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# Global Distribution, Prevalence, and Severity of Crossing Sea States

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# Wave Breaking in Crossing Seas



*“[In crossing seas] breaking becomes less crest-amplitude limiting for sufficiently large crossing angles and involves the formation of near-vertical jets”*

M. L. McAllister et al., 2019

# Wave Breaking in Crossing Seas



## Experiments

FloWave Circular Basin  
Shanghai Jiao Tong

## Numerics

University College Dublin  
Boundary element method

## Theory

Limiting steepness in crossing seas  
Extreme value distribution

## Implementation

ECMWF partnership  
Spectral model dissipation



UK Research  
and Innovation

# Aim

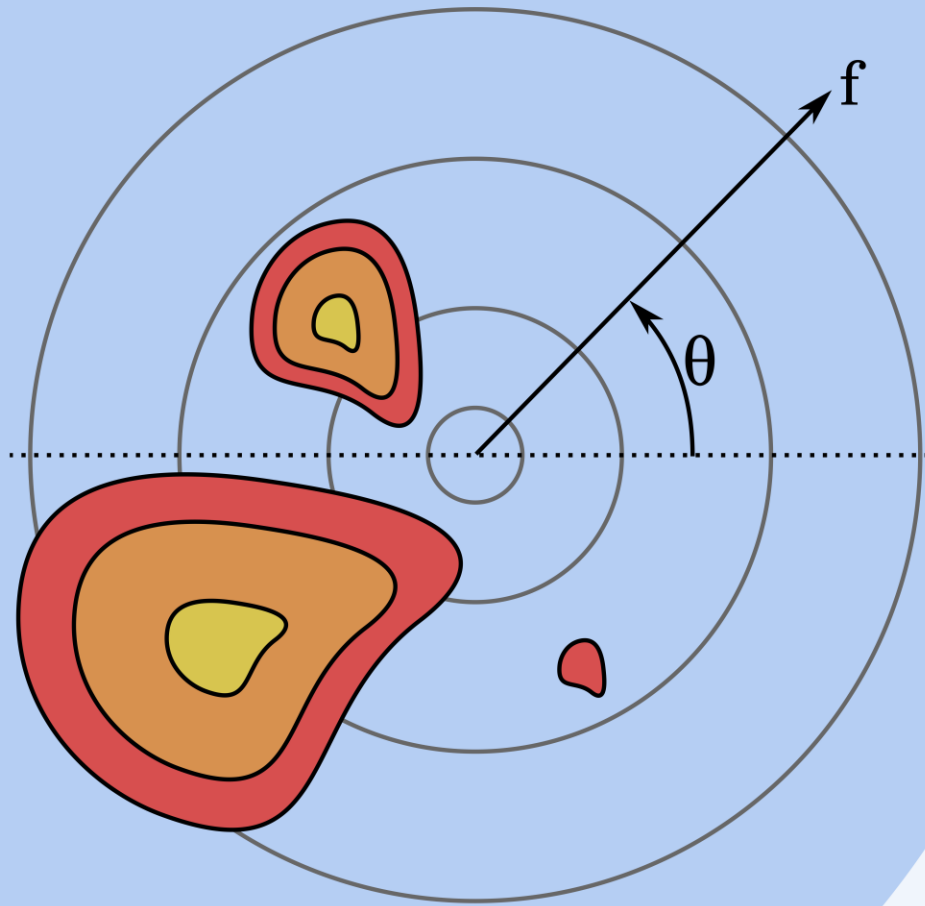


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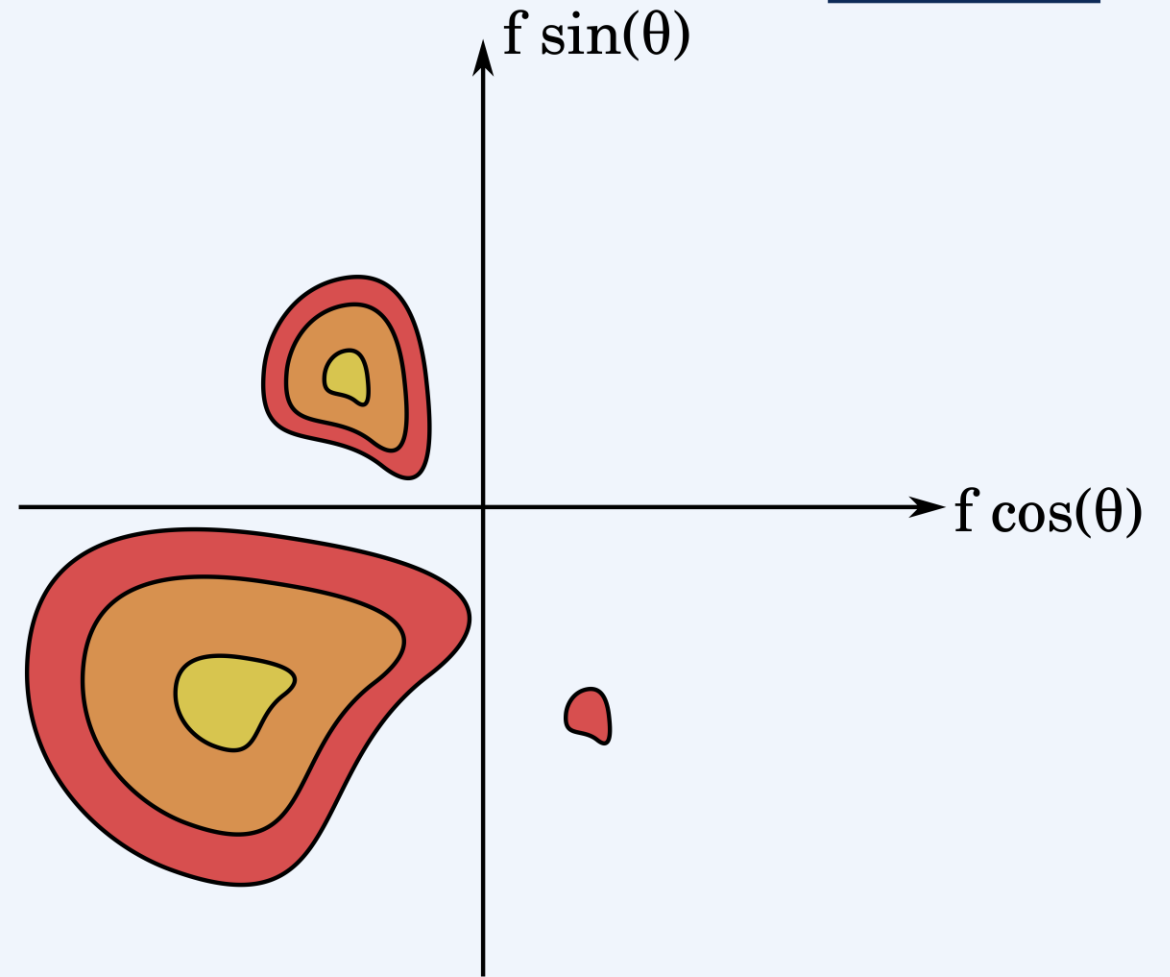
*Determine the conditions conducive to the formation of extreme waves in crossing seas*

- 1** Definition of directional seas
- 2** Characteristics of directional seas
- 3** Model to satellite comparison
- 4** Extreme crossing sea states

# The Directional Energy Spectrum



Polar coordinates

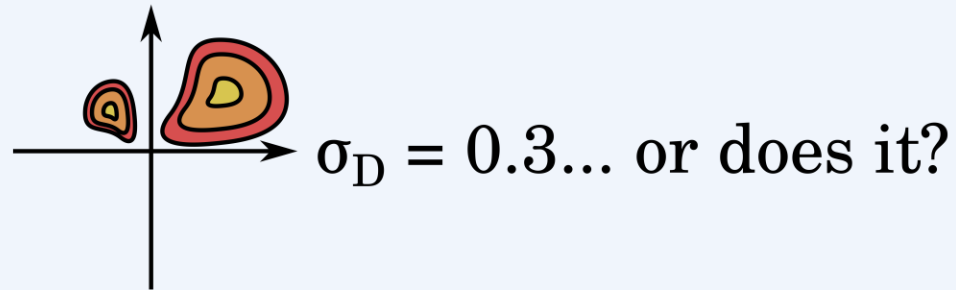


Cartesian coordinates

# Characterising Directionality

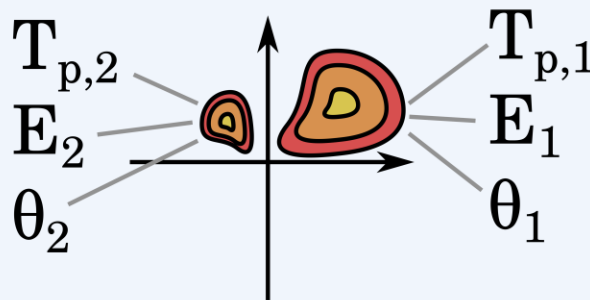
**Integrated:** Single value of directionality from a full spectrum

