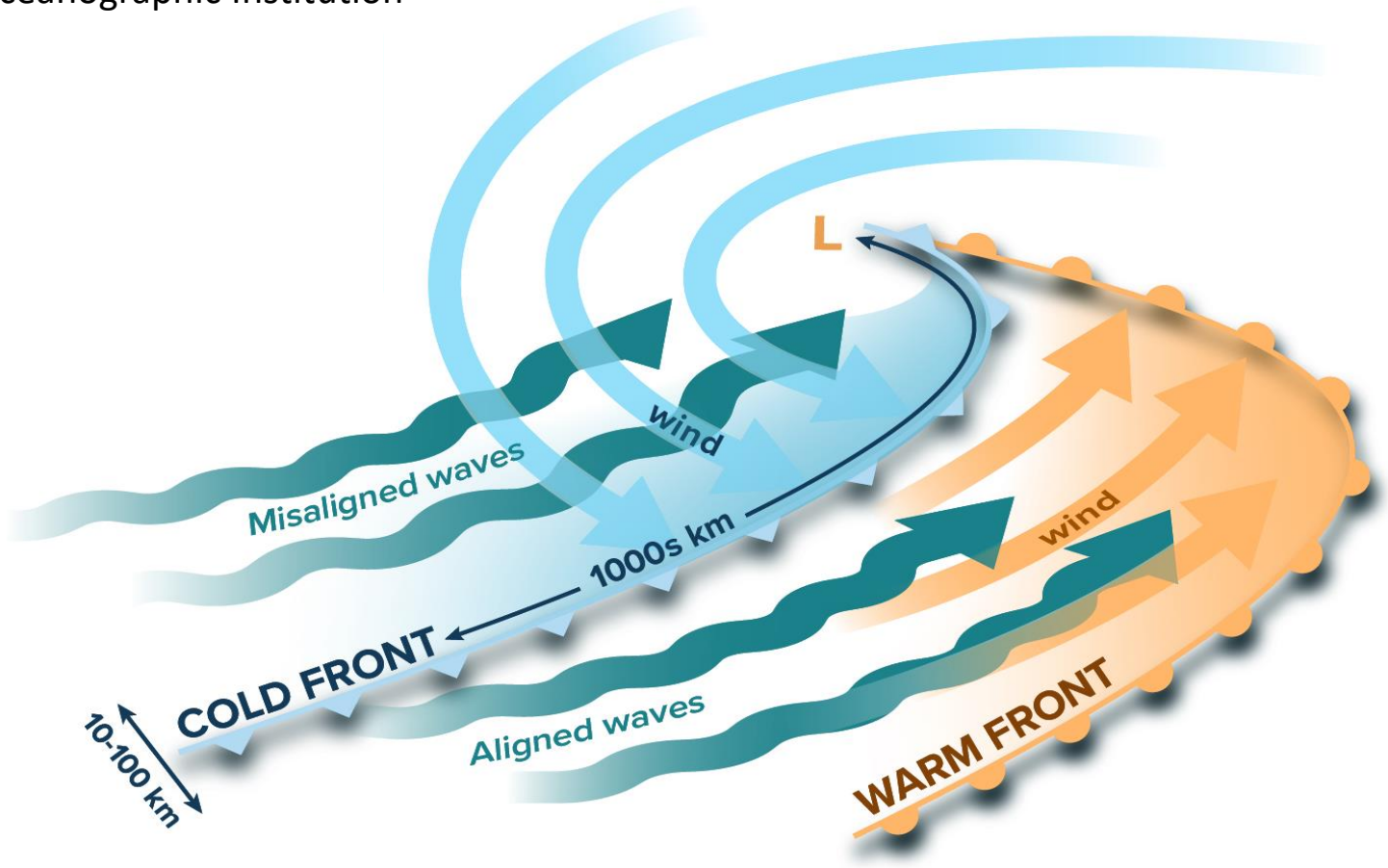
Misaligned Wind-Waves Behind Atmospheric Cold Fronts

César Sauvage[1], Hyodae Seo[1], Benjamin W. Barr[1], James B. Edson[1] and Carol Anne Clayson[1]

1-Woods Hole Oceanographic Institution



5th Workshop on Waves and Wave-Coupled Processes
10-12 April 2024

Contact: csauvage@whoi.edu

Introduction

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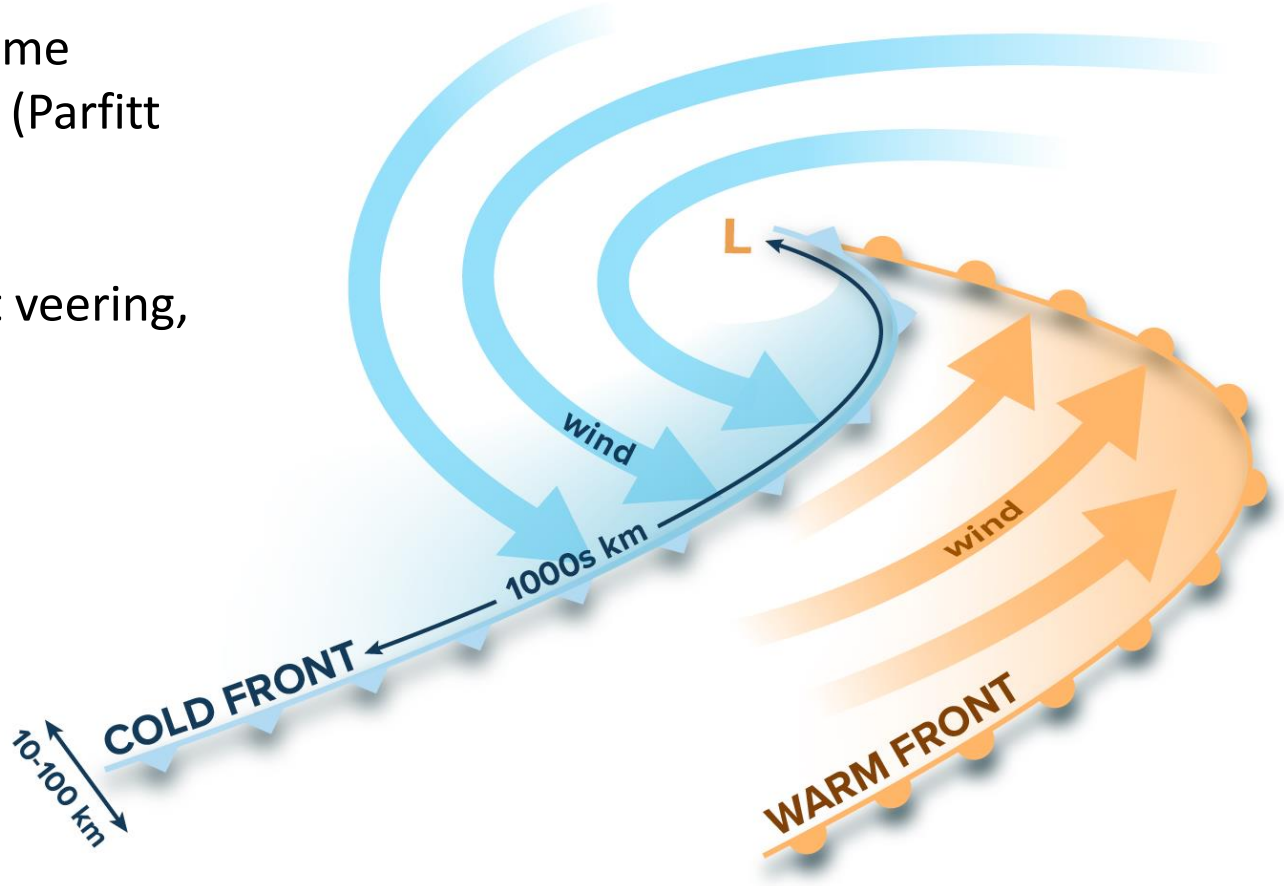
They are characterized by high wind speed, abrupt veering, and rapid translation.



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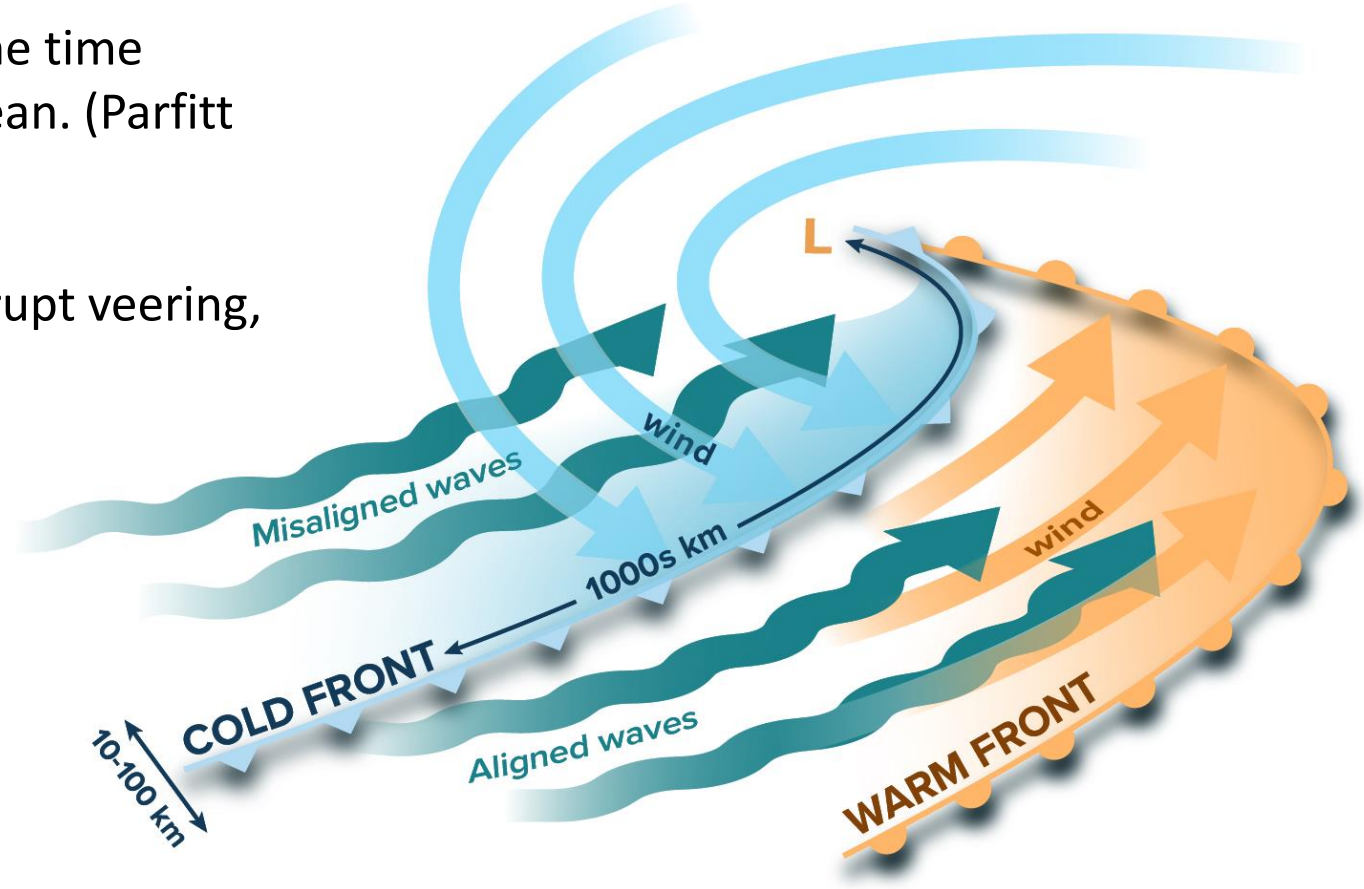

