Characterization of atmospheric stability conditions across different offshore markets and a detailed analysis of the vertical wind shear conditions in Southern New England

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VindKraftNet (2020-01-23)

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Table of contents

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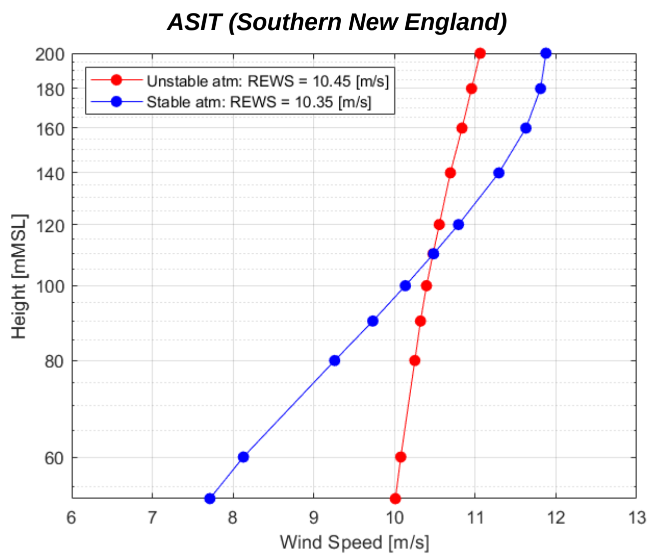
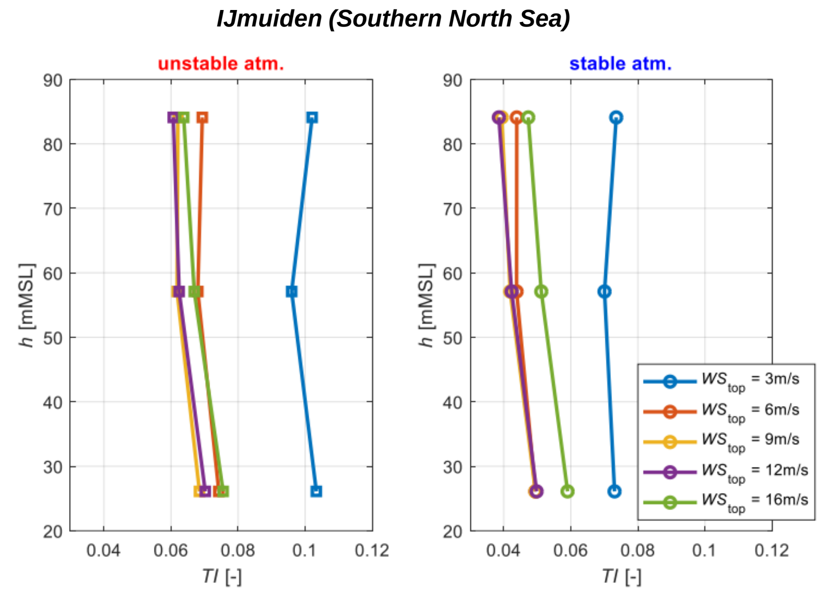
Offshore atmospheric stability: Theoretical considerations

- *Definition:*
  - *Stable:* $T_{air} > T_{water}$
  - *Unstable:* $T_{air} < T_{water}$
- *Why atmospheric stability matters:*





	Stable	Unstable
Vertical wind shear (In surface layer)	Large	Small
TI	Small	Large
Wind speed deficit in wake	Large	Small
Surface Layer	Shallow	Deep
Limitations of MOST	Significant	no significant

Site-specific power curve and TI for design — IEC 61400-3-1 (2019), IEC 61400-12-1 (2017)

Wake decay constant

$$k_w = \kappa \left[\ln\left(\frac{h}{z_o}\right) - \psi_m(h/L) \right]^{-1}$$

Peña et al., 2016

Vertical extrapolation of wind speed

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Offshore stability conditions might not be always similar to the one observed at the North Sea

Atmospheric stability: Theoretical considerations

- Bulk Richardson number (Ri_b) for offshore conditions (Grachev and Fairall, 1996).

$$Ri_b = -\frac{gz(-\Delta\theta + 0.61 T_z \Delta q)}{T_z U_z^2}$$

$$\Delta\theta = T_z + 0.0098z - SST$$

$$\Delta q = q_{sea} - q_z$$

Where:
q = specific humidity
T_z = Air temperature at height *z*.
U_z= Wind speed at height *z*.
g = gravity acceleration.

– For the Ri_b *calculation*: T_z, U_z, SST, P and RH measurements.

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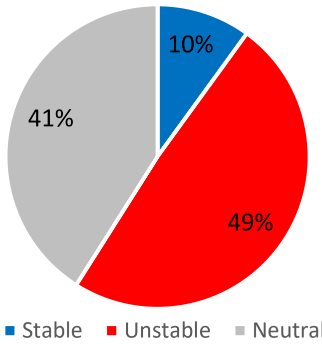
Case study 0: North Sea

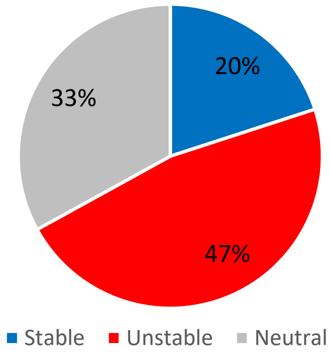
- *Stability conditions at the North Sea*
  - *Unstable and near-neutral conditions are prevailing.*

Adapted from Sathe et al., 2011
(Only westerly winds were considered)