- Quick, simple, but somewhat ambiguous



**Segmented:** Split spectrum into segments and compare their integrated properties

- Allows delineation between high spreading and crossing



**Algorithmic:** Markov Chain algorithms, (Lucas, 2011)

An Aside,  $\sigma_\theta = \sqrt{2(1 - R)}$ ,

### Definition within ERA5

- Integral of directional widths about each frequency's mean direction

$$R = \frac{\int_0^\infty \int_{-\pi}^\pi \cos(\theta - \bar{\theta}(f)) F(f, \theta) d\theta df}{E}$$

### Definition within WAVEWATCH

- Directional width about a global mean direction

$$R = \left| \frac{\int \int_{-\pi}^\pi F(f, \theta) e^{i\theta} d\theta df}{E} \right|$$

# Bimodal Definition

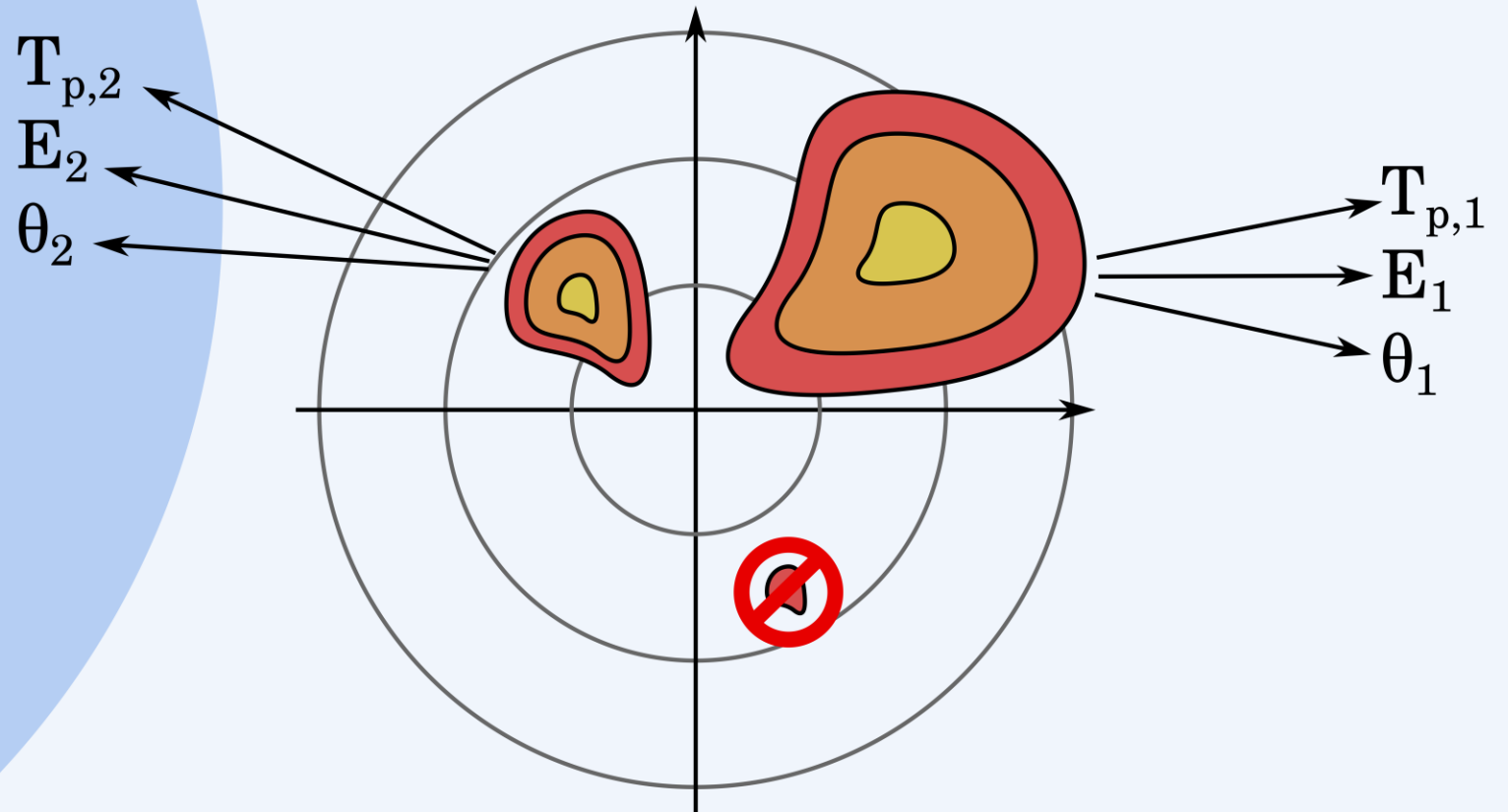
**Unimodal/Bimodal**

$$E_1 + E_2 > 0.99 E_{\text{all}}$$

**Multimodal**

Others

## Bimodal Energy Spectrum

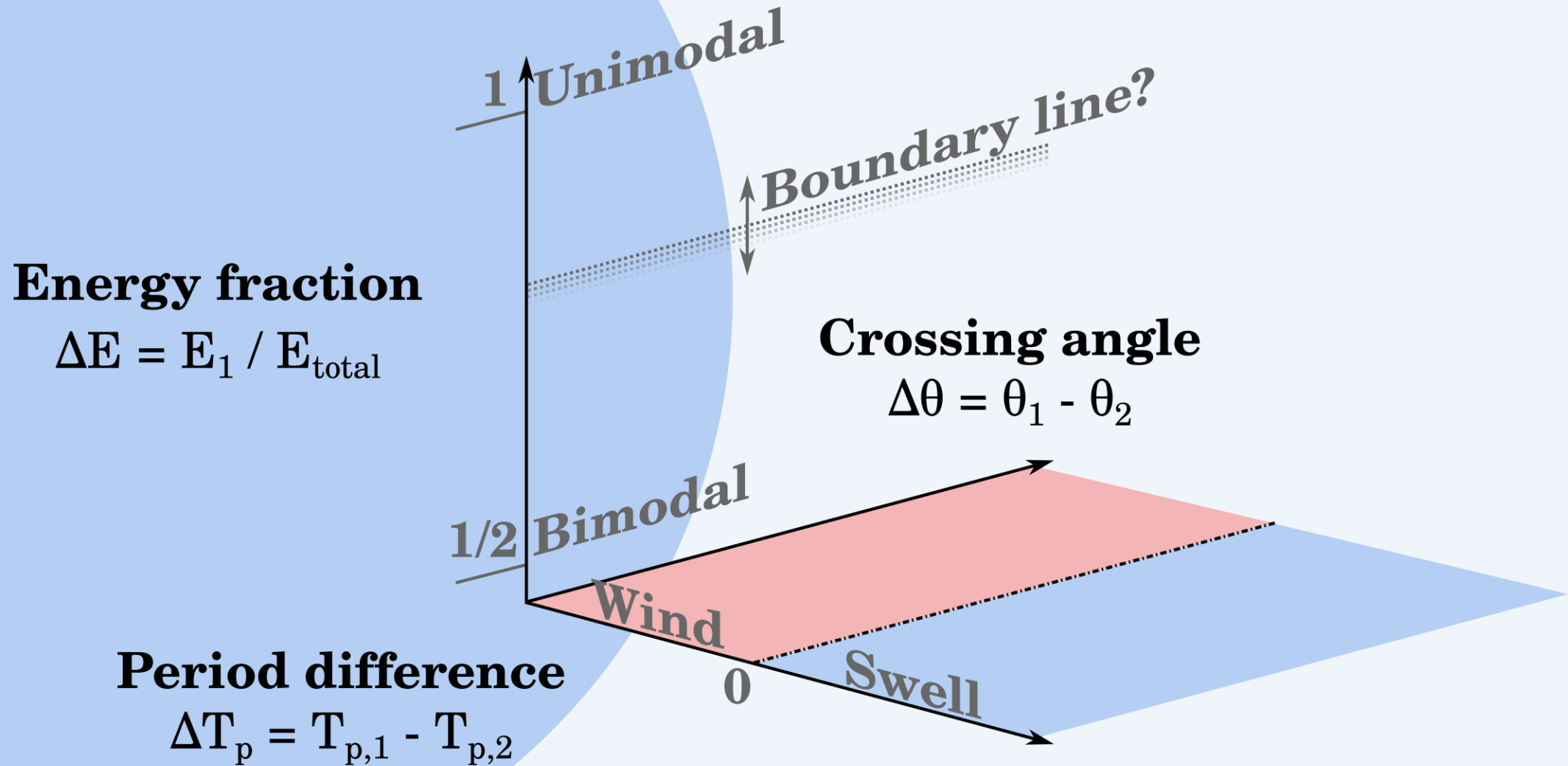




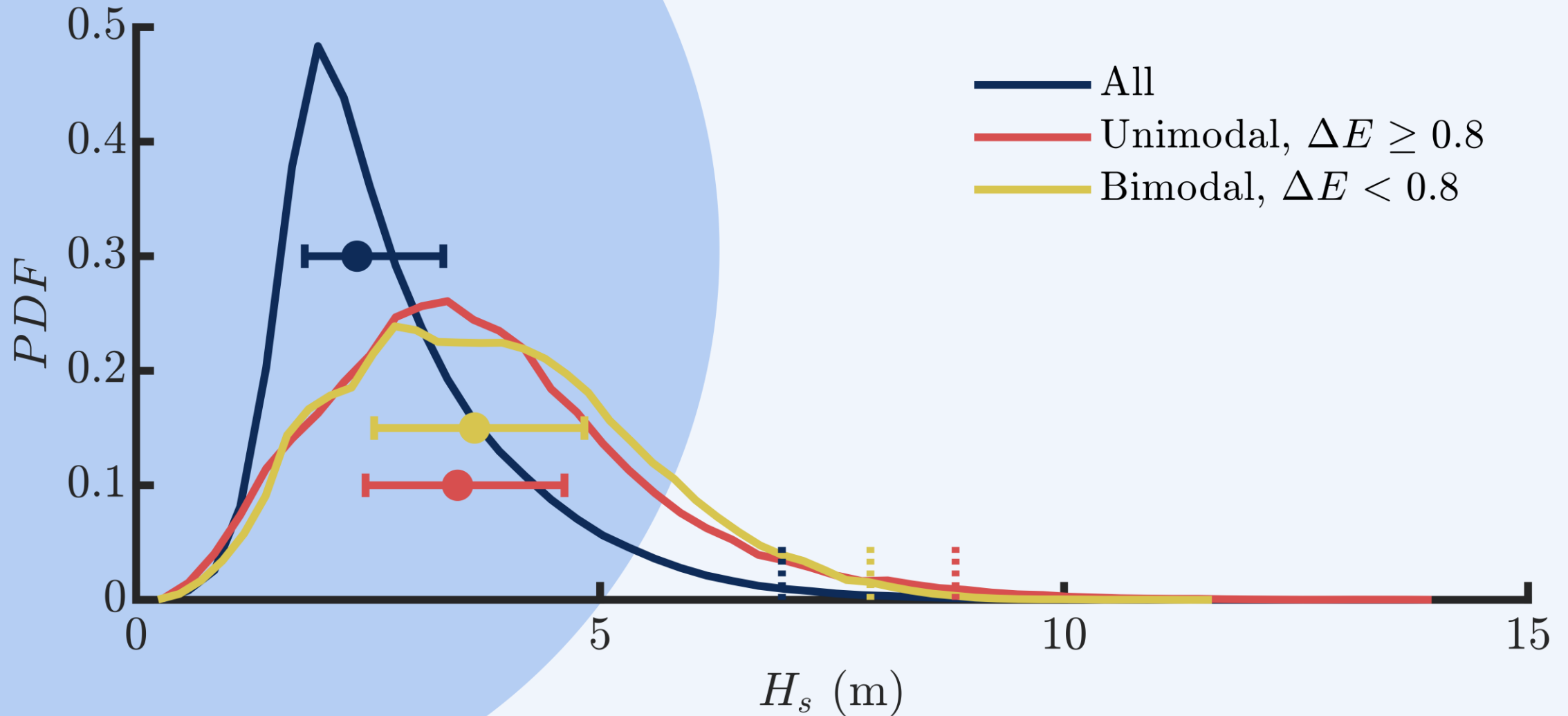
# Bimodal Space



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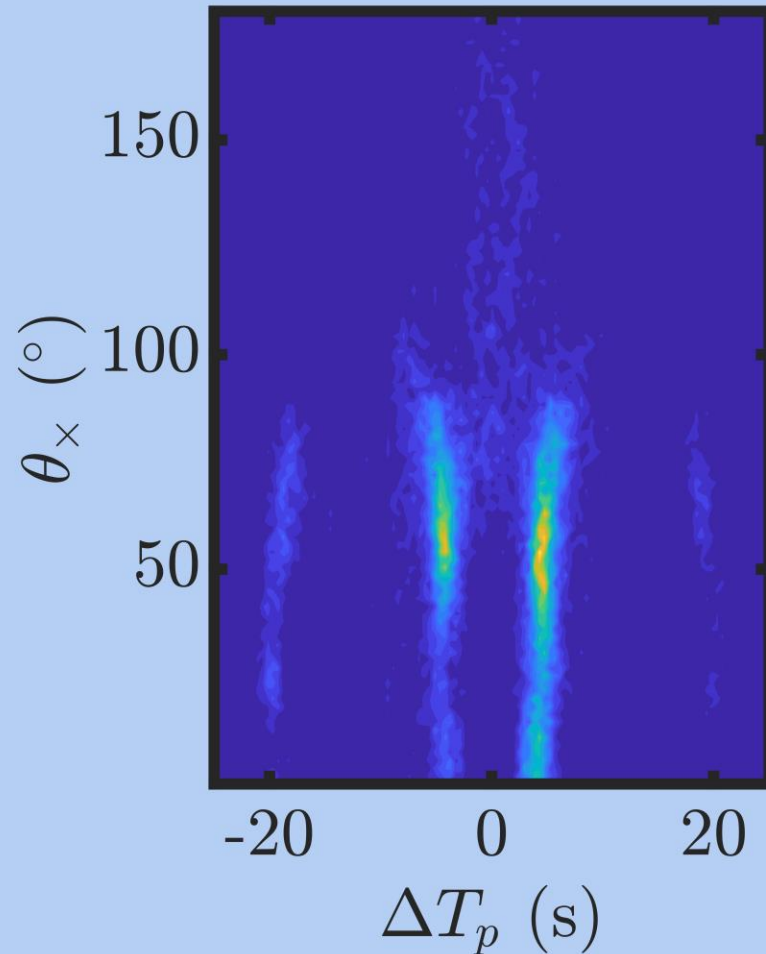


