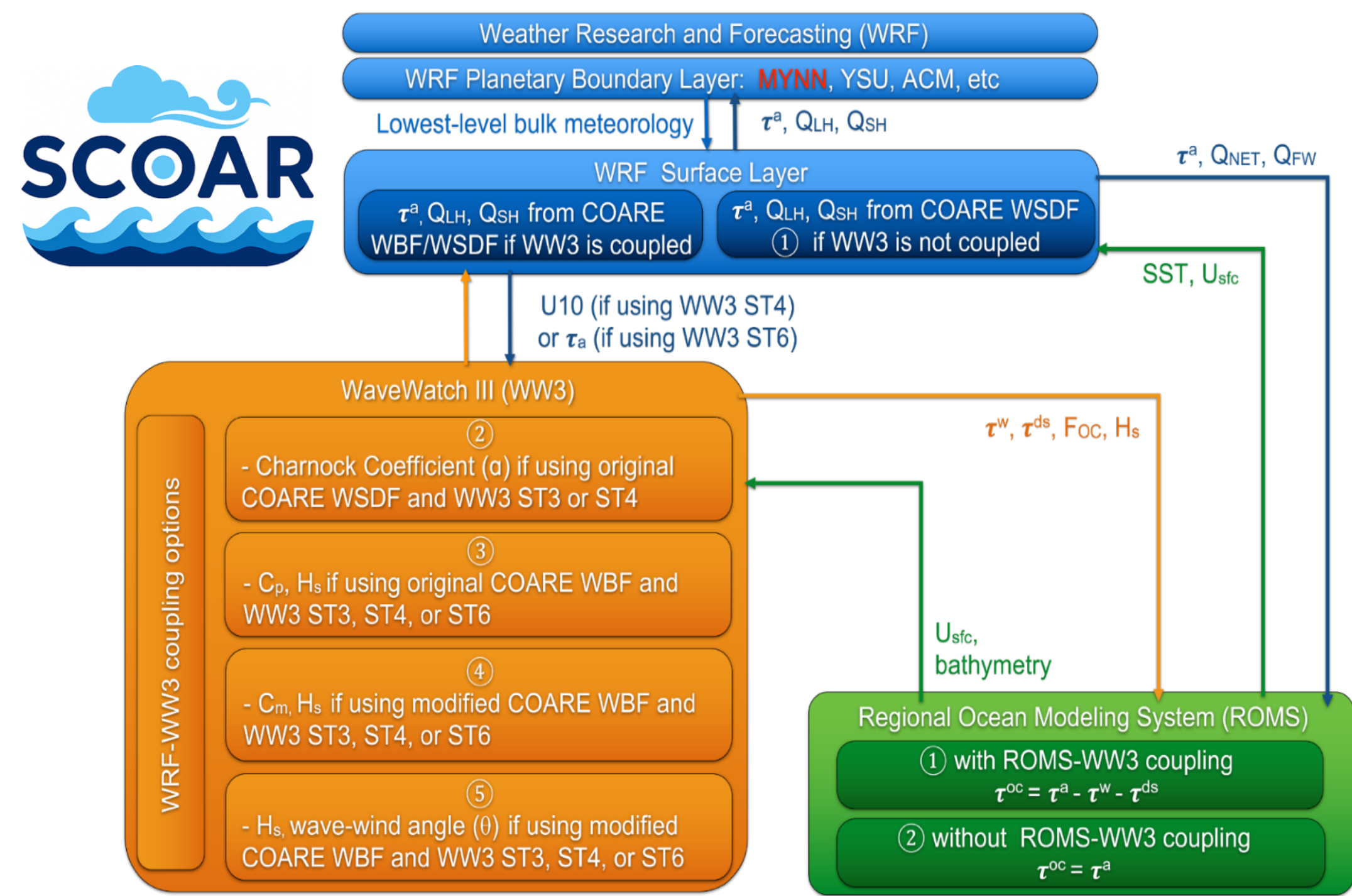
TKE Changes



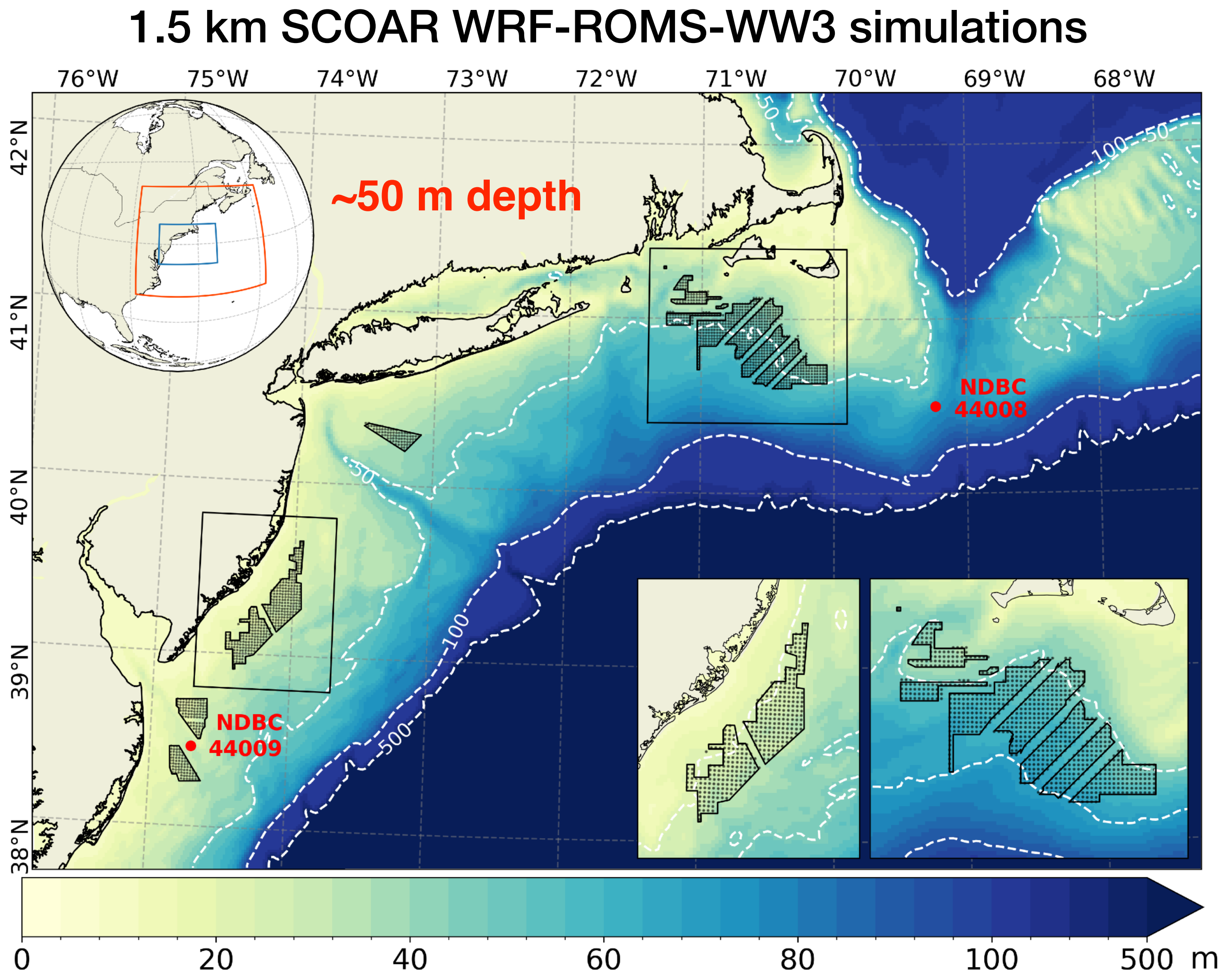
Fitch et al. (2012)

Wake-ocean interactions in a fully coupled mesoscale model

SCOAR Regional Coupled Model
Seo et al. (2007, 2016), Sauvage et al. (2024)



Experiment	Wind Farm (WF)	Ocean Coupling (OC)
OC_WF	Yes	Yes
OC_NWF	No	Yes
NOC_WF	Yes	No



1418 X 12MW wind turbines in all MAB lease areas, with total installed capacity = 17016 MW

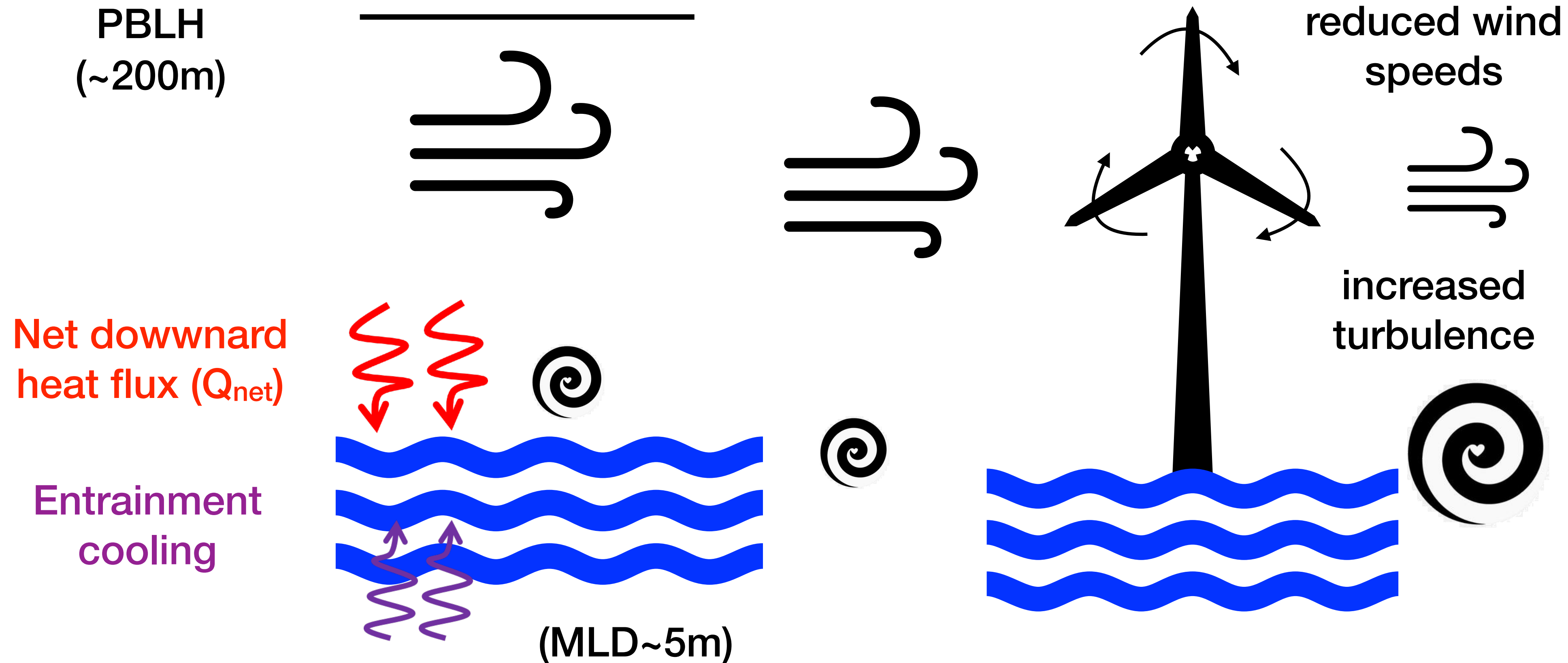


Vineyard Wind 1: 62x 13 MW turbines with a total capacity of 806 MW. → Largest completed offshore wind project in the US

Wake-ocean interactions

OC_NWF (unperturbed)

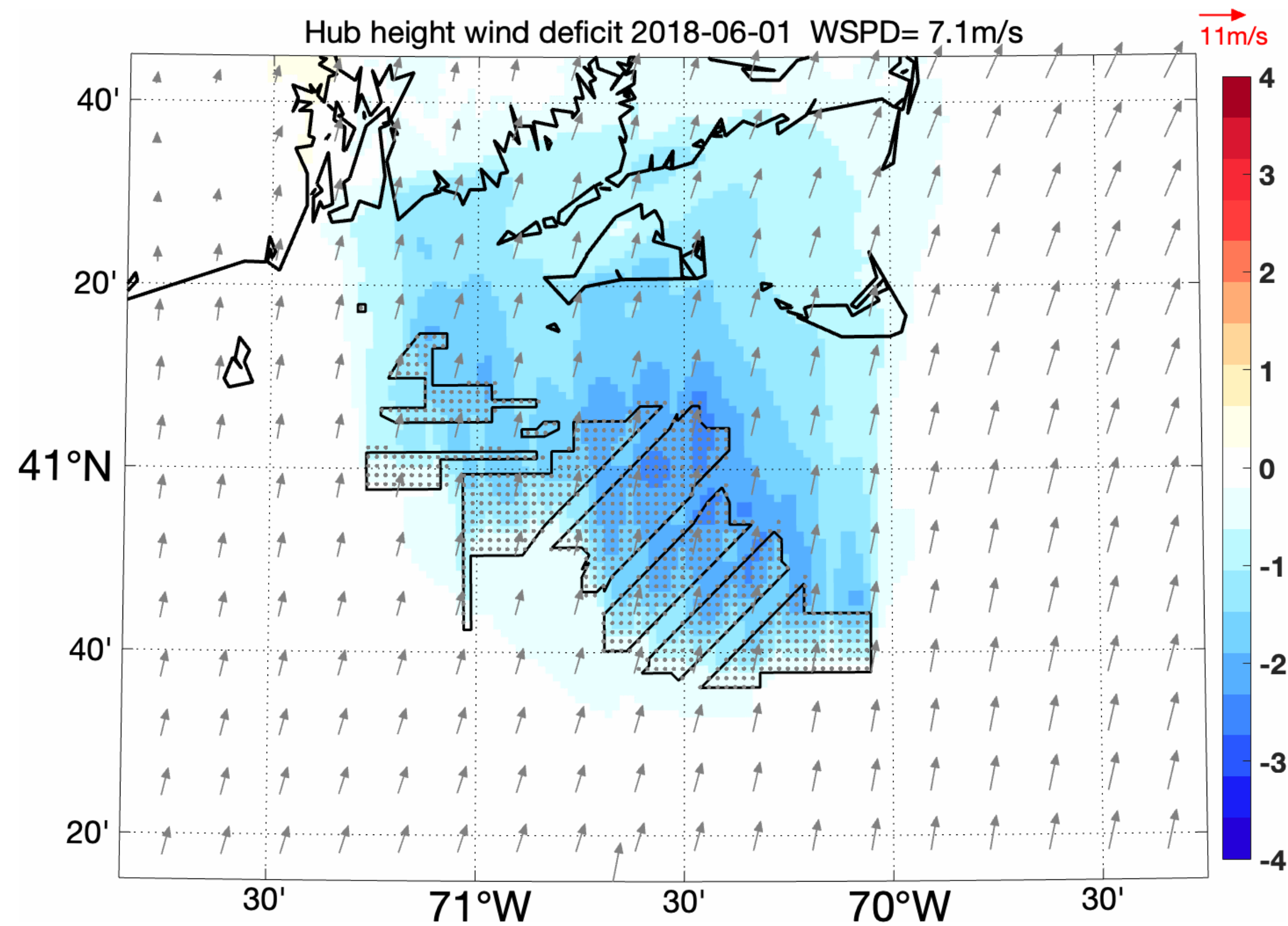
OC_WF (with wind farms)



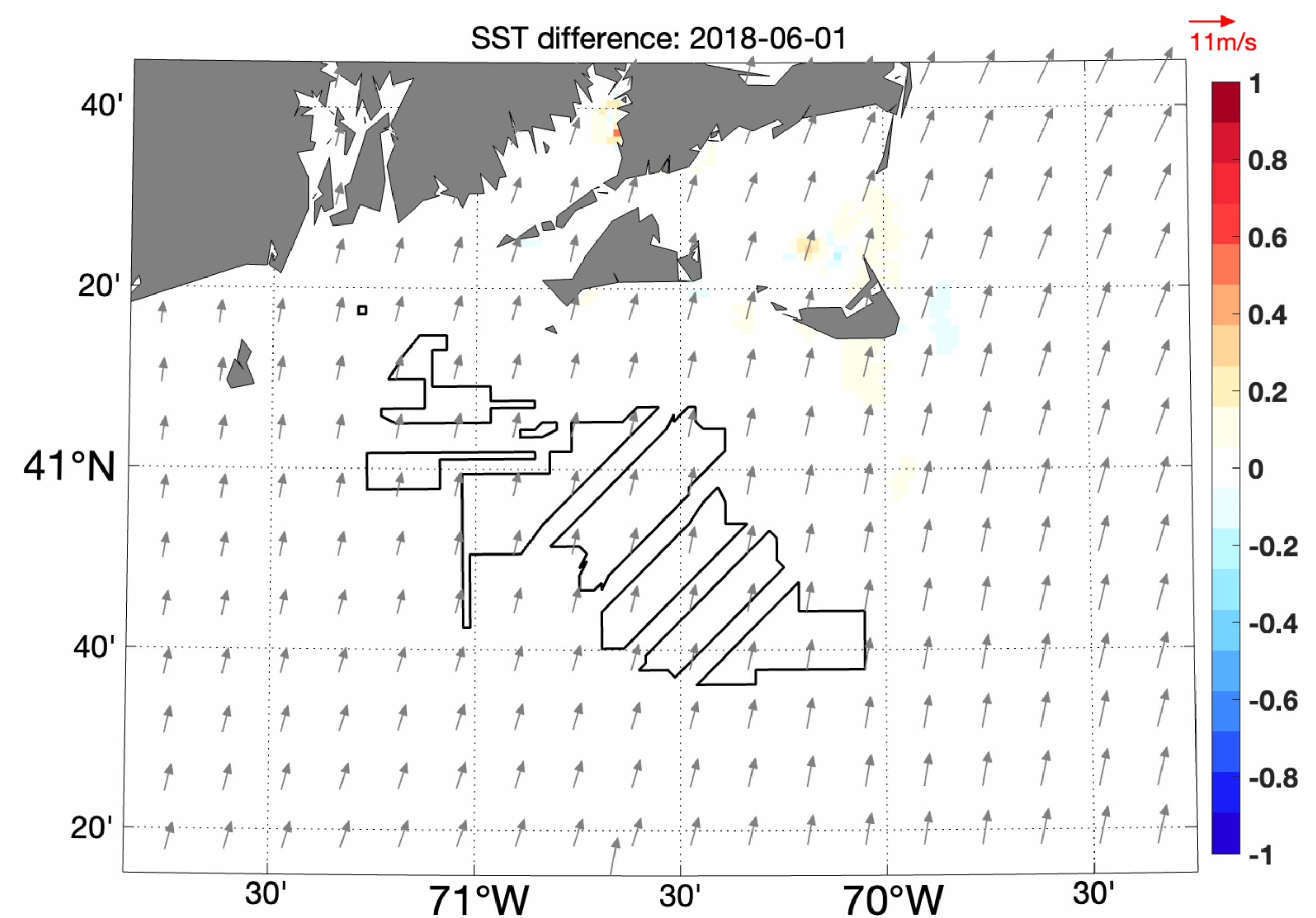
Diagnose the
impacts on air-
sea interactions
induced by wind
wake effects

Parameterized wake effects in the coupled model: OC_WF - OC_NWF

Wind deficit @ hub height (138 m)