Egmond aan Zee Offshore Wind Farm

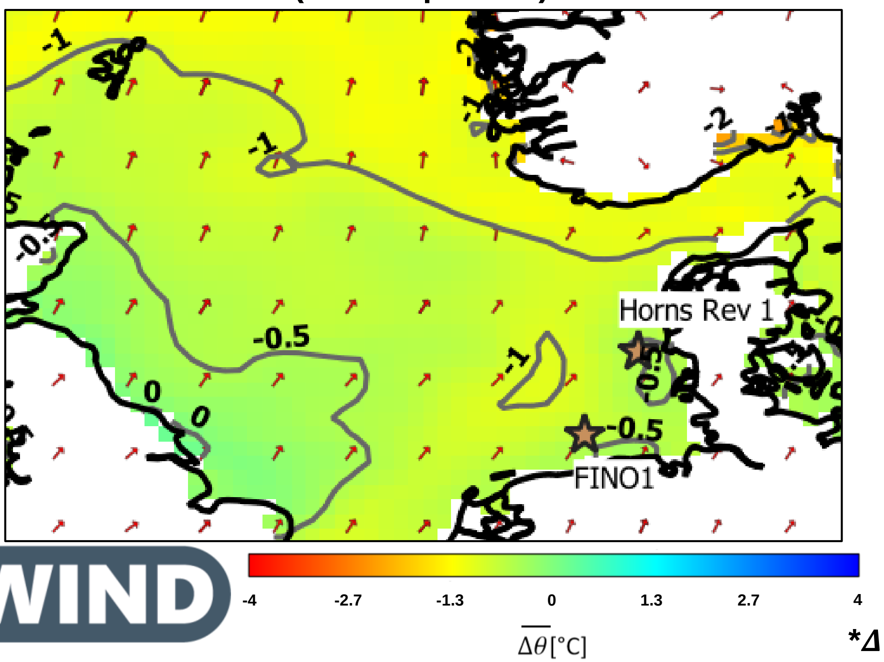


Horns Rev1

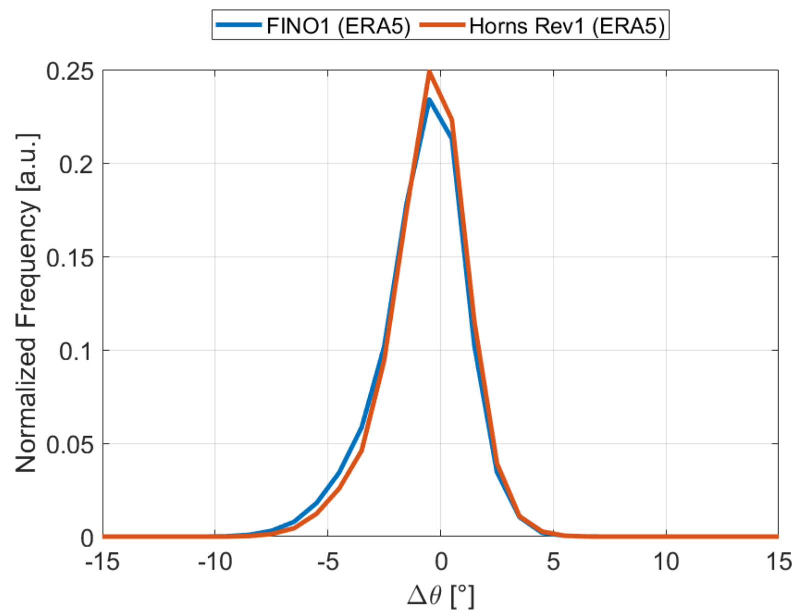


- *Reanalysis ERA5 (C3S, 201)*

Mean synoptic conditions (1979 to present)