# Sea State Characteristics

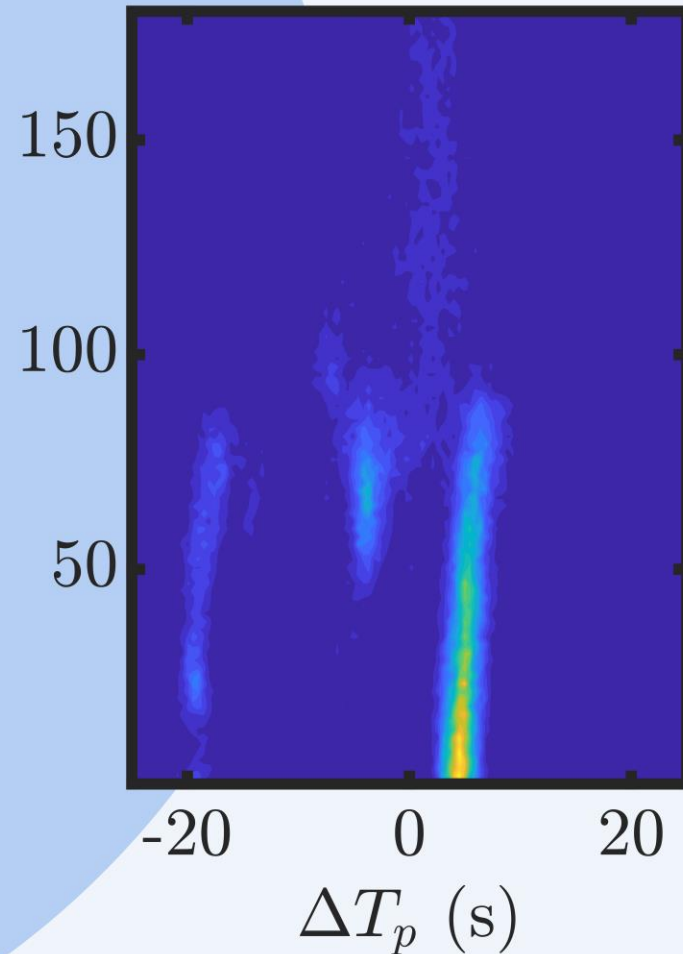


# Bimodal Sea Population

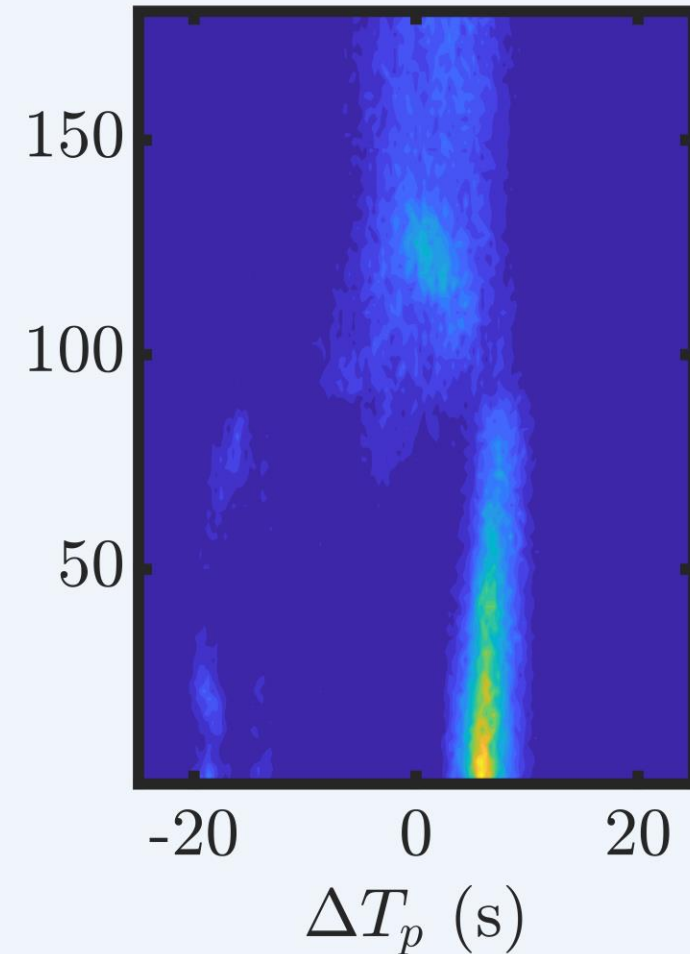
$\Delta E < 0.6$ , 15%



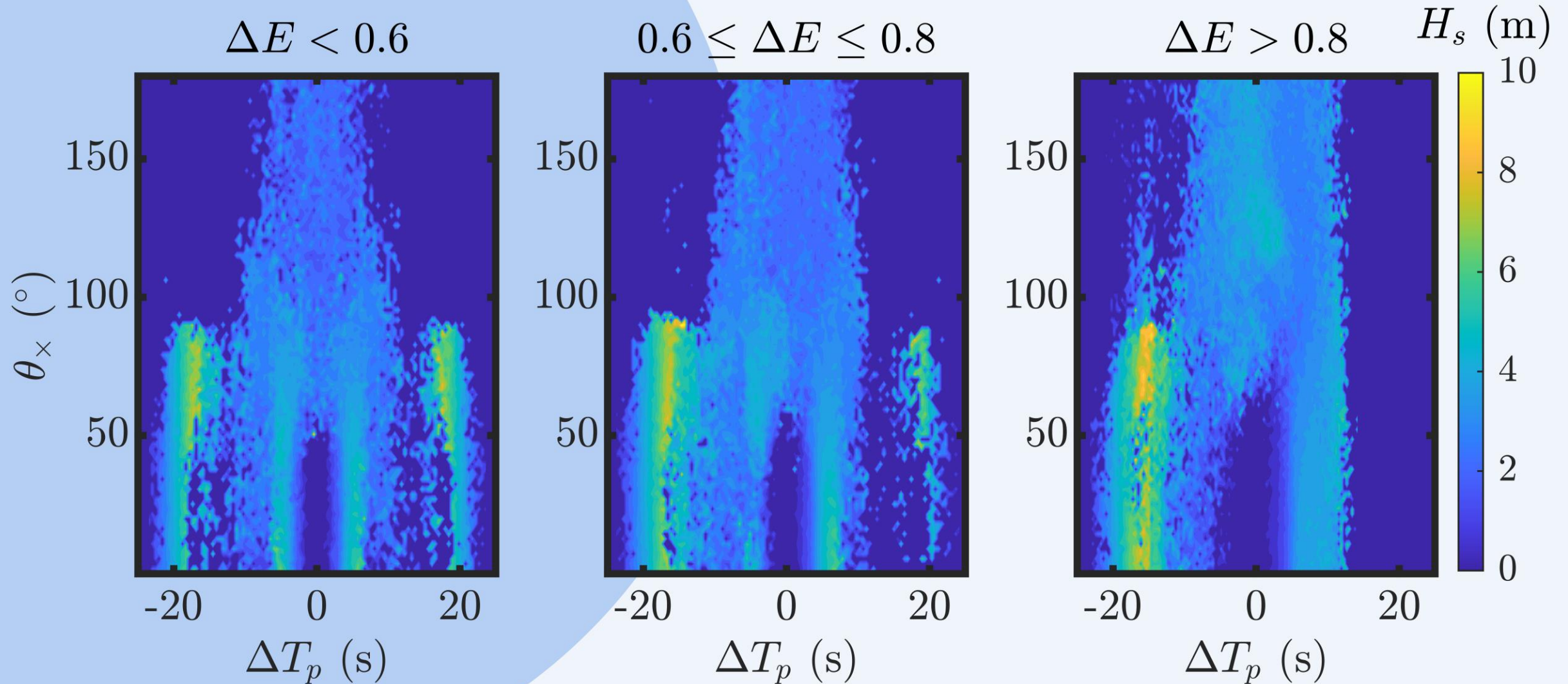