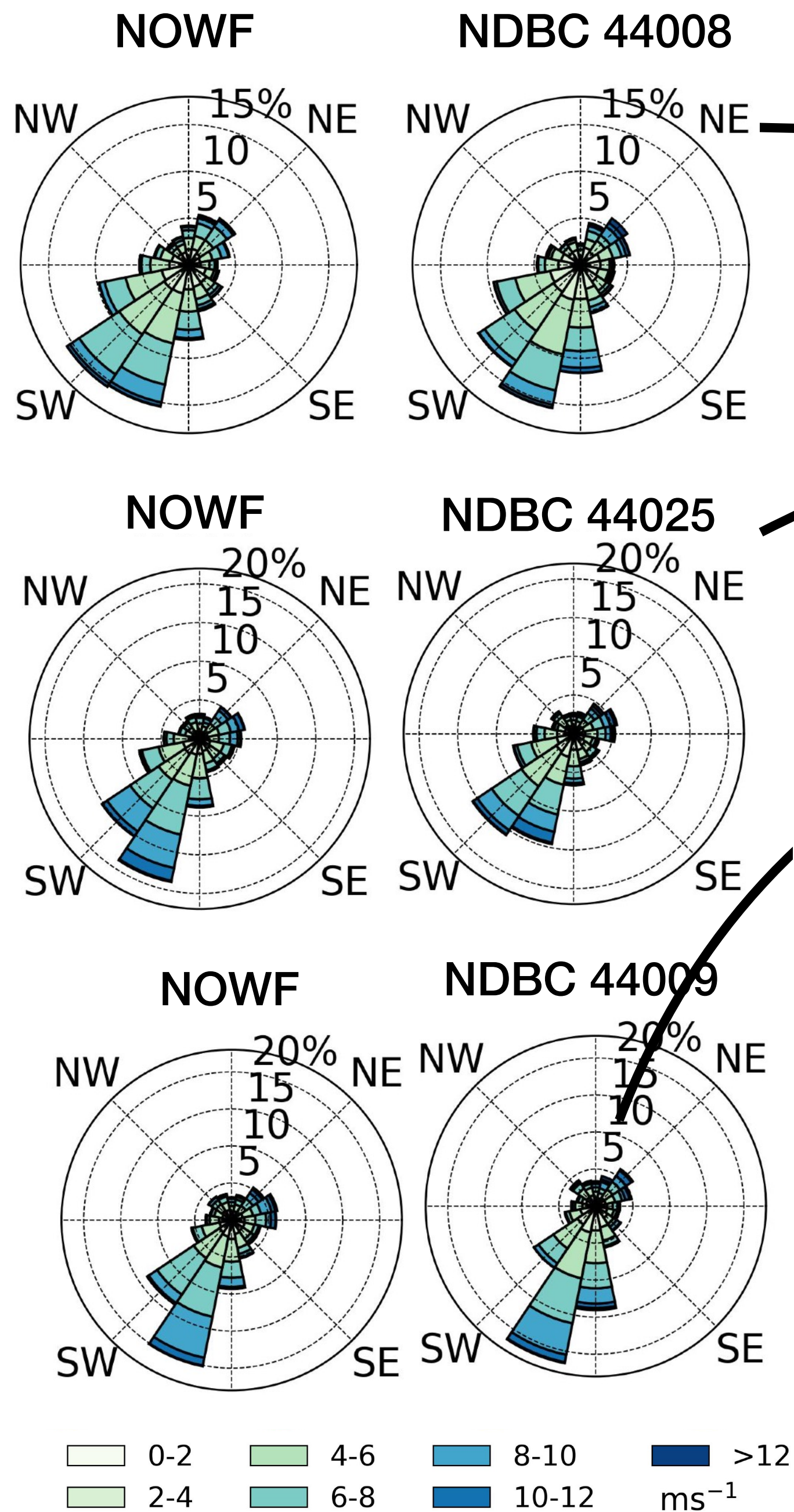


Sea surface temperature response

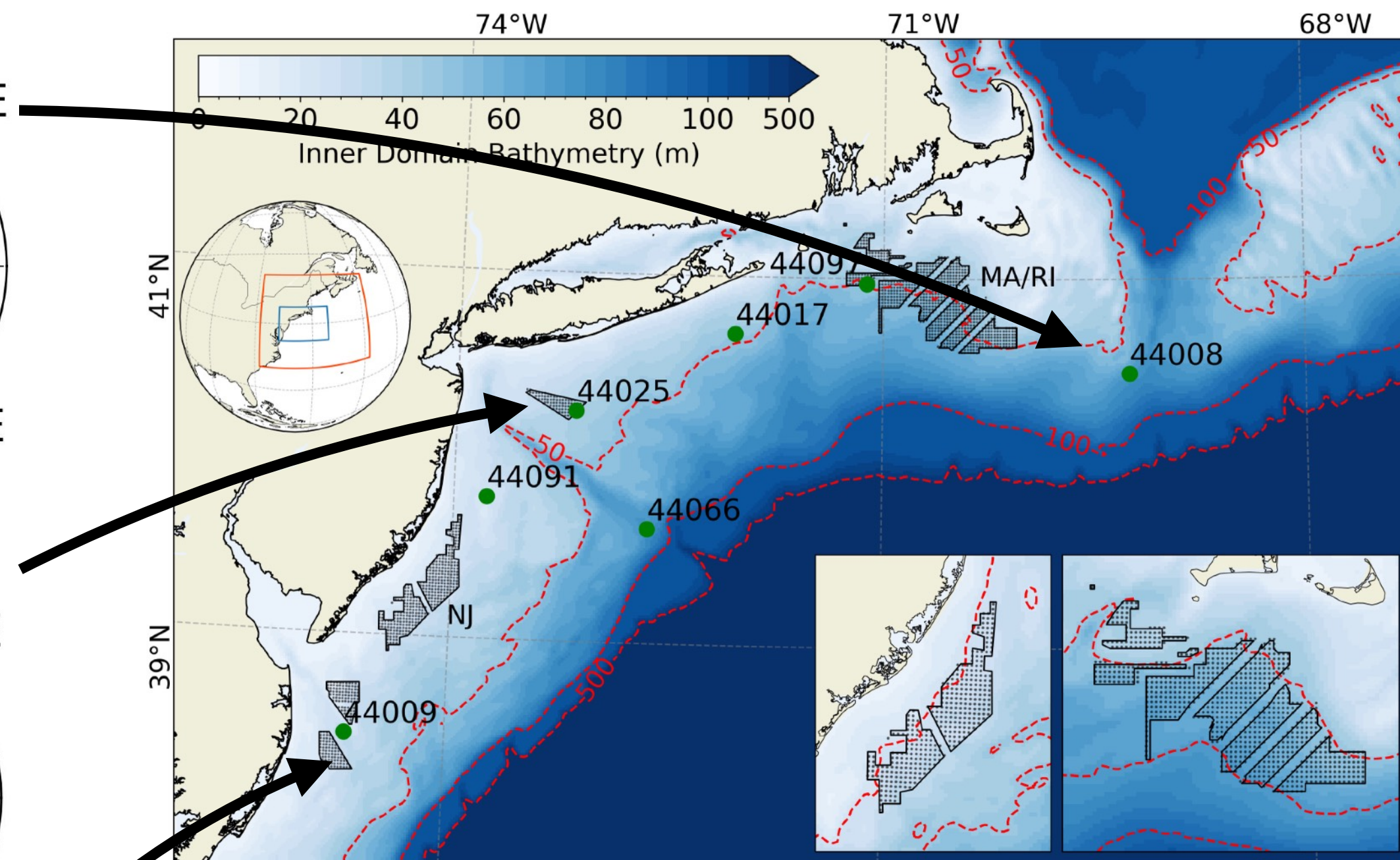


>11m/s: rated speed

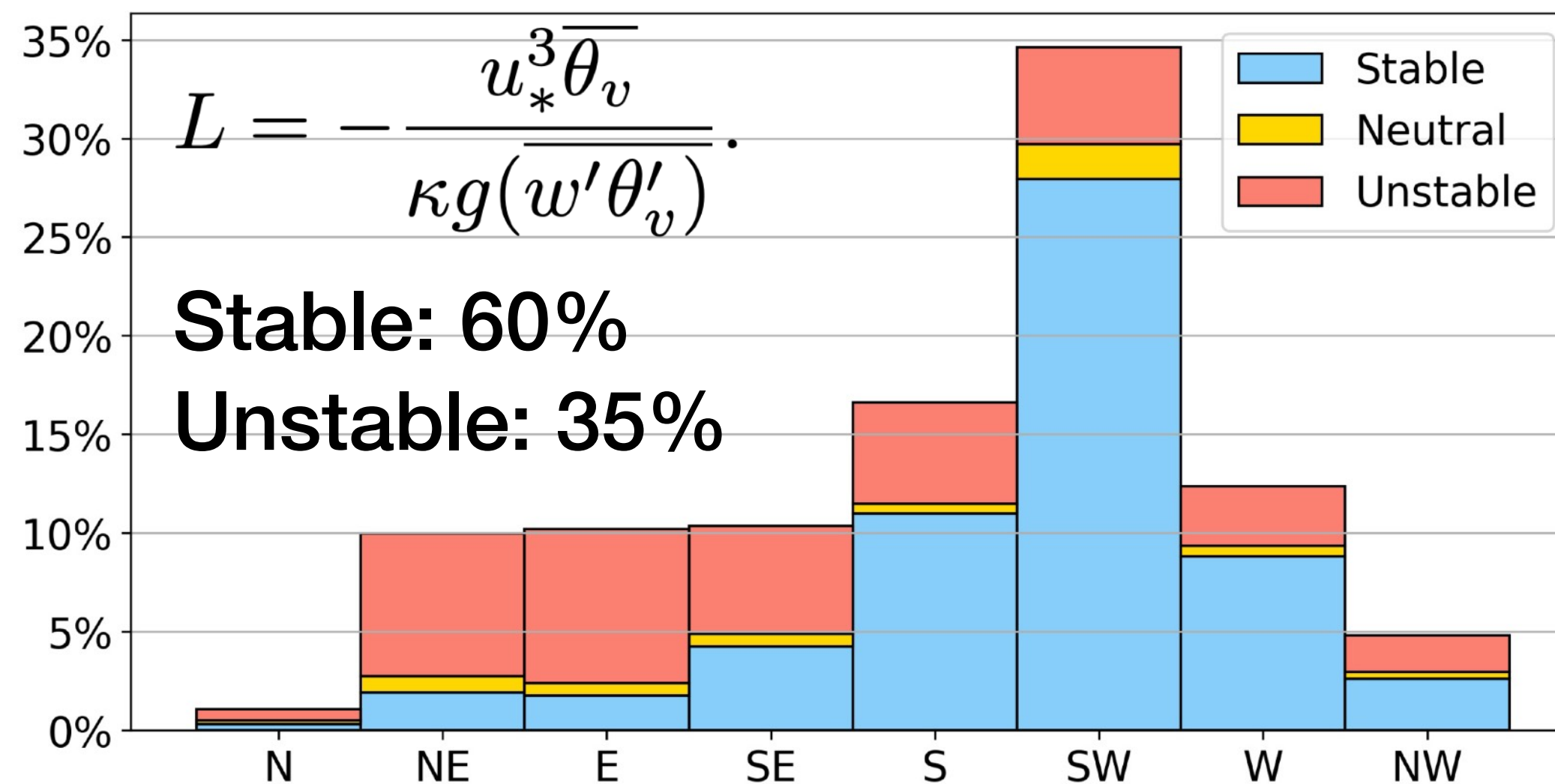
Wind



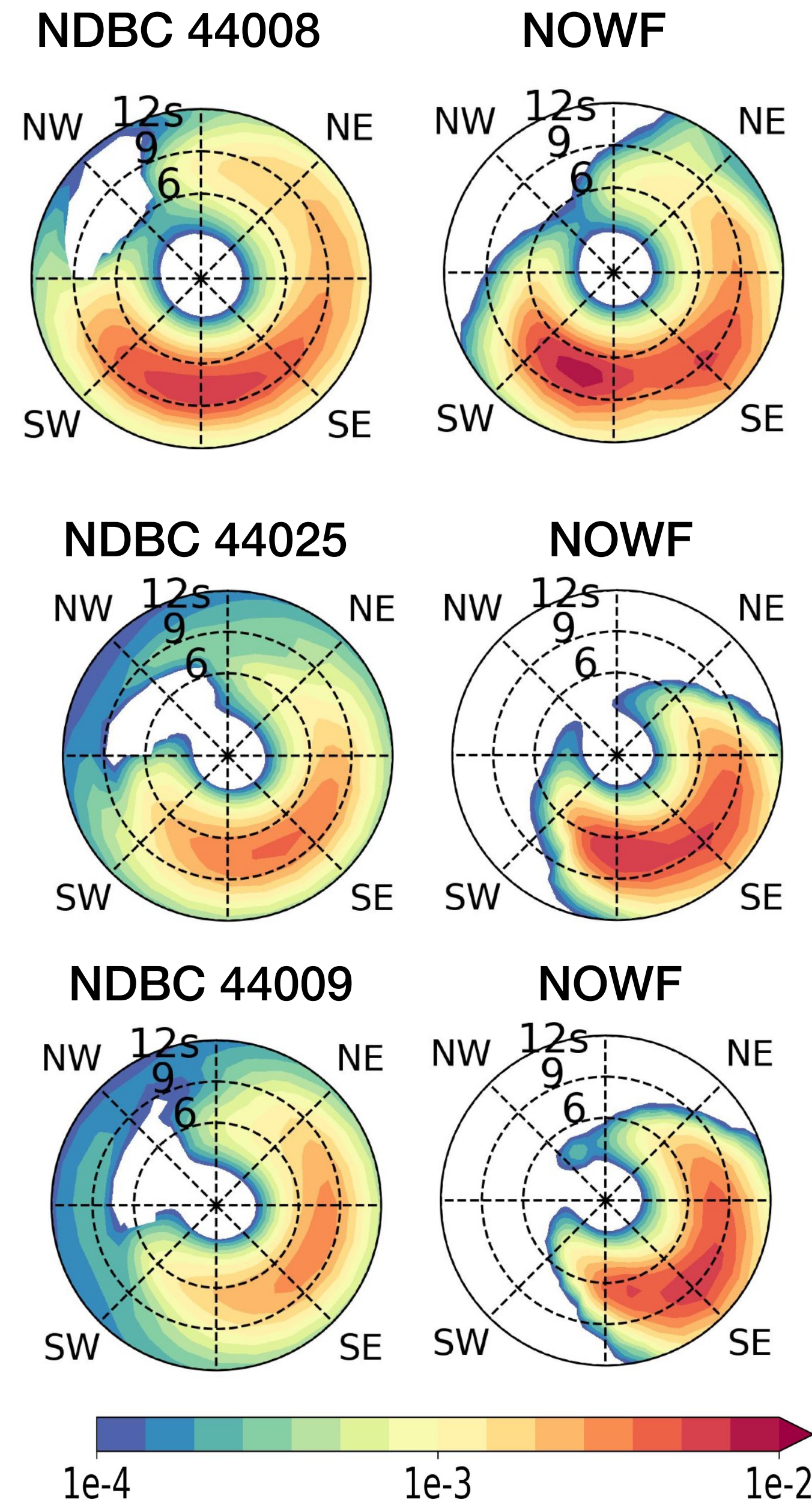
JJA Climatology



(a) Atmospheric stability conditions over MA/RI

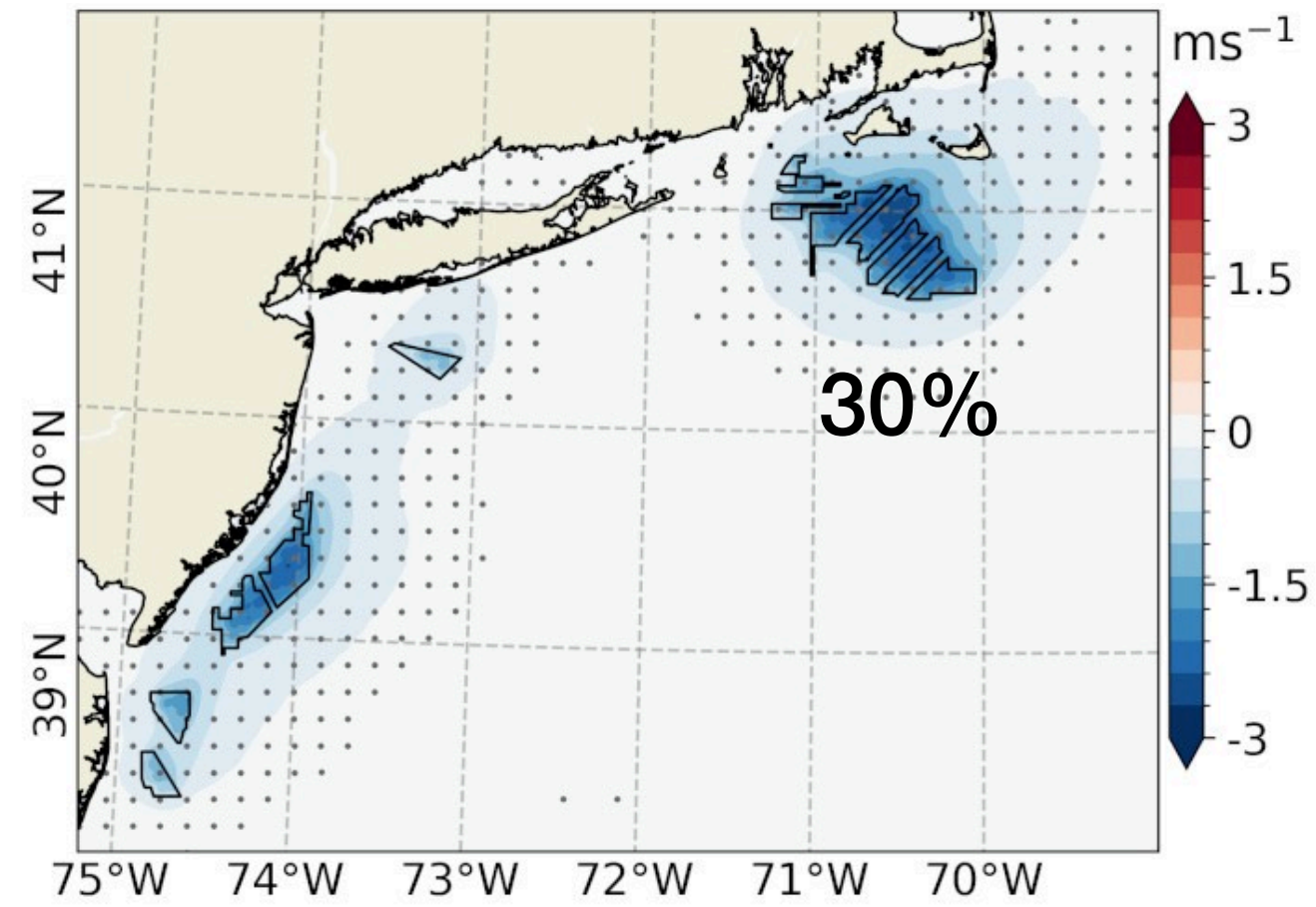


Wave

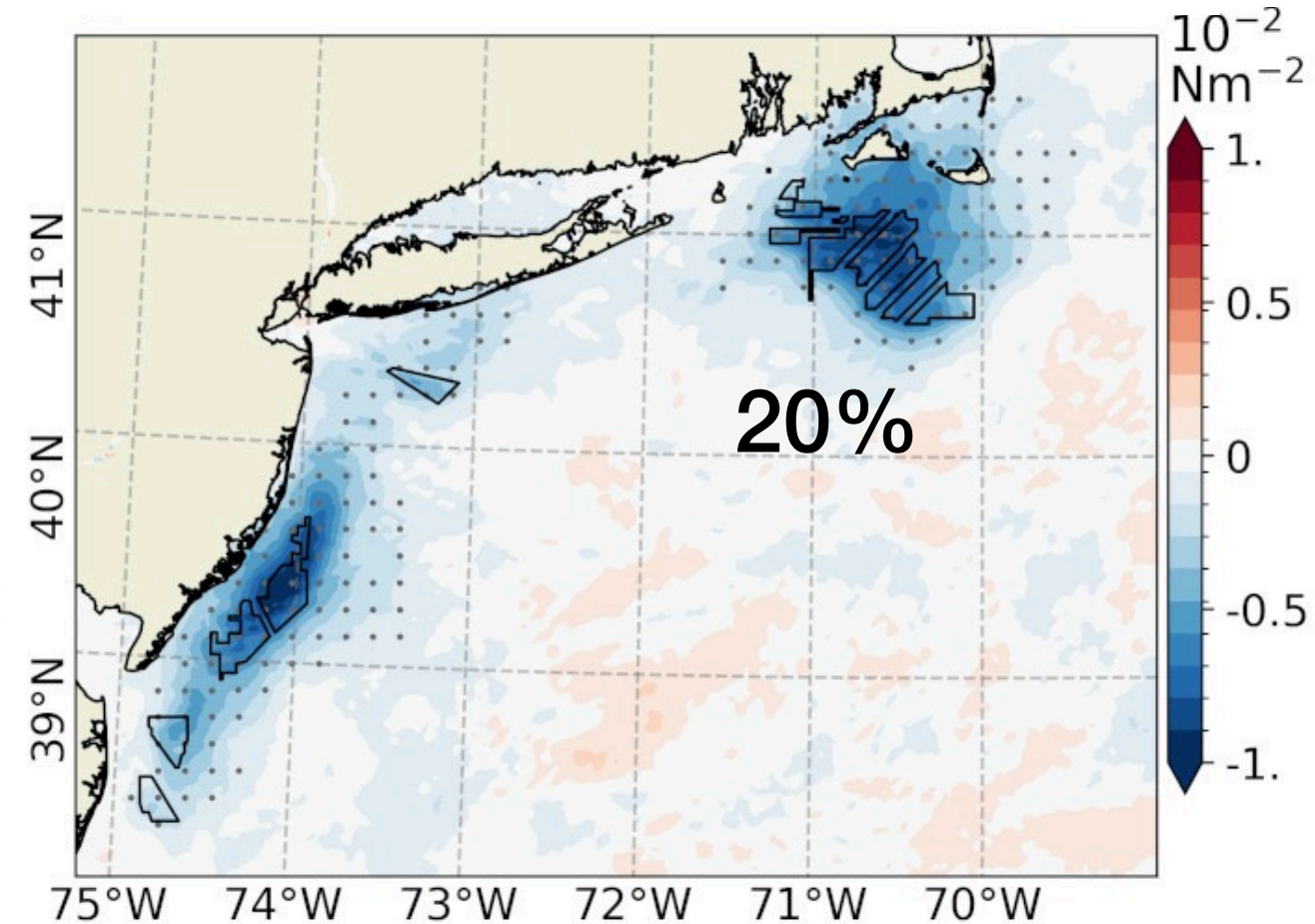