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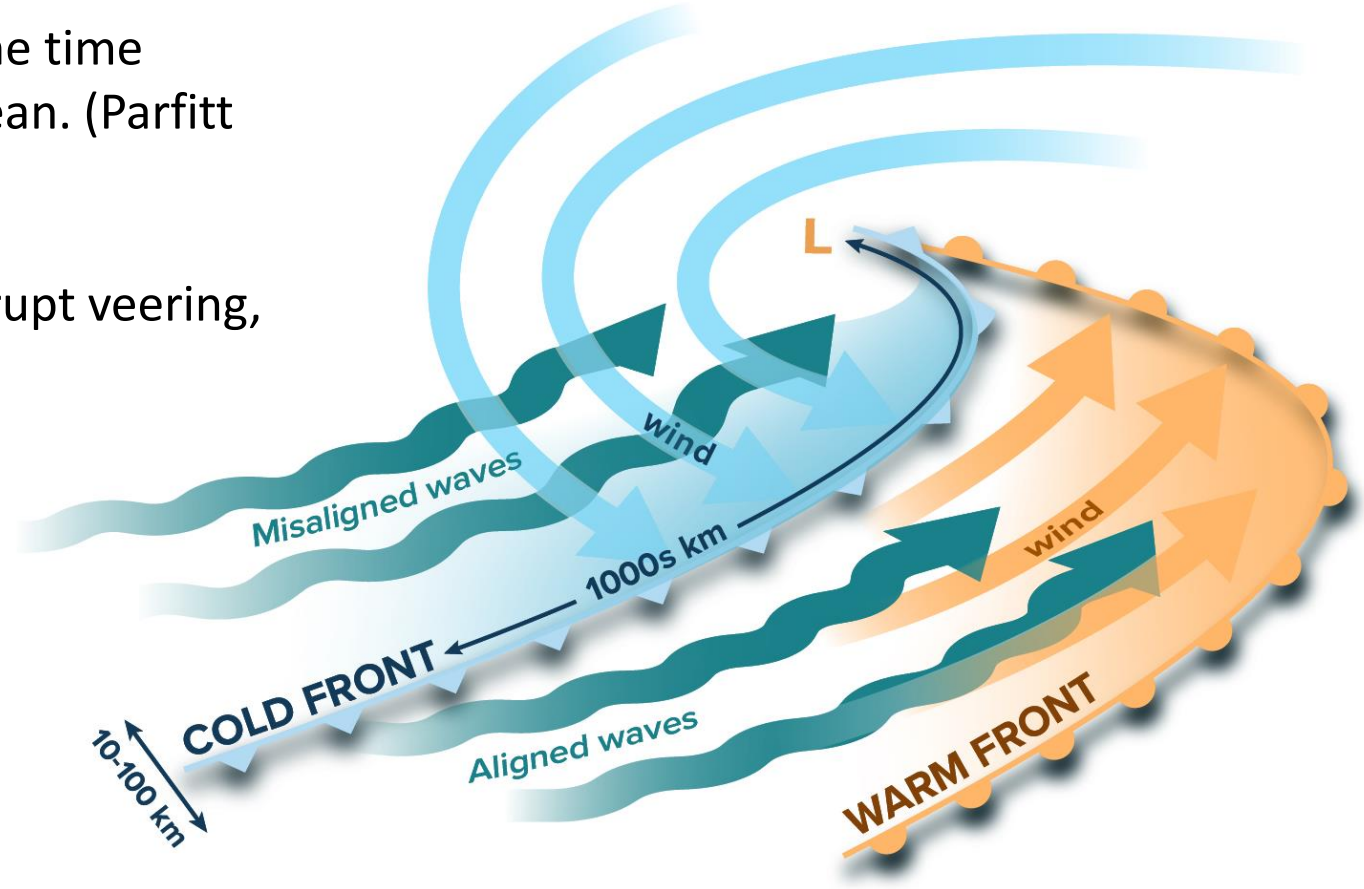
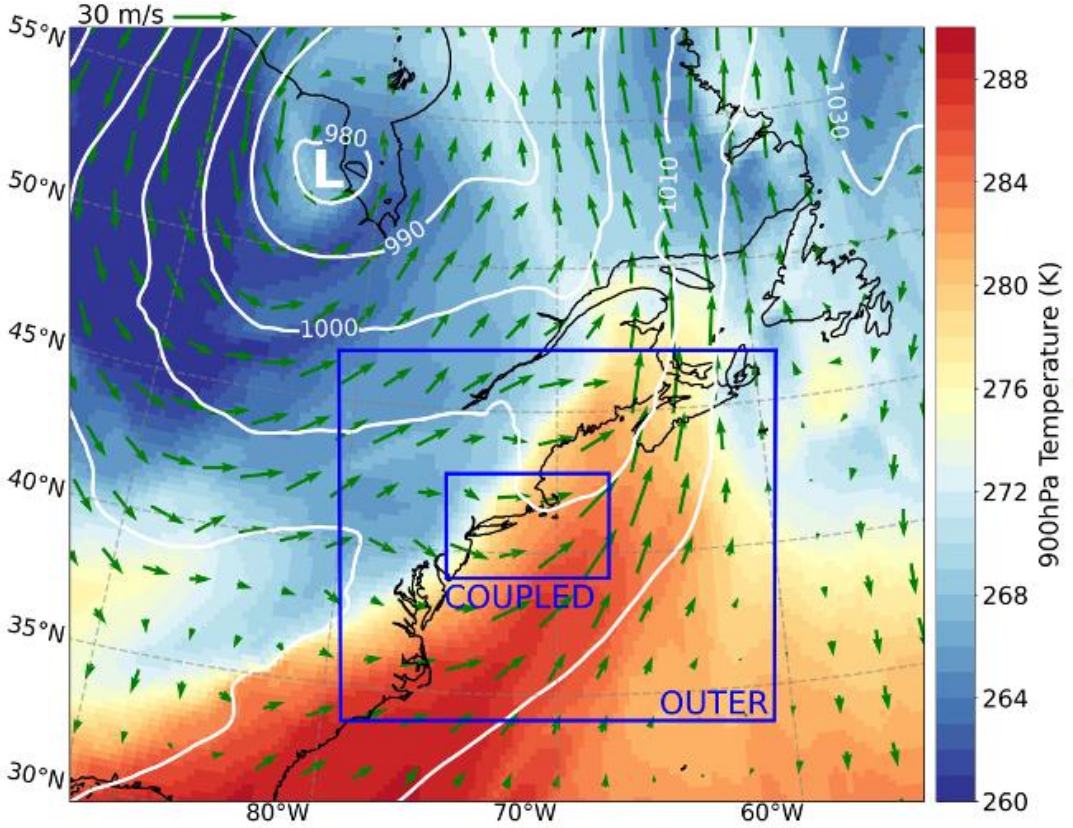


What are the resulting impacts on the surface drag and the air-sea momentum flux?

Coupled Modeling and Observation

SCOAR Regional Coupled Modeling
(i.e., Seo et al. 2007, 2016, 2021 ; Sauvage et al 2023)

WRF nested configuration: OUTER domain at 7.5 km
WRF-ROMS-WW3 COUPLED domain at 1.5 km



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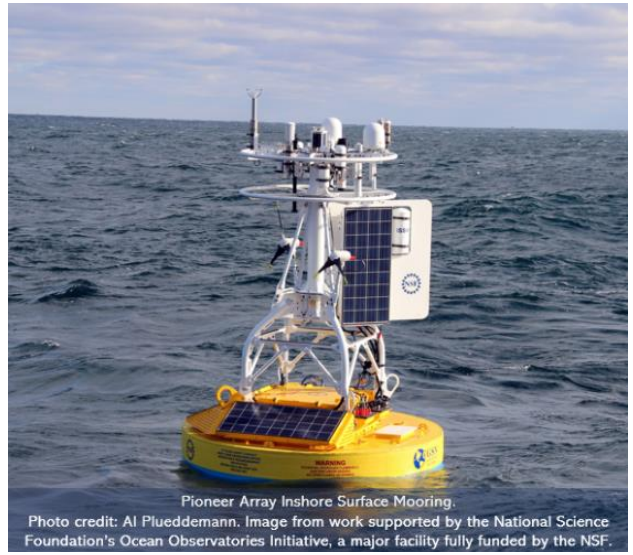
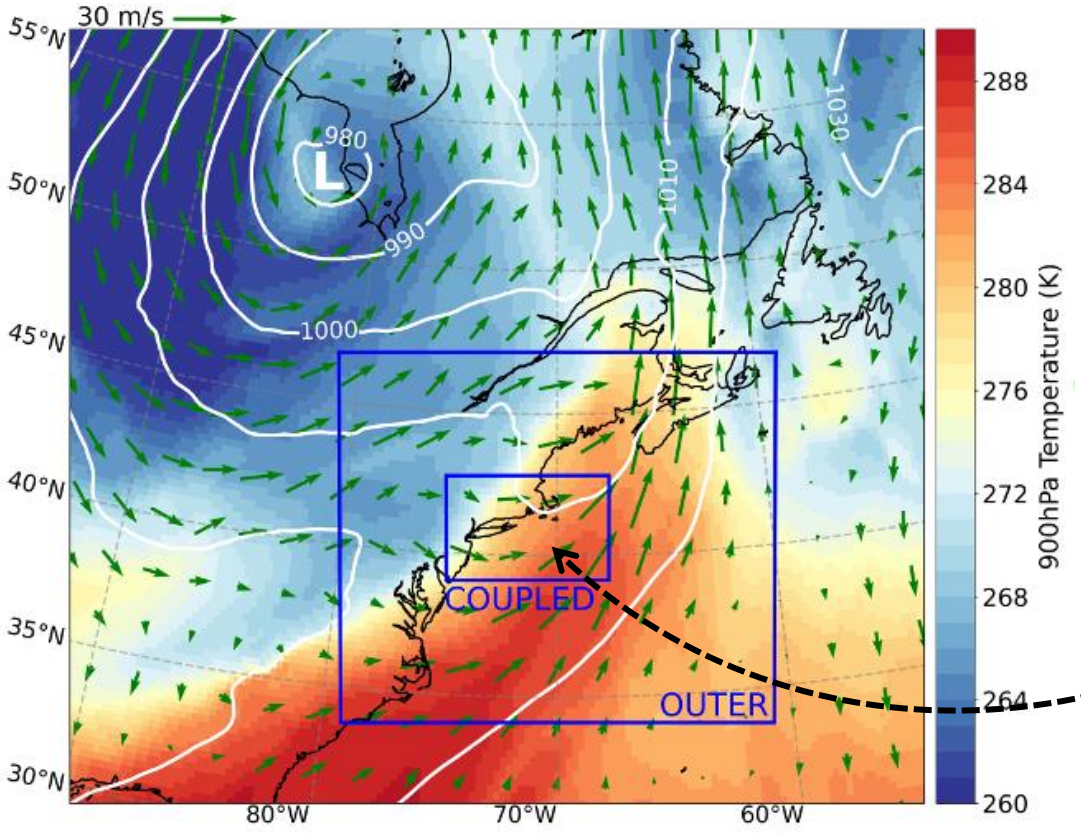
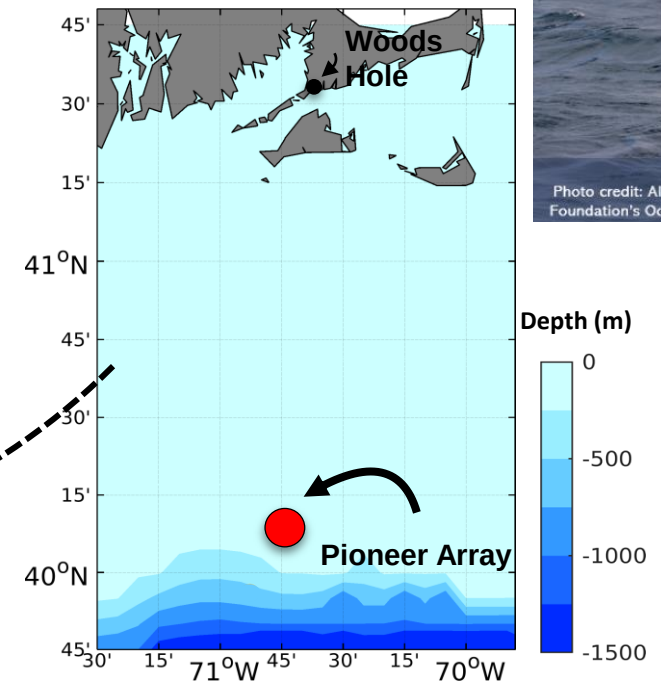
Ocean Observatories Initiative
Pioneer Array (2014-2022)







