Study of Coastal Effects relevant for Offshore Wind Energy using Spaceborne Synthetic Aperture Radar (SAR)

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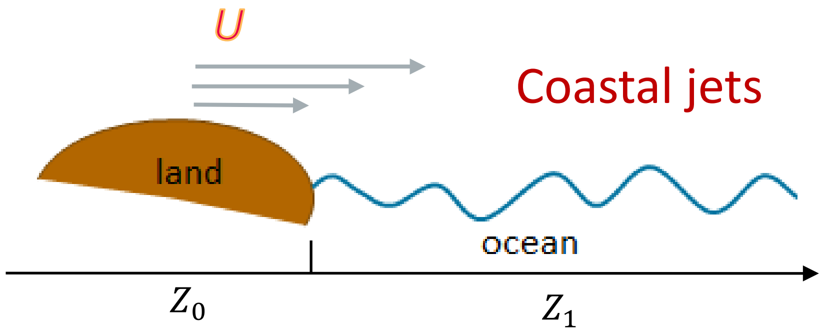
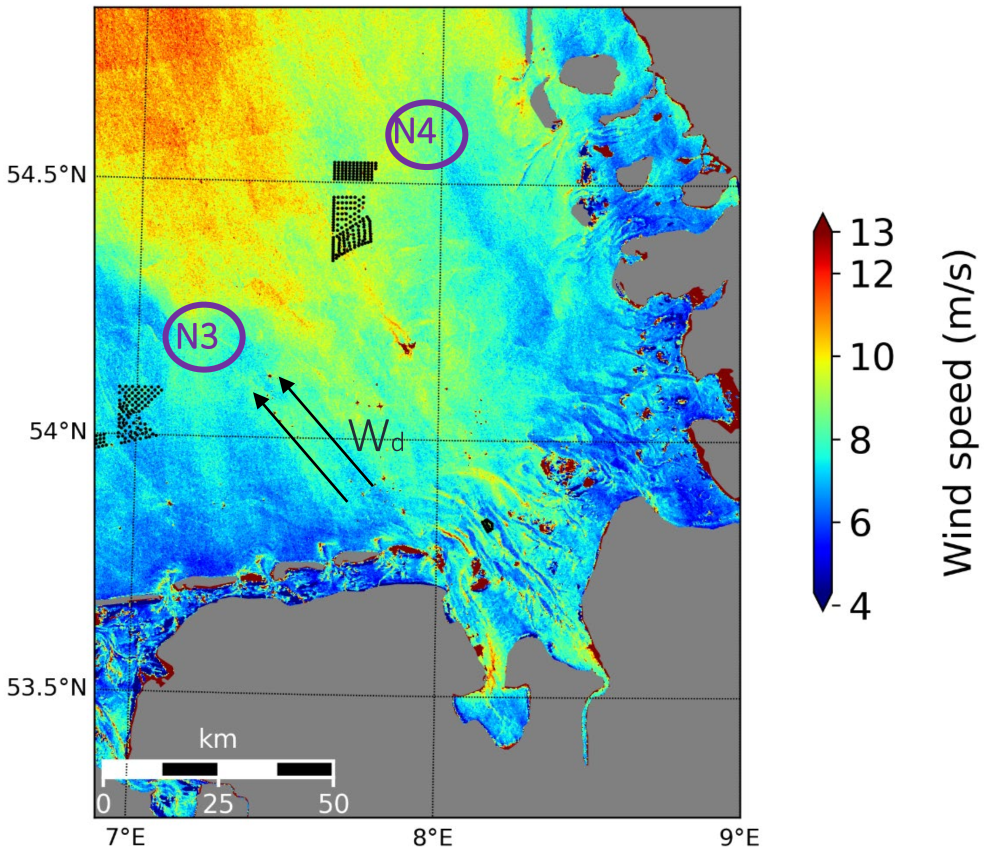
Coastal gradients…

Complex atm. phenomena due to coastal discontinuity (momentum, heat fluxes)