Climatological effects of wind wakes

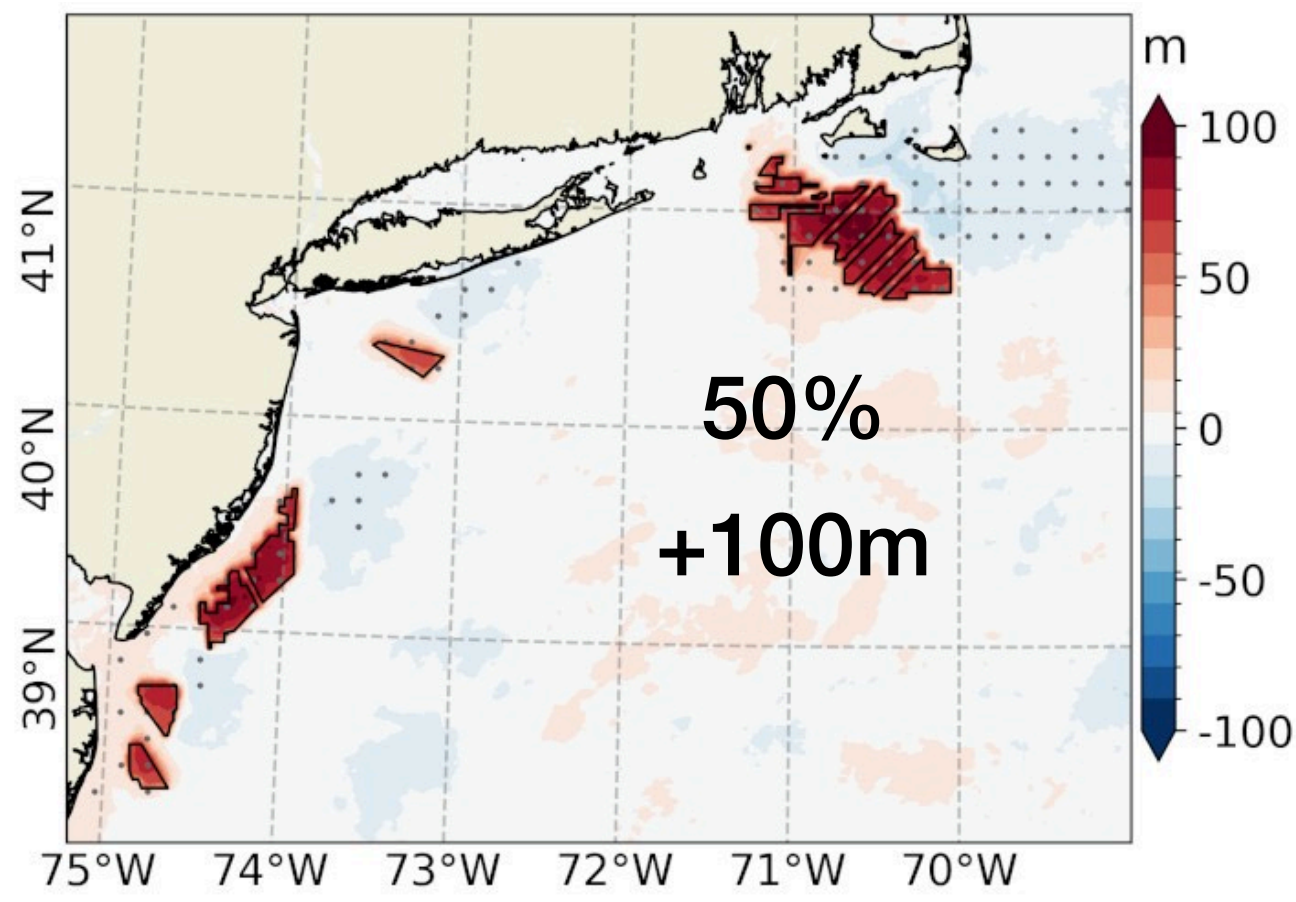
Hub height wind speeds



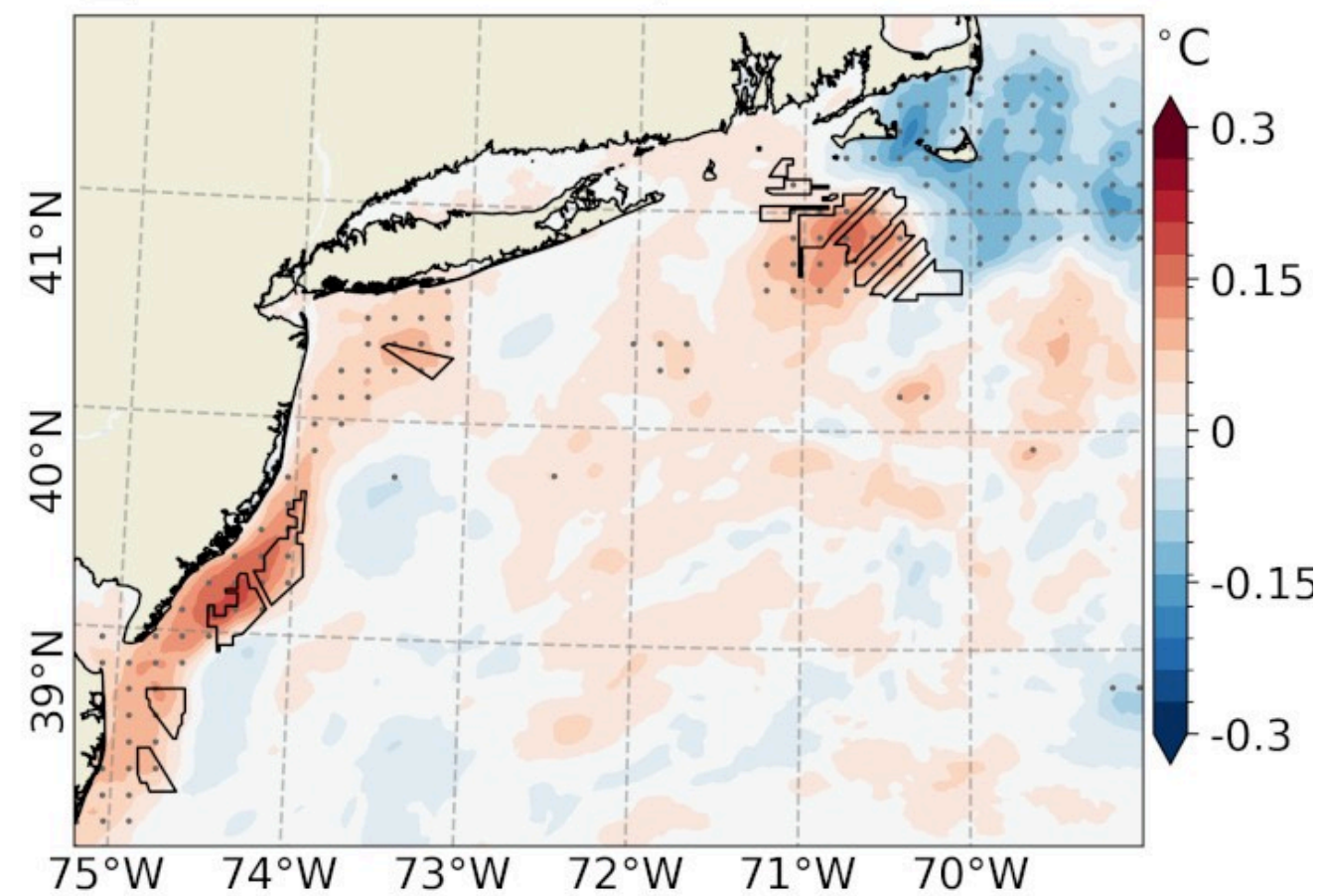
Wind stress



PBLH

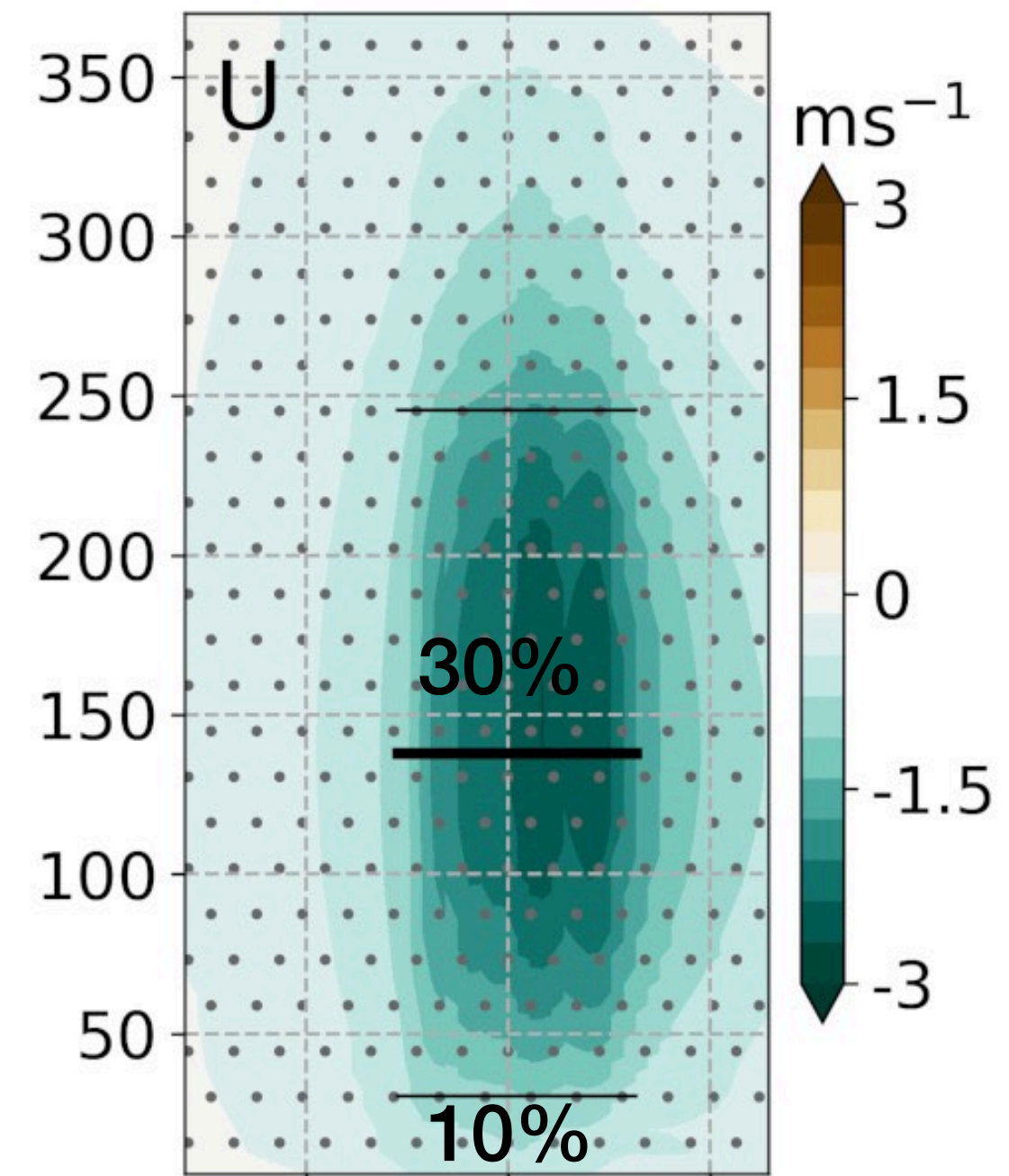


T2



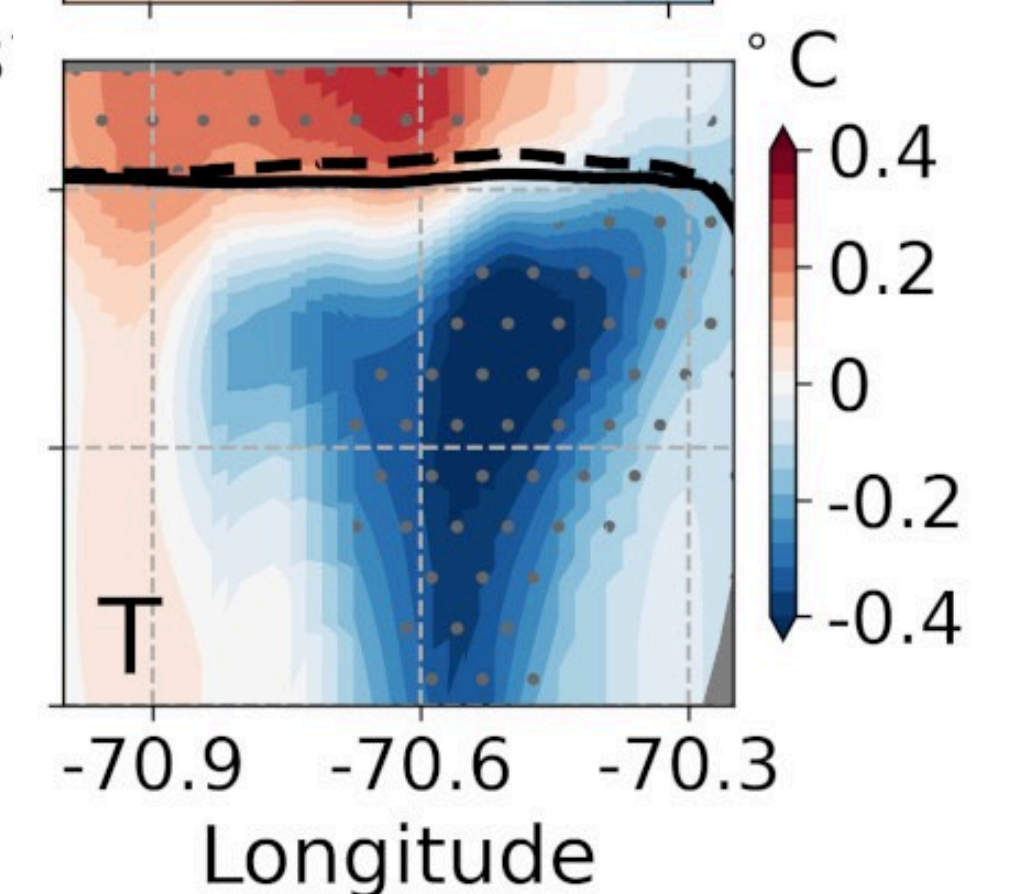
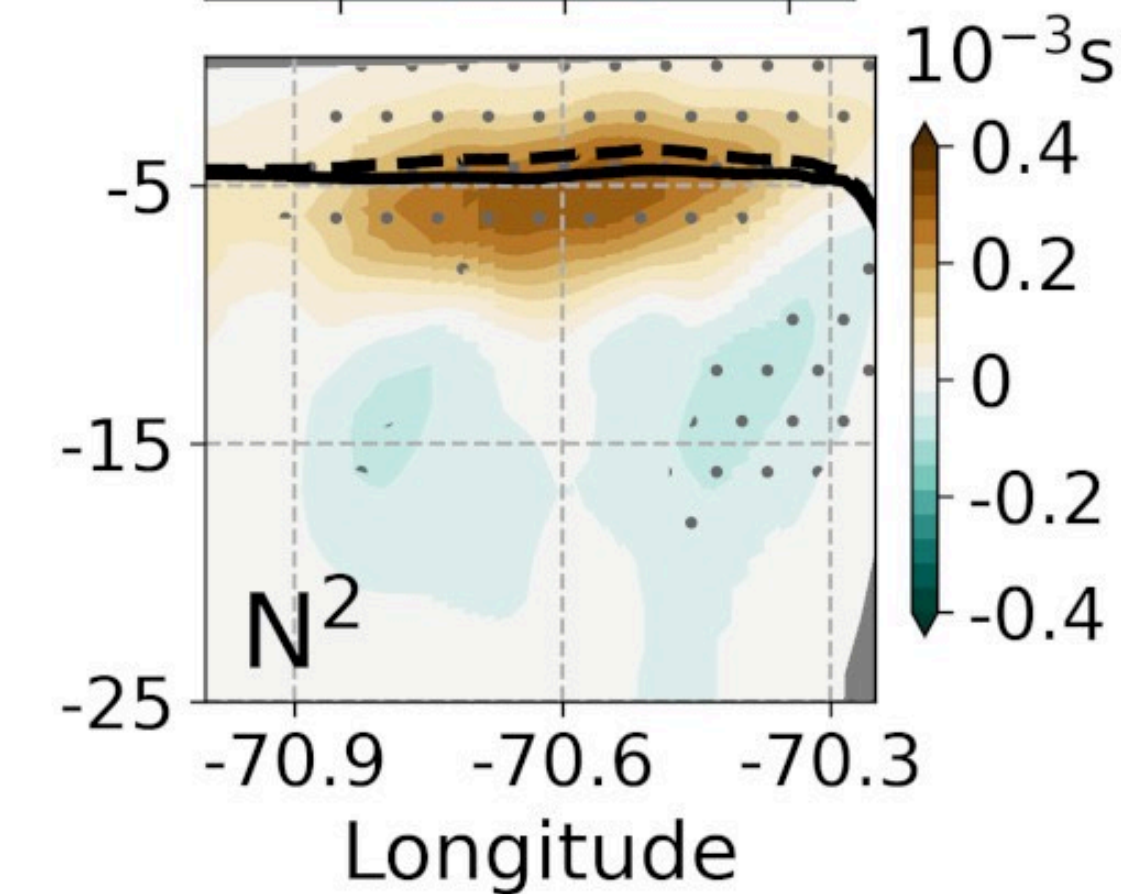
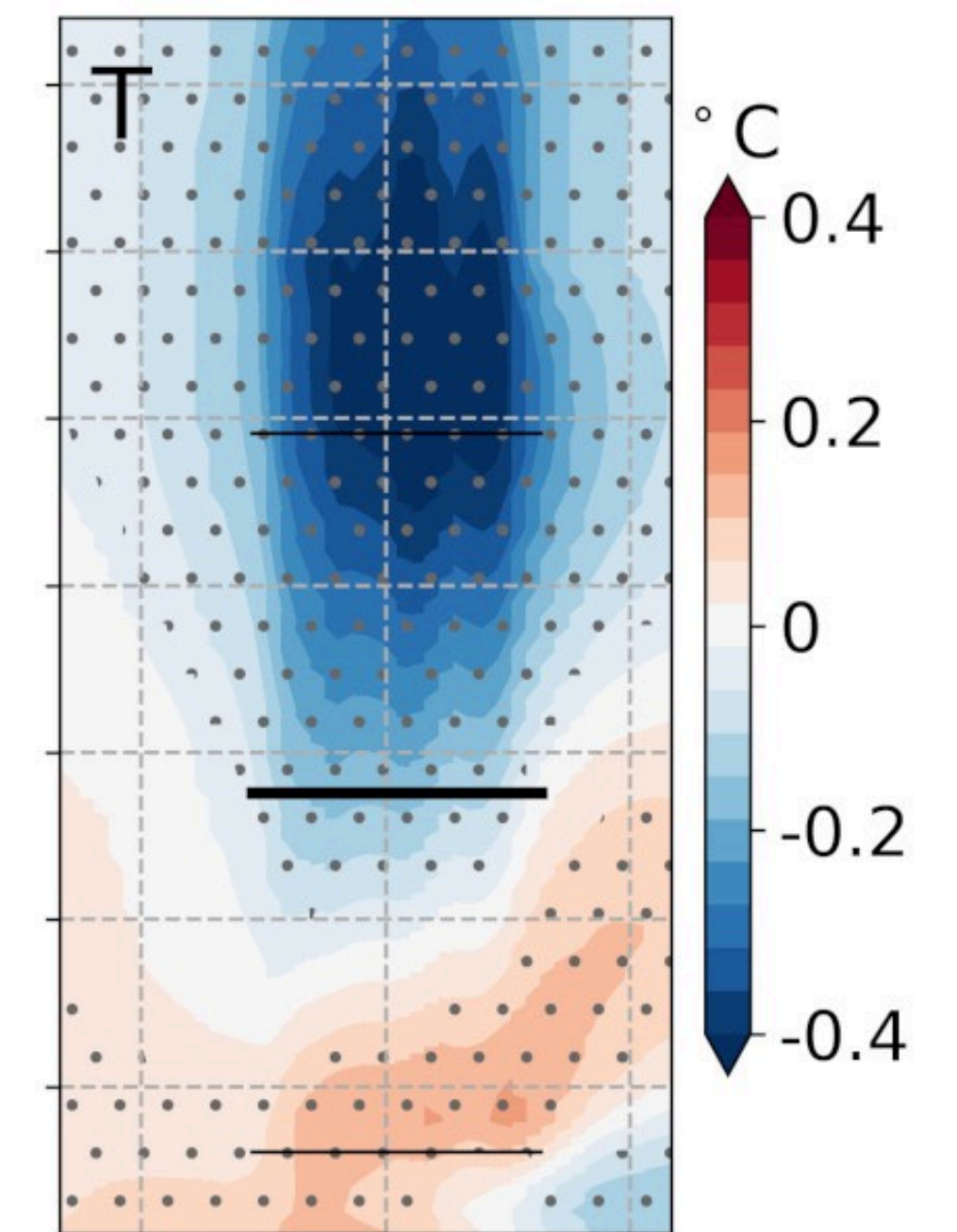
Wind speed