$0.6 \leq \Delta E \leq 0.8$ , 32%



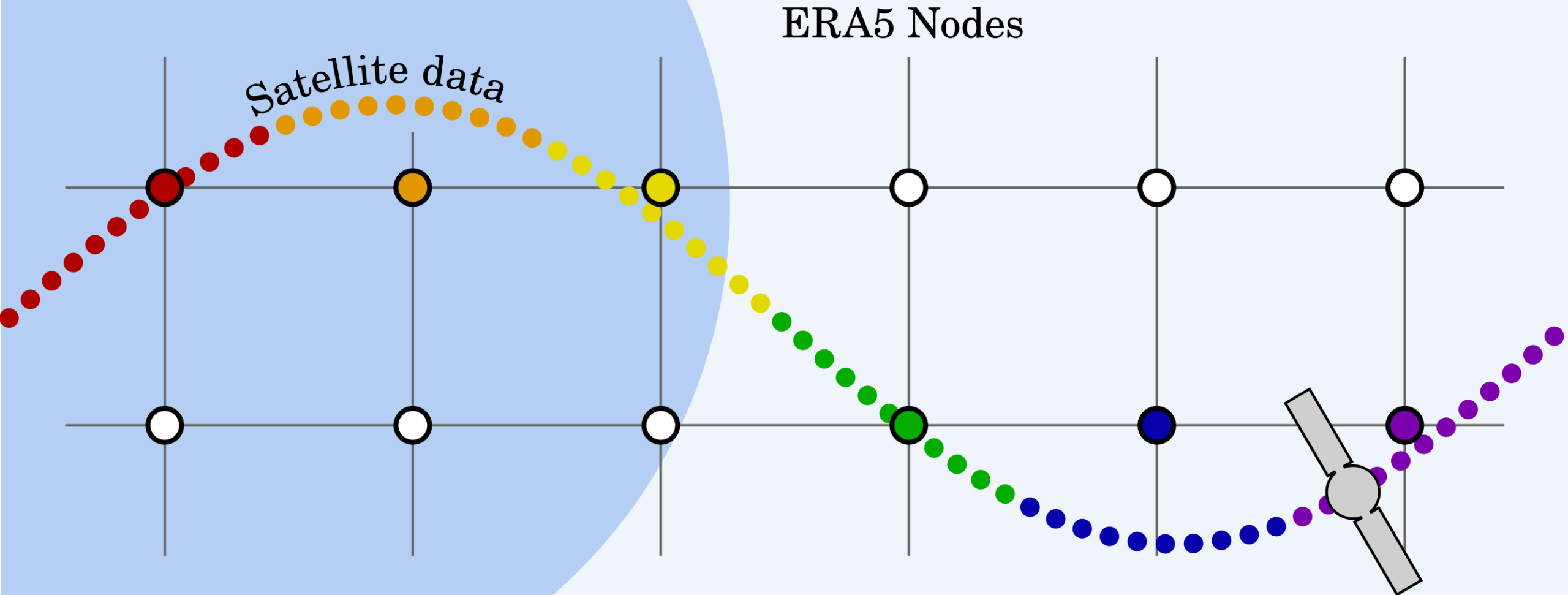
$\Delta E > 0.8$ , 53%



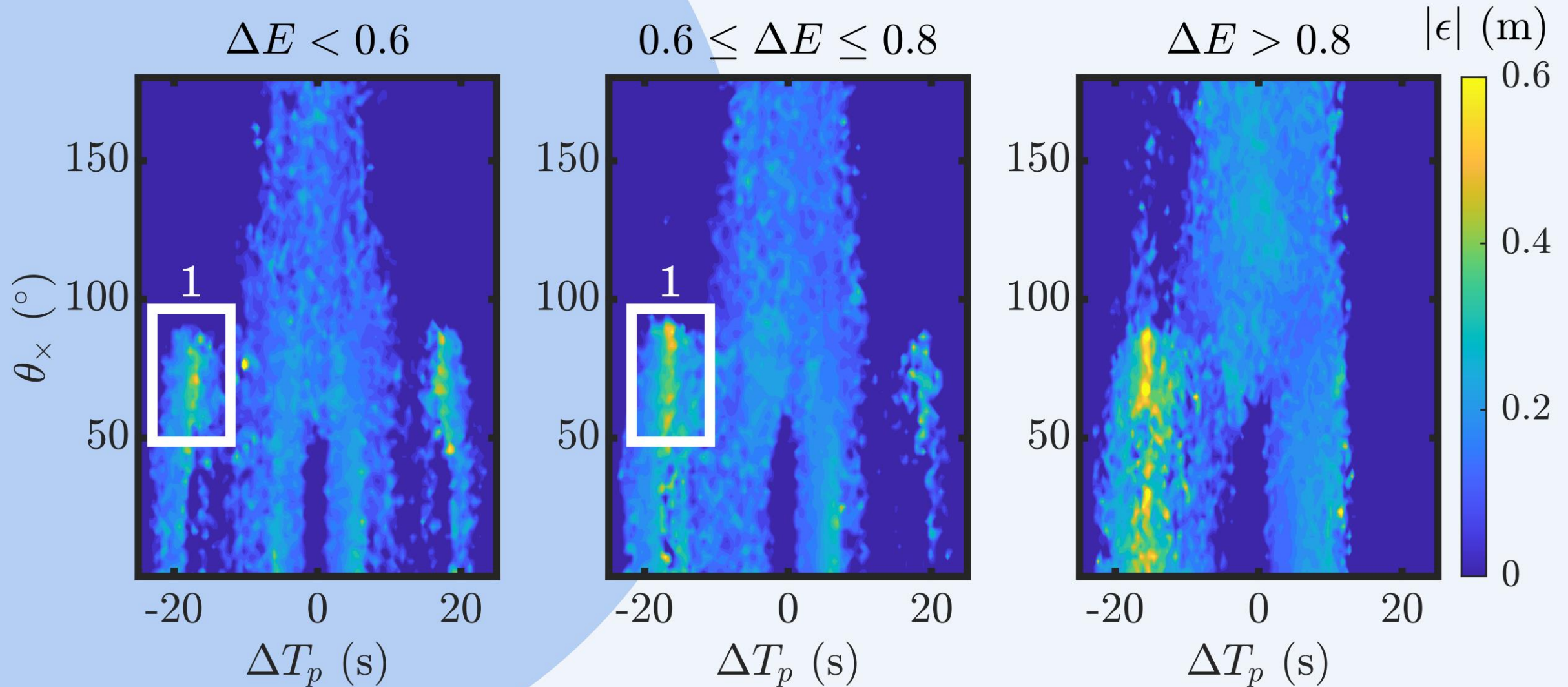
# Bimodal Sea Wave Height



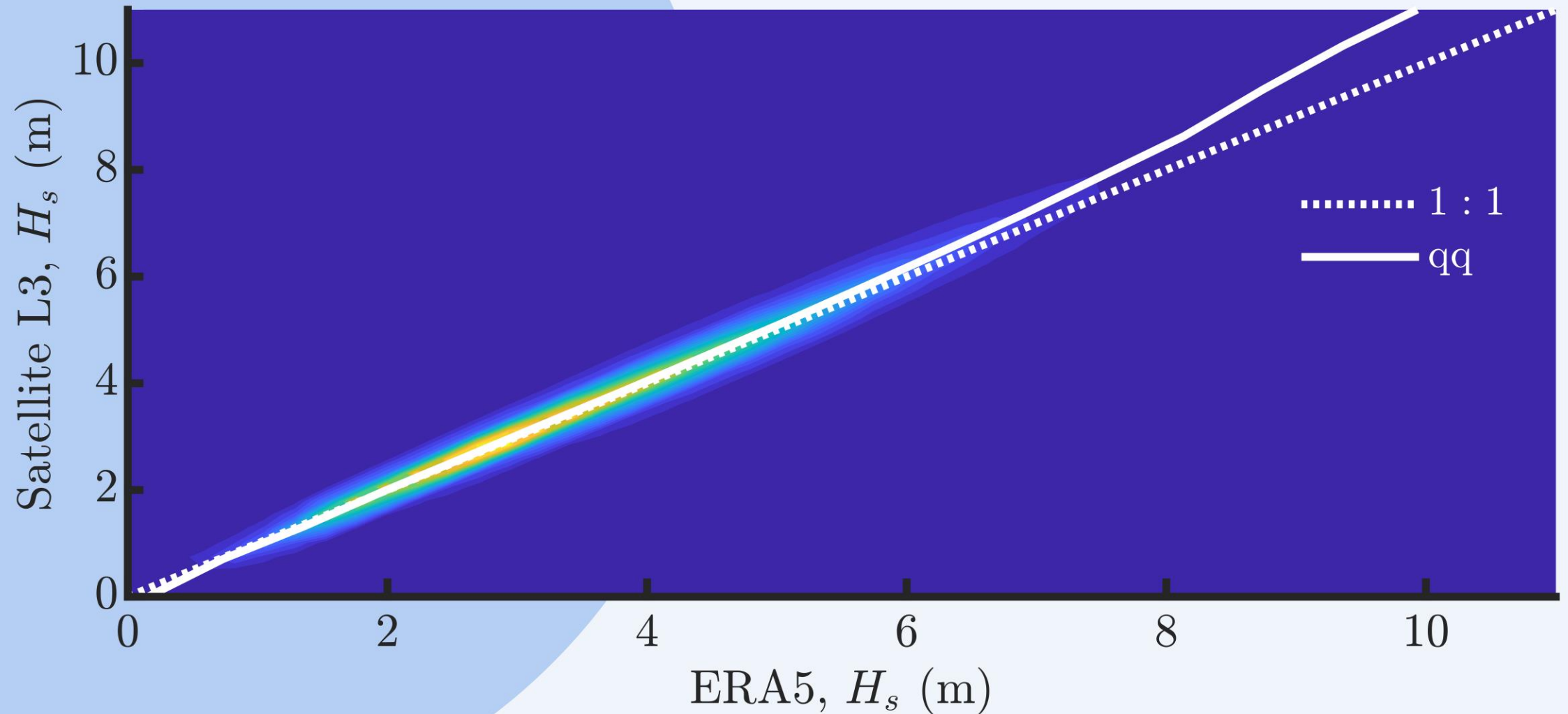