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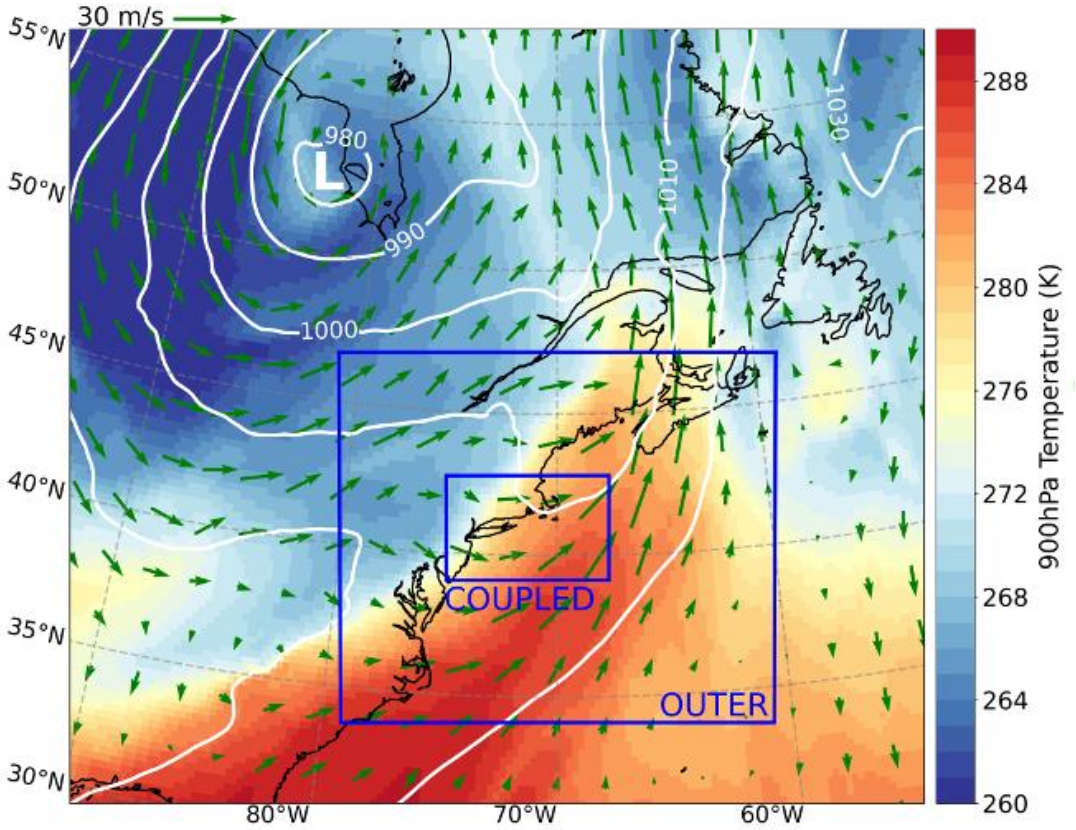

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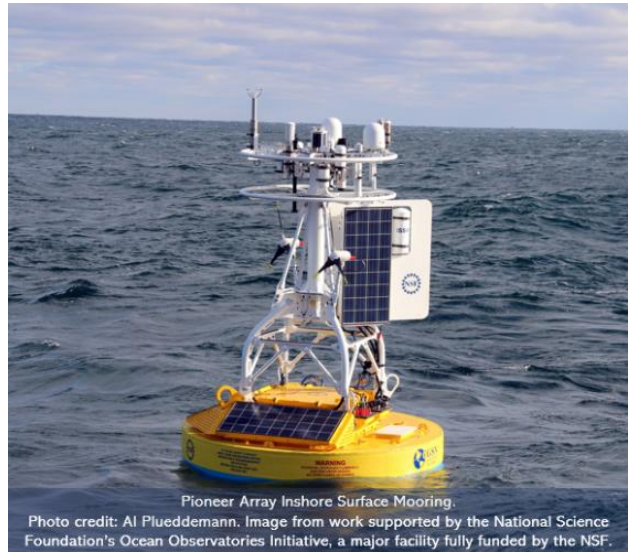
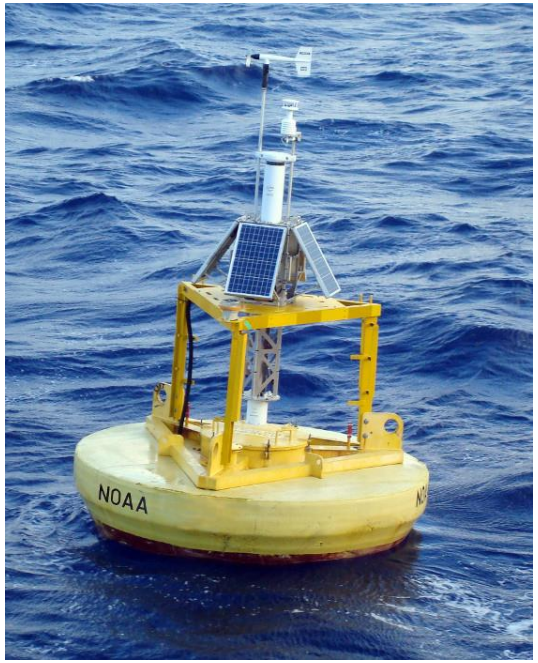
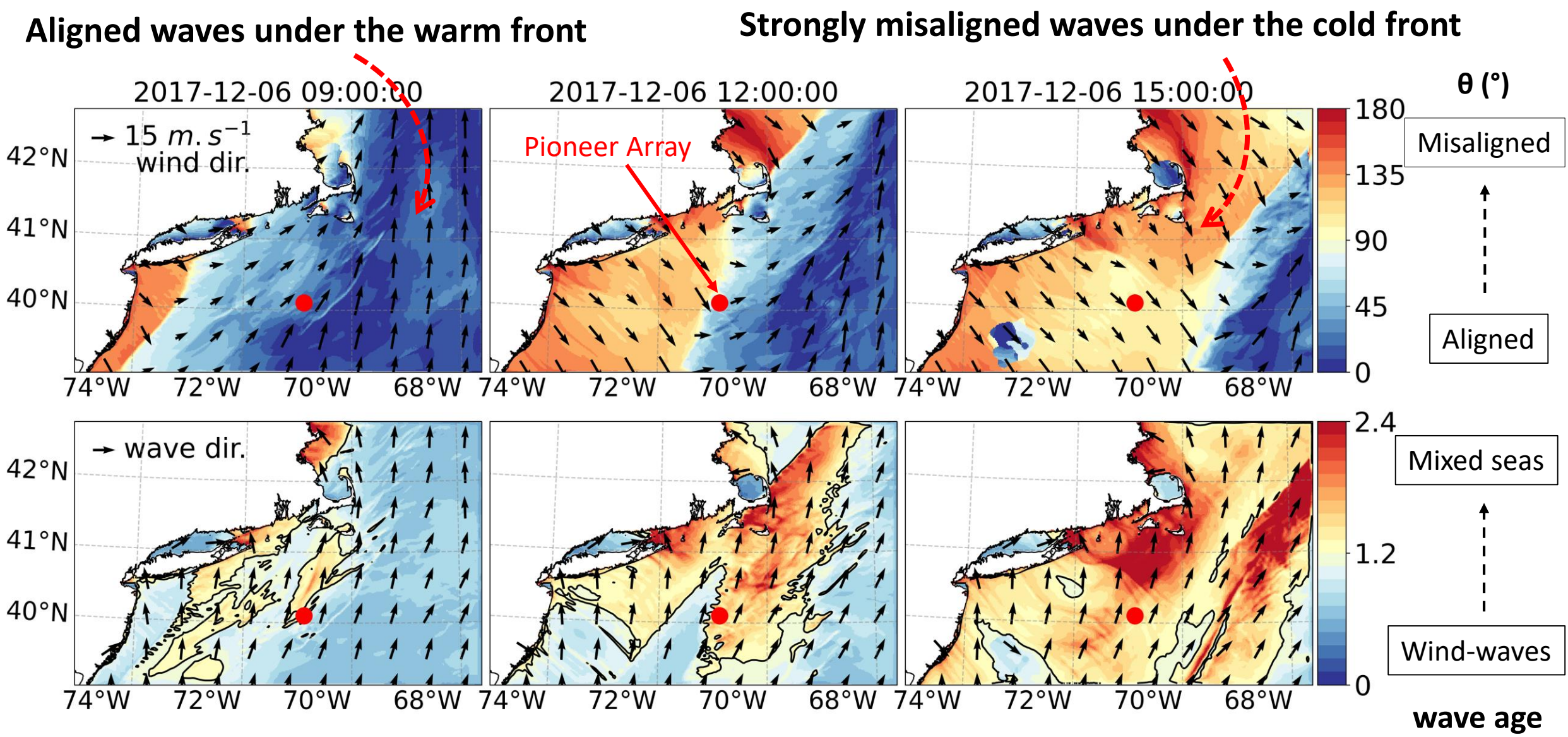

Pioneer Array Inshore Surface Mooring.
Photo credit: Al Plueddemann. Image from work supported by the National Science Foundation's Ocean Observatories Initiative, a major facility fully funded by the NSF.

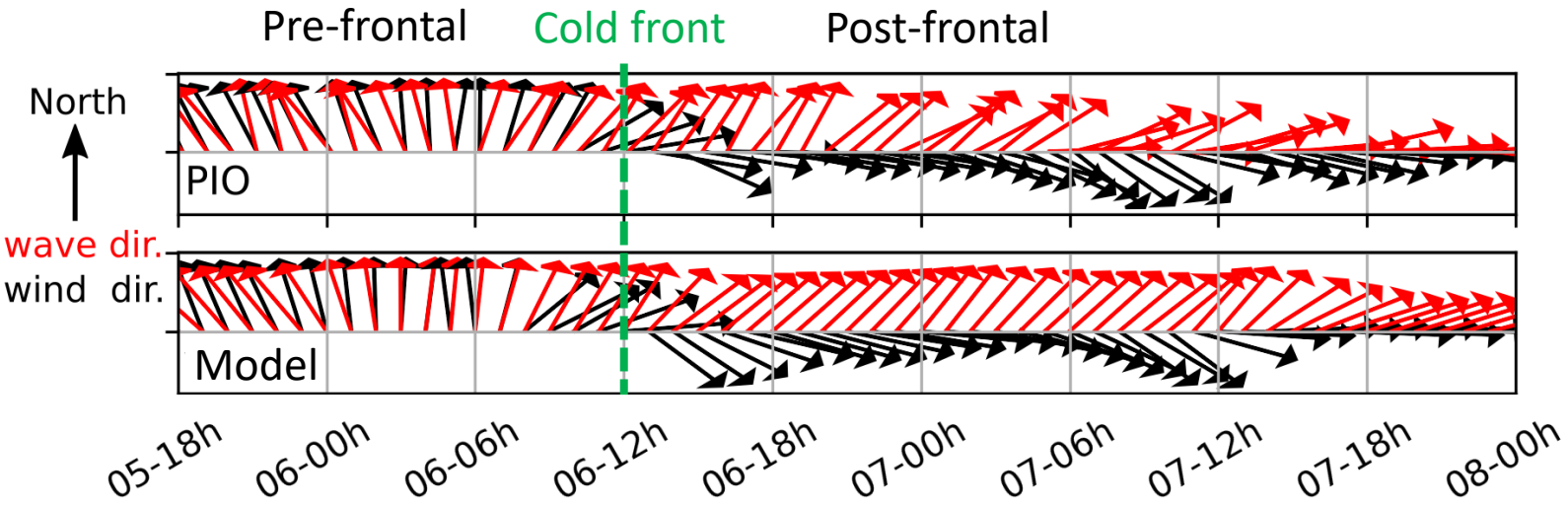


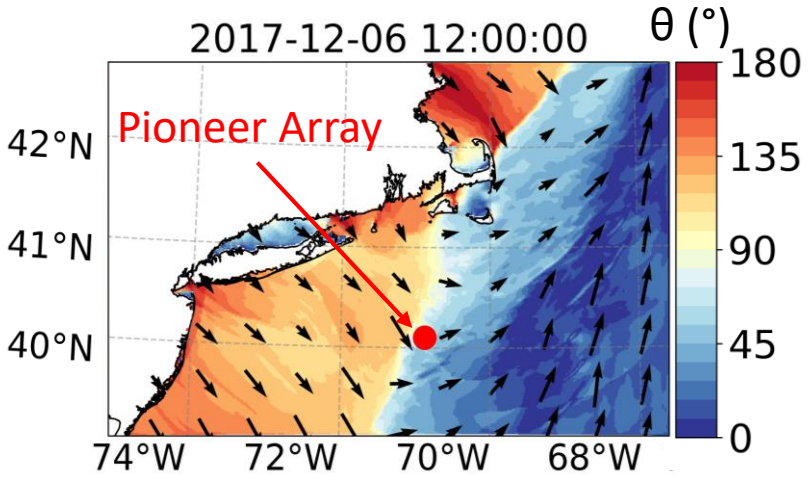
National Data Buoy Center
(NDBC)

Atmospheric cold front passing on December 6th 2017



Ocean Observatories Initiative: Pioneer Array (PIO)





Waves stayed strongly misaligned more than 12h hours after the passage of the cold front ..!