- Airflow over surface roughness jump

- Roughness $Z_0 > Z_1$
- Speed up over smoother ocean sea surface

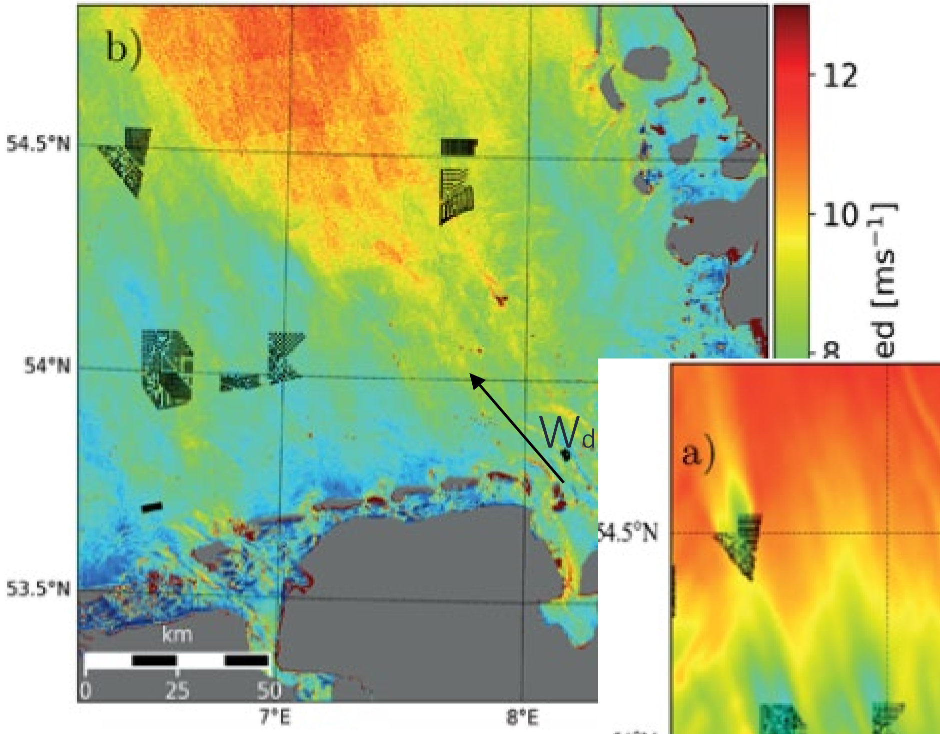




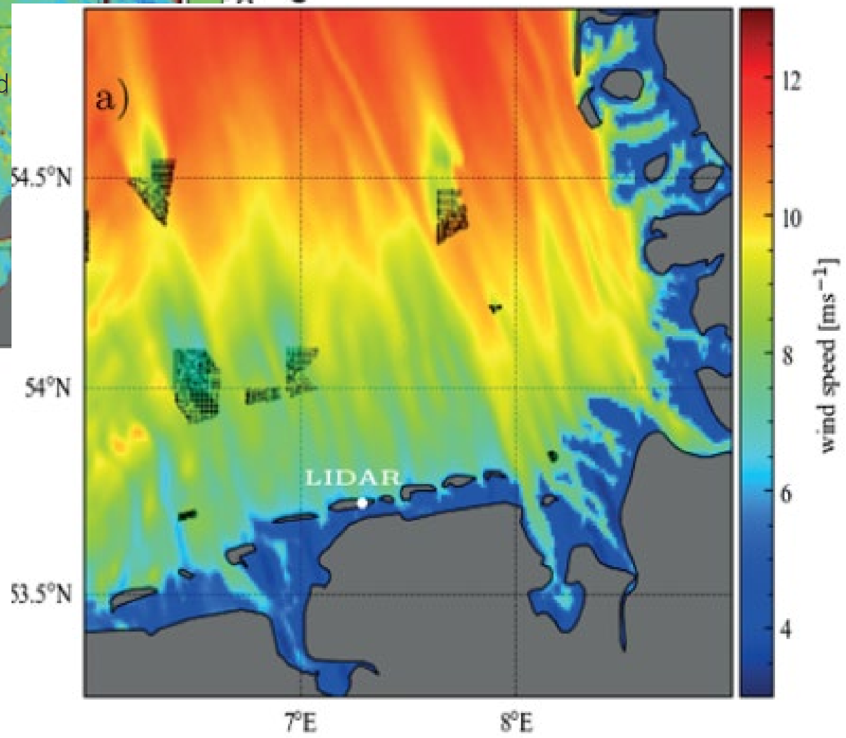
Derived 10-m wind speed from Sentinel-1B on 14.03.2020 at 17:16 showing an increase wind from Southeast.

Evidence of Coastal Gradients

SAR

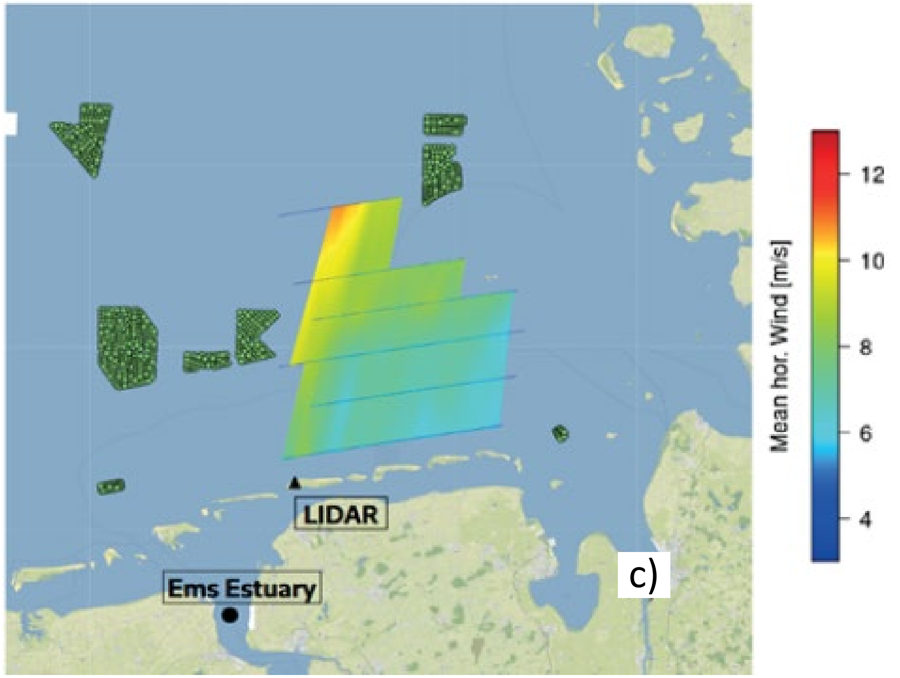


WRF



(a) 10-m wind from WRF and (b) 10-m wind speed from SAR on 14.03.2020 at 17:16 UTC

Aircraft



(c) Wind speed at hub height (100 m-120 m) from aircraft measurements on 23 July 2020 at 12 UTC

Stronger winds over the sea away from the coast

REF: Schulz-Stellenfleth, J., Emeis, S., Dörenkämper, M., Bange, J., Cañadillas, B., Neumann, T., Schneemann, J., Weber, I., zum Berge, K., Platis, A., Djath, B., Gottschall, J., Vollmer, L., Rausch, T., Barekzai, M., Hammel, J., Steinfeld, G., Lampert, A. (2022). Coastal impacts on offshore wind farms – a review focussing on the German Bight area. MetZet. https://doi.org/10.1127/metz/2022/1109

Objectives

Understanding the coastal effects …

- Examination of the horizontal gradient of wind field from land to sea
- Distance over which the wind speed from the coast increases
- Impact of the atmospheric stability