# ERA5 - Satellite Comparison



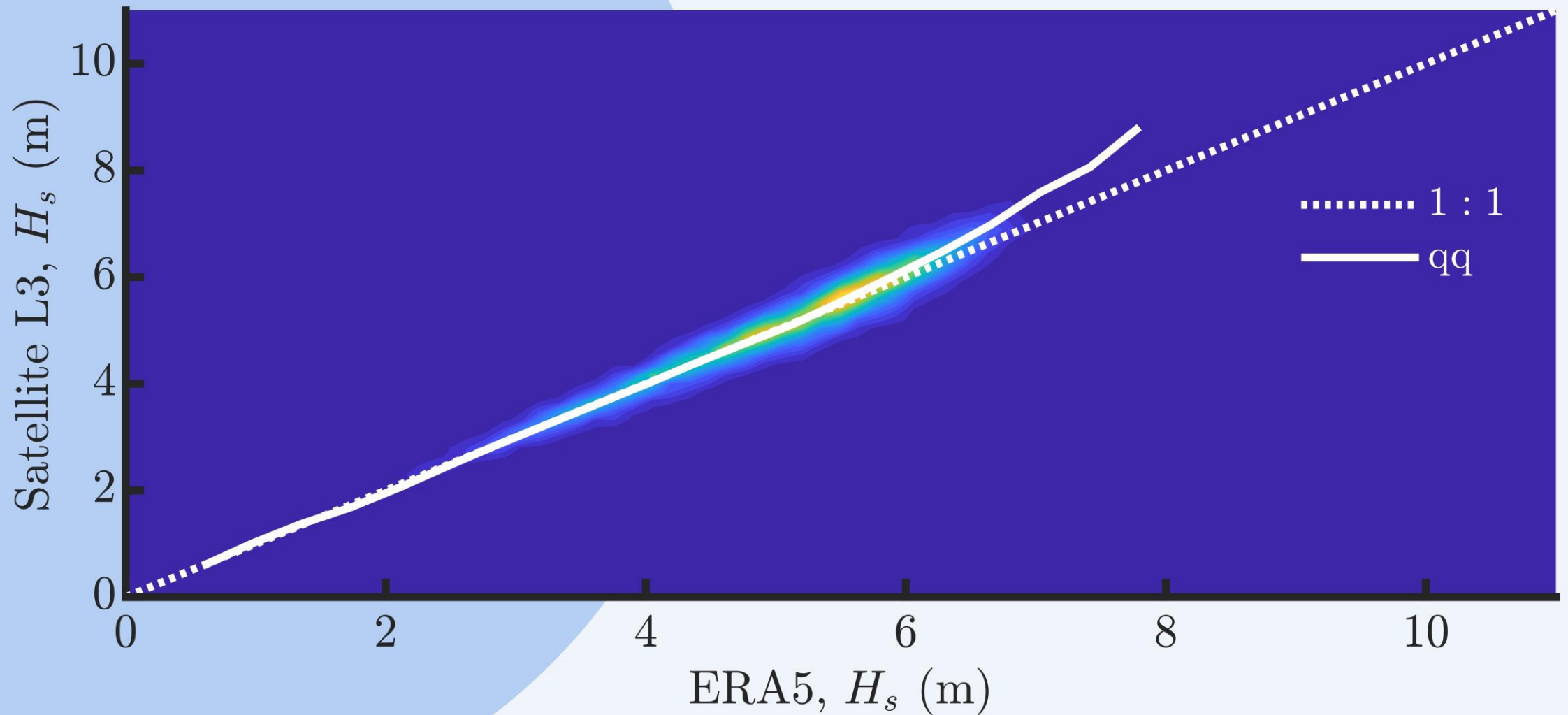
# ERA5 - Satellite Comparison



# All Bimodal ( $\Delta E < 0.8$ )



# Partition 1

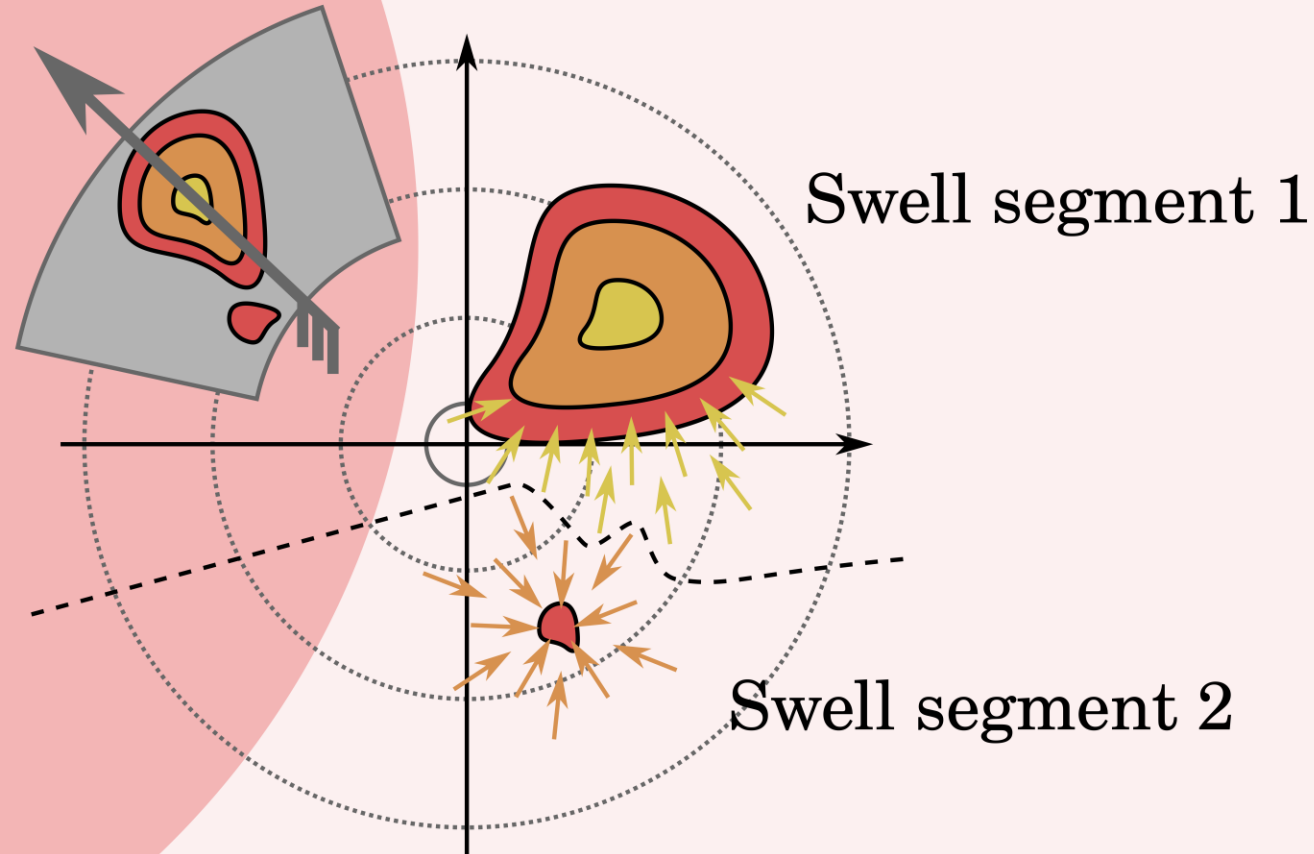




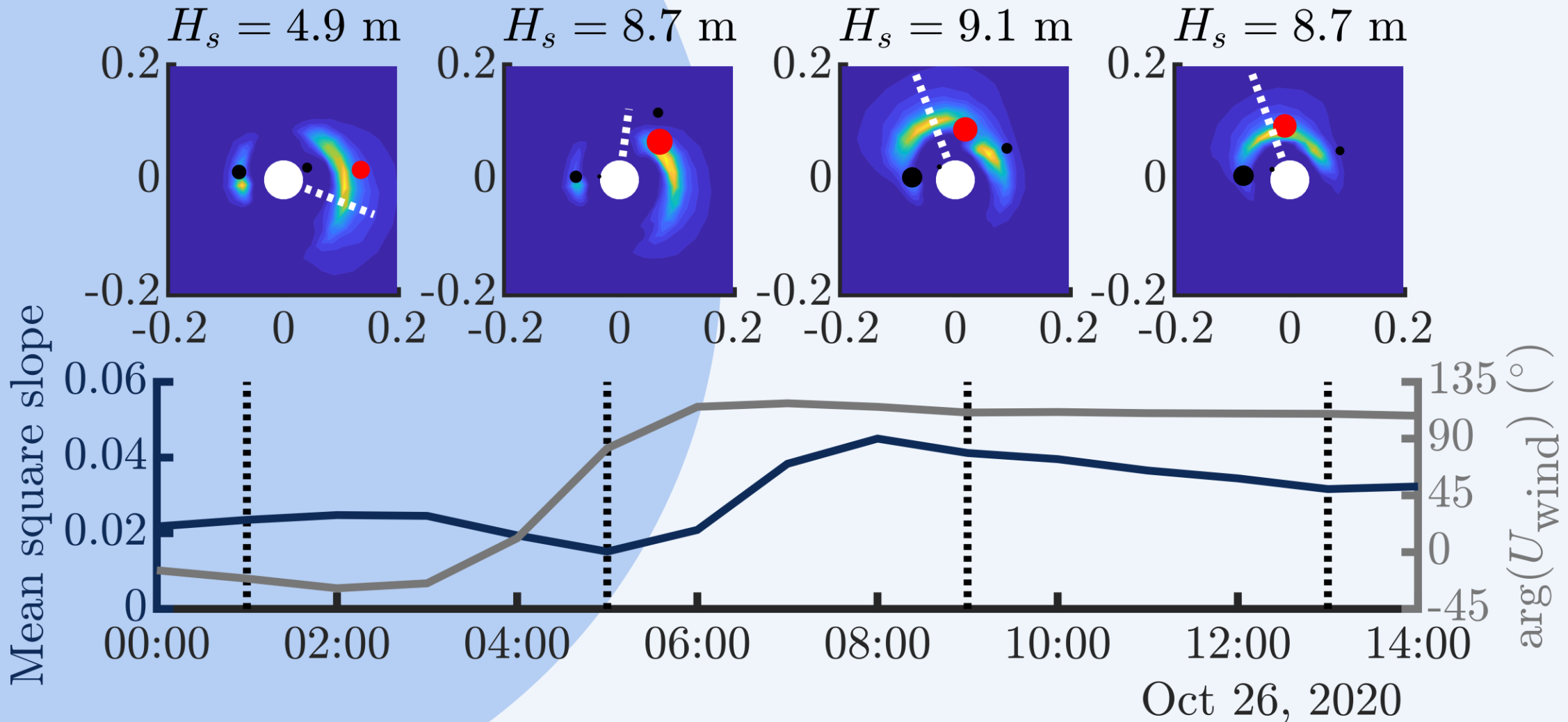