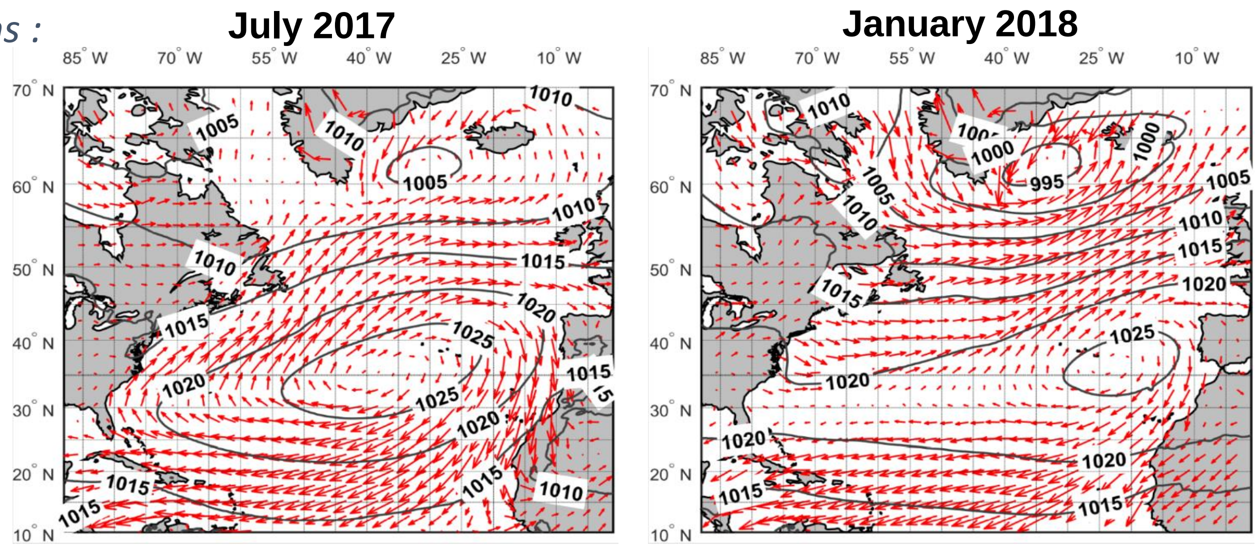
1990/01/01 – 2018/12/31



$*\Delta\theta = T_z 0.0098z - SST$

Case study 1: Southern New England

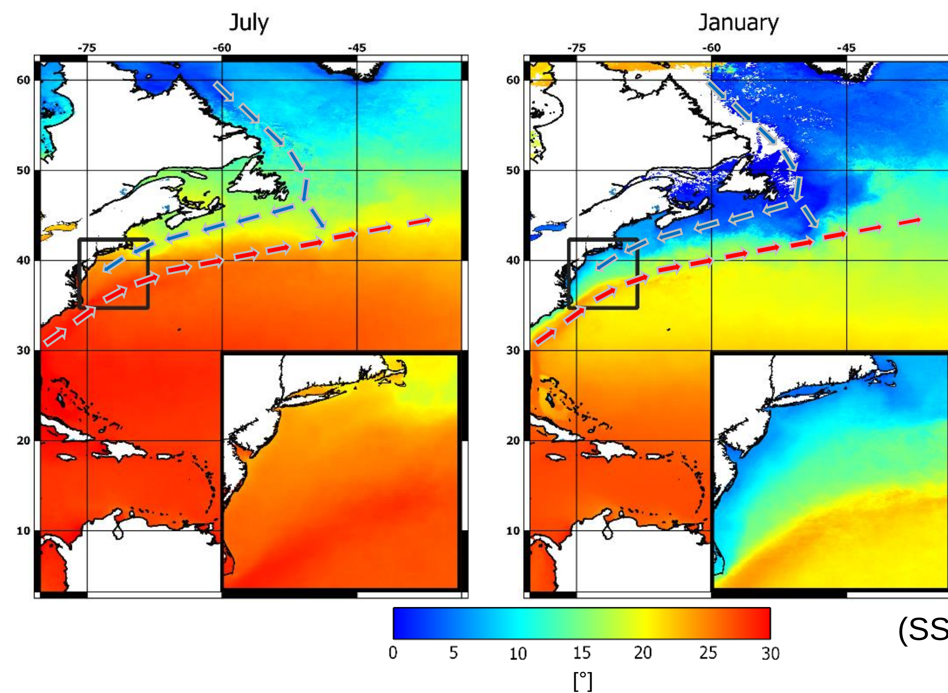
- *Mean synoptic conditions :*
  - *Bermuda-Azores high*



(MSLP, u_{100} and v_{100} from ERA5)

- *SST:*
  - *Warm sea current: Gulf stream*
  - *Cold sea current: Labrador current*

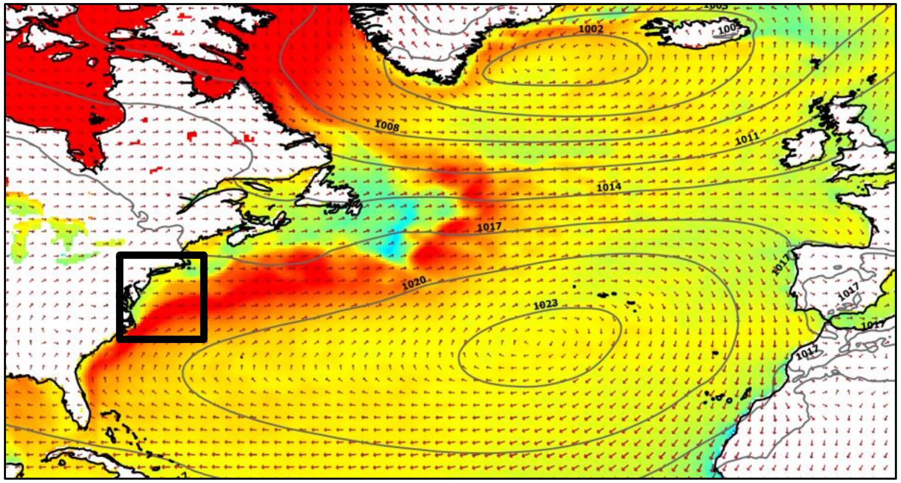
Daniault et al. (2016)

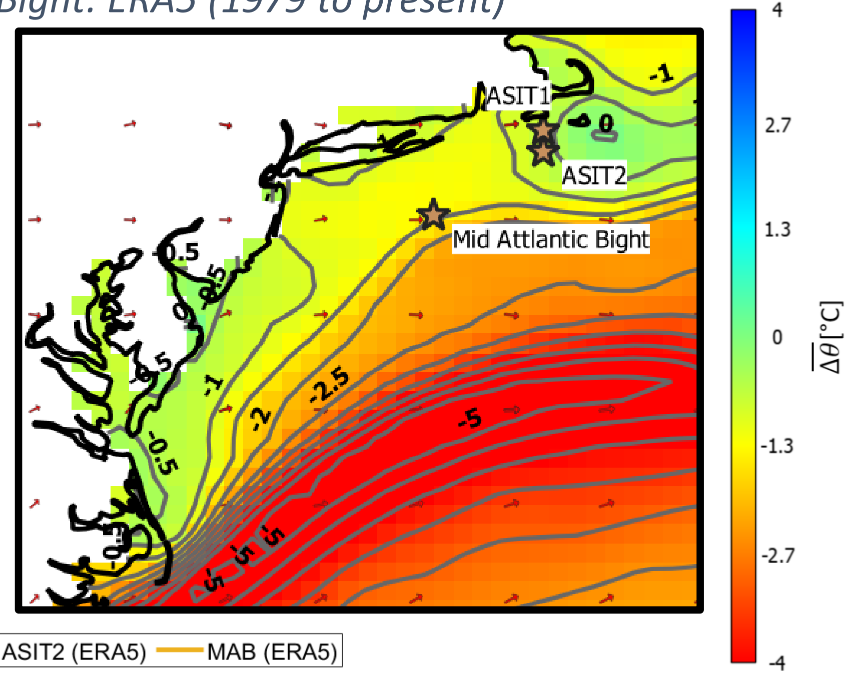


(SST MODIS Aqua)

