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Coastal wind study based on Sentinel-1 and ground-based scanning lidar

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1) Introduction

Winds in the coastal zone have importance for near-shore wind farm planning. Recently the Danish Energy Agency gave new options for placing offshore wind farms much closer to the coastlines than previously. SAR wind retrievals give uniquely detailed spatial information on offshore wind fields. Wind maps can be retrieved from SAR observations at resolutions finer than 1 km. The high resolution make SAR images suitable for wind retrievals in the coastal zone, but the Geophysical Model Functions (GMF) for the wind retrieval are tuned for open sea conditions [1]. DTU routinely retrieves SAR wind fields from the Sentinel-1A satellite using APL/NOAA's SAROPS system with GFS model wind directions as input. For the presented cases CMOD5.n is used. Ground-based scanning lidar located on land can also cover near shore areas. In order to improve wind farm planning for near-shore coastal areas, the project "Reducing the Uncertainty of Near-shore Energy estimates from meso- and micro-scale wind models" (RUNE) was established. The lidar measurement campaign started November 2015 and ended in February 2016 at the Danish North Sea coast at around **56.5°*N*, 8.2°*E***. 107 satellite SAR scenes were collected during the same period.

2) RUNE campaign – a short overview

Figure 1 shows the experimental setup of RUNE. Multiple lidar systems were deployed: Five ground based profilers and one floating lidars, two time synchronized scanning lidars in dual Doppler configuration provide transects along three heights, and one additional scanning lidar. Note that dual Doppler points close to the coast are problematic because the beams are parallel which causes high uncertainties in the reconstruction. The generated data sets gives a very complete overview of the wind conditions in this $\mathbf{8 \times 8 km}$ large area.

3) RUNE scanning patterns

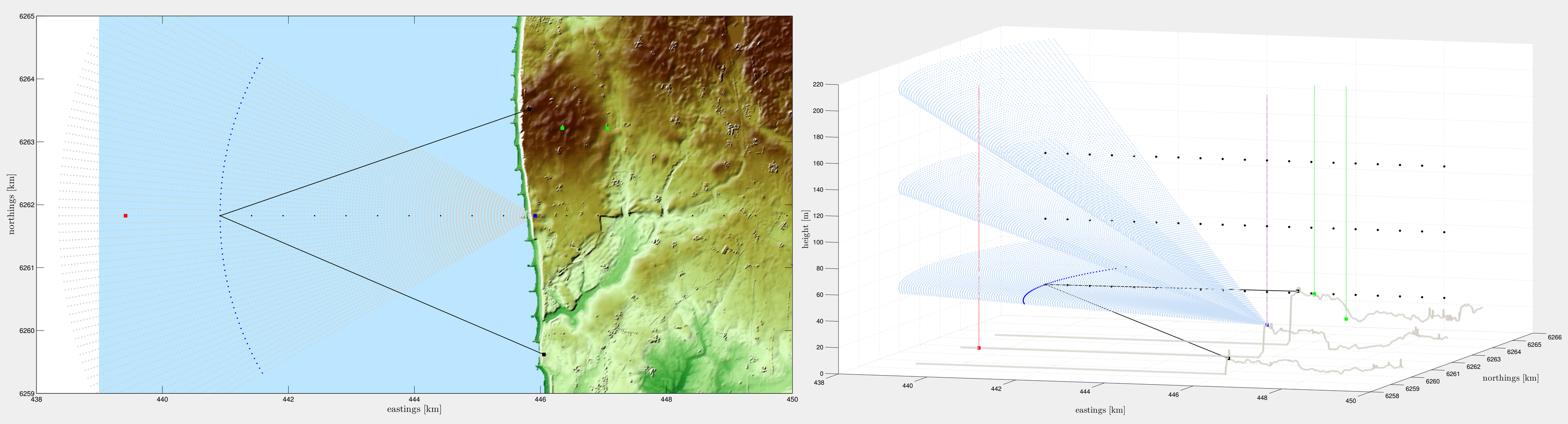

Figure 1: Scanning lidar patterns for RUNE campaign. Sector scans blue, dual Doppler black.