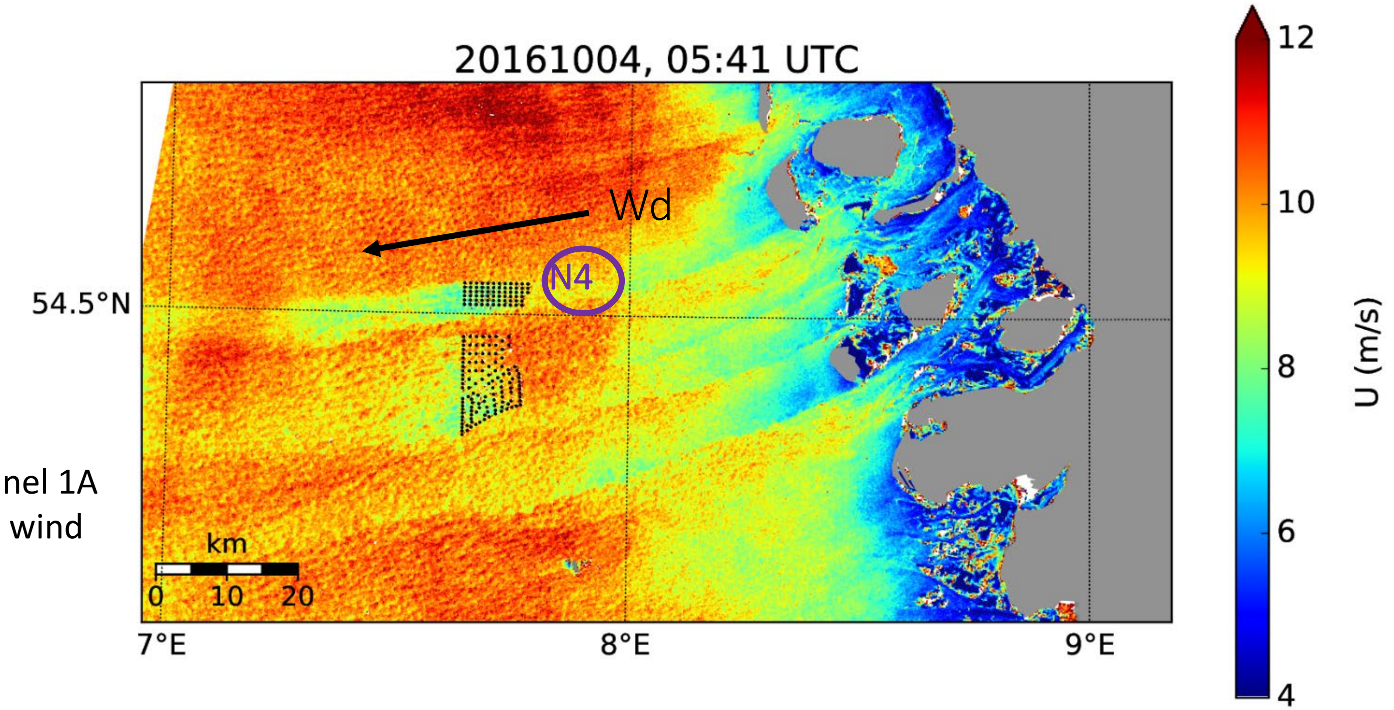


Figure: Derived 10-m wind speed from Sentinel 1A on 04.10.2016 at 05:41 showing an increase wind from East to West.

Outline

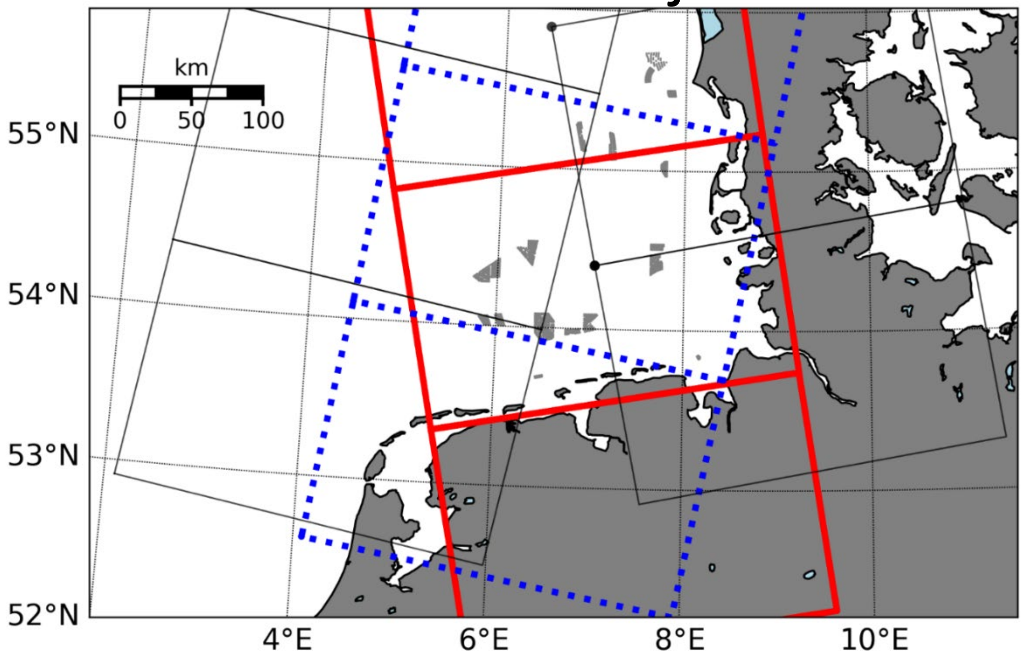
- Data/methodology: wind field from Sentinel 1 (SAR)
- Horizontal wind gradients
  - Case study
  - Statistical analysis
  - Impact of atmospheric stability
- Summary

Data: 10-m derived wind from SAR

Sampling Sentinel-1A/B (2017-Dec. 2020)

- Morning (Descending orbit) : 5 UTC (244 samples)
- Evening (Ascending orbit) : 17 UTC (243 samples)
- Regular 6-days (repeat cycle)

S1 trajectories



➢ Swathes covering the entire GB are used (red and blue frames)

Principle

- Backscattering (Bragg) of generated small scales roughness by the wind (NRCS)