OC_WF-OC_NWF



Temperature

OC_WF-OC_NWF

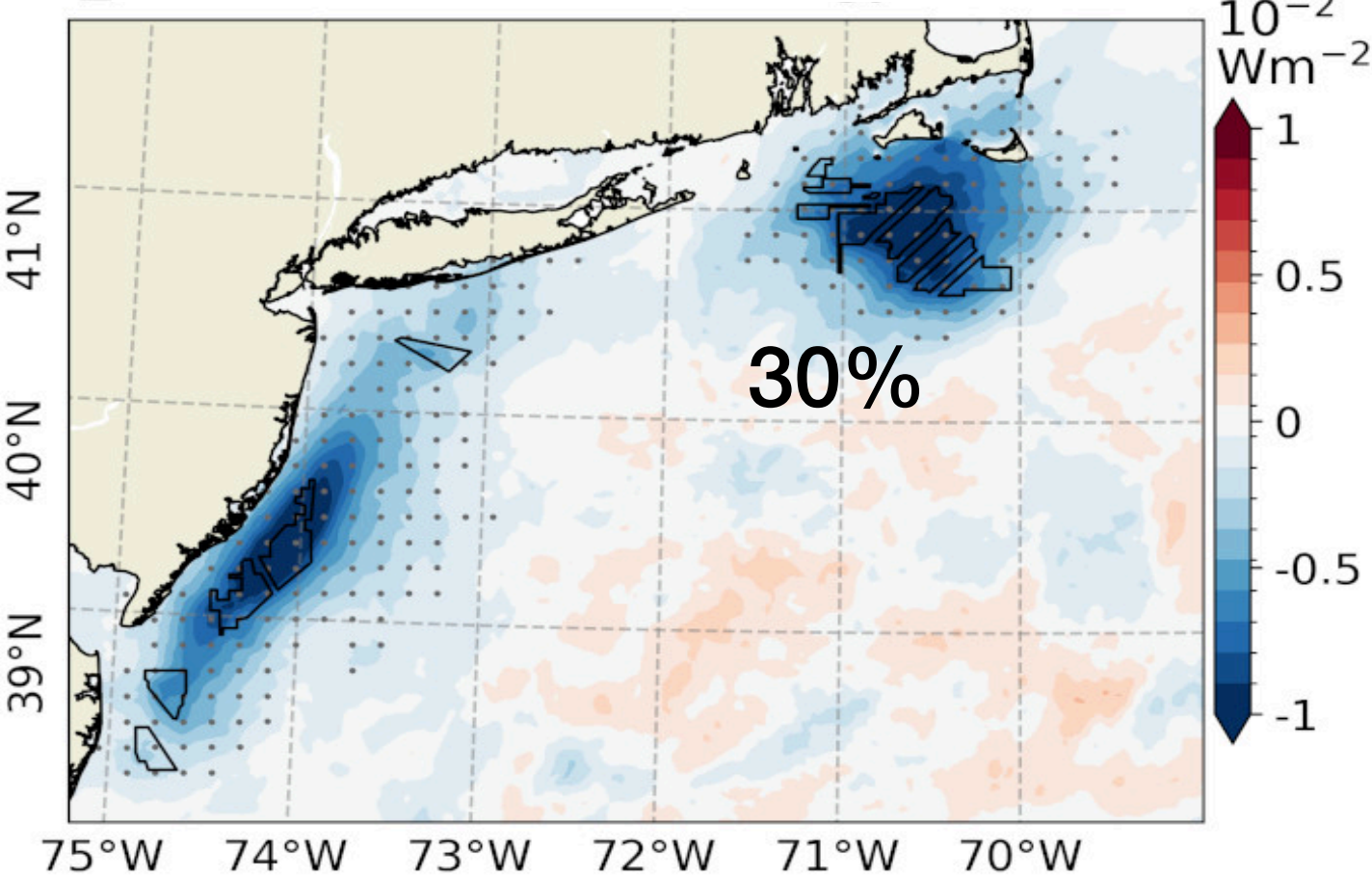


dots: 99% confidence level

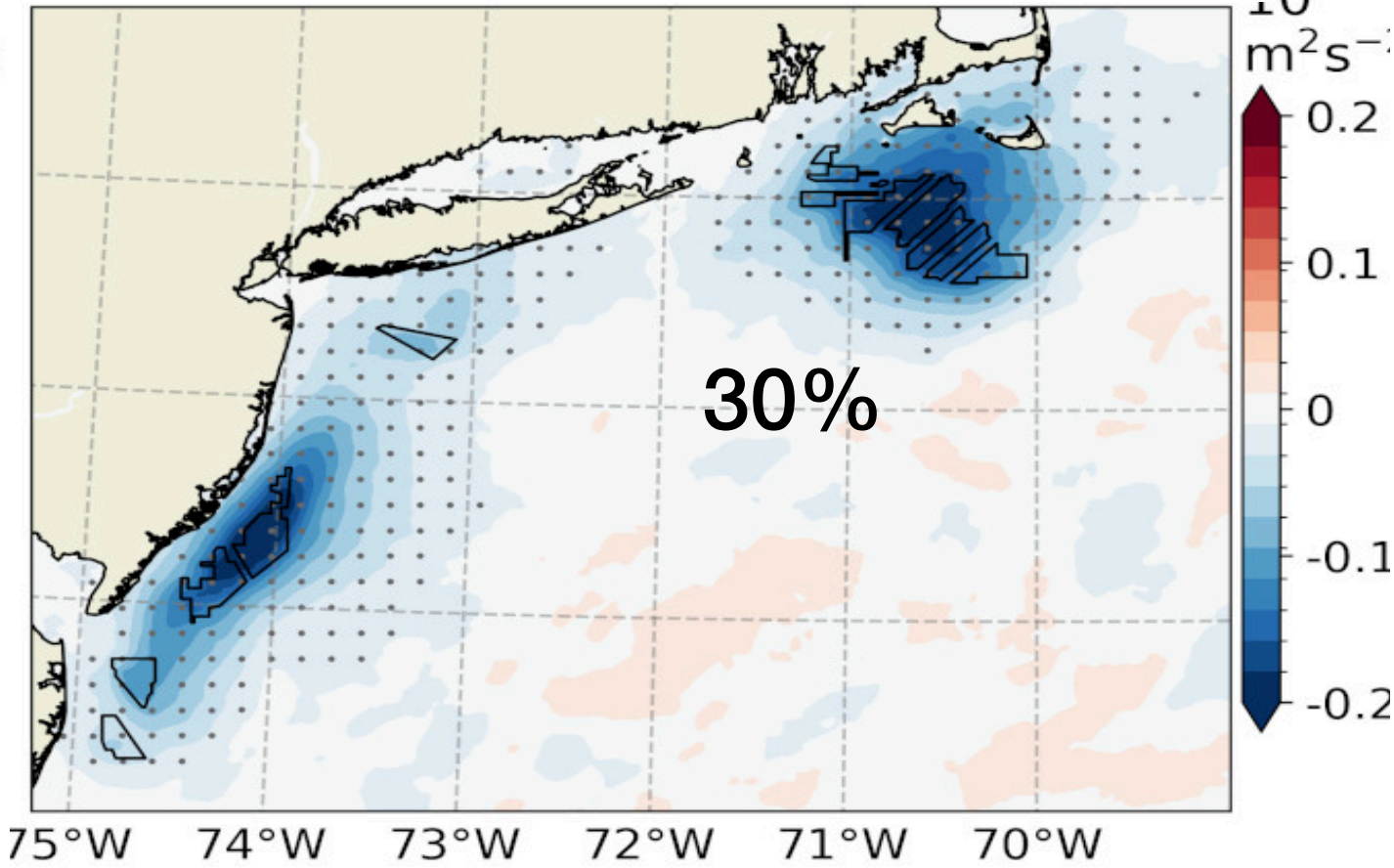
Climatological effects of wind wakes on the ocean