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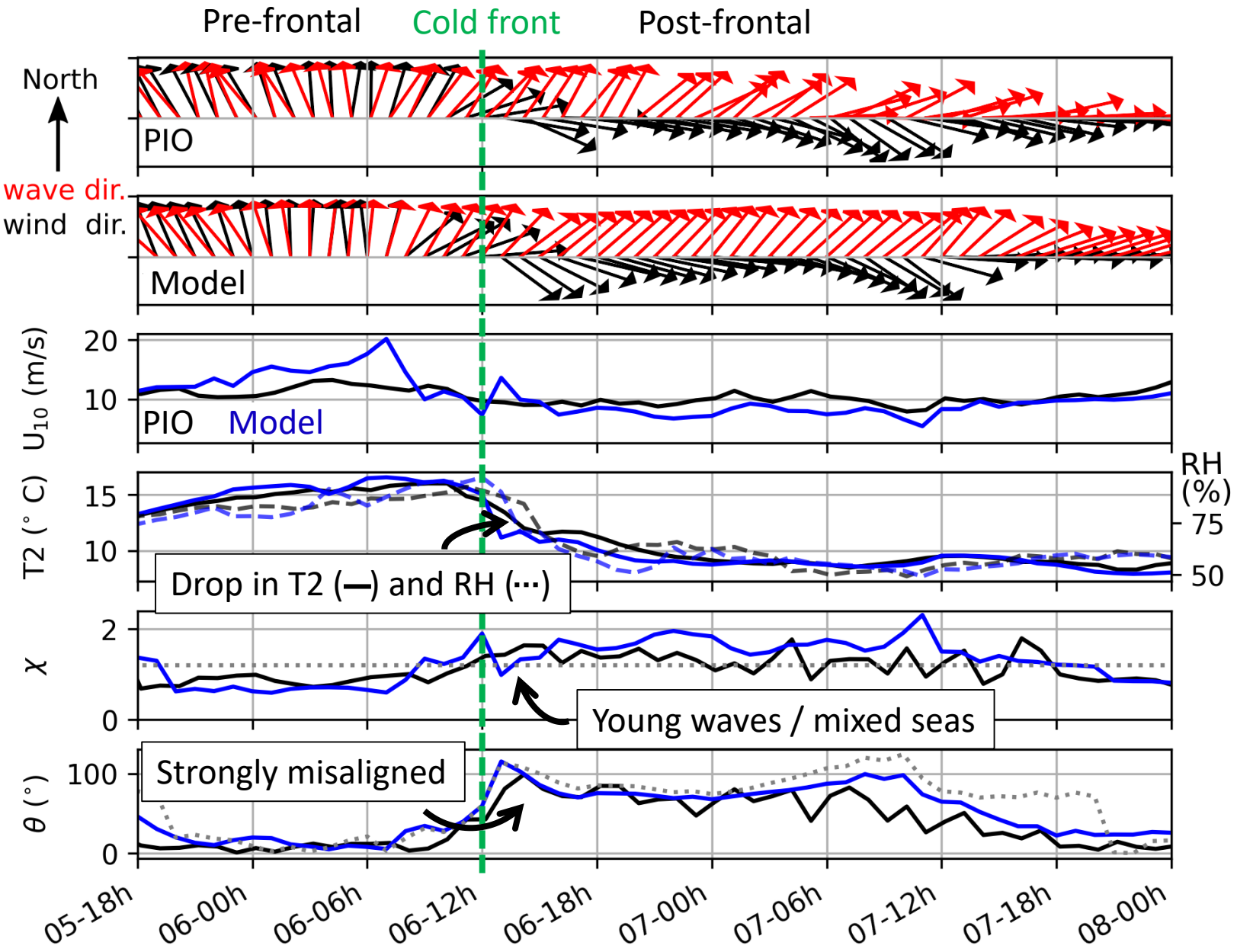

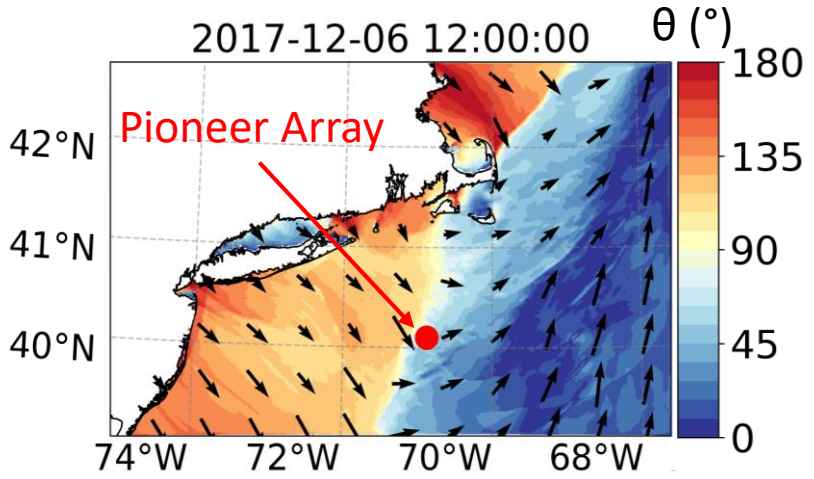

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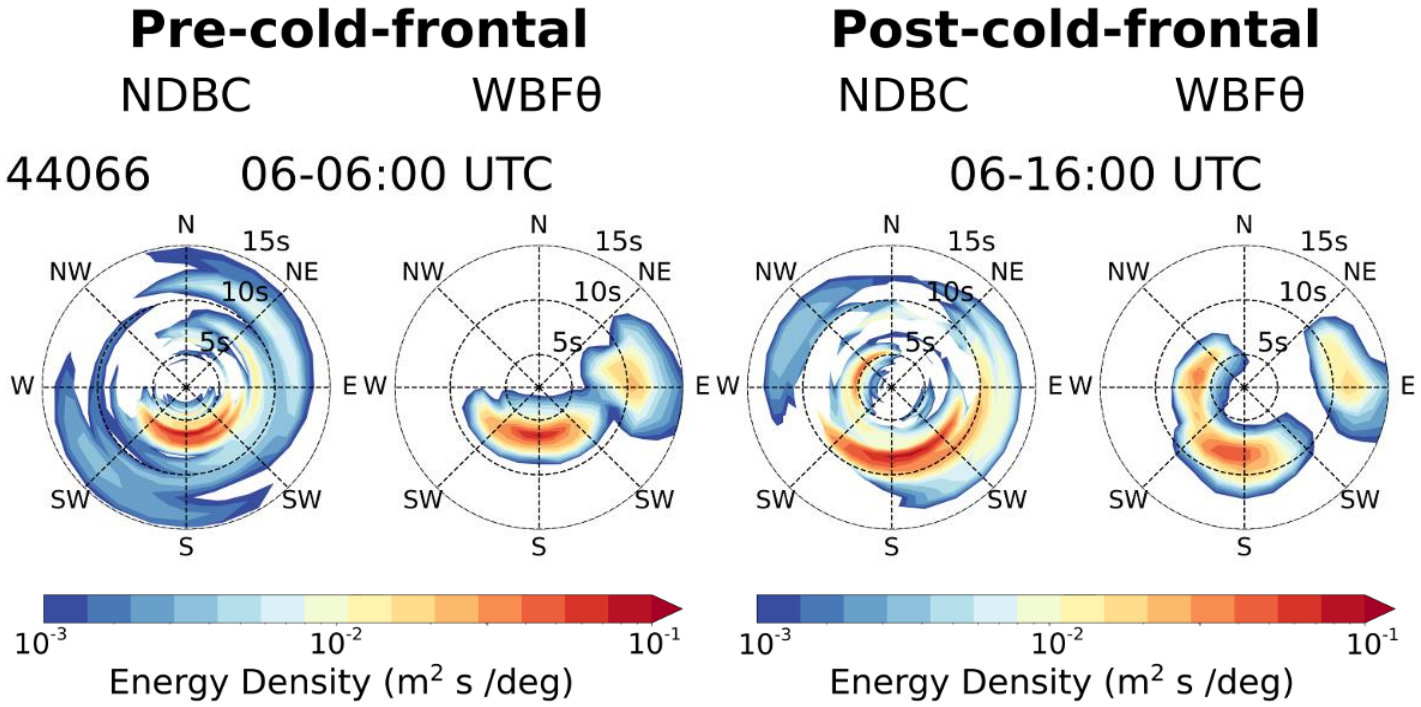
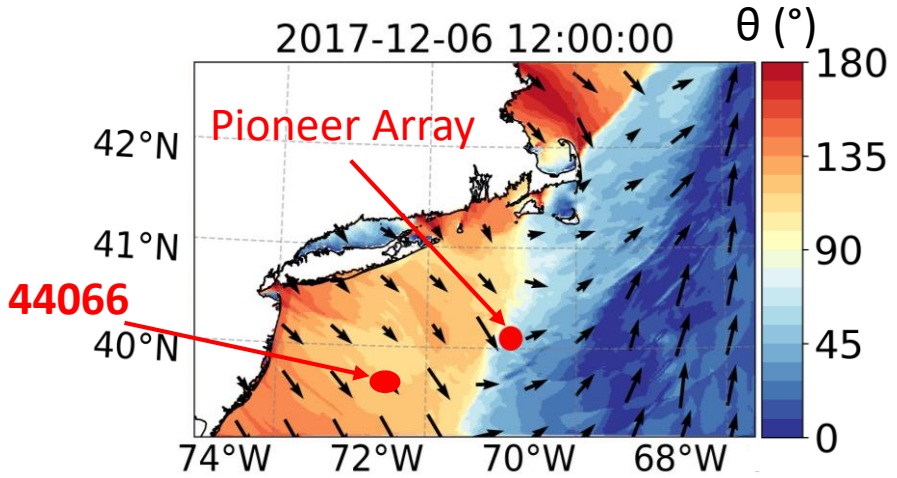
Wave Directional Spectrum

Comparison of wave spectrum energy density at different NDBC moorings against our coupled model.





Strong southerly waves aligned with the wind in the pre-cold-frontal conditions.

While the wind shifted to northerly, strong southerly waves were still present leading to strong misalignment during the post-cold-front conditions.

To be noted that after the cold front, younger waves are generated following the northwesterly wind, contributing to the mixed sea state conditions.

COARE v3.5

Momentum flux :

$$\tau = \rho u_*^2 = \rho C_D \Delta U^2$$

COARE 3.5 Wave based formulation (**WBF**) (Edson et al. 2013)

$$z_{rough} = H_s \cdot 0.09 \cdot \left(\frac{u_*}{C_p}\right)^2$$

→ Assumes waves aligned with winds

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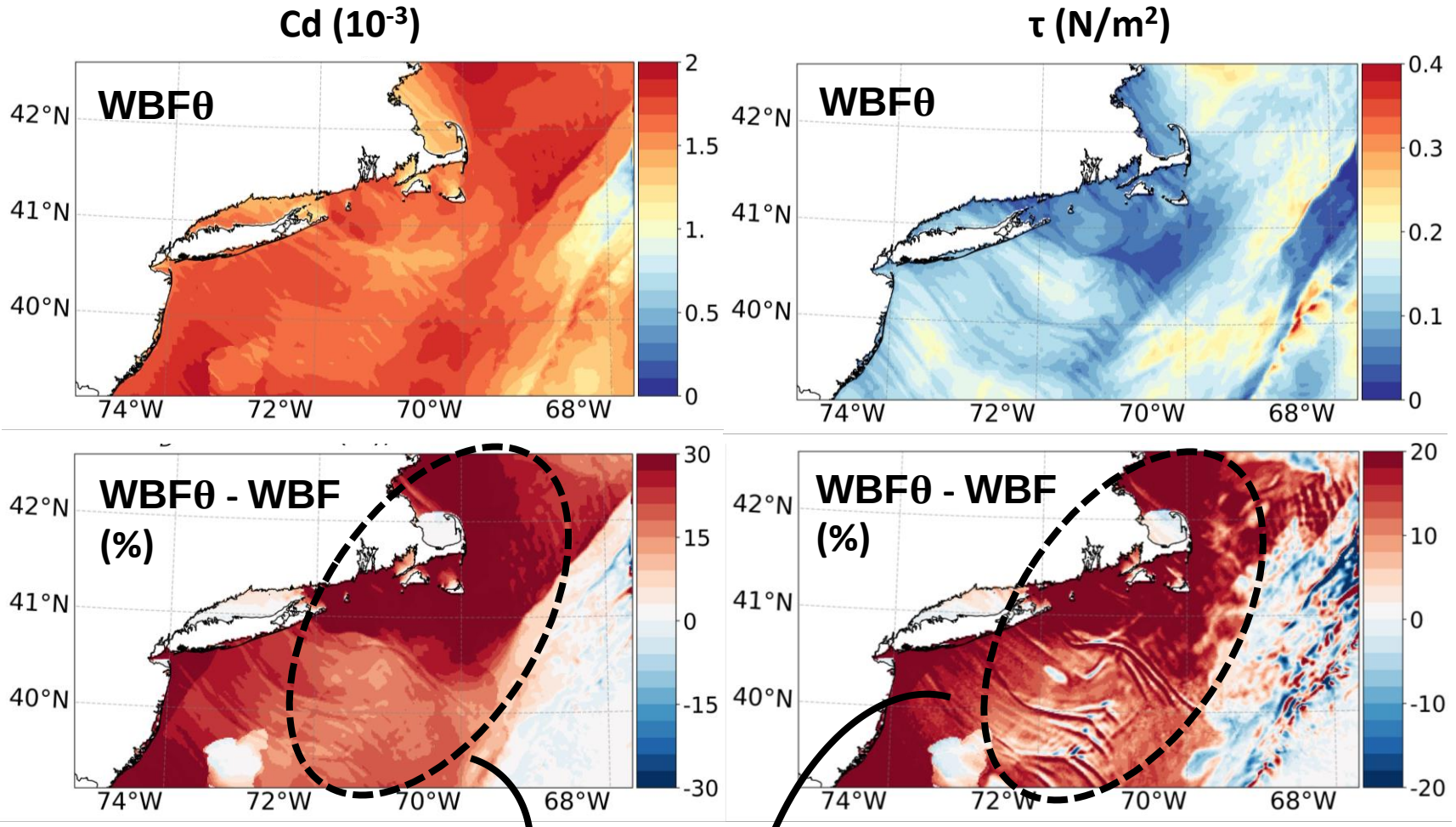
Modified COARE 3.5 Wave based formulation (**WBF**θ)
(Porchetta et al 2019, Sauvage et al. 2023)