Wind field

- Relationship between roughness scales and surface wind

NRCS → CMOD5N → 10-m wind field

Focus on offshore wind directions

- Predominant wind: westerly wind
- Offshore wind: easterly, south, south-easterly/-westerly

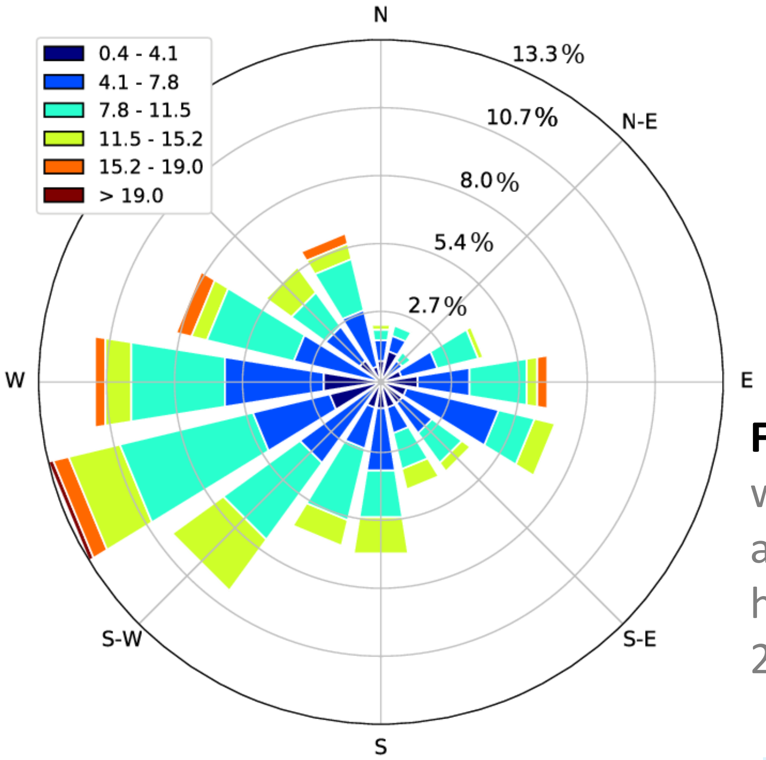


Figure: Distribution of wind speeds (in m/s) and directions at 10m height from DWD for 2017-2020

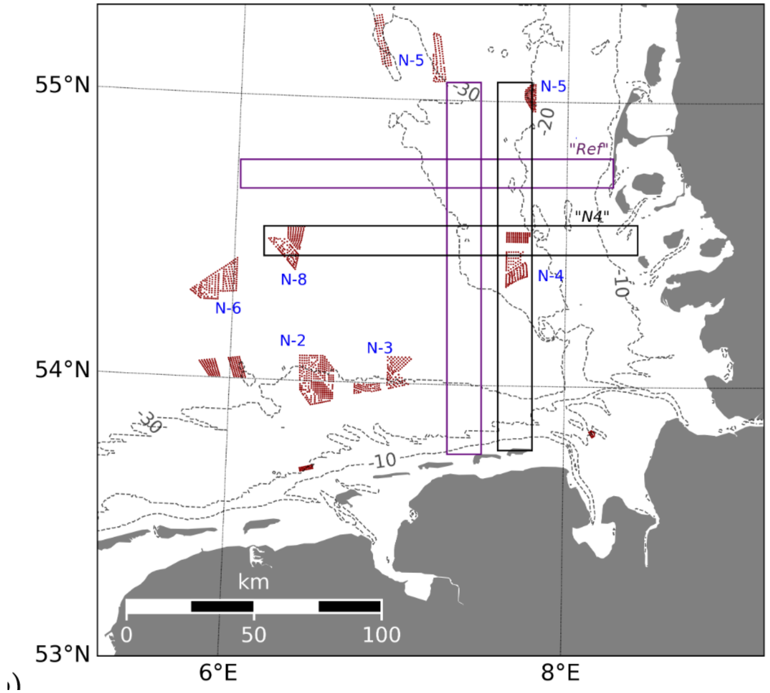


Figure: Bathymetry from GEBCOO 2014. Red dots represent operating wind arms (status in 2020).

- Easterly wind: $90^\circ \pm 30$
- Southerly wind: $180^\circ \pm 20$

1 transect for wind profile for each WD

- Reference: no wake interference

Atmospheric stability: thermal (DWD)

- SST, air temperature (DWD)
- Thermal stability

$$\frac{\partial \theta}{\partial z} = \frac{\frac{T_2 - T_1}{z_2 - z_1} - \Gamma}{z_2 - z_1} \qquad (1)$$

- Stability depending on air temperature - SST
- Stable for $\frac{\partial \theta}{\partial z}$ >0 and unstable for $\frac{\partial \theta}{\partial z}$ <0

	DWD
Air temperature	**T at 2 m**
SST	

X-WAKES

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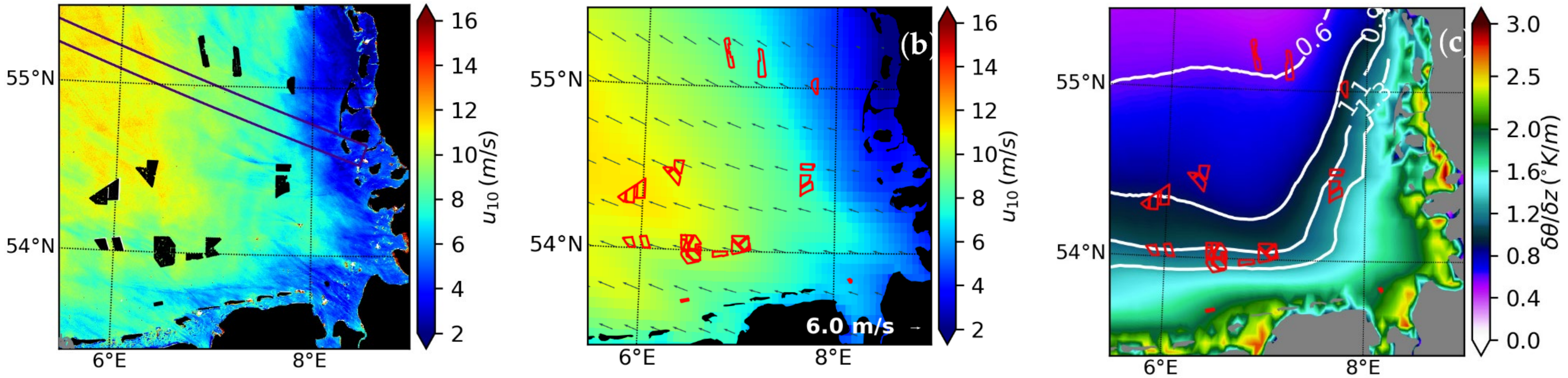
Coastal effects: case on 06.04.2018 at 17:16 UTC (S1A)