Wave to ocean energy flux

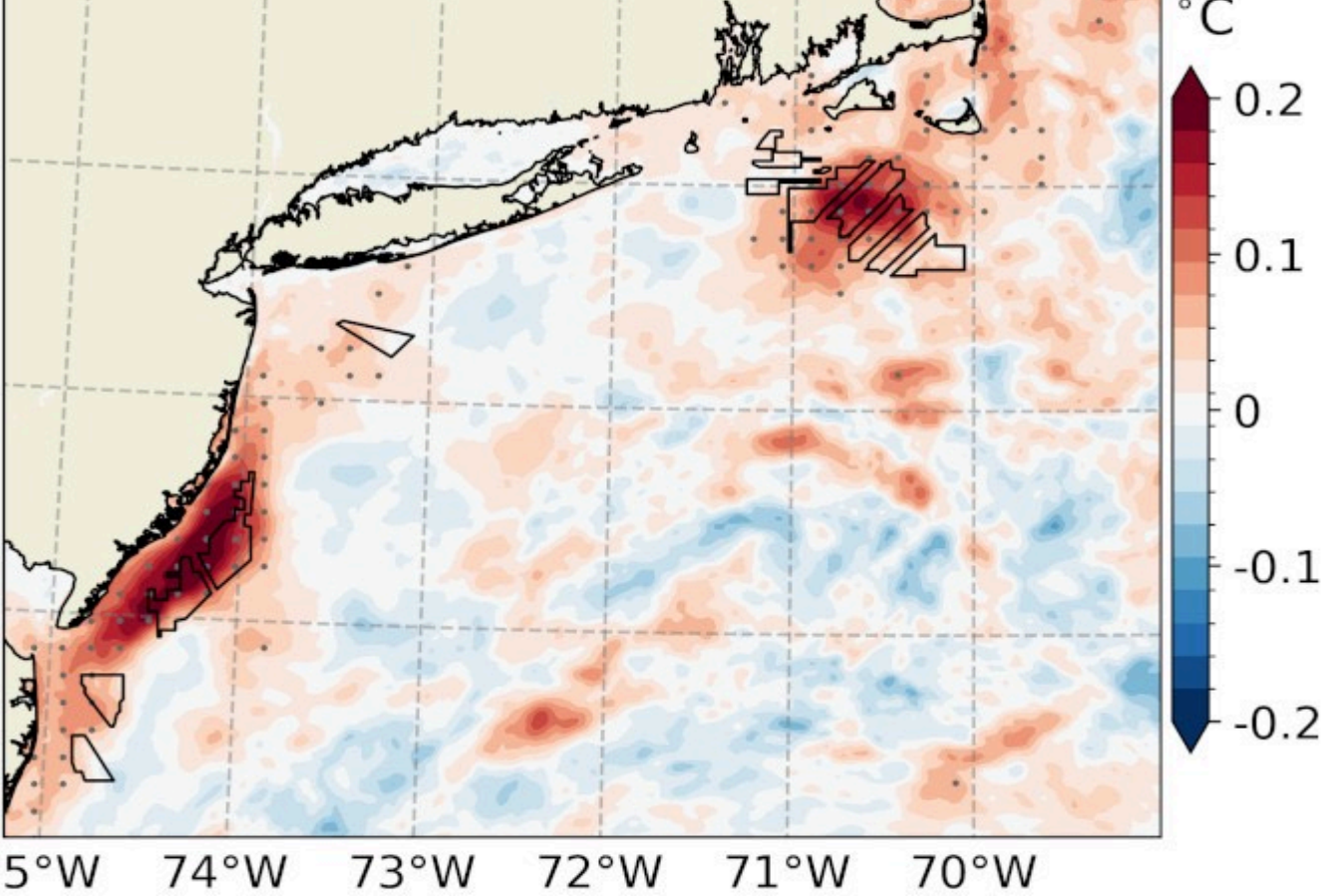
E



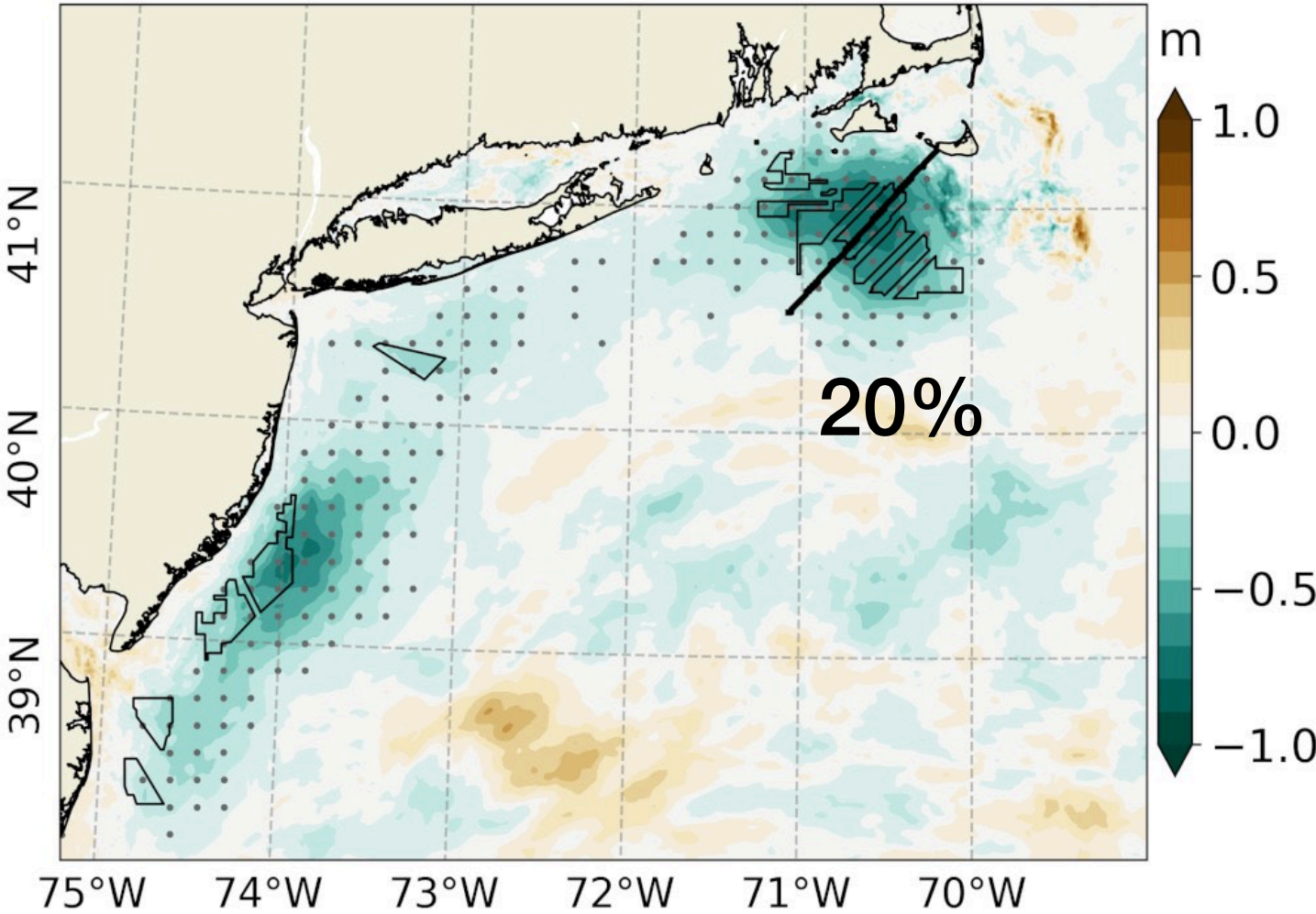
Near-surface TKE



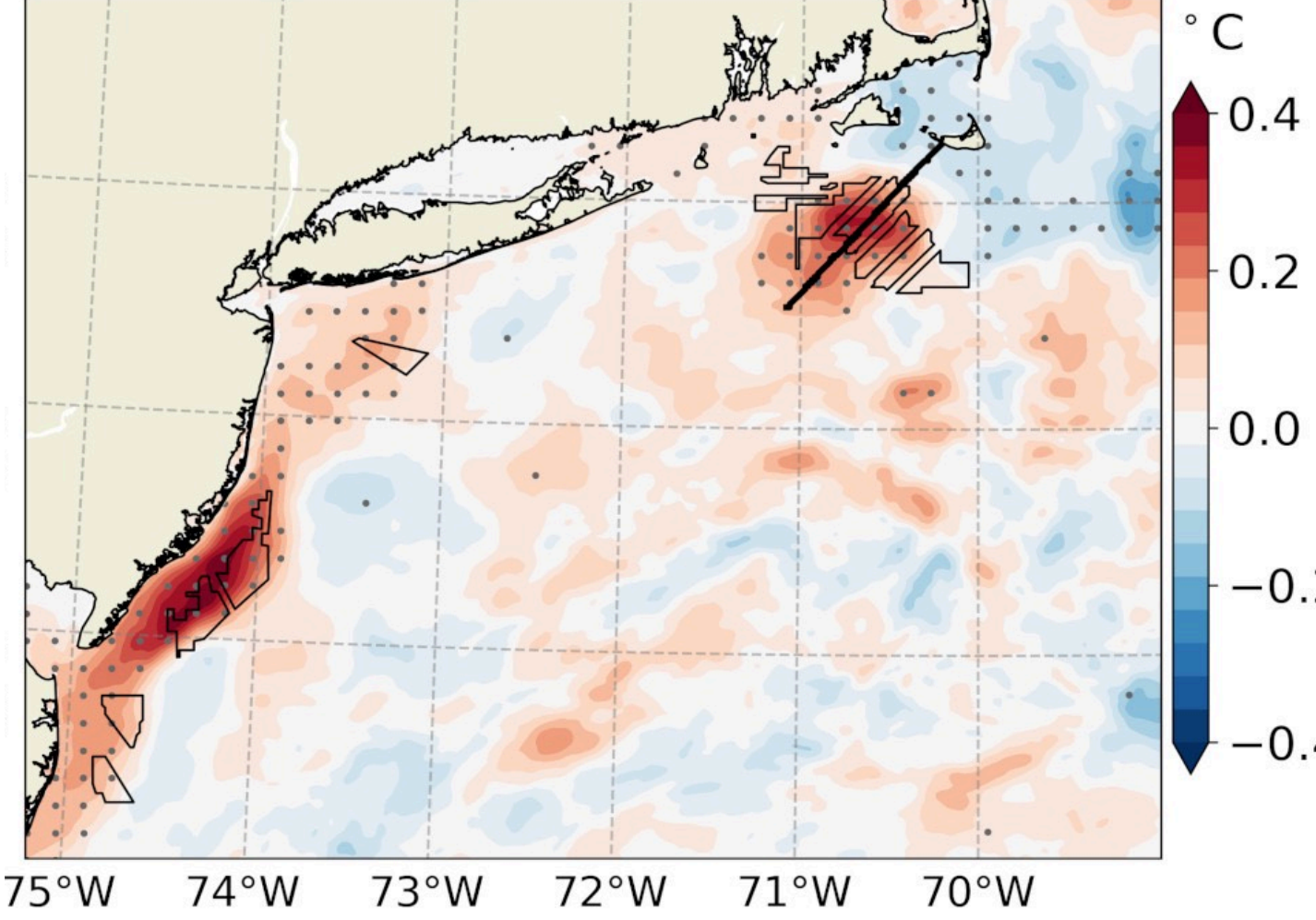
SST-T2



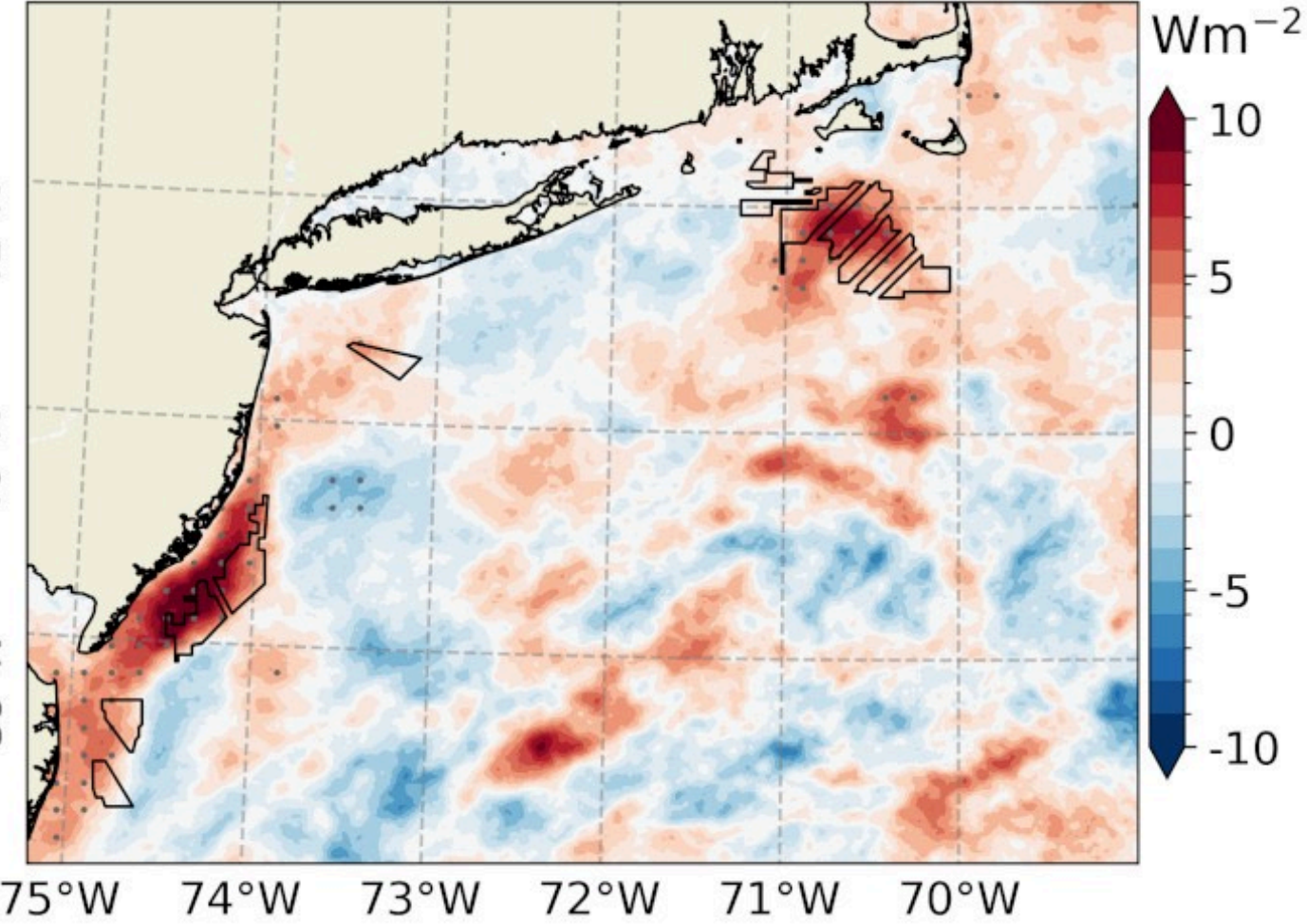
MLD



SST



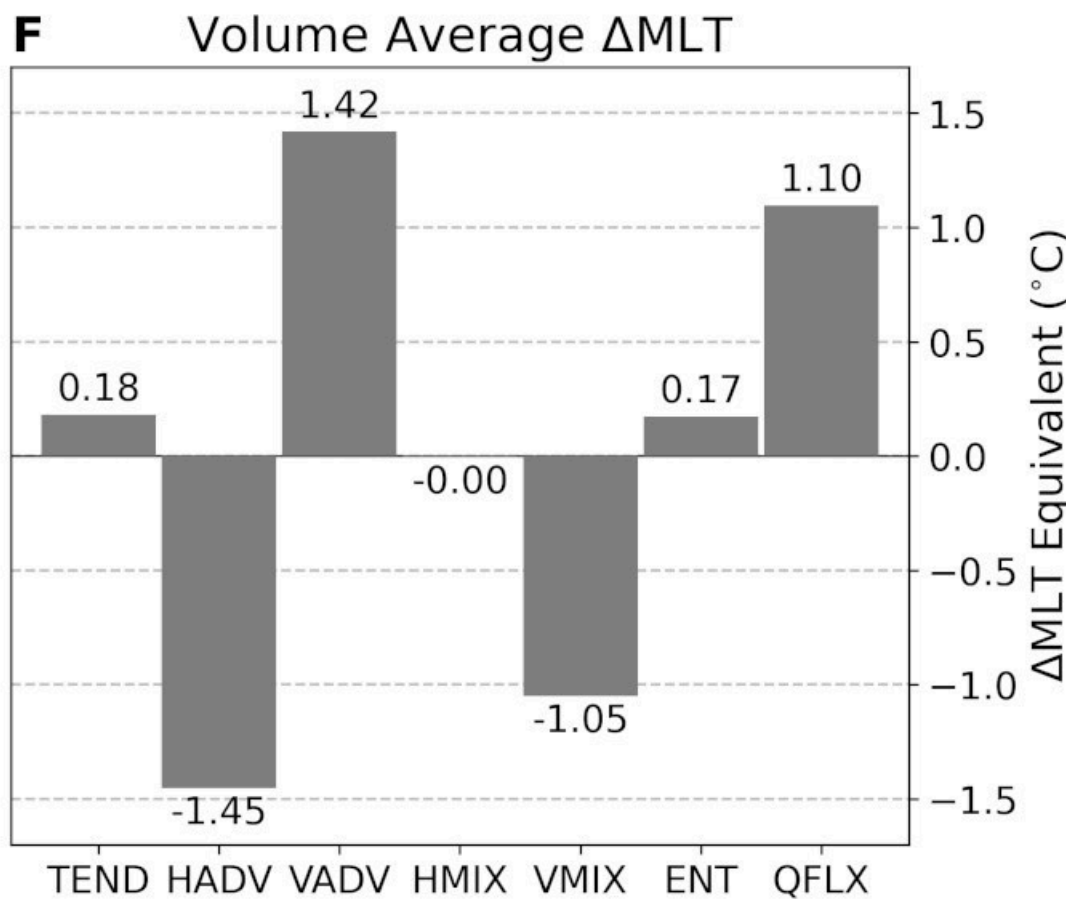
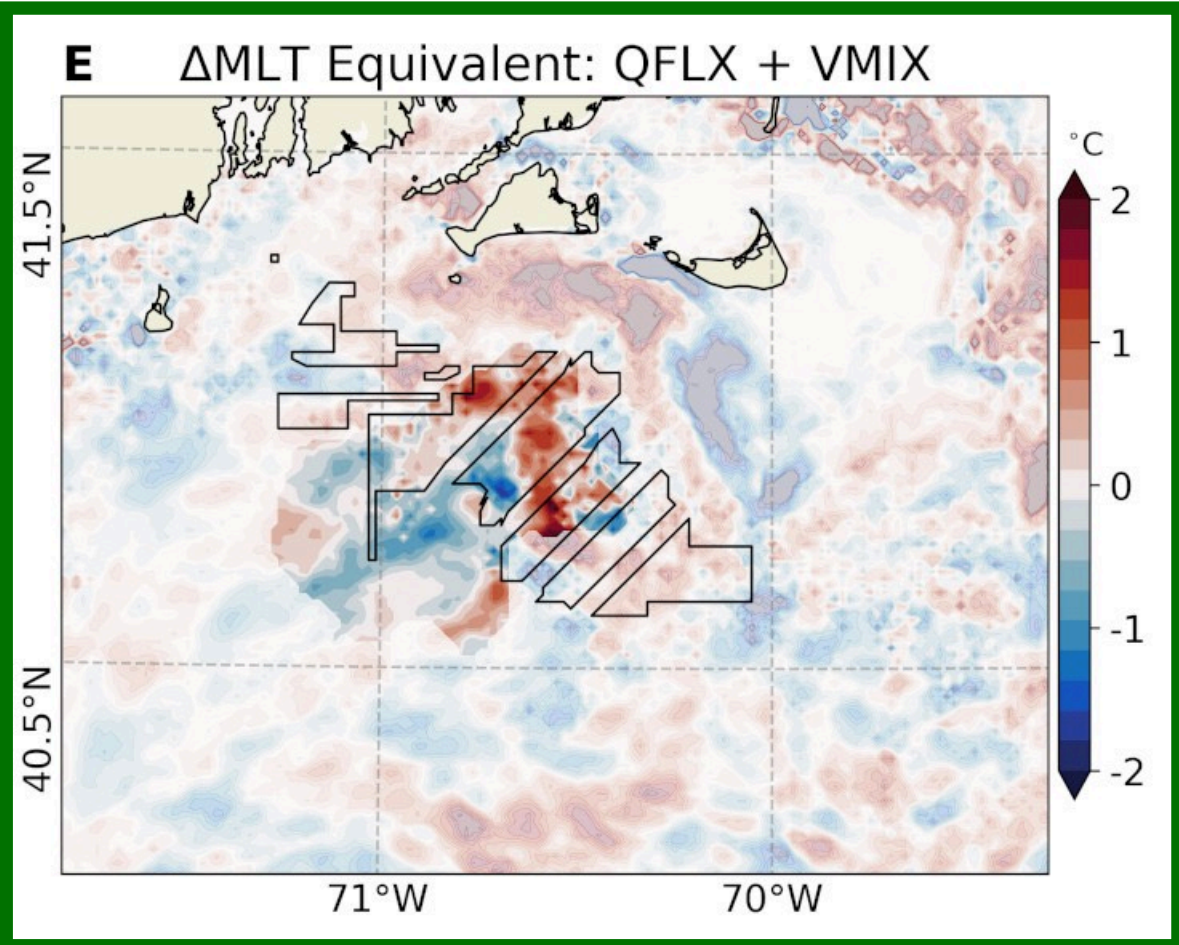
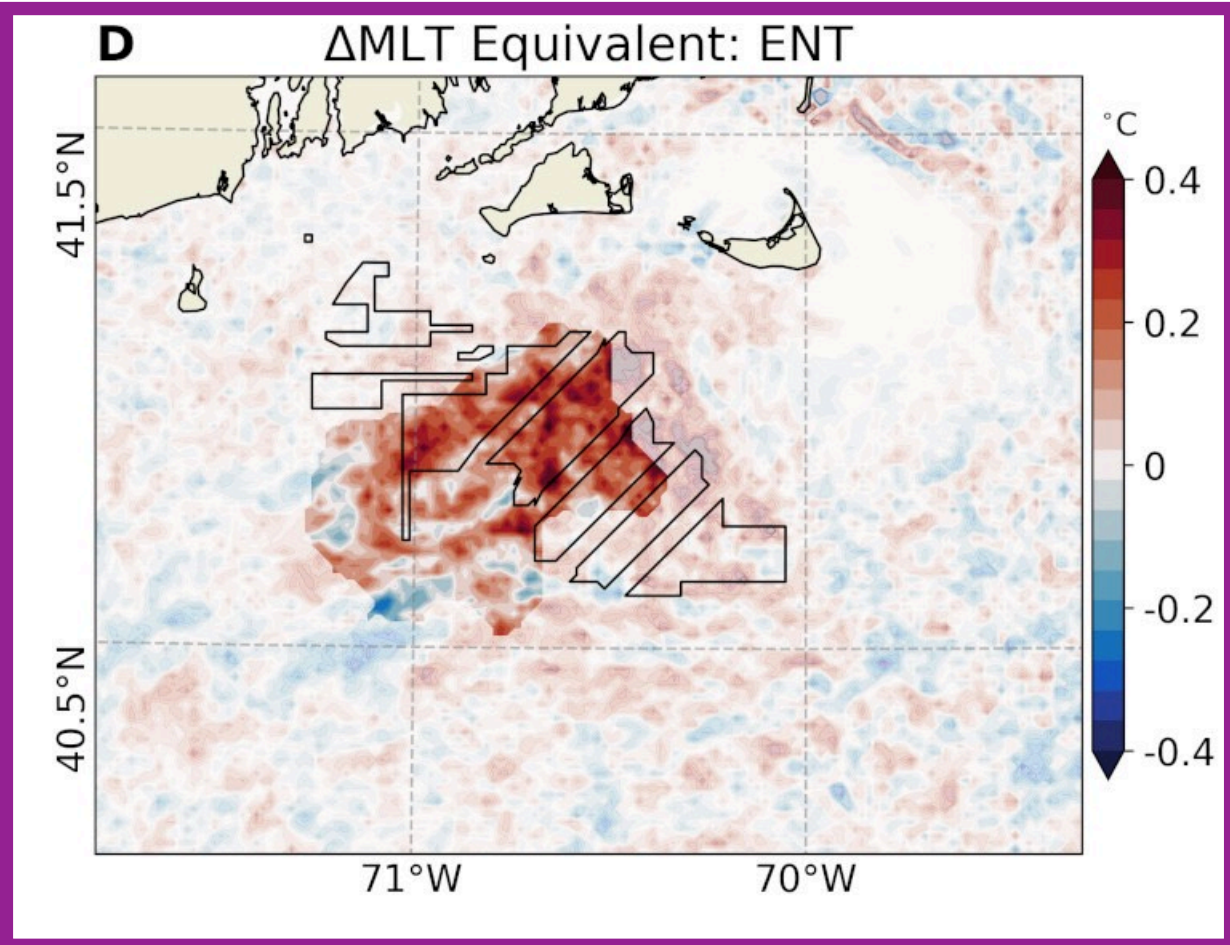
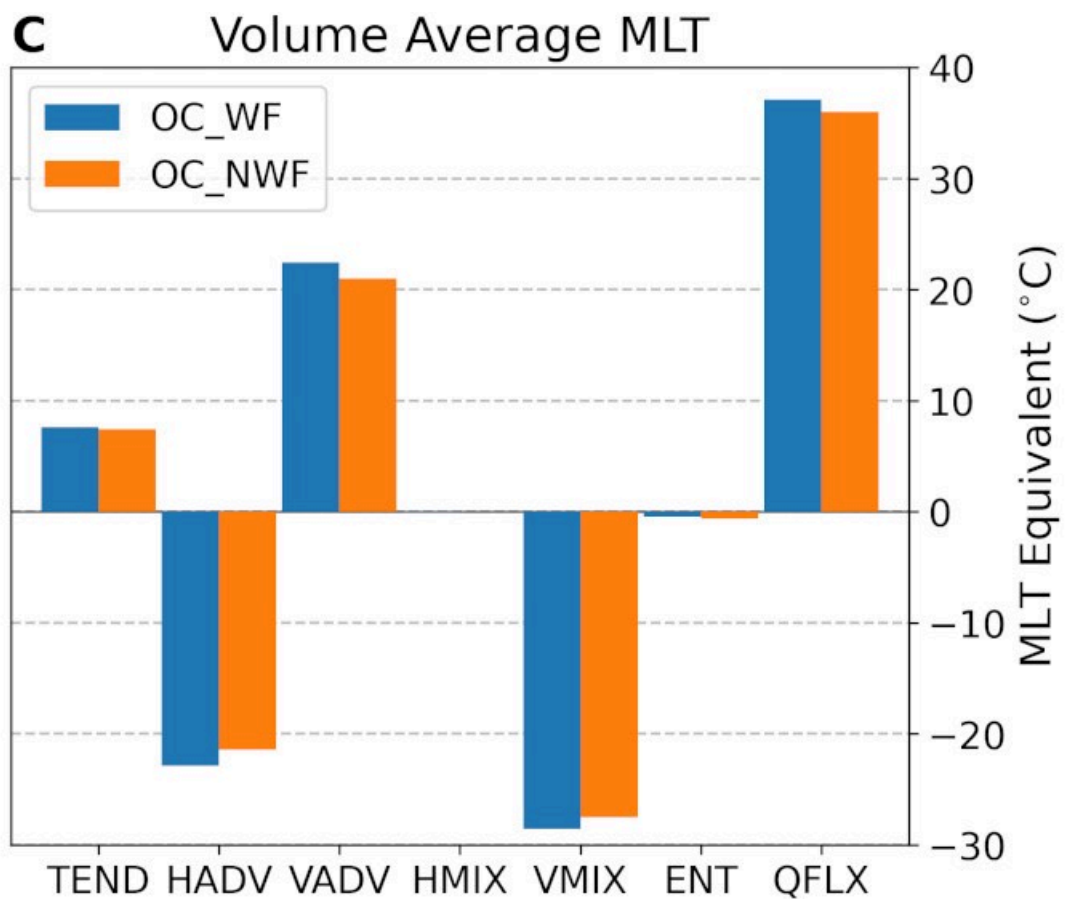
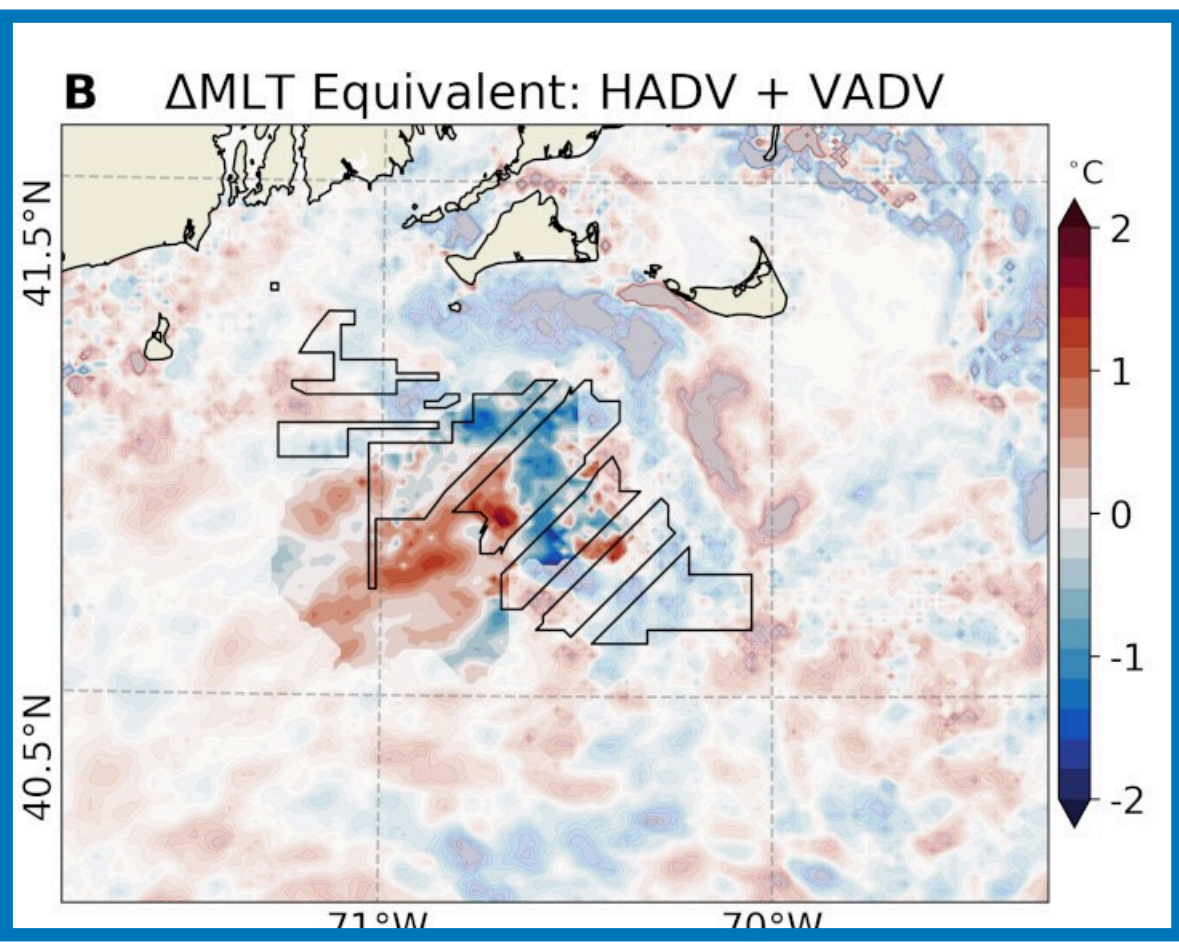
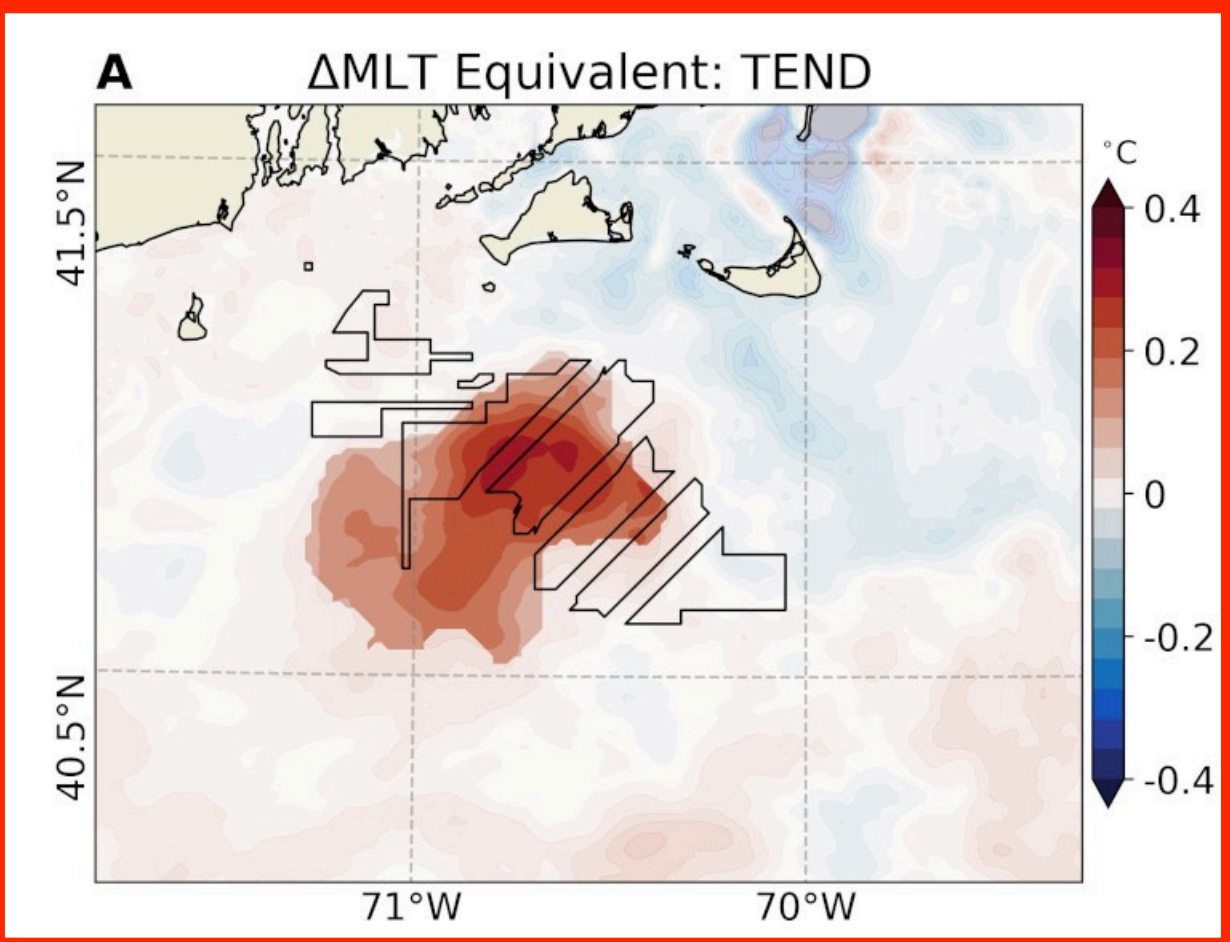
Upward Qnet