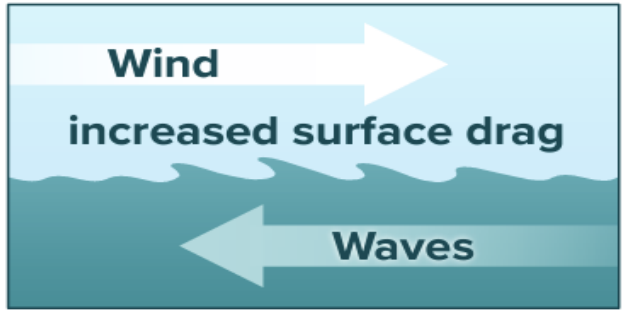
$$z_{rough} = H_s \cdot 0.09\cos(0.4\theta) \cdot \left(\frac{u_*}{C_p}\right)^{2\cos(-0.32\theta)}$$

→ Takes into account wind and wave misalignment

Misaligned waves impact on momentum flux

2017-12-06-15:00





Surface drag coefficient and momentum stress increase by 20% and 11% on average behind the cold front

Misaligned waves impact on momentum flux

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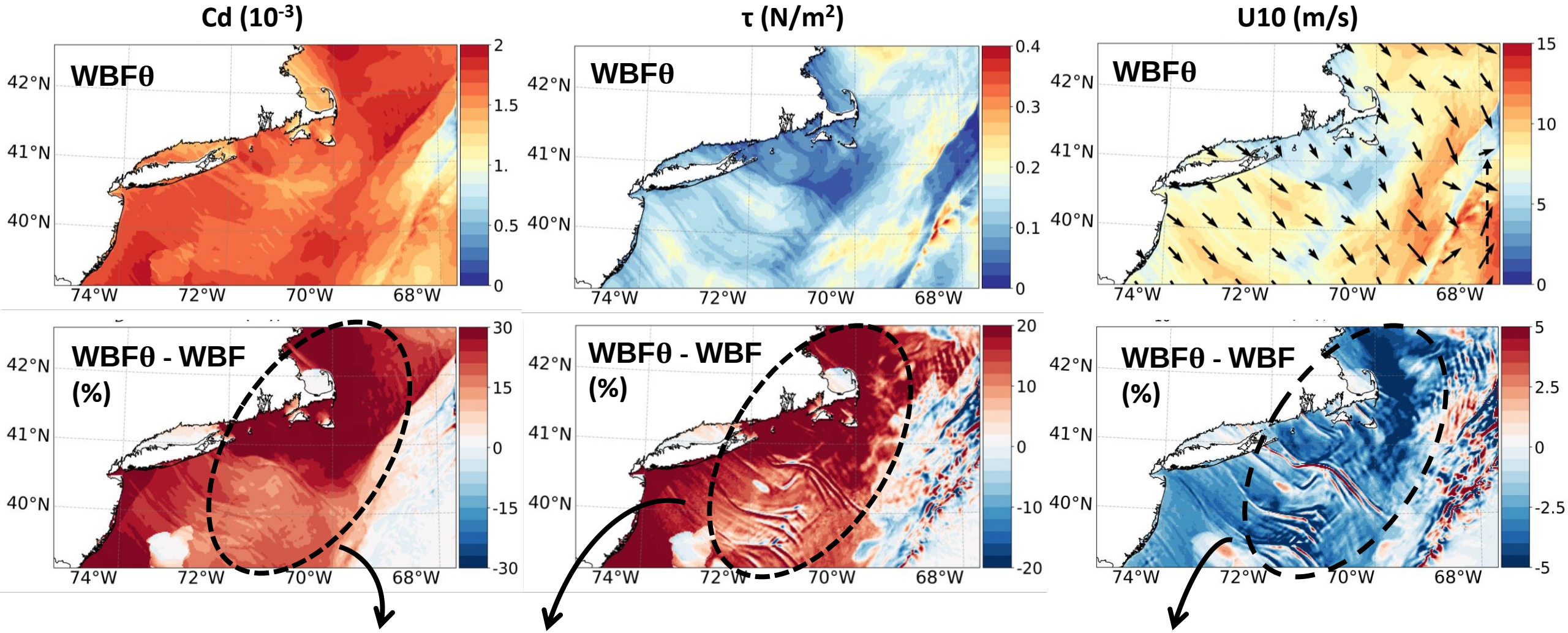
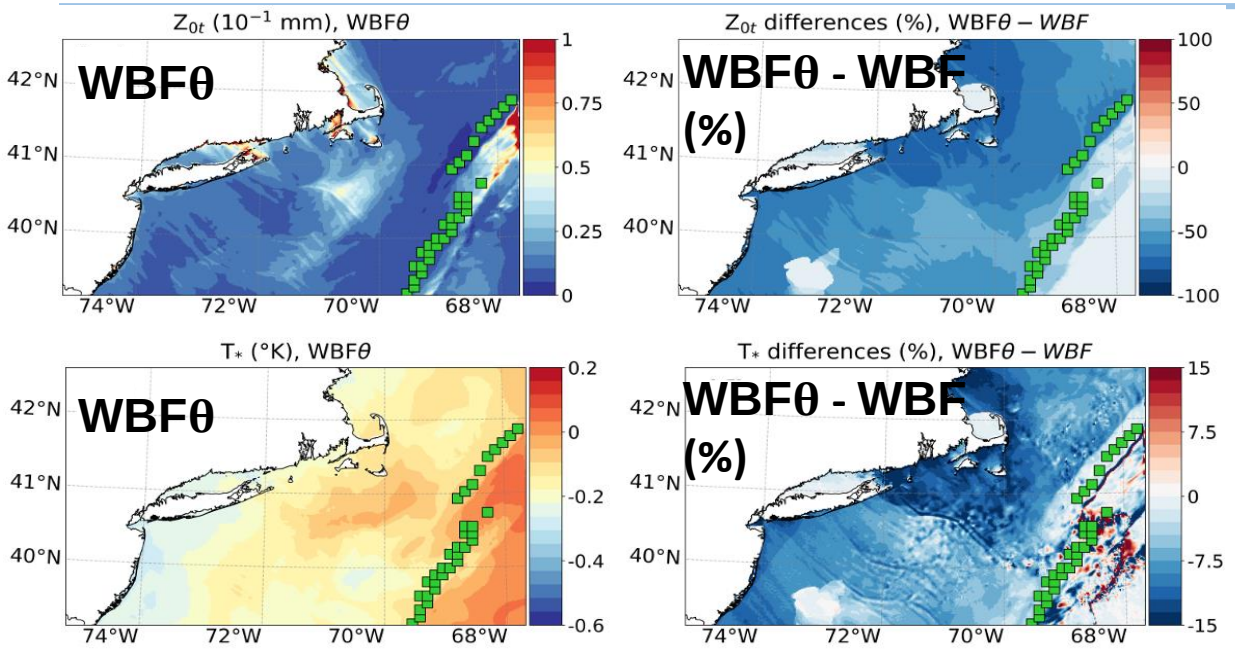


Surface drag coefficient and momentum stress increase by 20% and 11% on average behind the cold front

Direct impact on the surface wind speed which decreases by 2% on average

Misaligned waves impact on heat fluxes



$$H_s = -\rho_a C_{pa} u_* T_*,$$

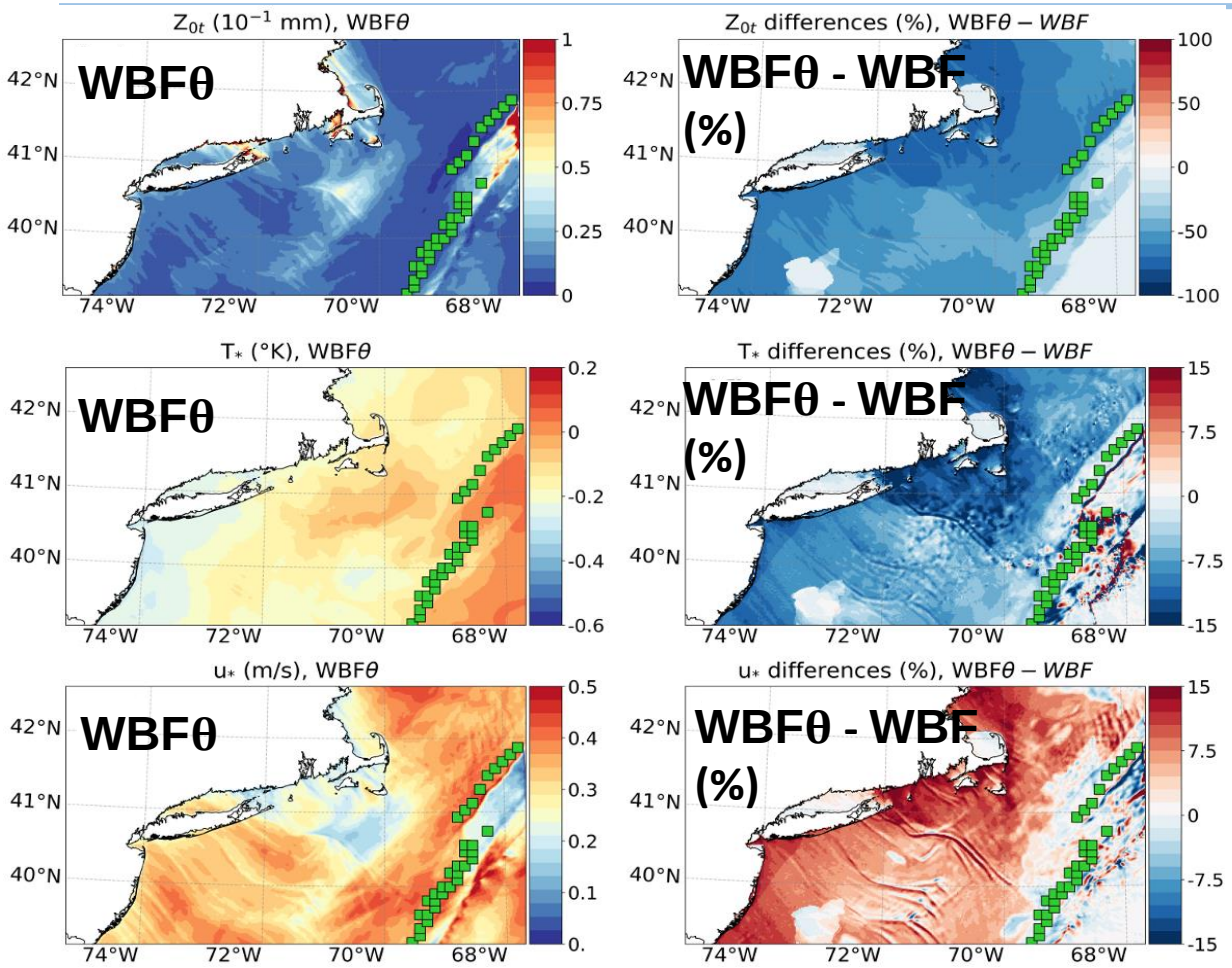
$$H_l = -\rho_a L_e u_* q_*,$$

$$R_r = \frac{u_* z_0}{\nu}, \quad z_{0t} = \frac{5.8e^{-5}}{R_r^{0.72}},$$

The scalar roughness Z_{0t} is decreased by 60%, leading to a decrease of T_*.