# An Aside, Partitioning

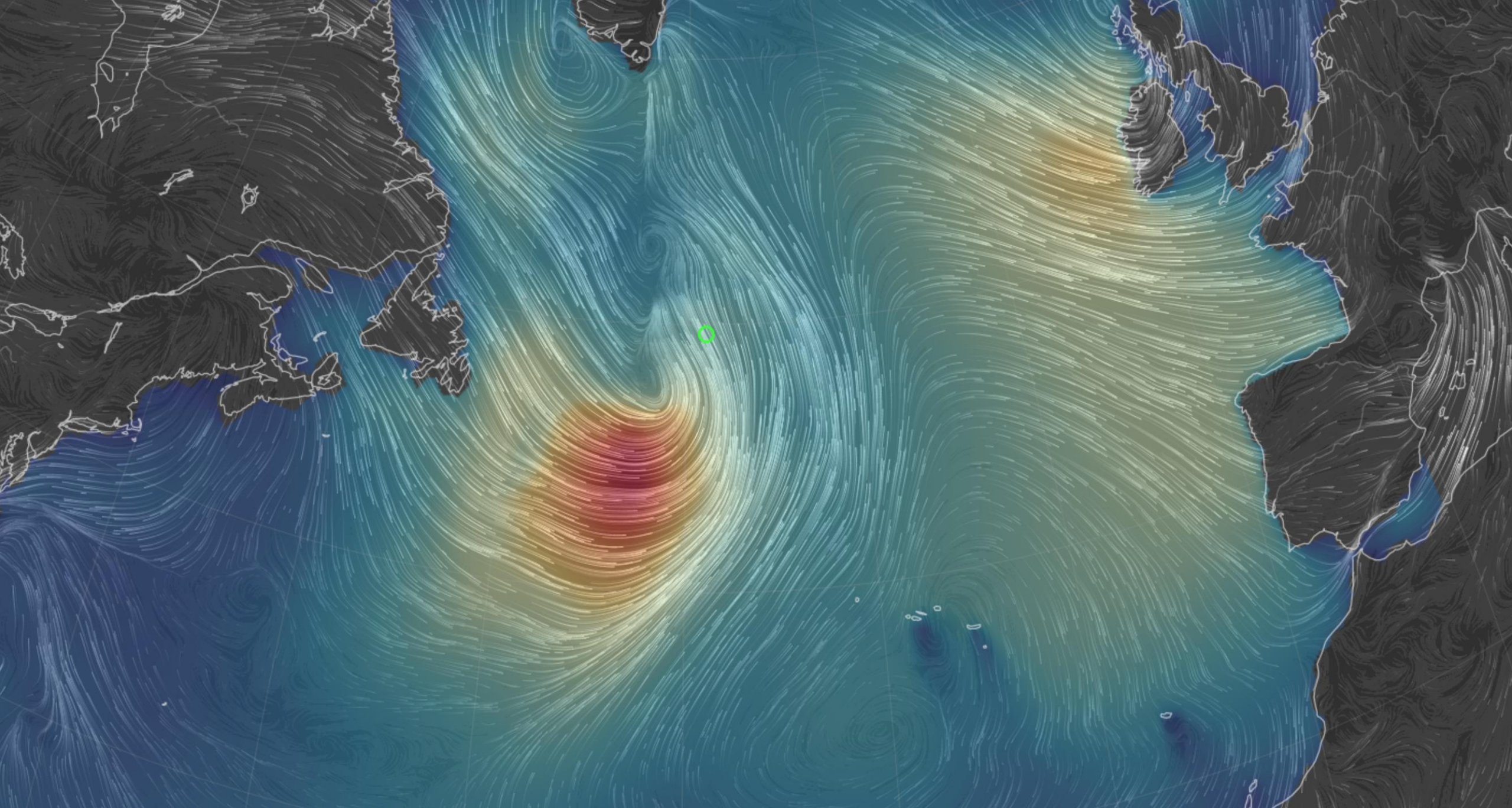
Windsea segment

$$1.2 \times 28(u_*/c) \cos(\theta - \phi) > 1,$$



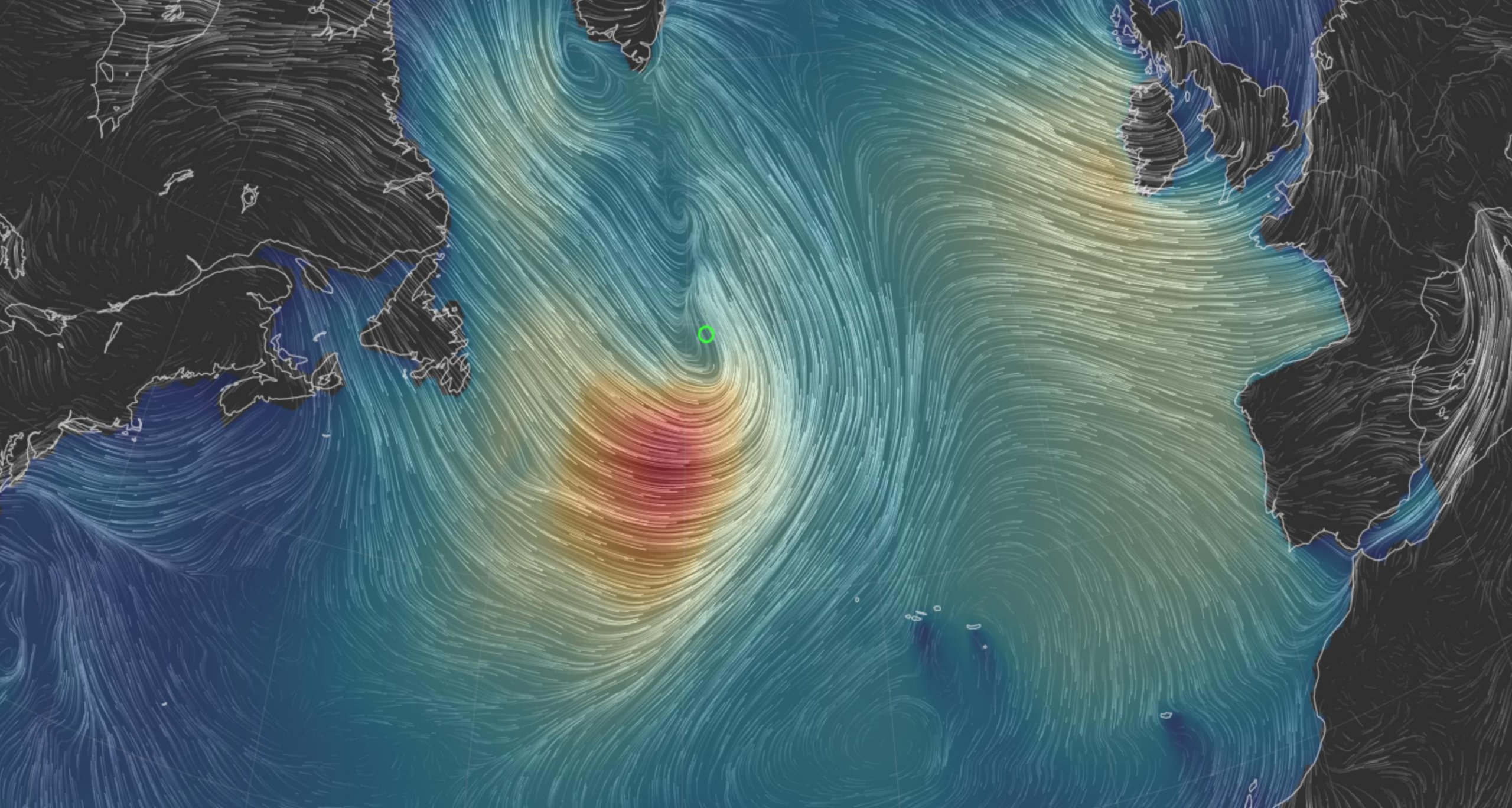
# Example: October 2020 N. Atl.