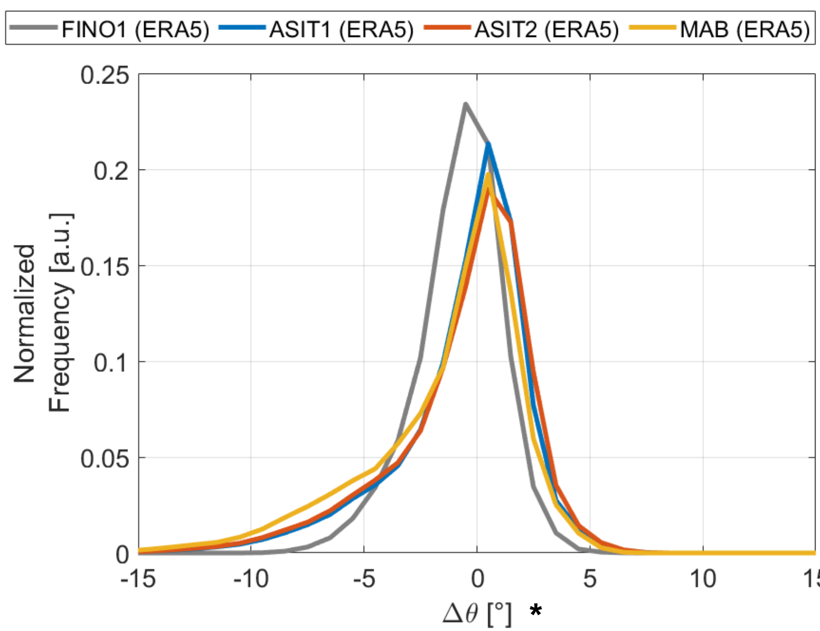
Case study 1: Southern New England

- *Mean Atmospheric conditions at Mid Atlantic Bight: ERA5 (1979 to present)*





- ***Δθ** Distribution: 1990/01/01 – 2018/12/31*



Stable conditions occurs with a larger frequency in Southern New England than in the North Sea

$*\Delta\theta = T_z 0.0098z - SST$

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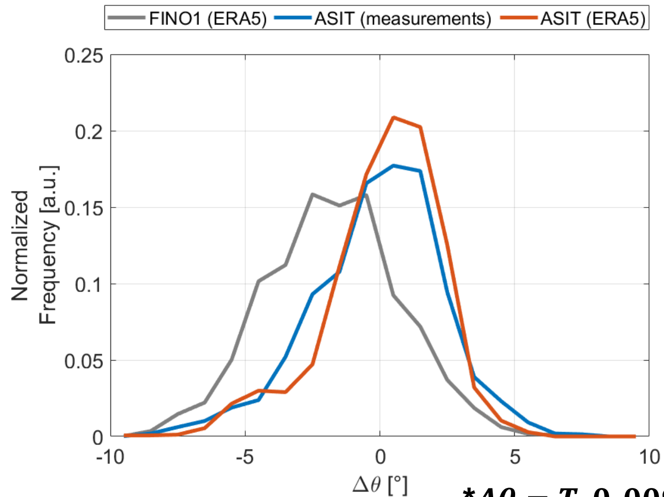
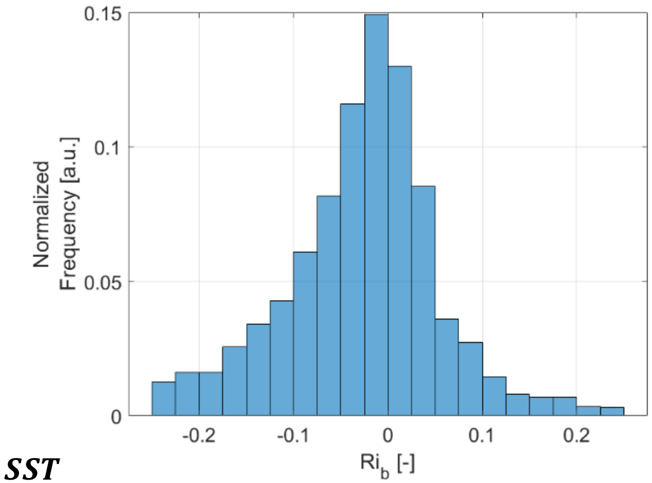
Case study 1: Southern New England

- *Atmospheric conditions at Mid Atlantic Bight: In-situ measurements (Air Sea Interaction Tower):*
  - *Stable conditions occurs with a larger frequency than in the North Sea*
  - *Unstable conditions occurs with a smaller frequency than in the North Sea*

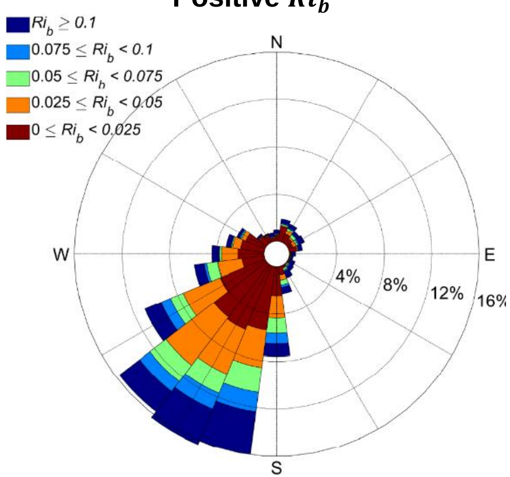




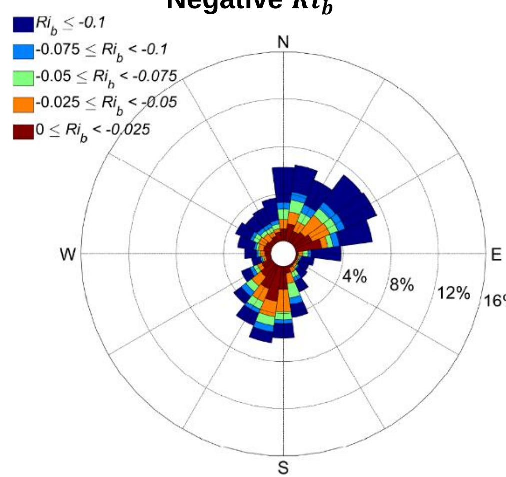
$$^*\Delta\theta = T_z 0.0098z - SST$$

  - Positive values of Ri_b were observed mostly for Southwesterly winds (Mostly summer)
  - Negative values of Ri_b were observed for all wind directions