SAR DWD DWD

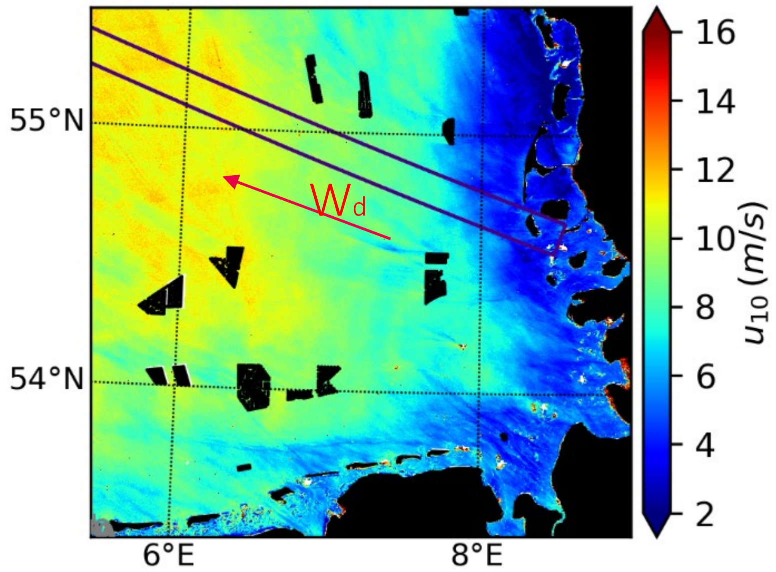


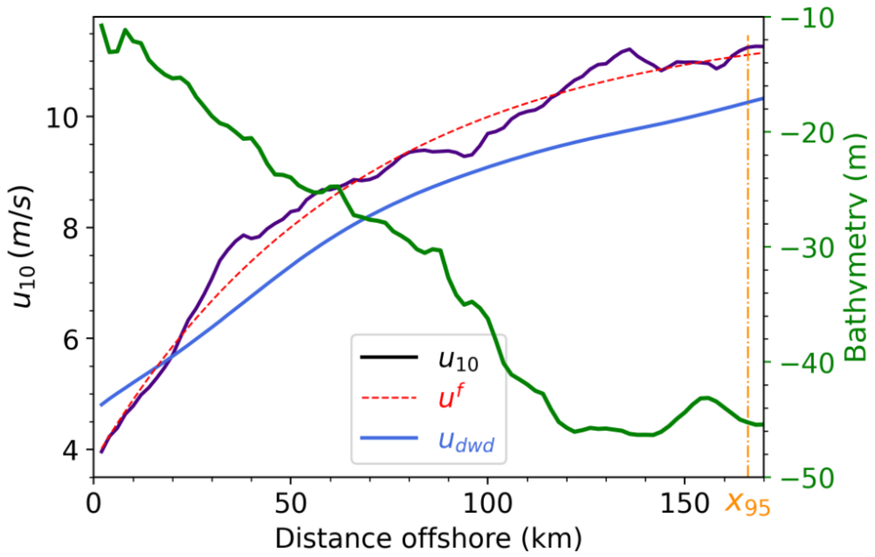
- **Important wind speed gradient**
- **Consistency between DWD and SAR**

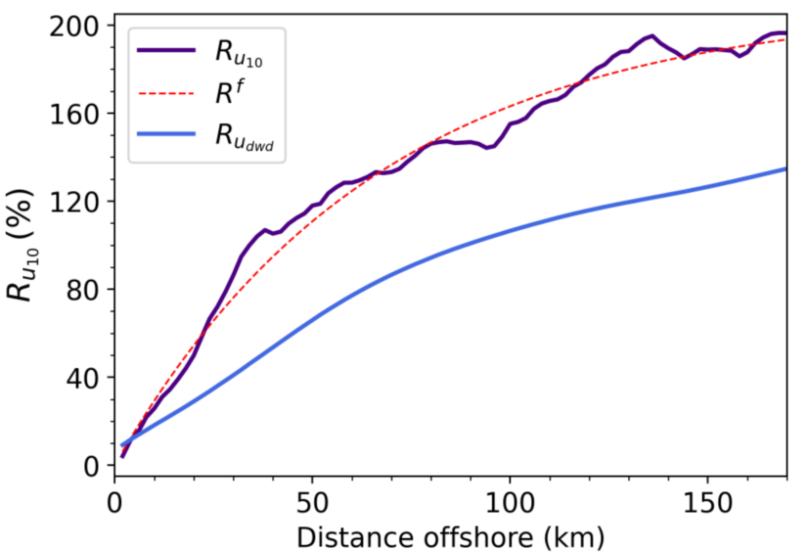
REF: Djath, B., Schulz-Stellenfleth, J., and Cañadillas, B.: Study of Coastal Effects Relevant for Offshore Wind Energy Using Spaceborne Synthetic Aperture Radar (SAR). *Remote Sensing* 14, no. 7 (March 31, 2022): 1688. https://doi.org/10.3390/rs14071688.