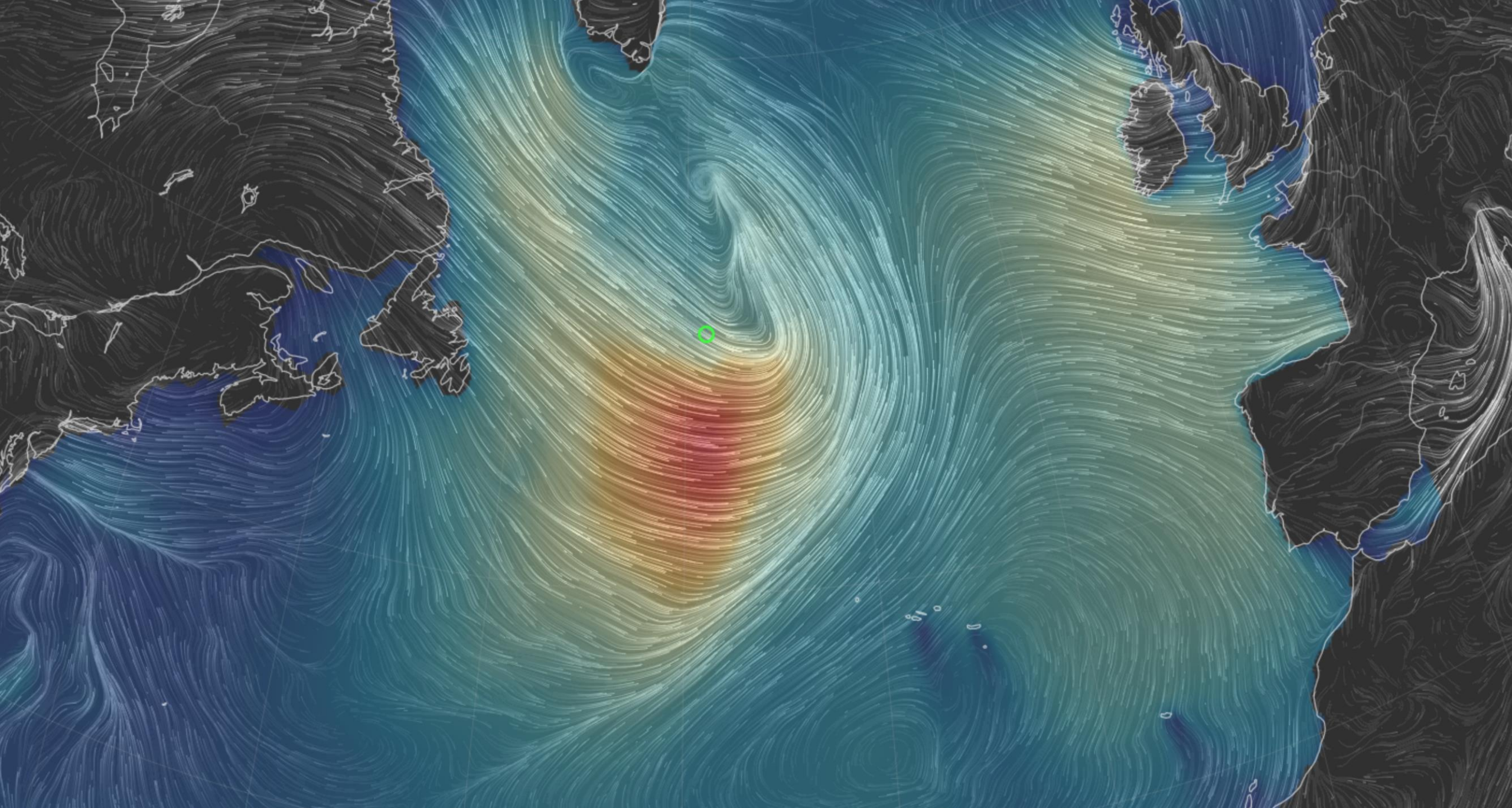
October 26th 2020, 00:00

earth.nullschool.net, Cameron Beccario



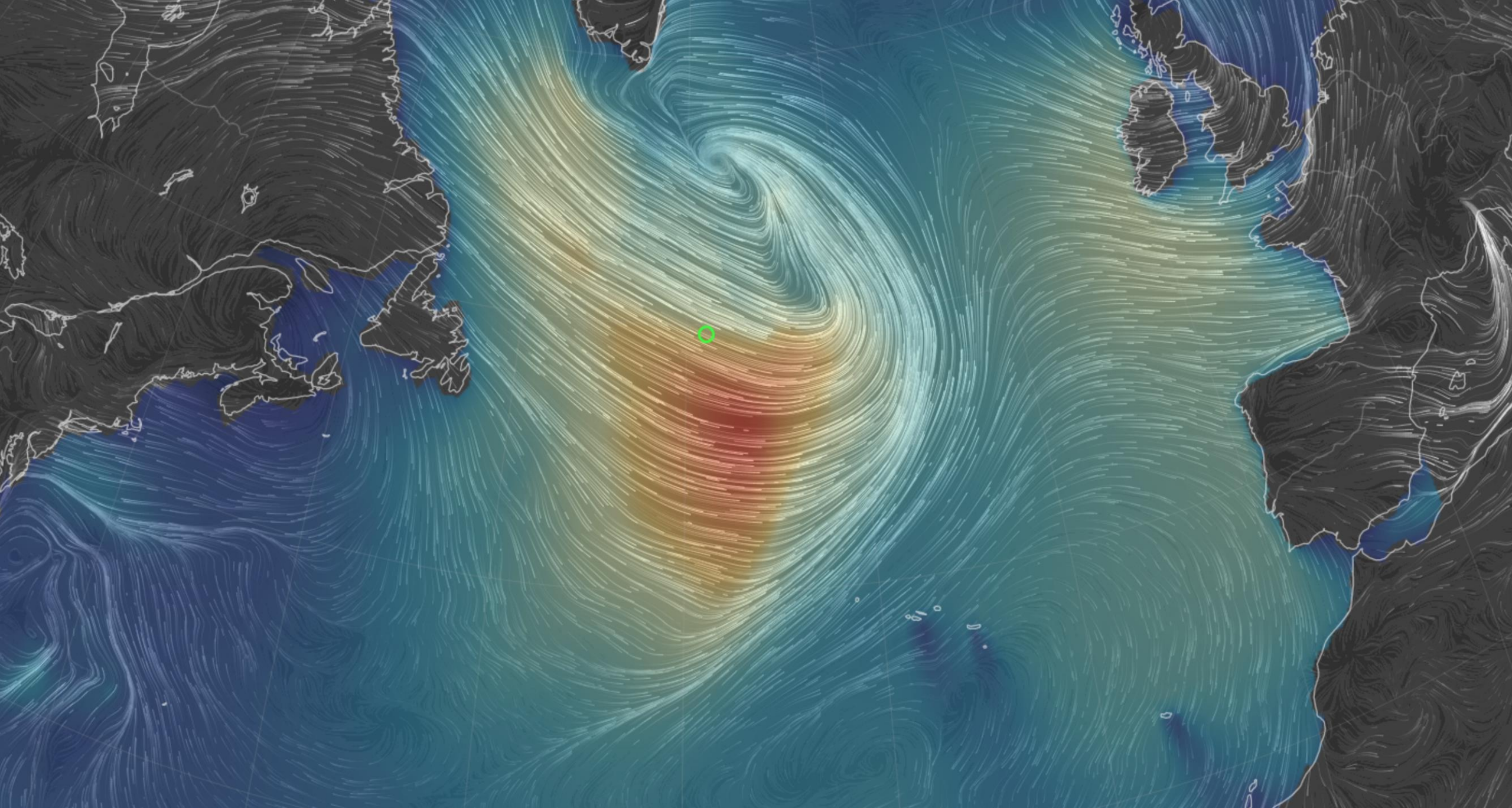
October 26th 2020, 03:00

earth.nullschool.net, Cameron Beccario



October 26th 2020, 06:00

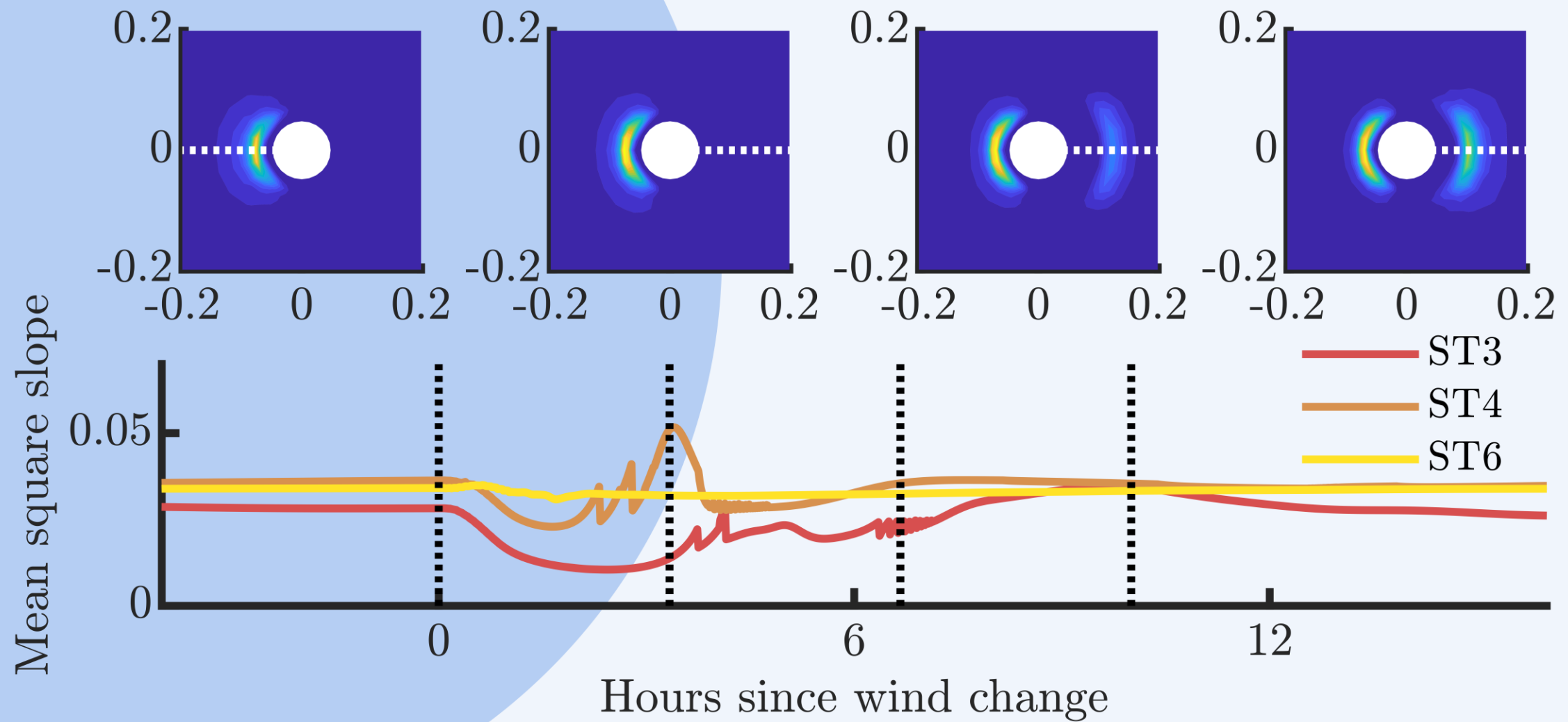
earth.nullschool.net, Cameron Beccario



October 26th 2020, 09:00

earth.nullschool.net, Cameron Beccario

# Point Model



# Conclusions & Future Work

- Extreme waves in crossing sea states are rarely found in ERA5 reanalysis data
- The highest discrepancies between model and satellite data occur in conjunction with segmentation issues
- These issues are a symptom of rapid changes in wind direction
- Point models subjected to rapid wind changes can exhibit extreme crossing sea states
- Investigation into causes of source term package discrepancy





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# Questions and Comments

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