Positive Ri_b

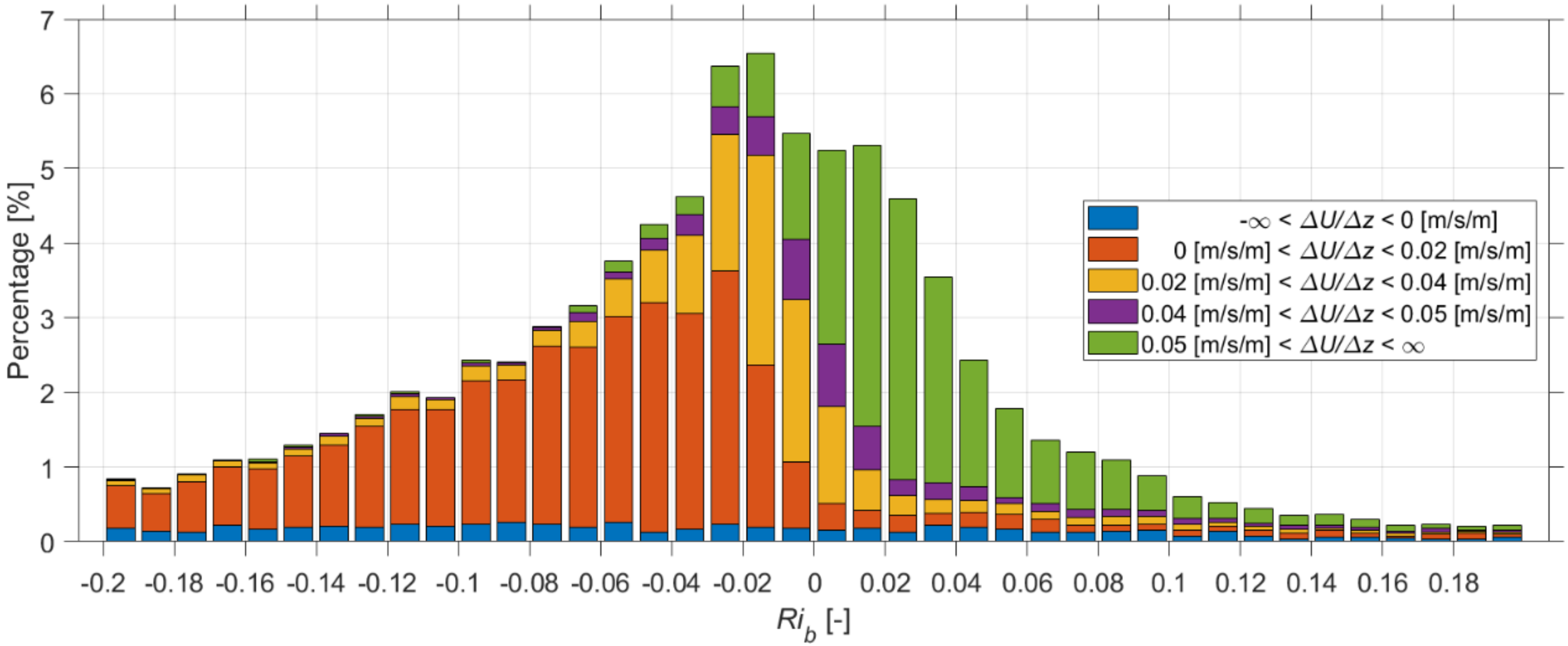


Negative Ri_b



Case study 1: Southern New England

- *Atmospheric conditions at ASIT: Implications*
  - Vertical wind shear ($\frac{\Delta U}{\Delta z}$) obtained from LiDAR wind measurements at 60 and 53 mMSL.