Cold front location

Misaligned waves impact on heat fluxes



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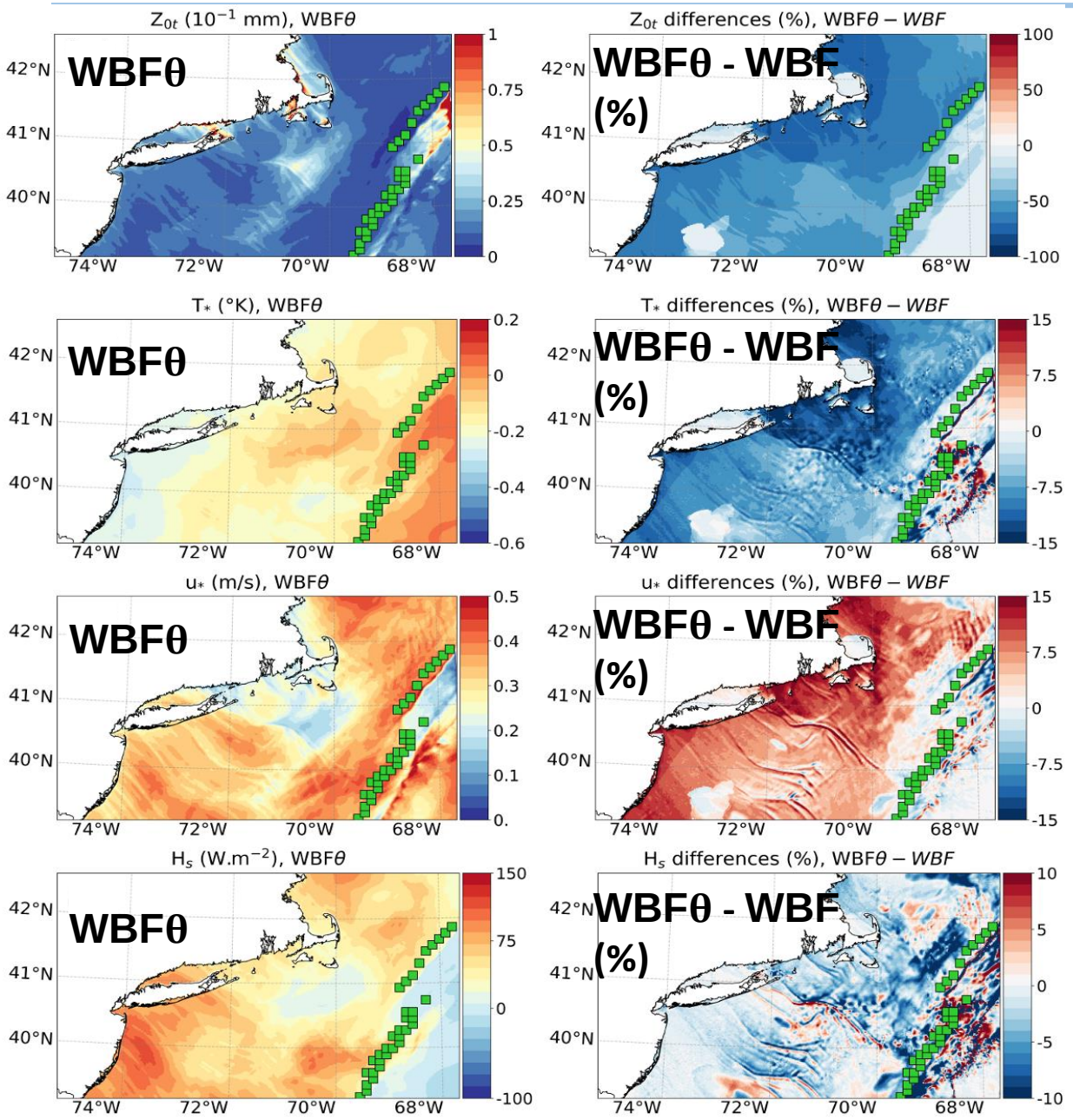

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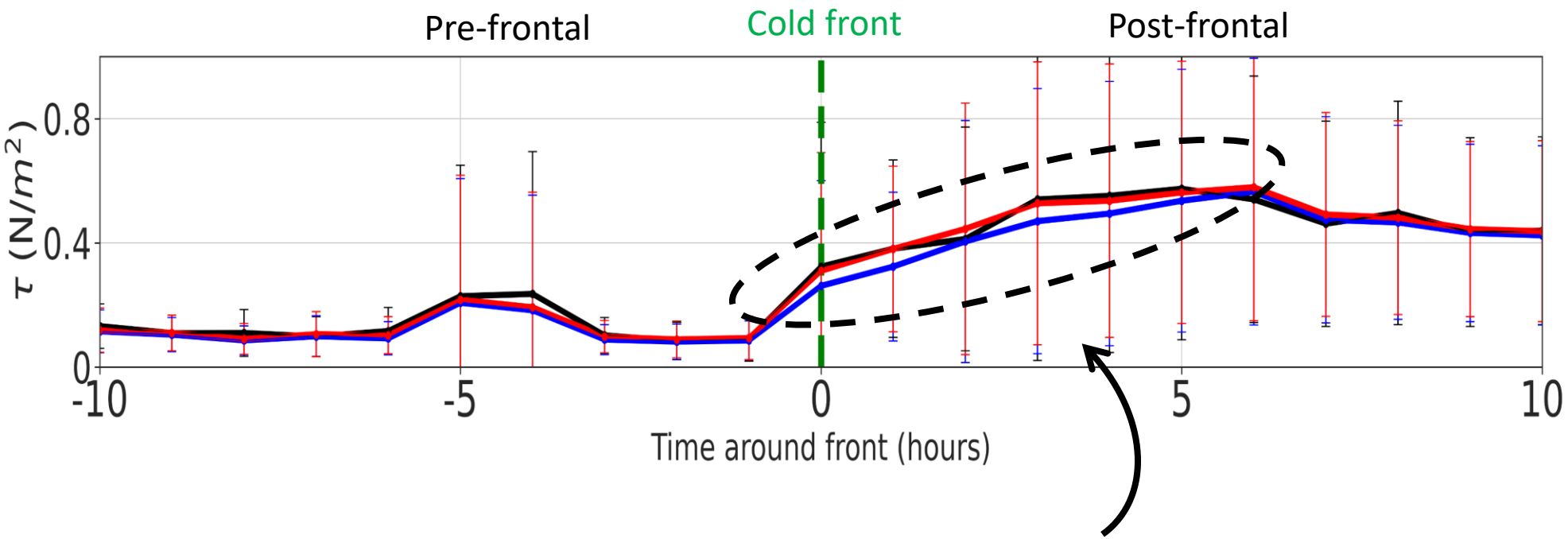
The increase of u* is of similar magnitude.

The overall effect on heat fluxes is generally small, reduced in average by 2~3%.

Cold front location

Direct covariance flux system measurements at Pioneer Array

20 atmospheric cold fronts detected during the period when momentum flux observations are available.



Using **WBF** $\boldsymbol{\theta}$ generally increases the flux by 7% (up to 16%) in case of strongly misaligned waves after the cold front.

Taking into account misalignment generally reduces the bias from -4.8% in **WBF** to 1.7% in **WBF** $\boldsymbol{\theta}$.

Conclusion

Sauvage et al. (Submitted)
"Misaligned wind-waves behind atmospheric cold fronts."

→ Atmospheric cold fronts lead to large areas of mixed sea conditions misaligned with local wind

→ On average waves can stay misaligned for 5 to 10h after the passage of the cold front

→ Surface drag and momentum are increased over the strongly misaligned waves

→ Taking into account misalignment in the flux parameterization generally reduces the bias compared to observations

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→ Taking into account misalignment in the flux parameterization generally reduces the bias compared to observations

→ Keep working toward a better understanding of the misalignment in different wind waves regimes (i.e., high wind regimes, cross-swell vs opposed swell…)

→ Need more long-term co-located observations (wind, waves, air-sea fluxes) like the Pioneer Array

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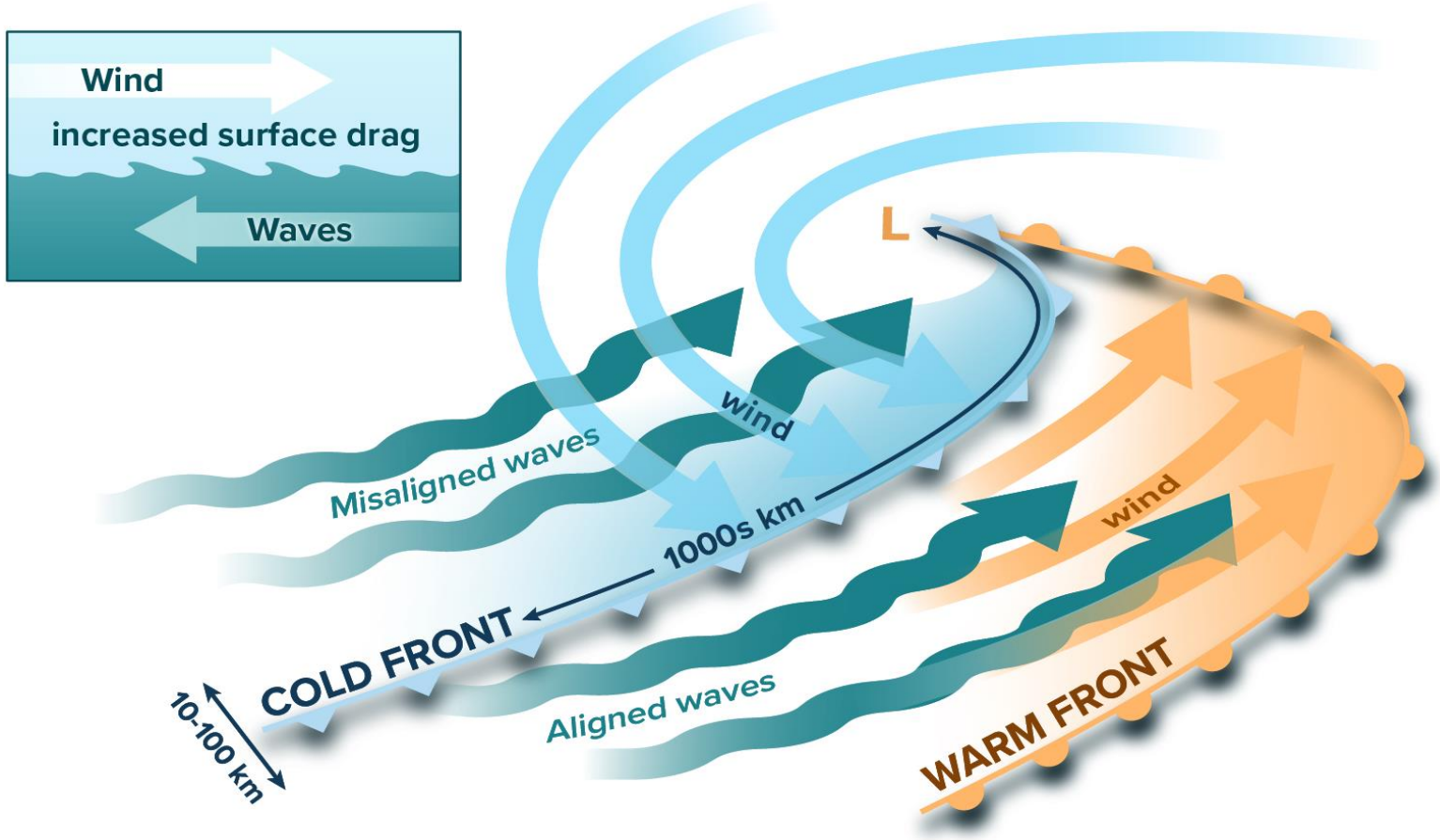

Thanks !