Coastal effects: case on 06.04.2018 (S1A)

SAR







$$u^f(x) = u_{land} + \left(u_{offshore} - u_{land}\right)\left(1 - \exp(-\frac{x}{\sigma})\right) \quad \textbf{(1)}$$

$$\Delta u = u_{offshore} - u_{land} \quad \textbf{(2)}$$

$$x_{95\%} = -\sigma \log\left(\frac{0.05\, u_{offshore}}{\Delta u}\right) \quad \textbf{(3)}$$

$$R^f(x) = \left(\frac{u_{offshore}}{u_{land}} - 1\right)\left(1 - \exp(-\frac{x}{\sigma})\right) \quad \textbf{(4)}$$

- **Transect of wind speed gradient described by an exponential function (Eq. 1)**
- **An increase Δu of 7.8 m/s ; R_{u10} of 180 % (SAR)**
- **Less increase for DWD: Δu of 5.5 m/s ; R_{u10} of 120 %**
- **Adjustment distance (equilibrium 95% $u_{offshore}$) of 165 km**

X-WAKES

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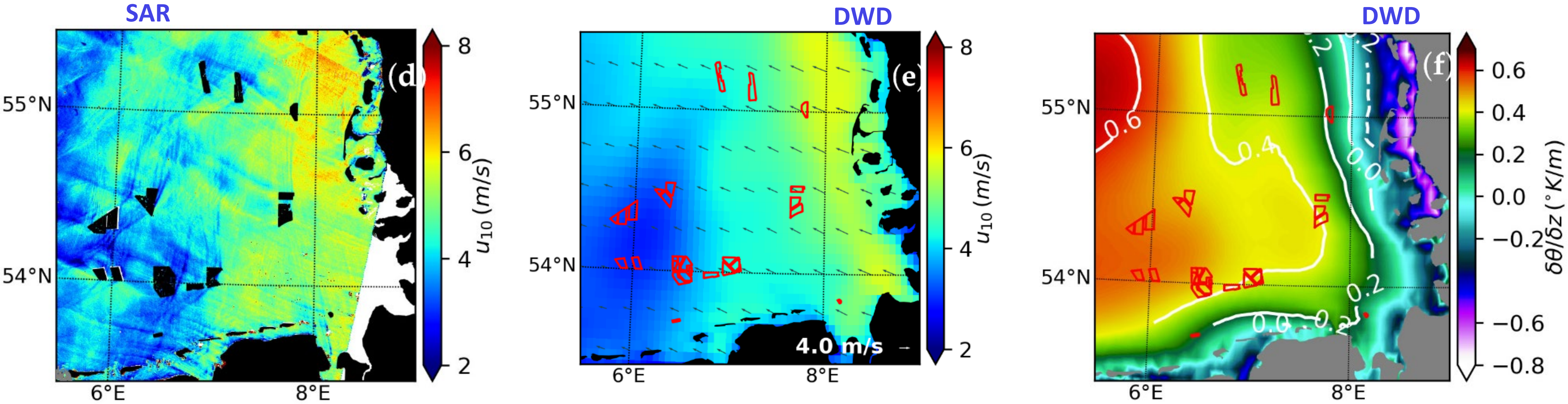
 REF: Djath, B., Schulz-Stellenfleth, J., and Cañadillas, B.: Study of Coastal Effects Relevant for Offshore Wind Energy Using Spaceborne Synthetic Aperture Radar (SAR). *Remote Sensing* 14, no. 7 (March 31, 2022): 1688. https://doi.org/10.3390/rs14071688.

Coastal effects: case on 25.08.2019 at 05:48 UTC (S1A)



- **Decrease in wind speed**
- **Consistency between DWD and SAR**
- **Occurrence in stable conditions**

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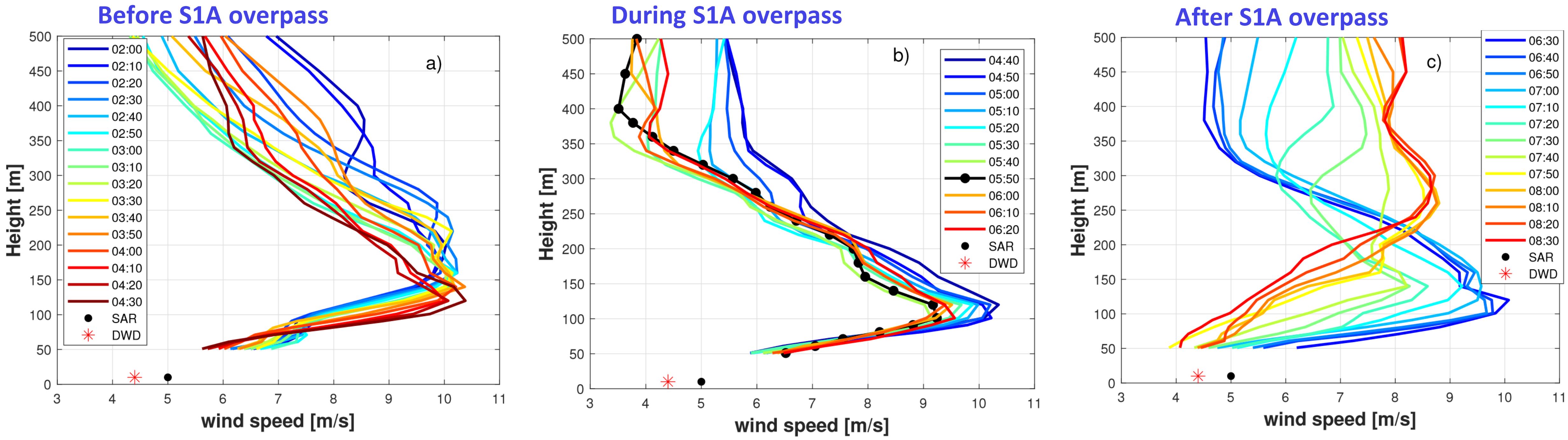
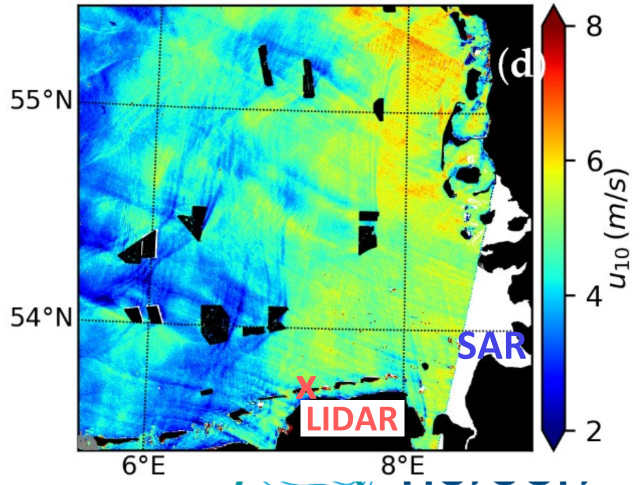
Coastal effects: case on 25.08.2019 (LIDAR)