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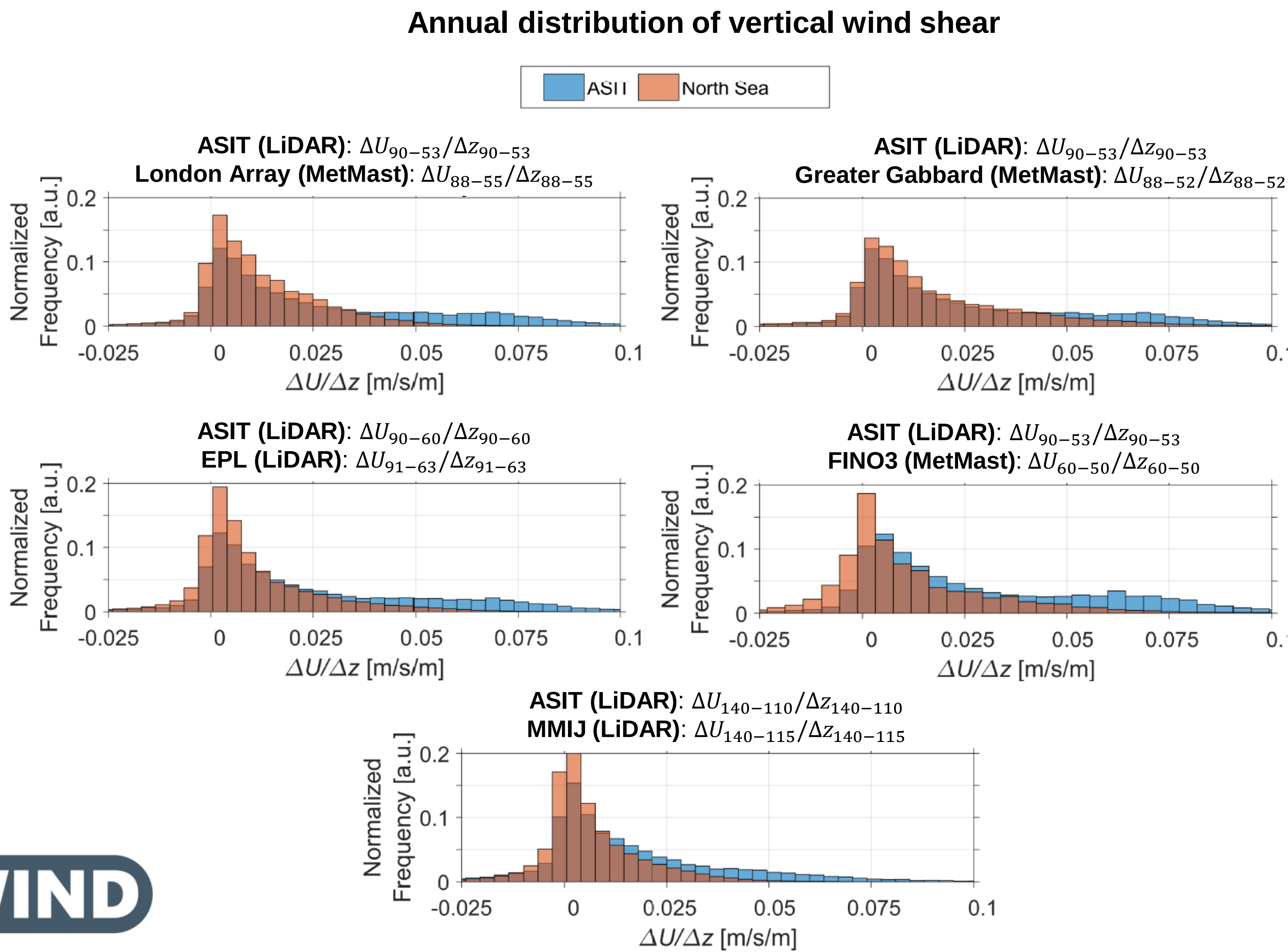
Case study 1: Southern New England

- *Atmospheric conditions at ASIT: Implications*
  - Larger occurrence of large vertical wind shears at ASIT compared with North Sea measurements.



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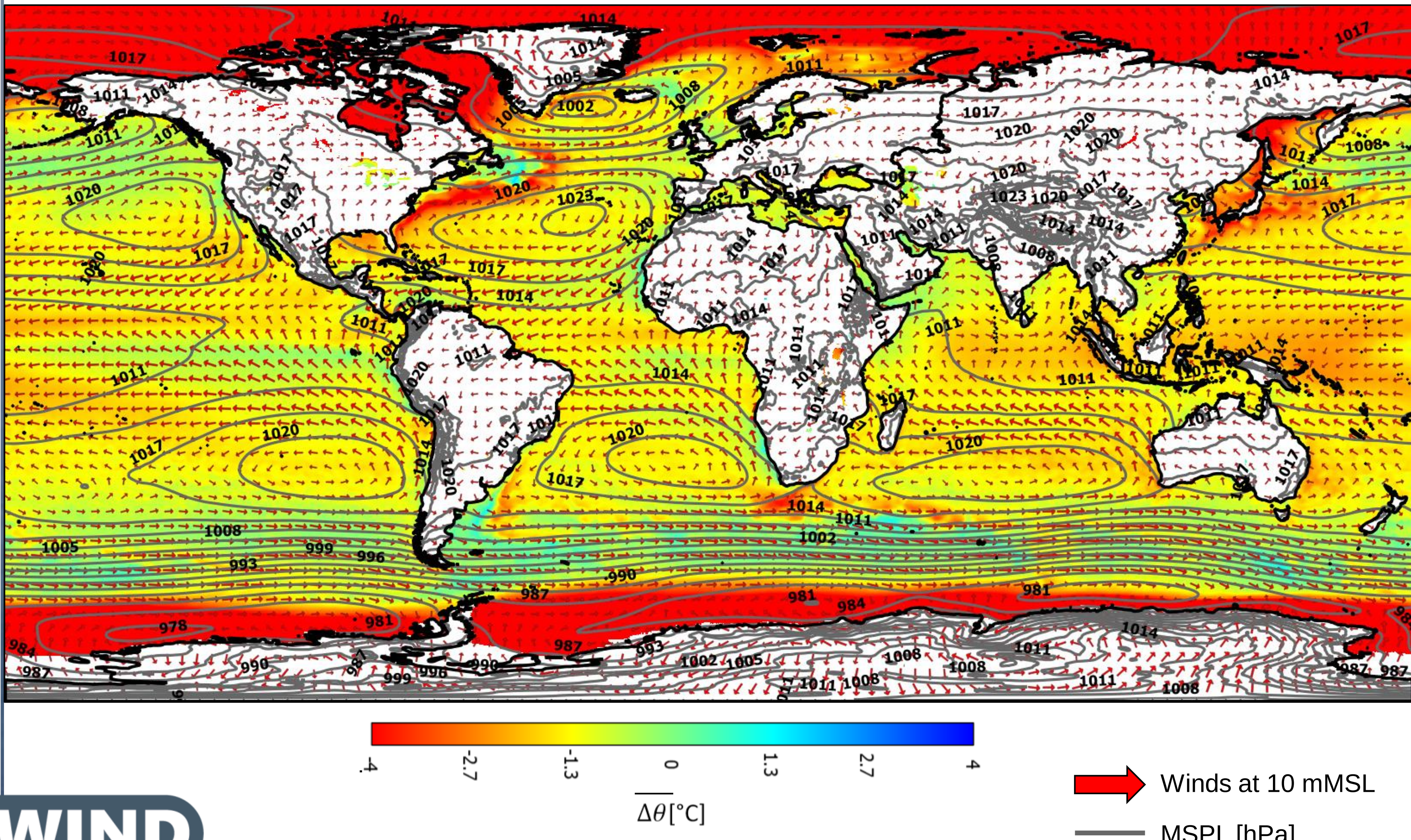
Case studies 2 and 3 are based only on ERA5 data