dots: 99% confidence level

Quantifying SST warming driven by ocean ML processes

$$\underbrace{\frac{\partial \langle T \rangle}{\partial t}}_{\text{TEND}} = \underbrace{-\langle \nabla \cdot (\mathbf{u}T) \rangle}_{\text{HADV}} + \underbrace{\frac{1}{H} (wT)_{z=-h}}_{\text{VADV}} - \underbrace{\langle \nabla \cdot (\kappa_h \nabla T) \rangle}_{\text{HMIX}} - \underbrace{\frac{1}{H} \left(\kappa_v \frac{\partial T}{\partial z} \right)_{z=-h}}_{\text{VMIX}} + \underbrace{\frac{Q_{\text{net}} - Q_{\text{sw}}|_{z=-h}}{\rho c_p H}}_{\text{QFLX}} - \underbrace{\frac{\Delta T}{H} \frac{\partial h}{\partial t}}_{\text{ENT}}$$

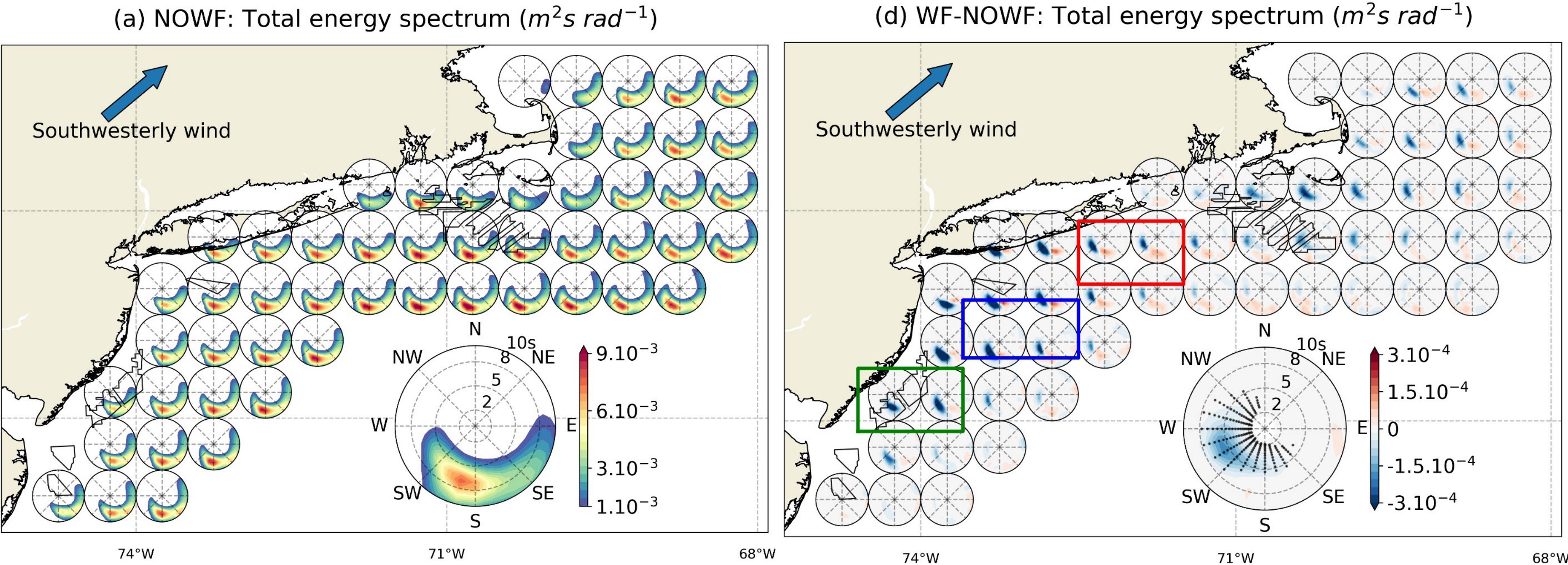


Time-integrated ROMS
online heat budget:

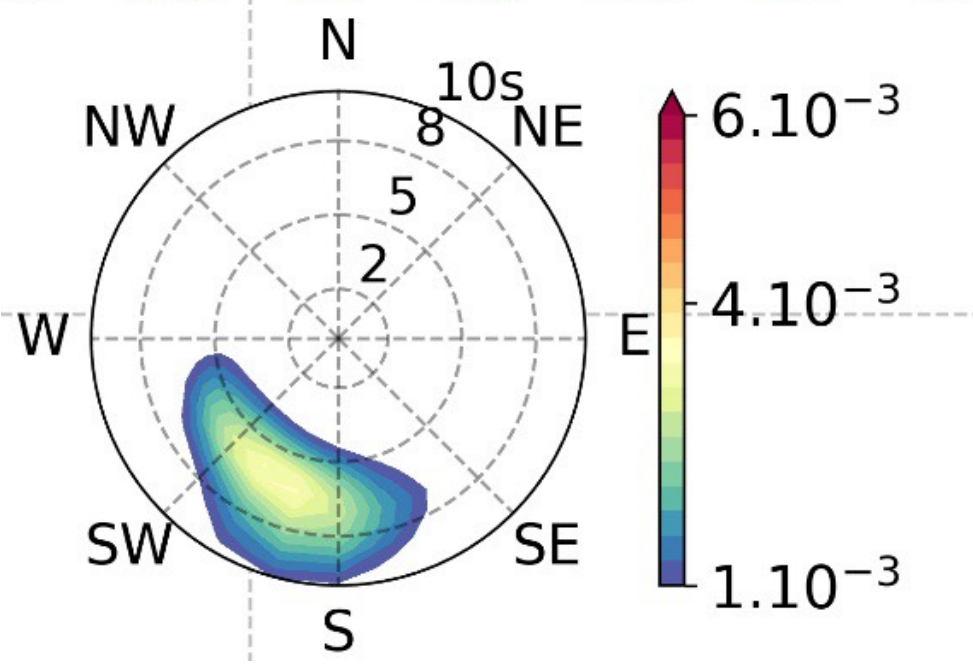
Reduced entrainment
cooling due to shallow MLD
plays a dominant role.

(not shown) In NJ, upwelling
change and vertical mixing
contribute as well.