- **Wind amplitude consistent between SAR, DWD and LIDAR**
- **Evidence of LLJ :**
  - **- (Prior) LLJ average jet core around 200 m,**
  - **- (during) decrease to 120 m (during S1A),**
  - **- (after) spread around 6:30 and disappear by 8:00**

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Outline

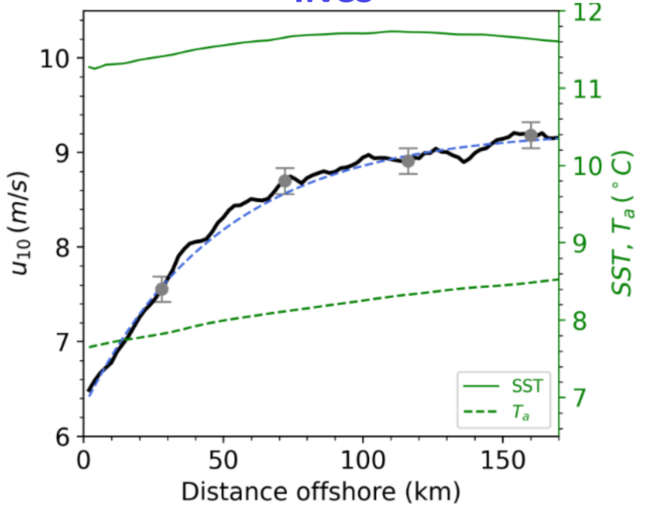
- Data/methodology: wind field from Sentinel 1 (SAR)
- **Horizontal wind gradients**
  - Case study
  - **Statistical analysis**
  - **Impact of atmospheric stability**
- Summary

Statistical analysis: increasing and decreasing wind gradients

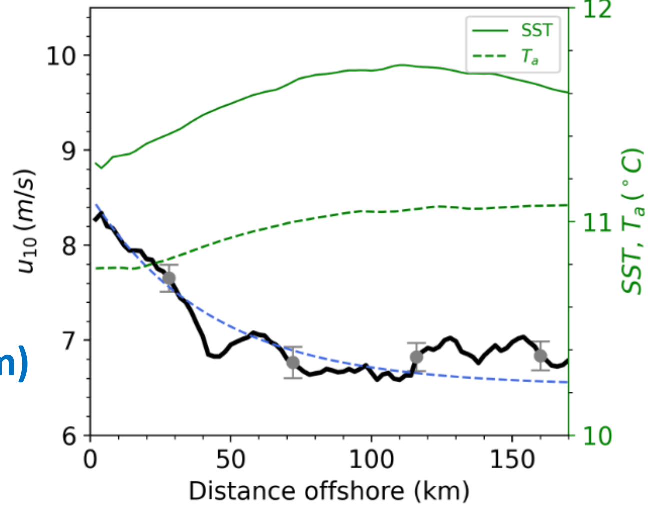
- **Period: 2017—2020**
- **Easterly wind:** $90^{\circ} \pm 30$
- **Southerly wind:** $180^{\circ} \pm 20$

Shape Types	Samples (Percentage)	$<\Delta u_{10}>$ (m/s)
Easterly wind		
Increasing ("INCS")	60 %	~ 3
Decreasing ("DECS")	22 %	~ -2
Late increasing ("LINCS")	15 %	~ 2
Southerly wind		
Increasing ("INCS")	62 %	~ 2
Decreasing ("DECS")	19 %	~ -1
Late increasing ("LINCS")	15 %	~ 2

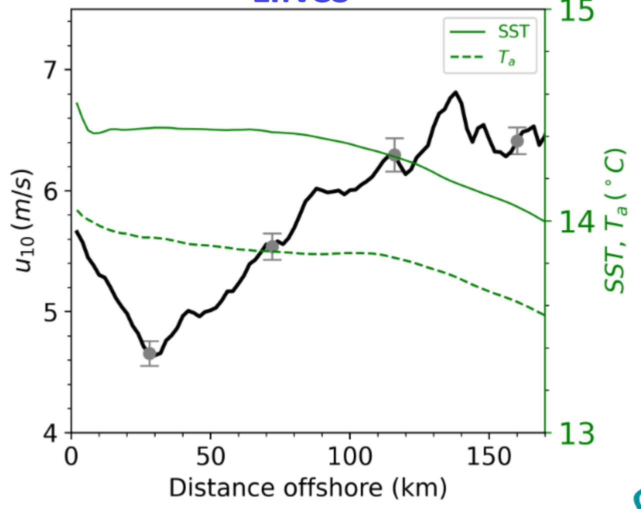
"INCS"



"DECS"



"LINCS"



"LINCS": combination of "DECS" (→40 km) and "INCS"