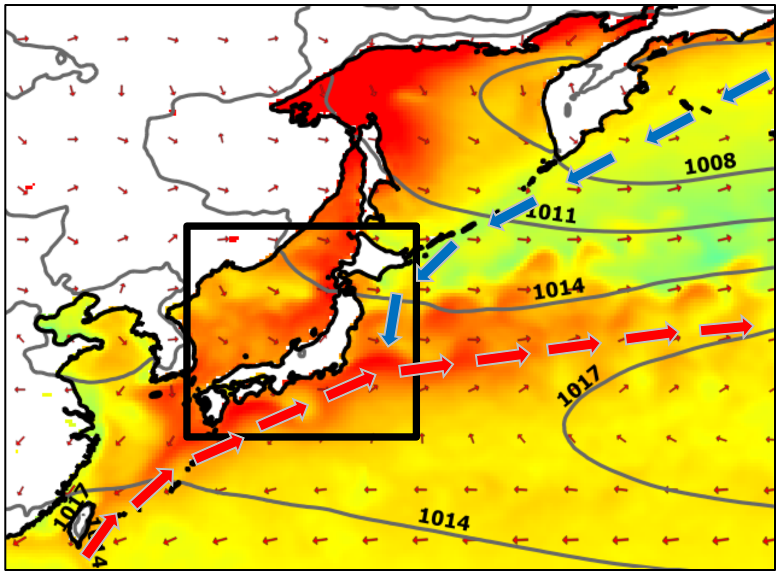
Mean synoptic conditions 1979 - present

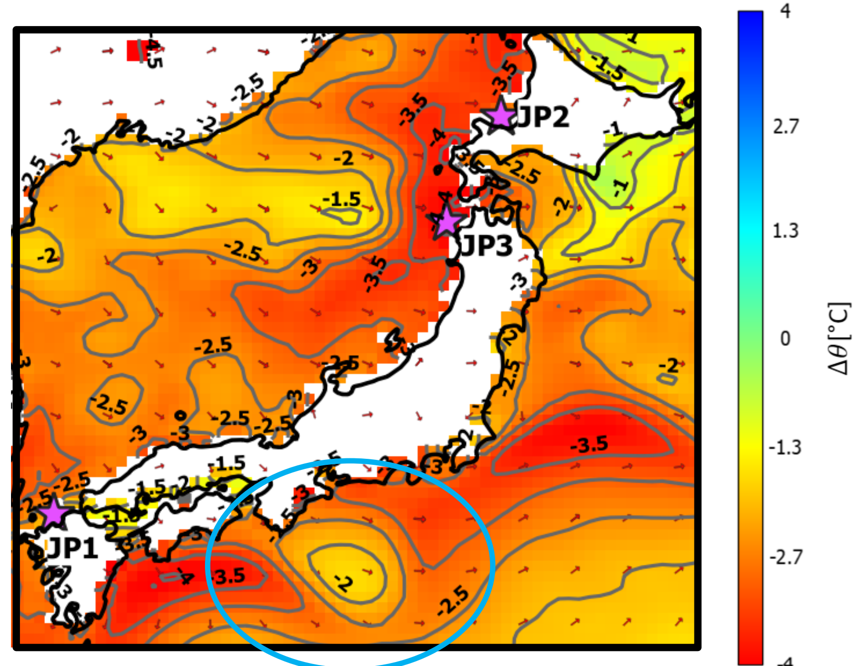


$$^*\Delta\theta = T_z 0.0098z - SST$$

Case study 2: Japan

- *Atmospheric conditions (from ERA5)*

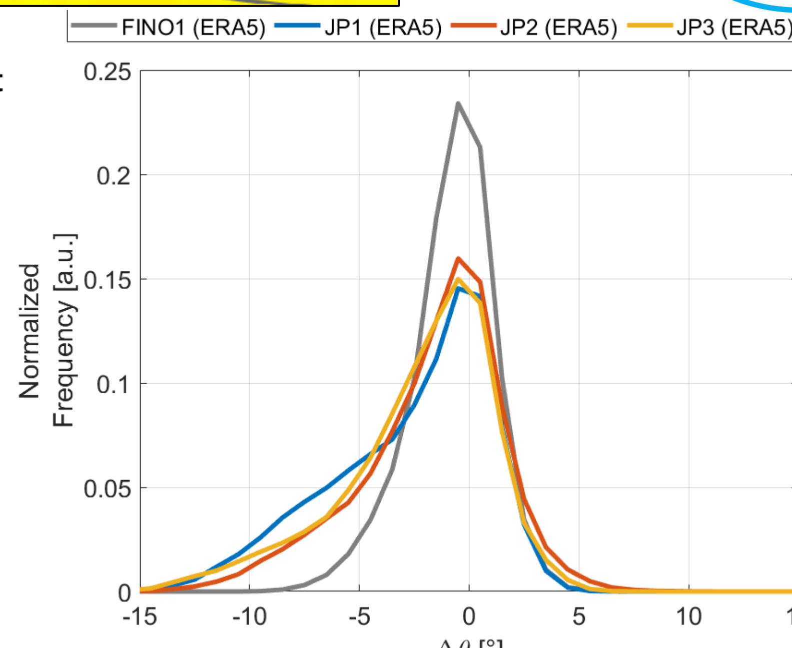




Kuroshio current

Oyashio current

Qiu (2019)