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Supplementary Figures

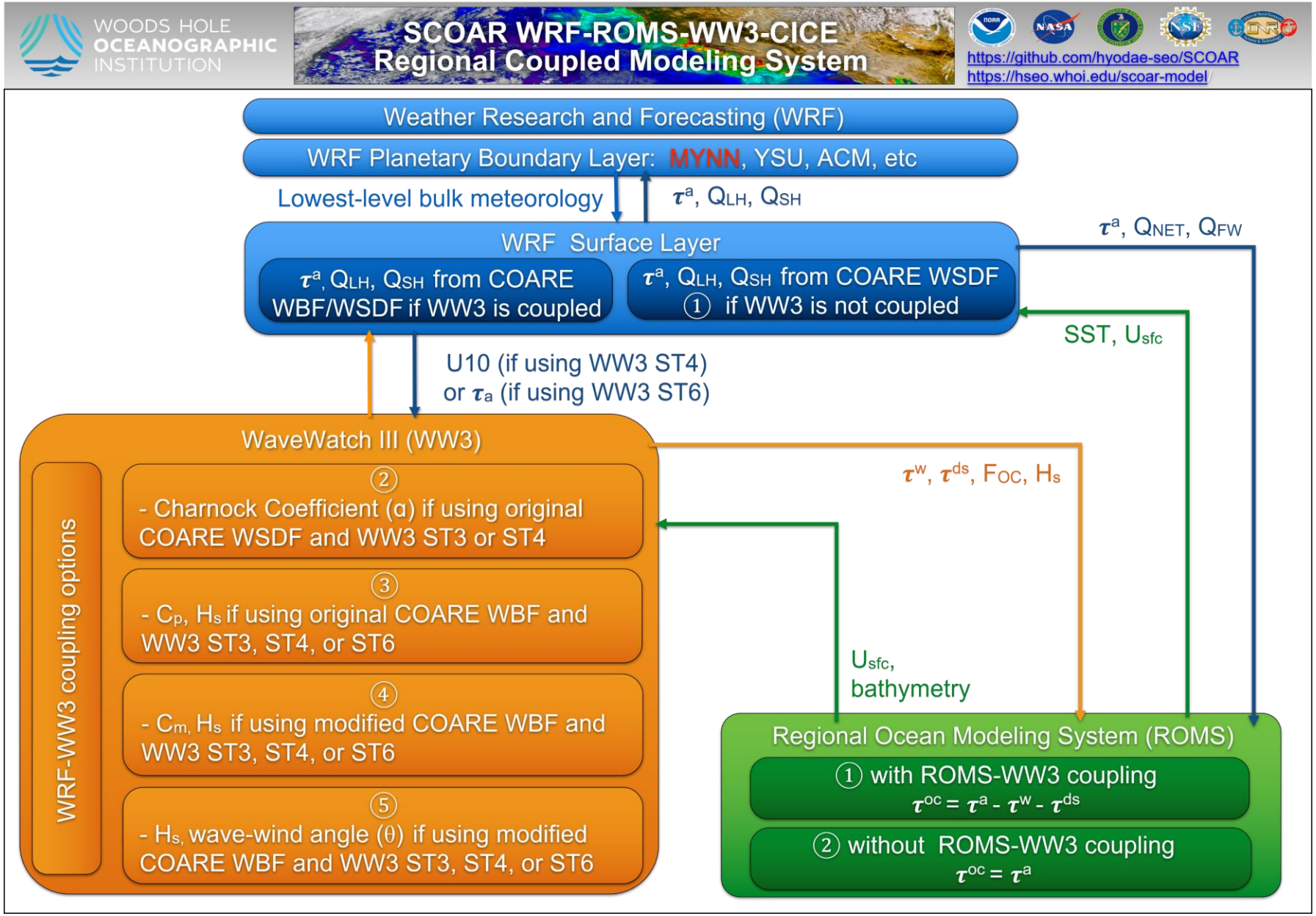
Coupling frequency 1h
Horizontal resolution : 1.5 km
(7.5 km for OUTER domain)

Boundary forcing:

Atmospheric forcing:
hourly ERA5

Ocean forcing:
Daily Mercator Ocean Inter.

Wave forcing:
3-hourly spectral points
(Ifremer global runs)



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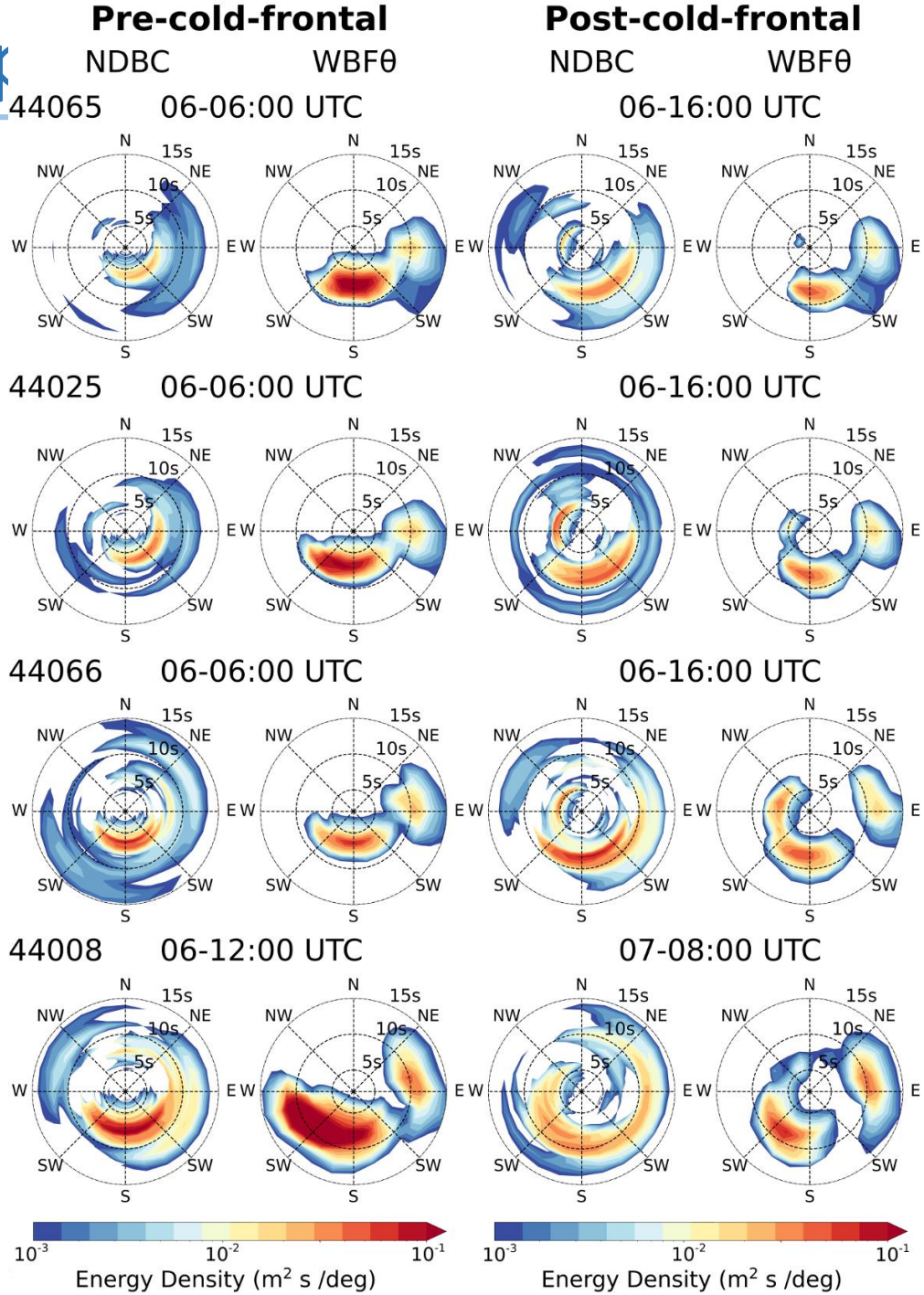

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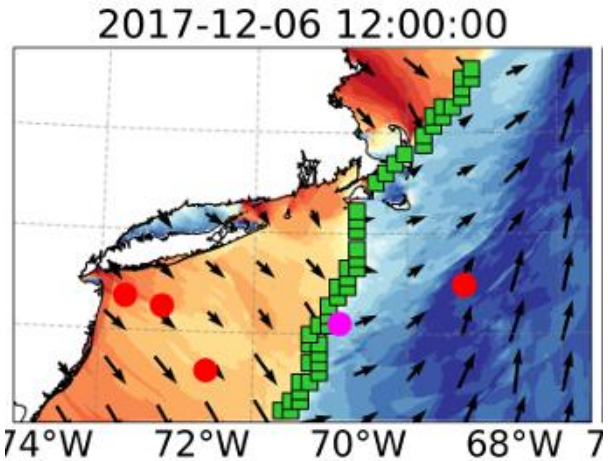
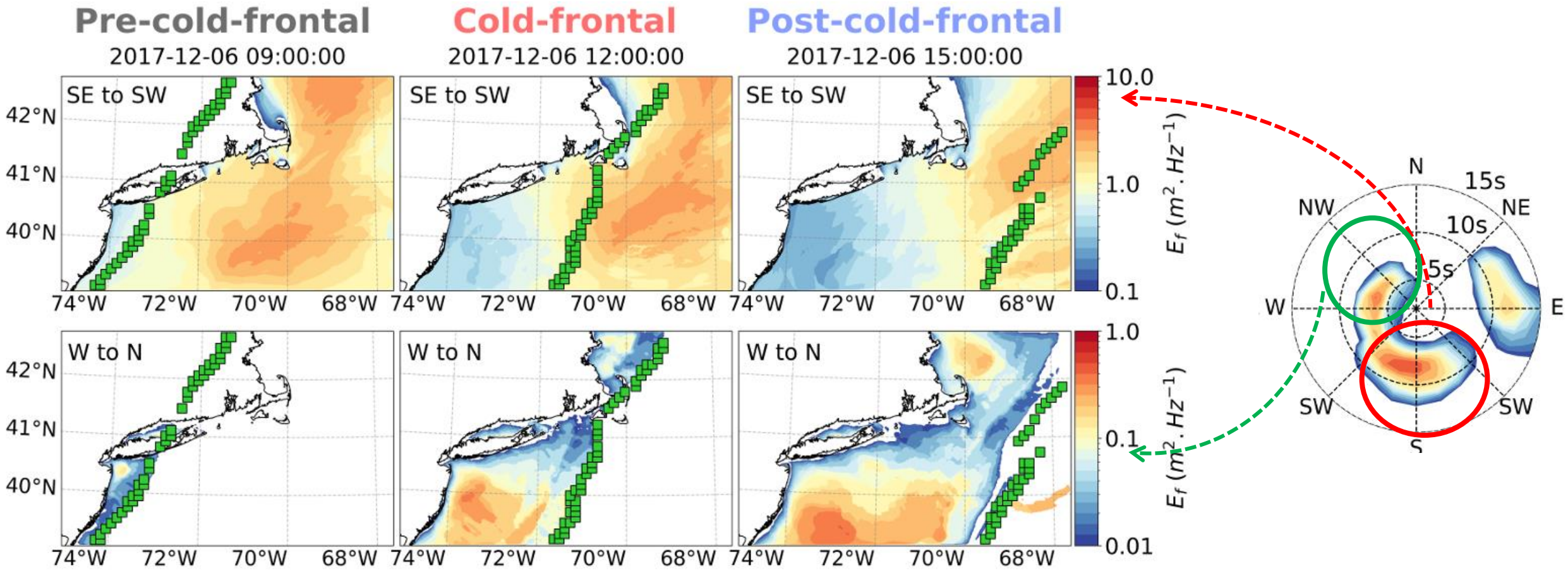
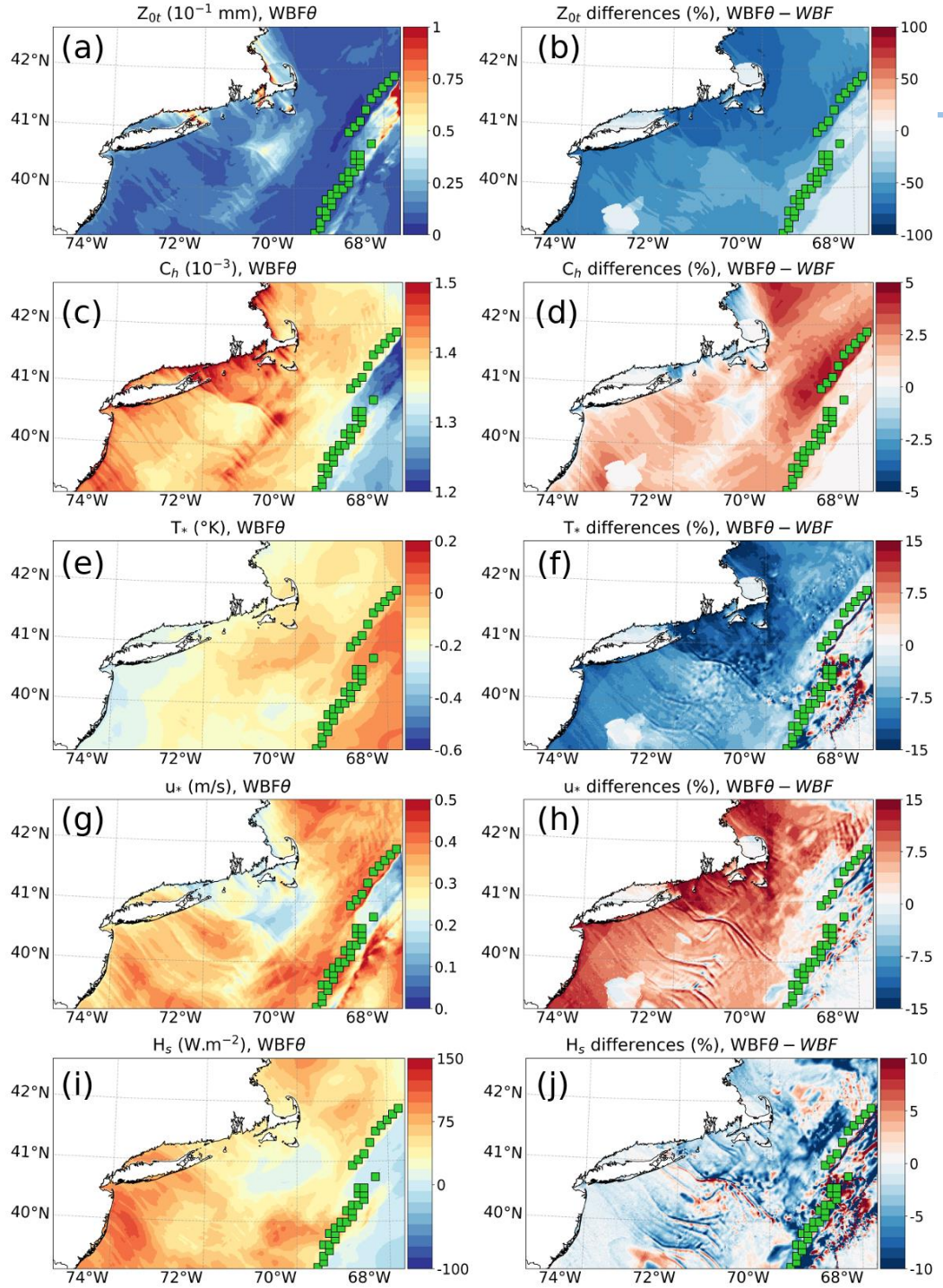