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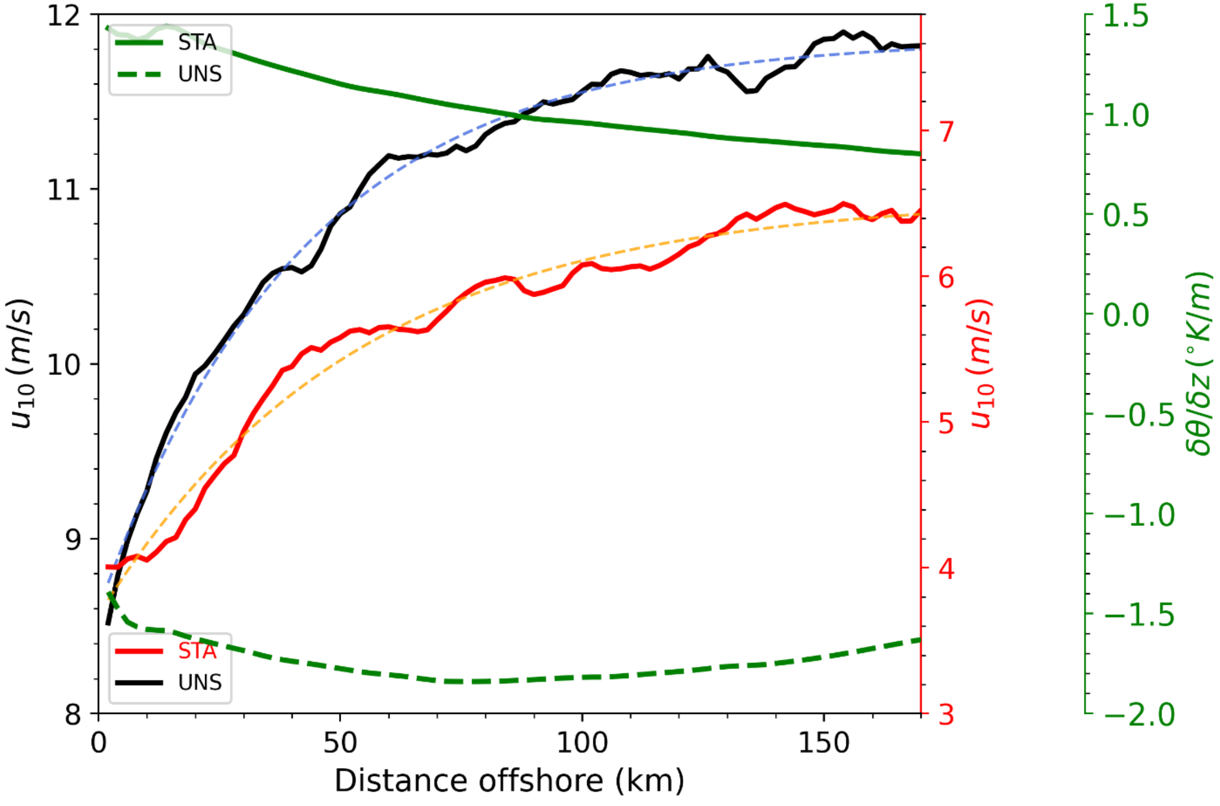
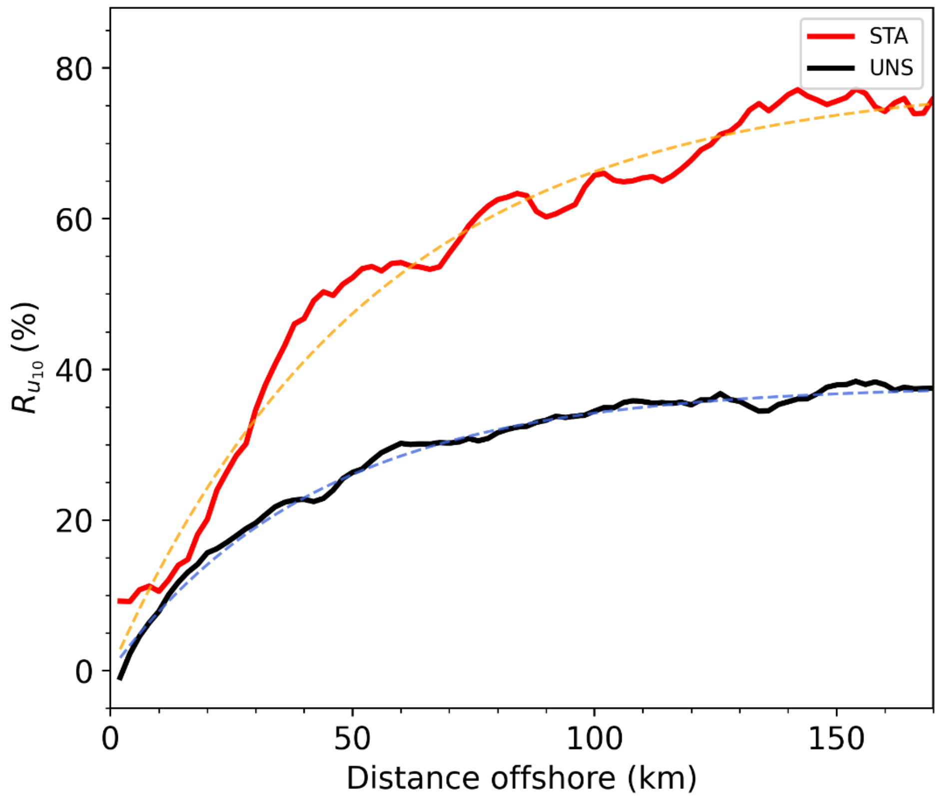
Statistical analysis: impact of atmospheric stability

Average wind speed gradient (East)





- $x_{95\%}$ shorter for "UNS" (72 km) than "STA" (112 km)
- R^{f}_{max} high for thermally stable cases

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Summary

- Valuable information about coastal effects from SAR
- Important horizontal gradient of wind speed

  (increasing and decreasing winds away from the coast)
- Impact of stability on the distance of wind equilibrium:

  - short distance for unstable conditions

  - longer distance for stable conditions

Vielen Dank!

Thank you!