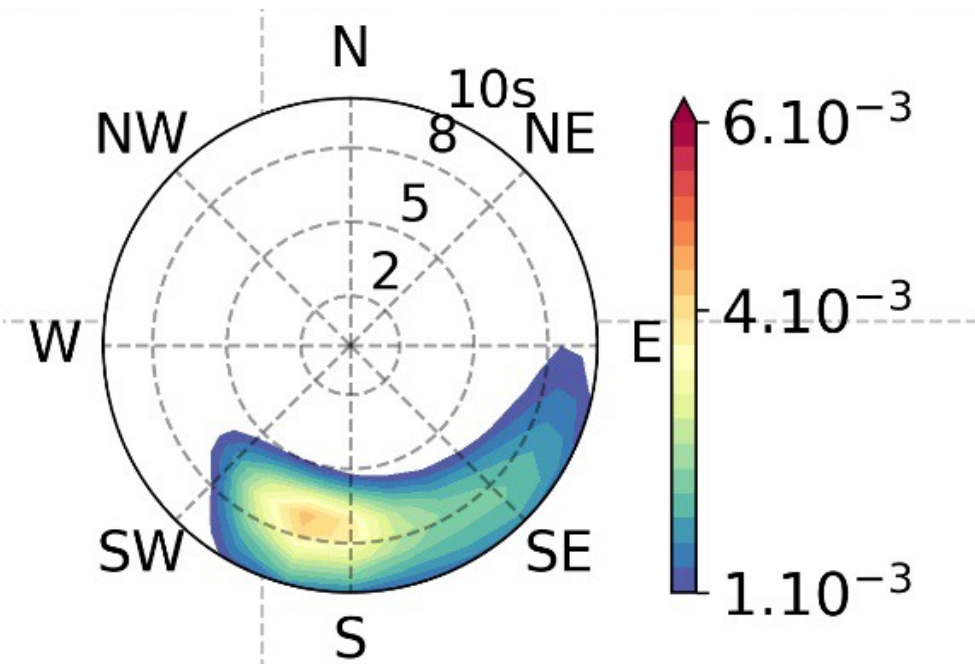
Directional Wave Spectra



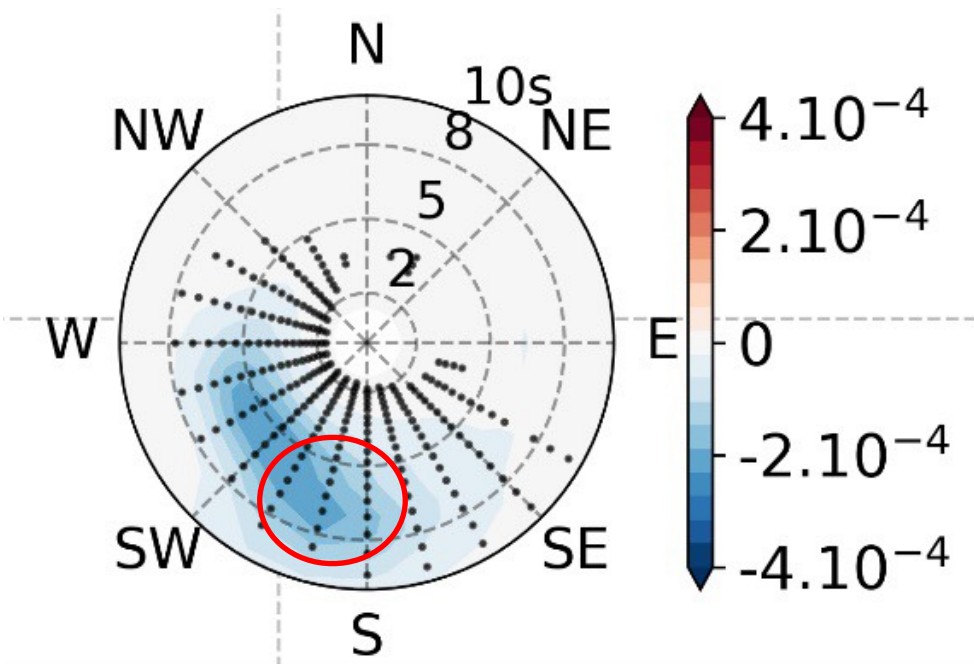
NOWF: wind-sea



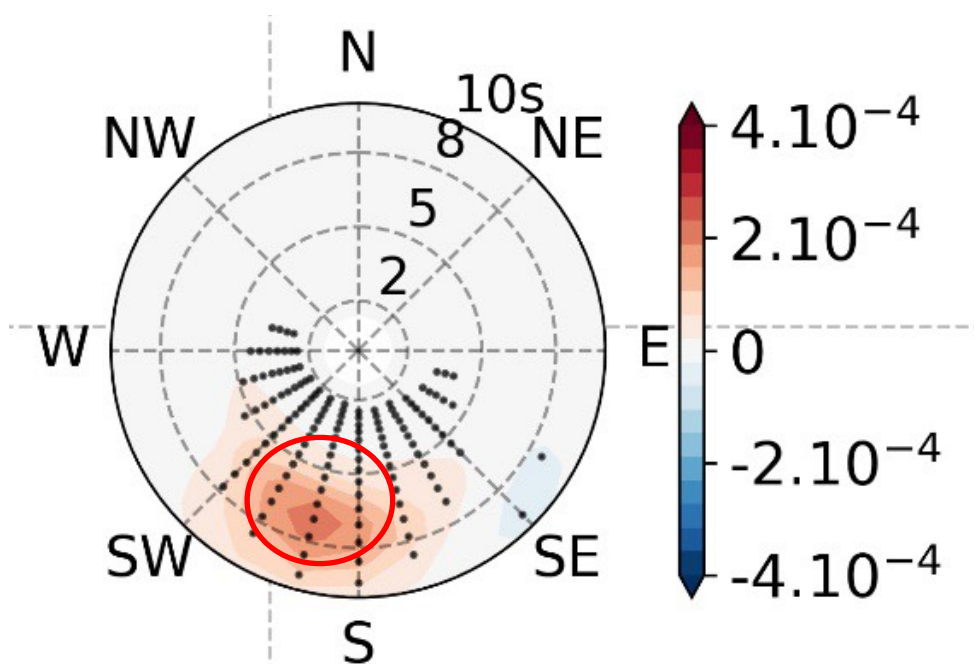
NOWF: swell



WF-NOWF: wind-sea



WF-NOWF: swell

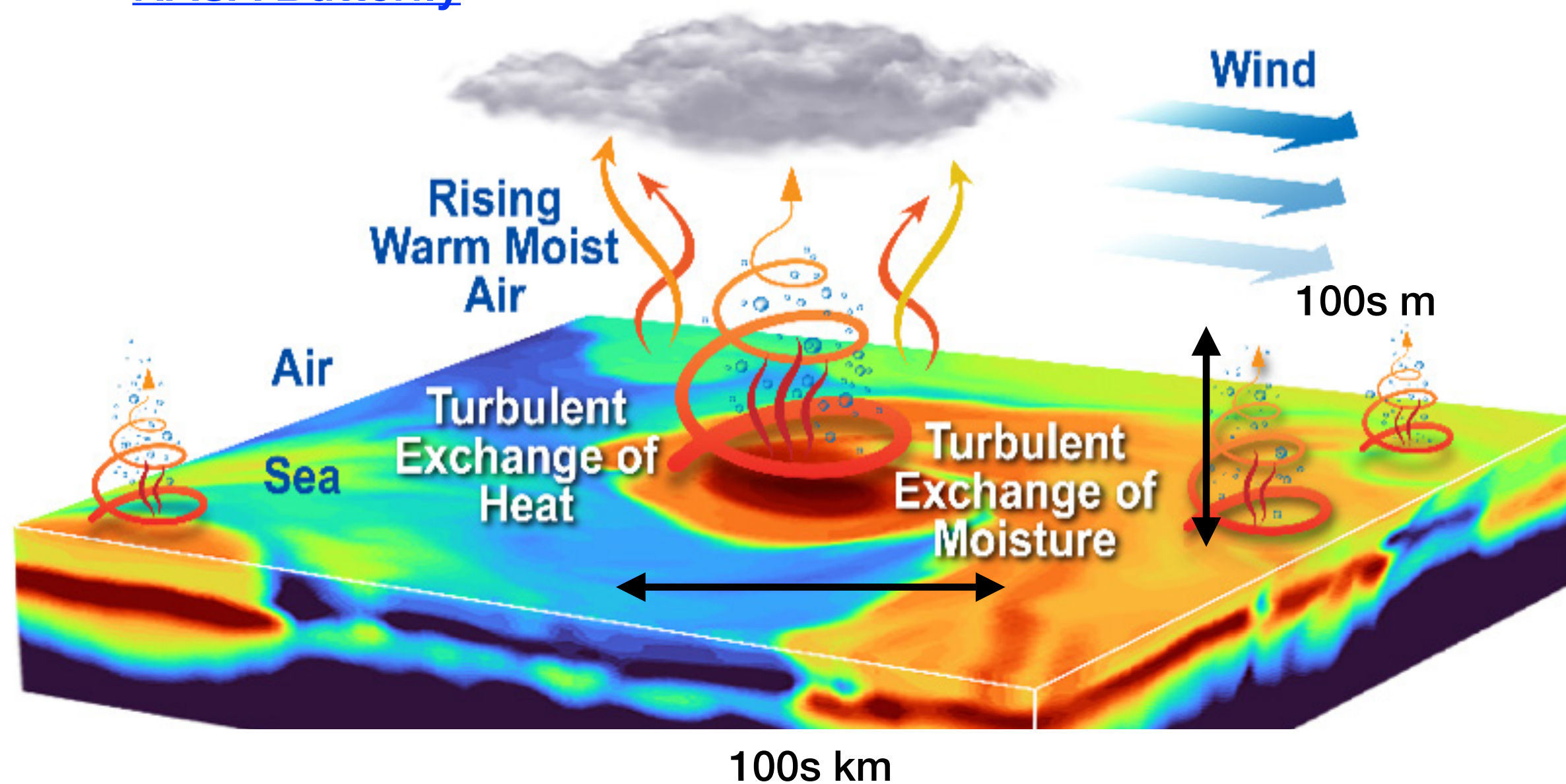


Wave regime shift from ‘wind-sea’ to ‘swell’ as the wind speed is reduced

Ocean Mesoscale Air-Sea Interaction

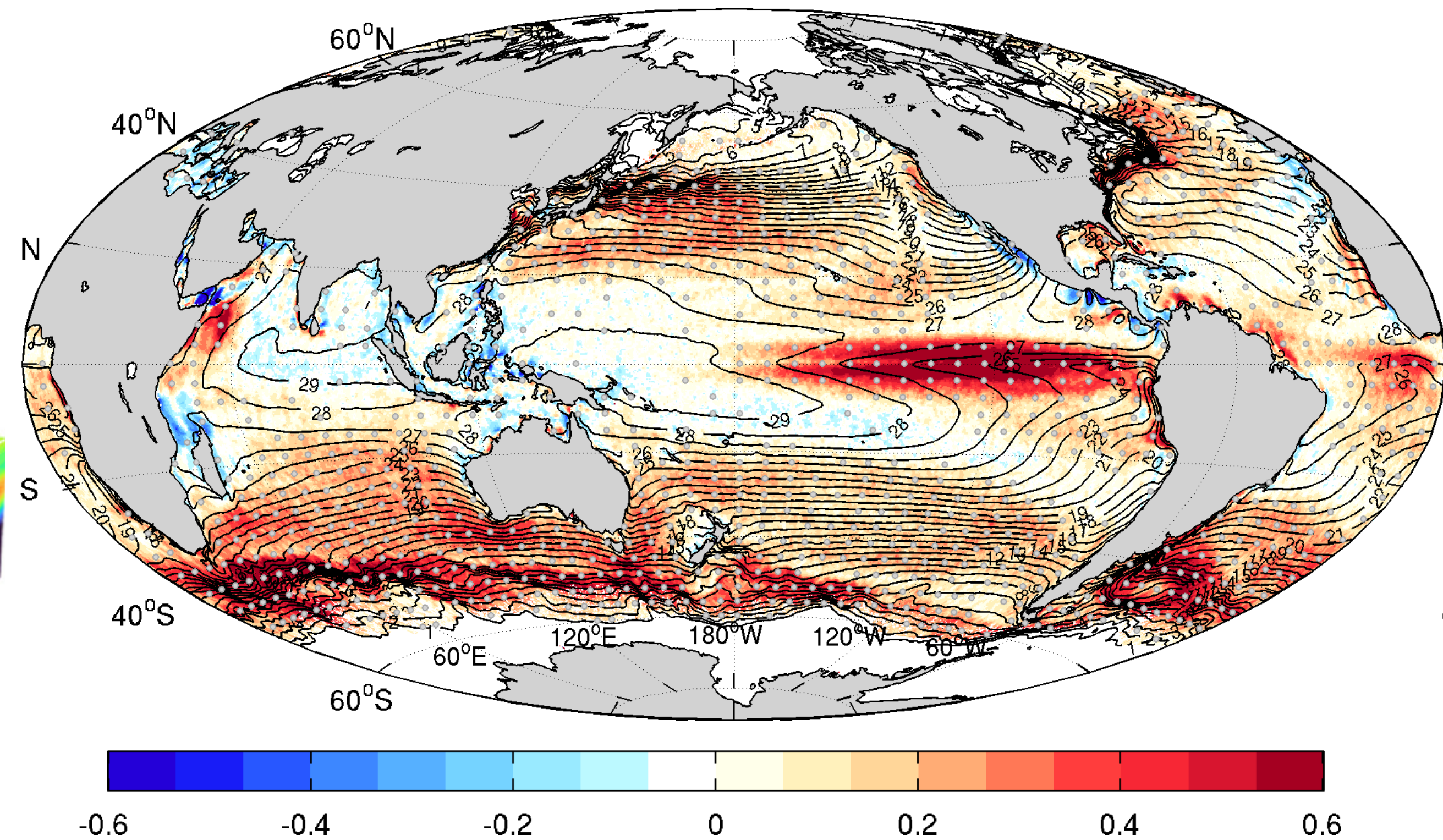
SST, current, and surface drag mediated by the ocean mesoscale eddies
modifies the MABL stability, surface wind, and air-sea flux
(e.g., Chelton et al. 2004; Small et al. 2008; Seo et al. 2023)

[NASA Butterfly](#)



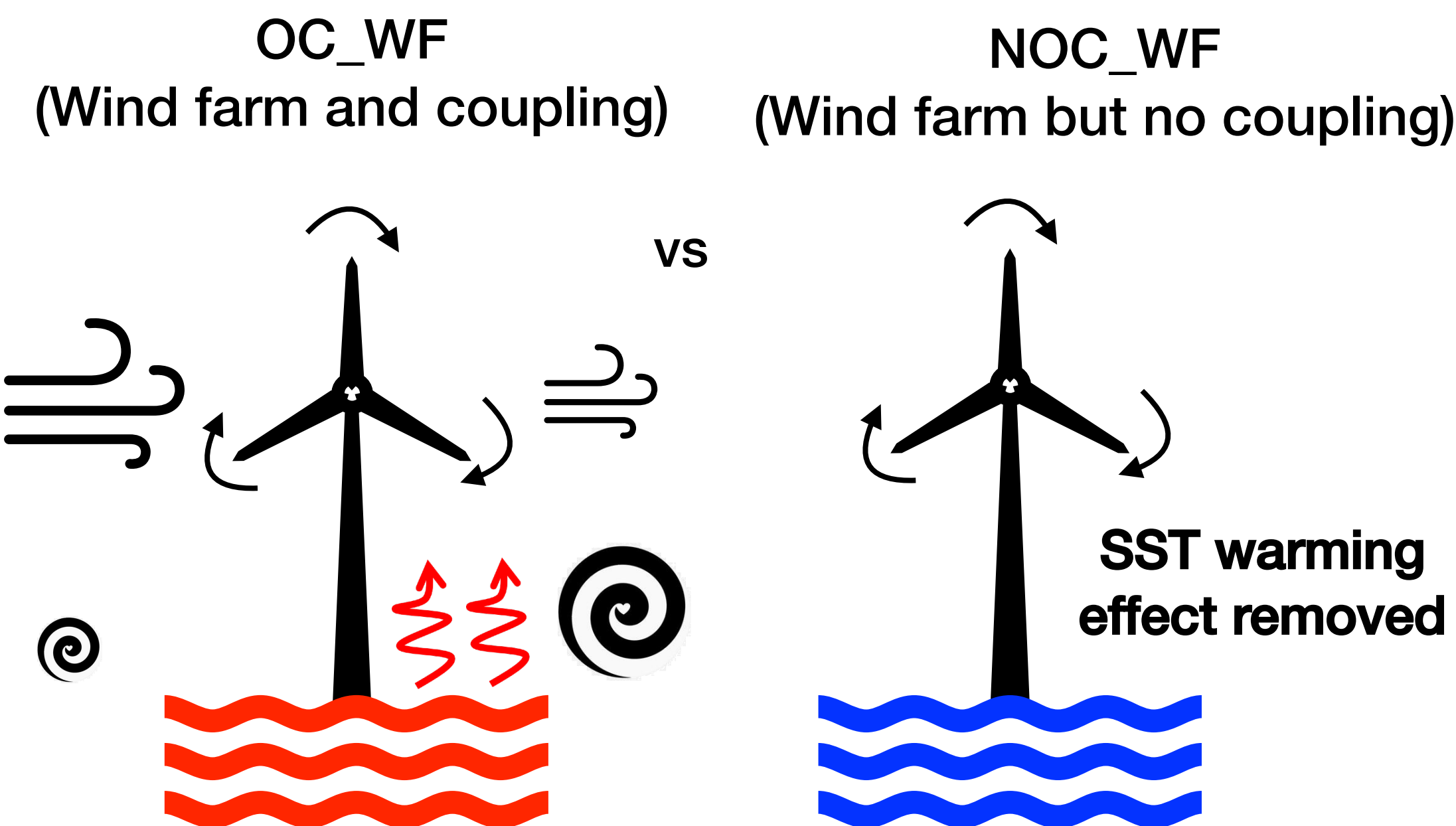
Gentemann et al. (2020)

Correlation bet'n wind and SST (spatially high passed)

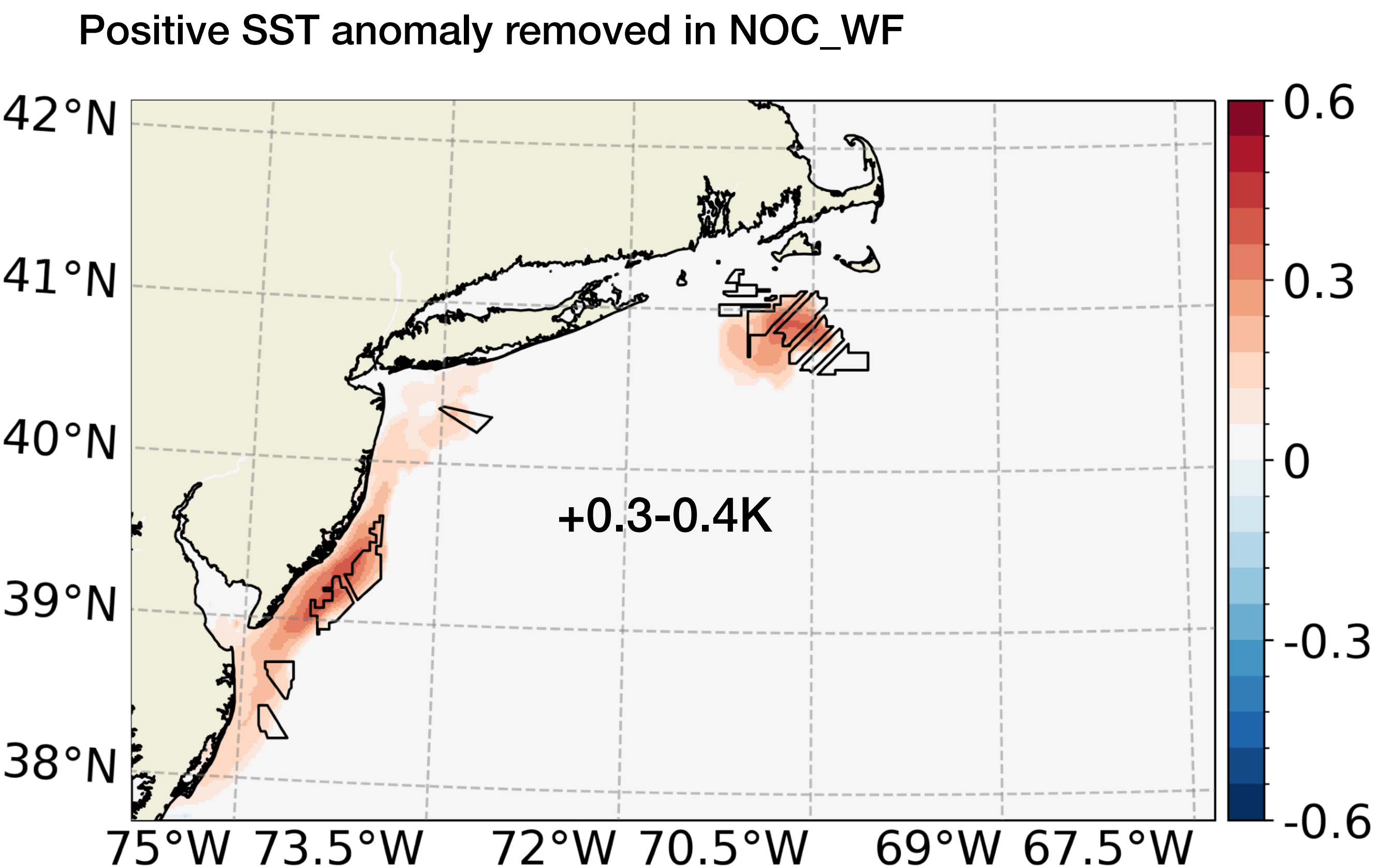


Seo (2017)

Isolating the coupled effect of offshore wind farms



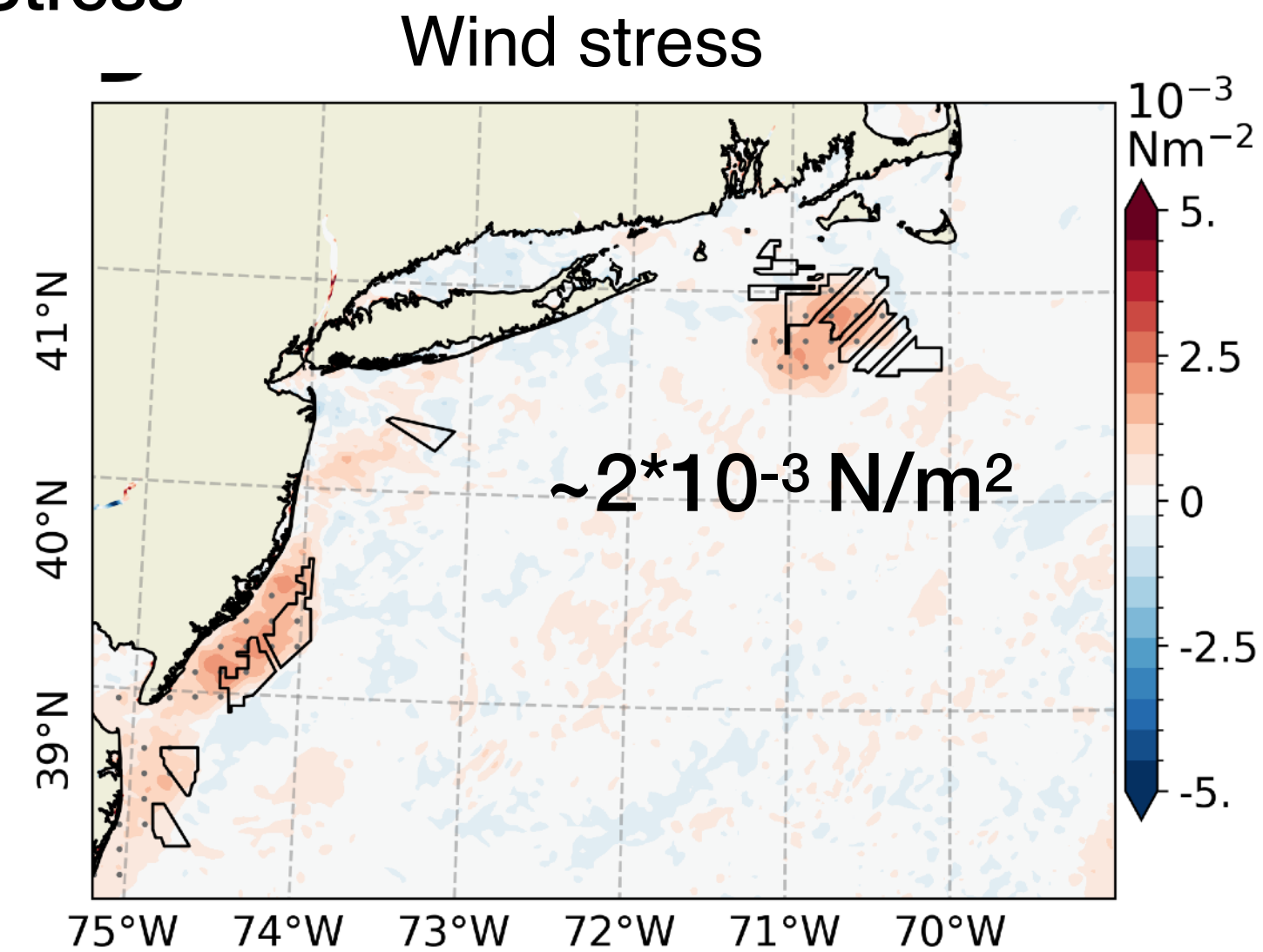
Experiment	Wind Farm (WF)	Ocean Coupling (OC)
OC_WF	Yes	Yes
OC_NWF	No	Yes
NOC_WF	Yes	No



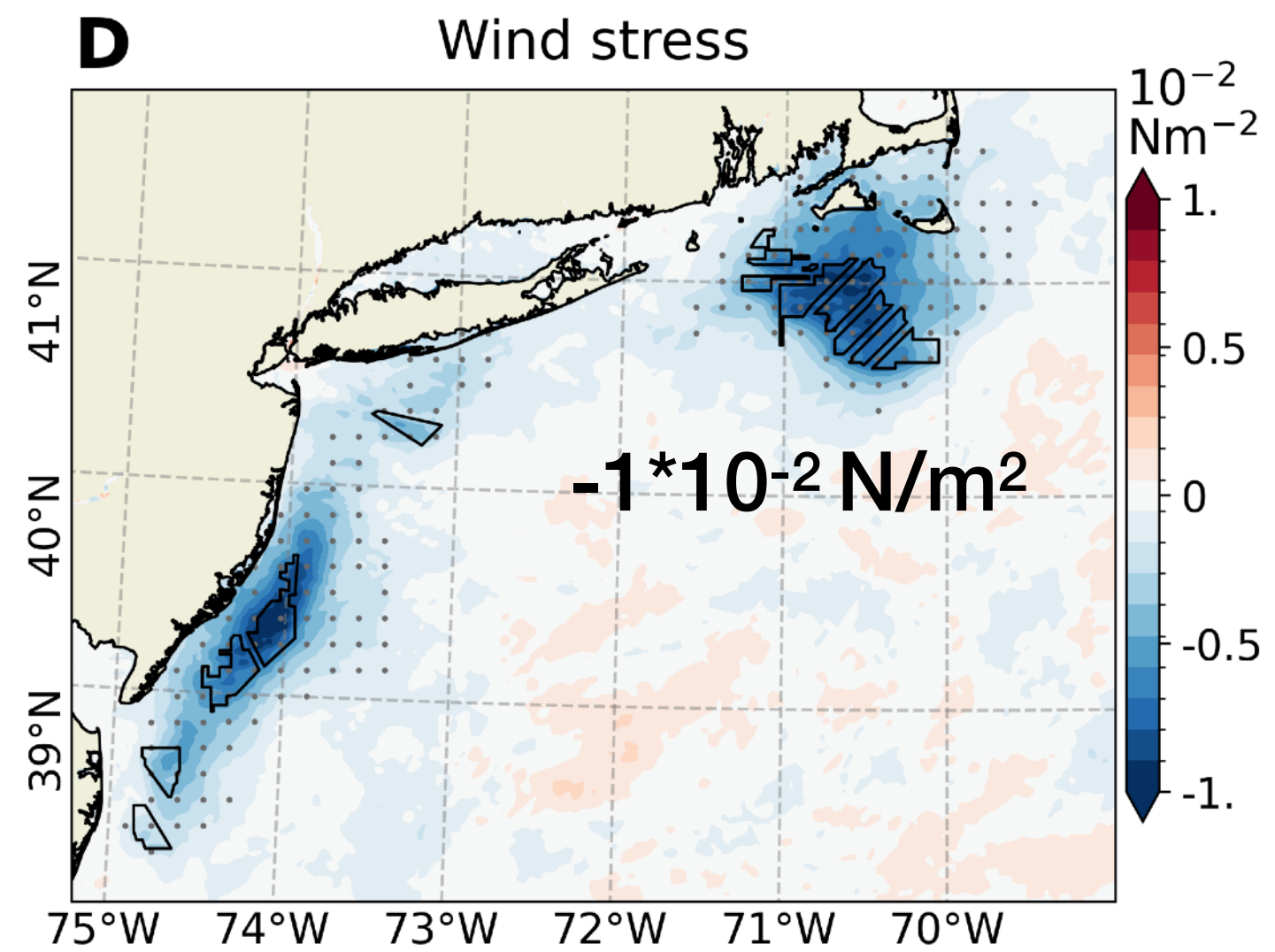
Isolating the coupled effect of offshore wind farms