Wave Spectrum Energy Density



Cold front location



Supplementary Figures

The surface exchange coefficients are increased by up to 5% behind the cold front.

The effect on heat fluxes is generally small, reduced in average by 2~3%.

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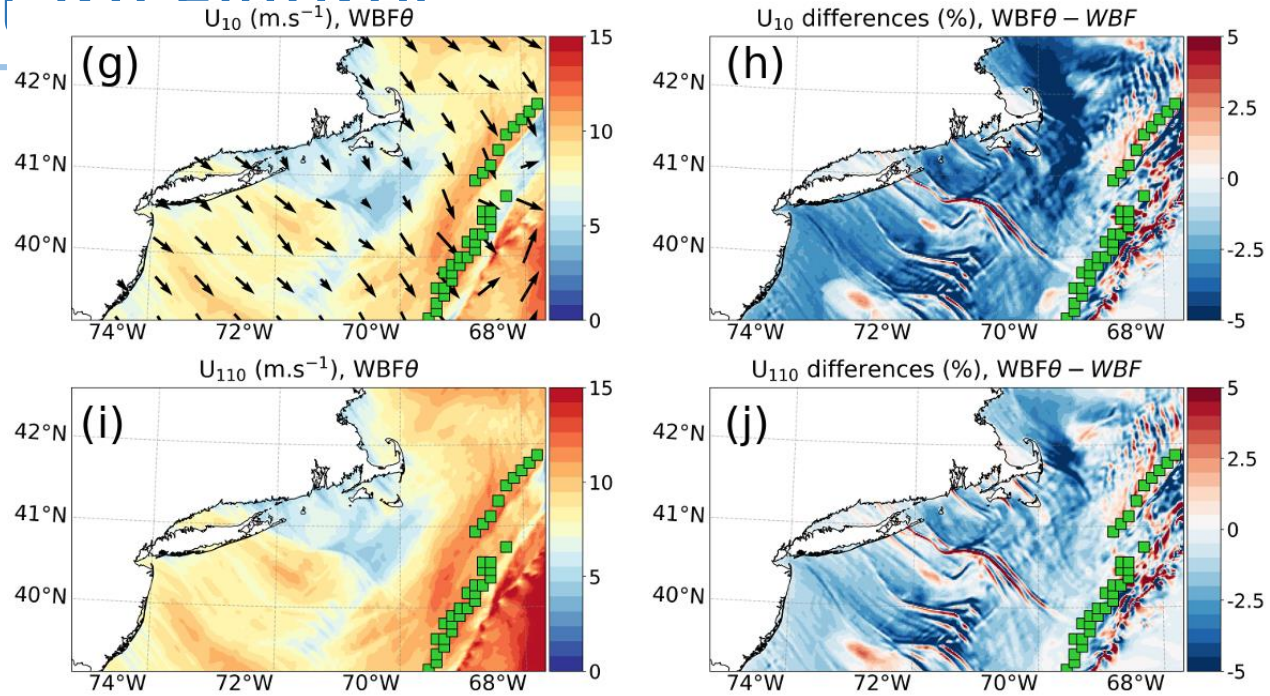

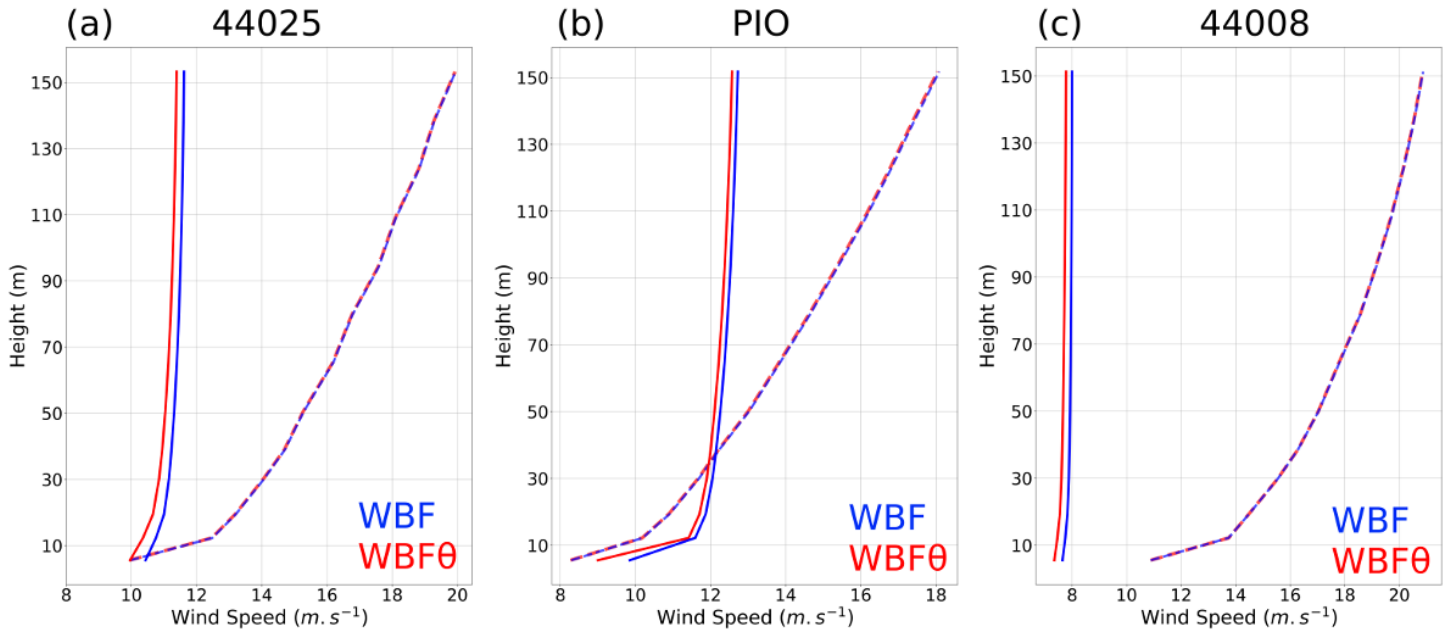

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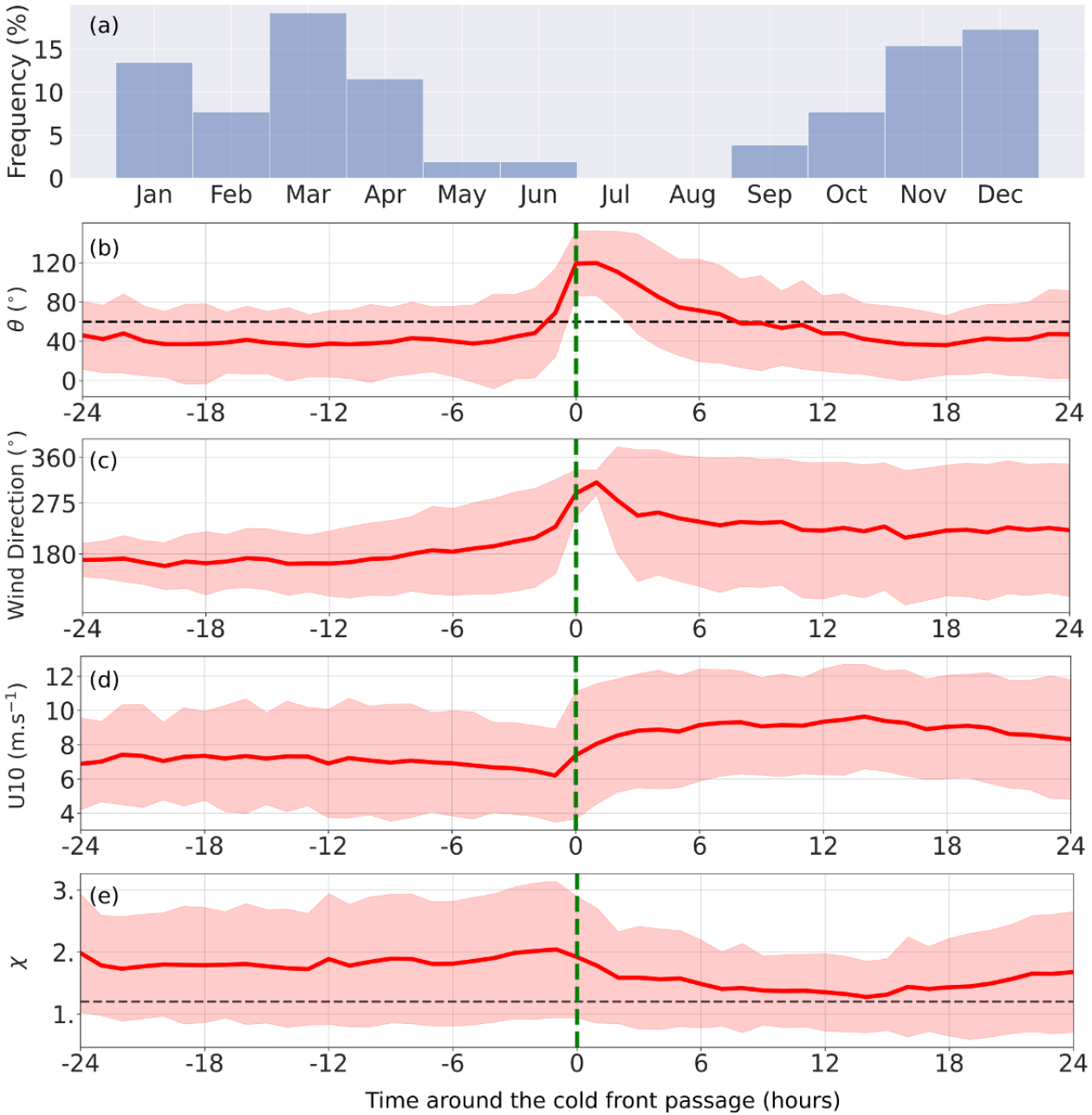

Most of the cold fronts occur during the extended winter months, November-March

70% of the detected cold fronts lead to strongly misaligned waves.

Waves can stay misaligned between 5h to 10h after the passage of the cold front.
(depending on the chosen threshold to define alignment vs misalignment)

Supplementary Figures