Unstable conditions occurs with a larger frequency in Japan than in the North Sea

$$*\Delta\theta = T_z 0.0098z - SST$$

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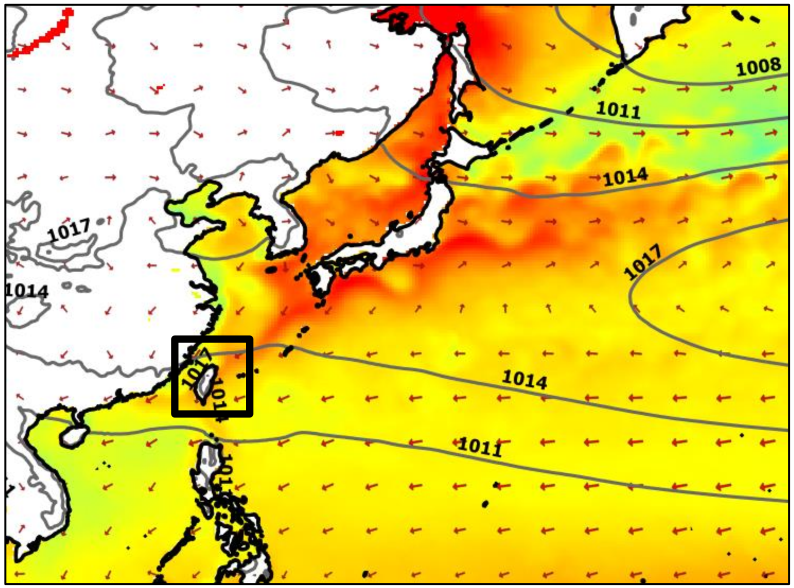
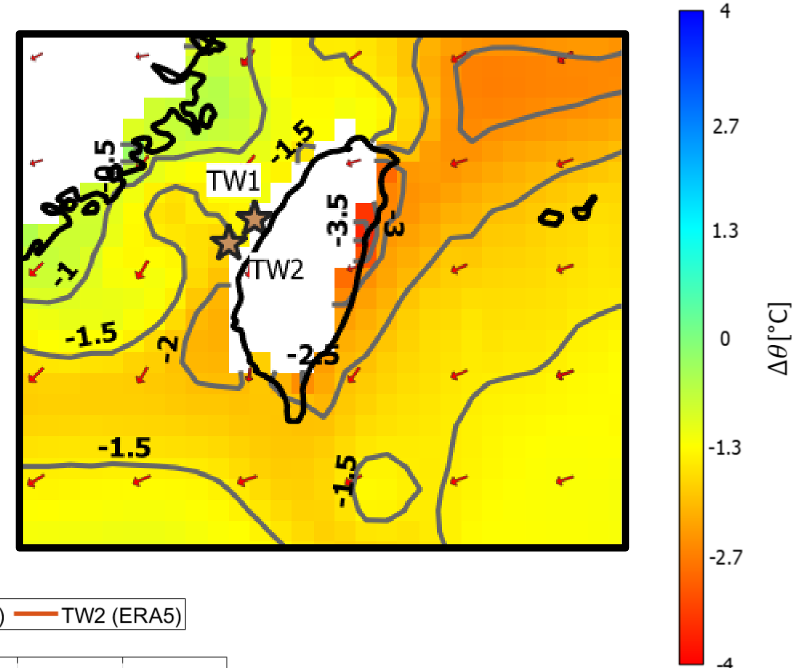
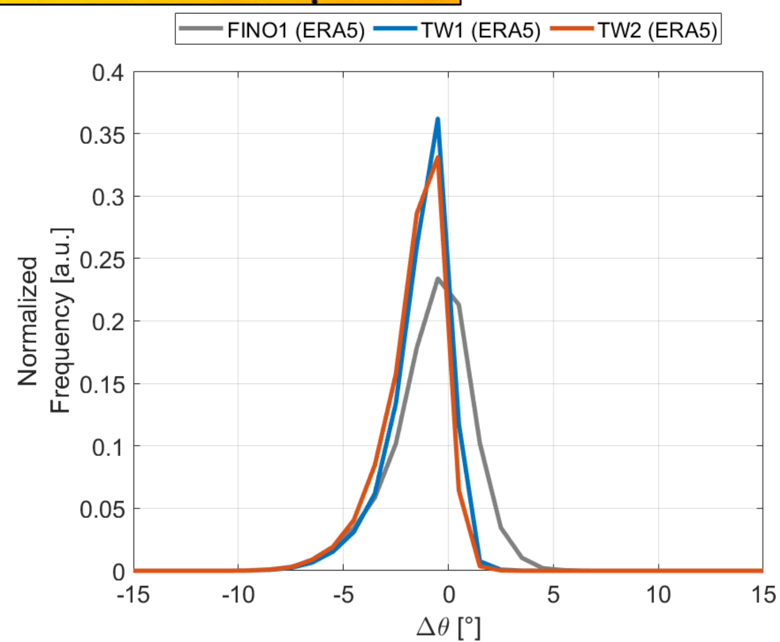
Case study 3: Taiwan

- *Atmospheric conditions (from ERA5)*







Unstable conditions occurs with a larger frequency in Taiwan than in the North Sea

$*\Delta\theta = T_z 0.0098z - SST$

Conclusions

- Stable conditions and large vertical wind shears in Southern New England occur with a larger frequency than in the North Sea.
- Based on ERA5 data, unstable conditions in the west coast of Taiwan and Japan occur with a larger frequency than in the North Sea.
- Offshore atmospheric stability are worth to be analyzed at a regional scale.
- It is important to consider the impact of the atmospheric stability conditions in terms of:
  - Turbulence intensity and Wind shear.
  - Wind turbine performance.
  - Wake losses.

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