Effect of wind farm
with ocean coupling

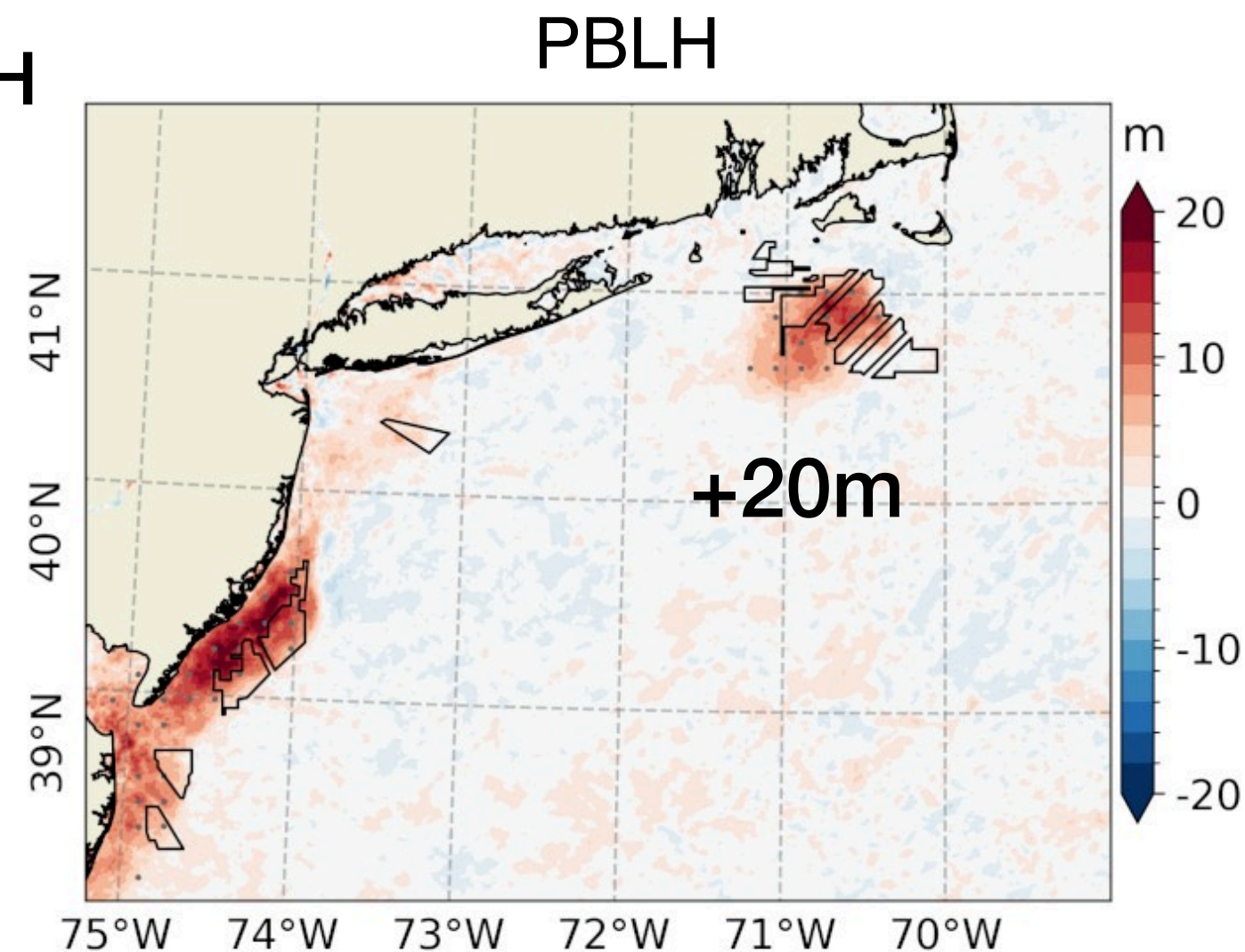
Wind Stress



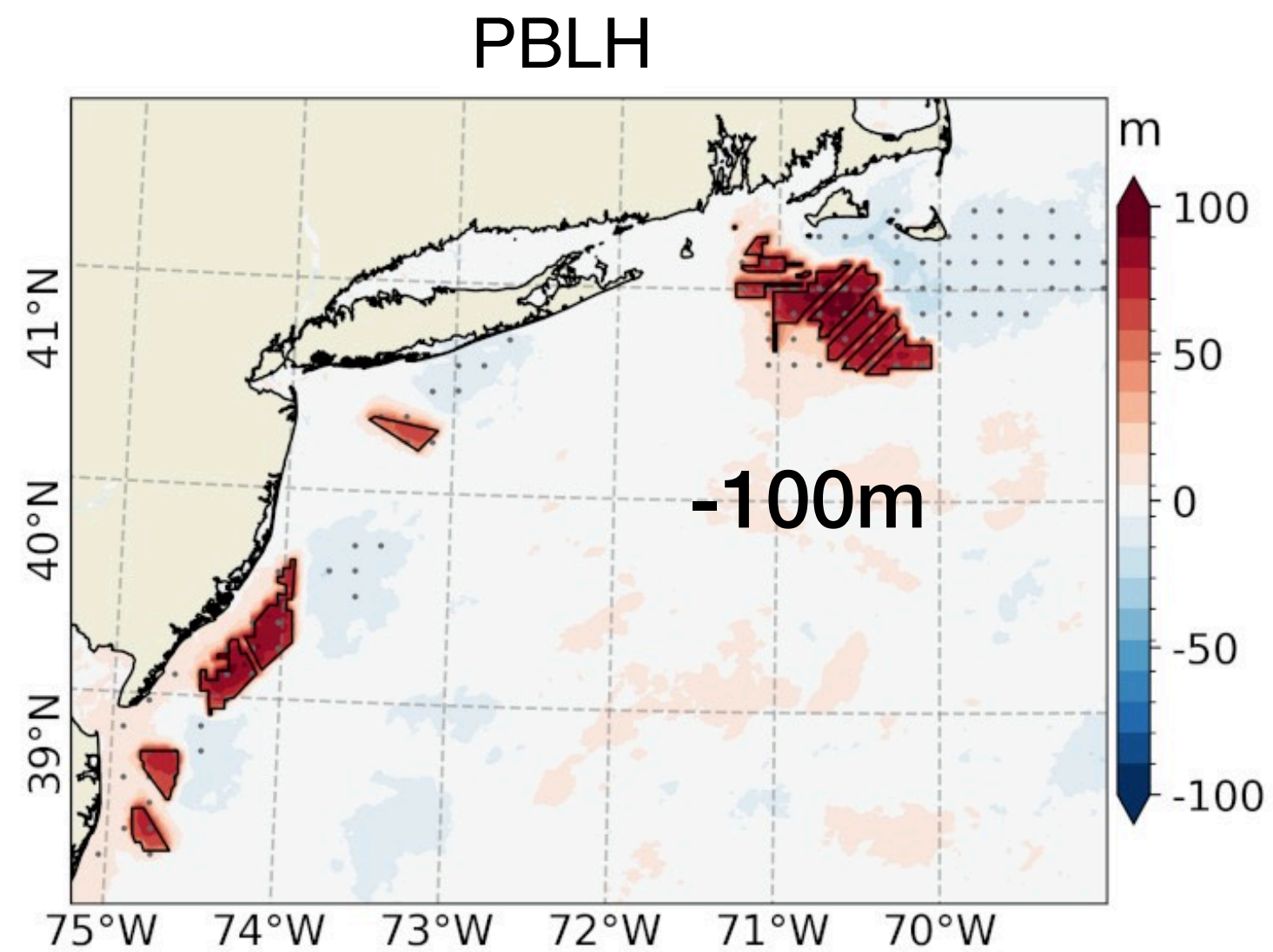
Effect of wind farm
without ocean coupling



PBLH



recall

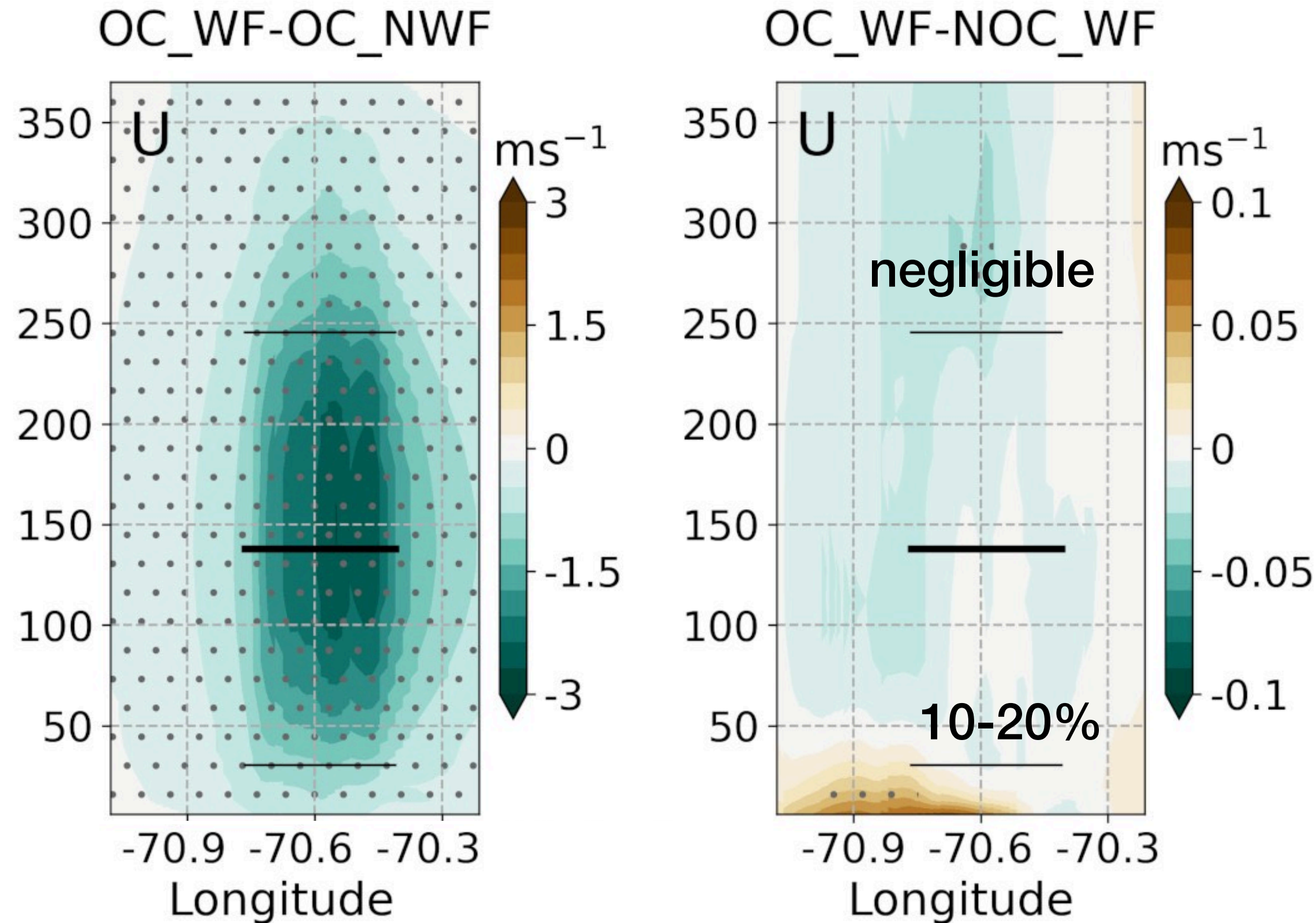


Local ocean coupling
increases, offsetting wind-
stress deficits and
contributing to PBL
deepening by 15-20%

Uncoupled models may
overestimate the stress
deficits and underestimate
the PBLH deepening.

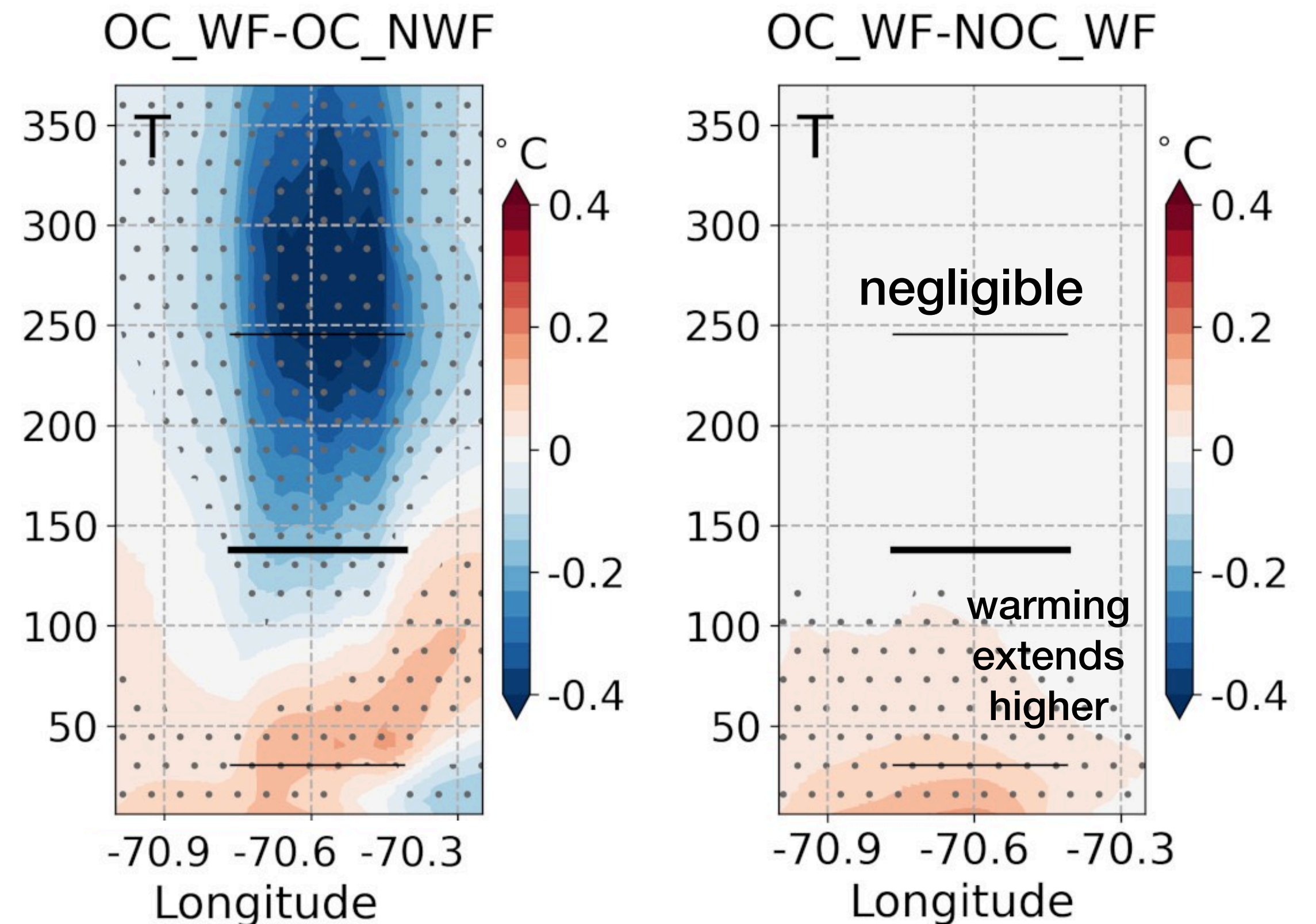
How high does the ocean coupling effect reach in the ABL?

Wind speed



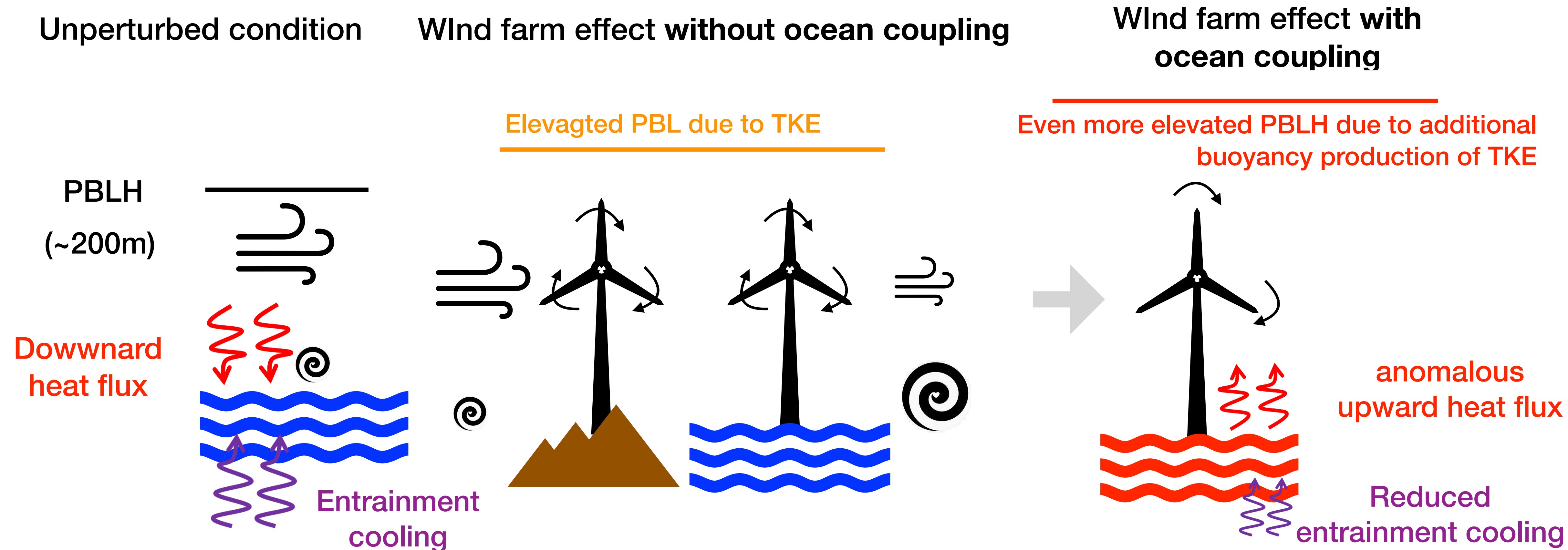
The wake-driven coupling modulates the ABL stability, but its impacts on wind appear to be limited to SL (<50 m).

Temperature



No evidence of the notable coupling effects on winds at turbine-relevant heights and hence accumulated power output.

Summary and Discussion



- Wake-driven wind stress reduction leads to anomalously warm SST of 0.3-0.4°C.
- SST warming is driven primarily by the ocean mixed-layer processes (bottom-up).
- The ocean coupling effect is most pronounced in the surface layer and has no impact at turbine-relevant heights.