4) Method for comparing SAR and Lidar winds

SAR/scanning lidar comparisons have previously been done at Fino2 to investigate offshore conditions and wakes [2]. Here we want to investigate performance of SAR wind retrievals in the coastal zone and the behaviour over the distance to shore and therefore choose the dual Doppler transects at 50m, 100m and 150m. Two issues arise, co-location in space and time: SAR wind retrievals represent the almost instantaneous wind speed at 10m. Therefore, we need to assume wind profiles to compare transects with SAR. Since wind profiles are valid for mean wind speeds, we use 10 min averages from the dual Doppler (4 measurements averaged) in order to find a good compromise for comparison of instantaneous SAR winds and the need for averaging. Figure 4 left shows differences in the 10m wind from the three transects using logarithmic wind profiles with a constant z_0 of 0.0002m roughly representing offshore conditions – onshore winds seem to agree better than offshore winds. The logarithmic wind profile will be used for onshore directions and a power law wind profile assuming the same shape as the profiling lidar for offshore directions.

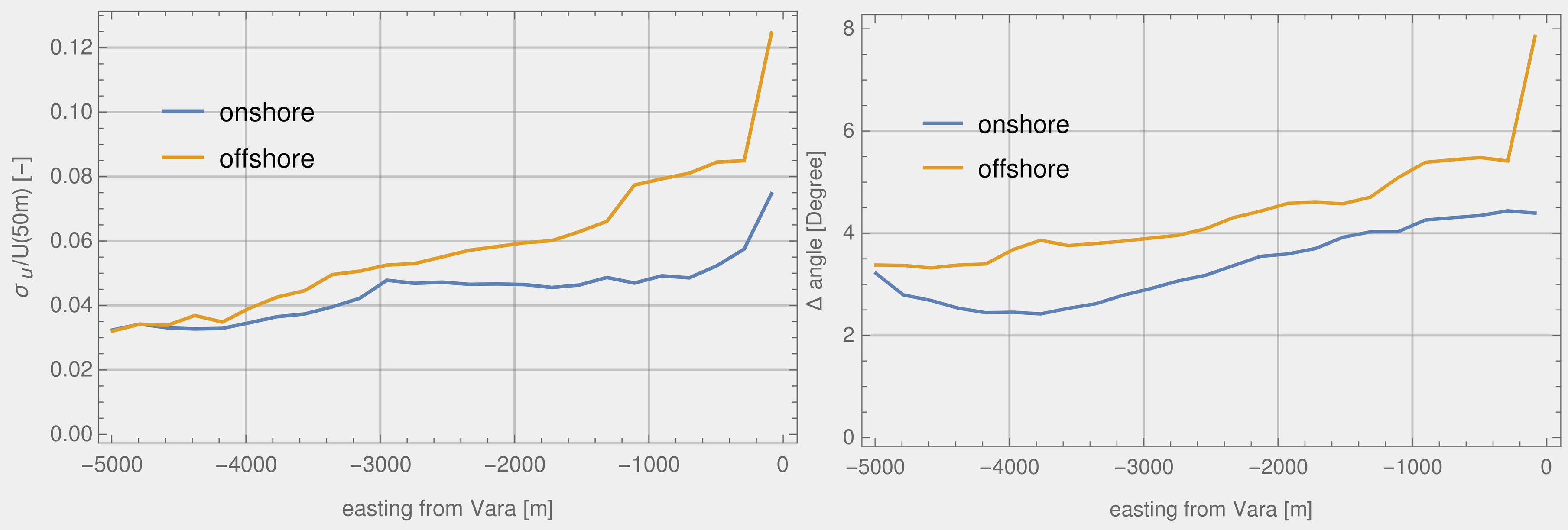

Figure 2: Left: Nondimensional difference between 10m winds derived from 50m and 100m with a logarithmic profile. Right: Difference in wind direction between 50m and 100m. Averaging time from Dec 2015 to Feb. 2016.

5) Example cases

Figures 3 to 5 two examples – on the left a case from the 09.12.2015 at 05:40 UTC (case 1) and on the right the 07.12.2015 at 17:09 UTC (case 2). The wind direction in case 1 is onshore from NW and has changed abruptly an hour before the SAR image (cf. Fig 5). The 10m wind speed estimations from the dual Doppler collapse very well indicating that the wind profile is in fact logarithmic (cf. Fig 4 left) – the time series also suggests a well mixed boundary layer (cf. Fig 5 left). SAR processing using default GFS model input overestimates the wind speed by up to 4m/s. Correcting the wind direction input by measurements results in much better agreement.
For case 2 the wind is offshore from SE. A power law wind profile from the ground based profiling lidar seems to fit well (cf. Fig 4 right) – SAR wind and dual Doppler agree well for for more than 2 km offshore. For this case the time series suggest a stable boundary layer with much wind veer and shear (cf. Fig 5 right).

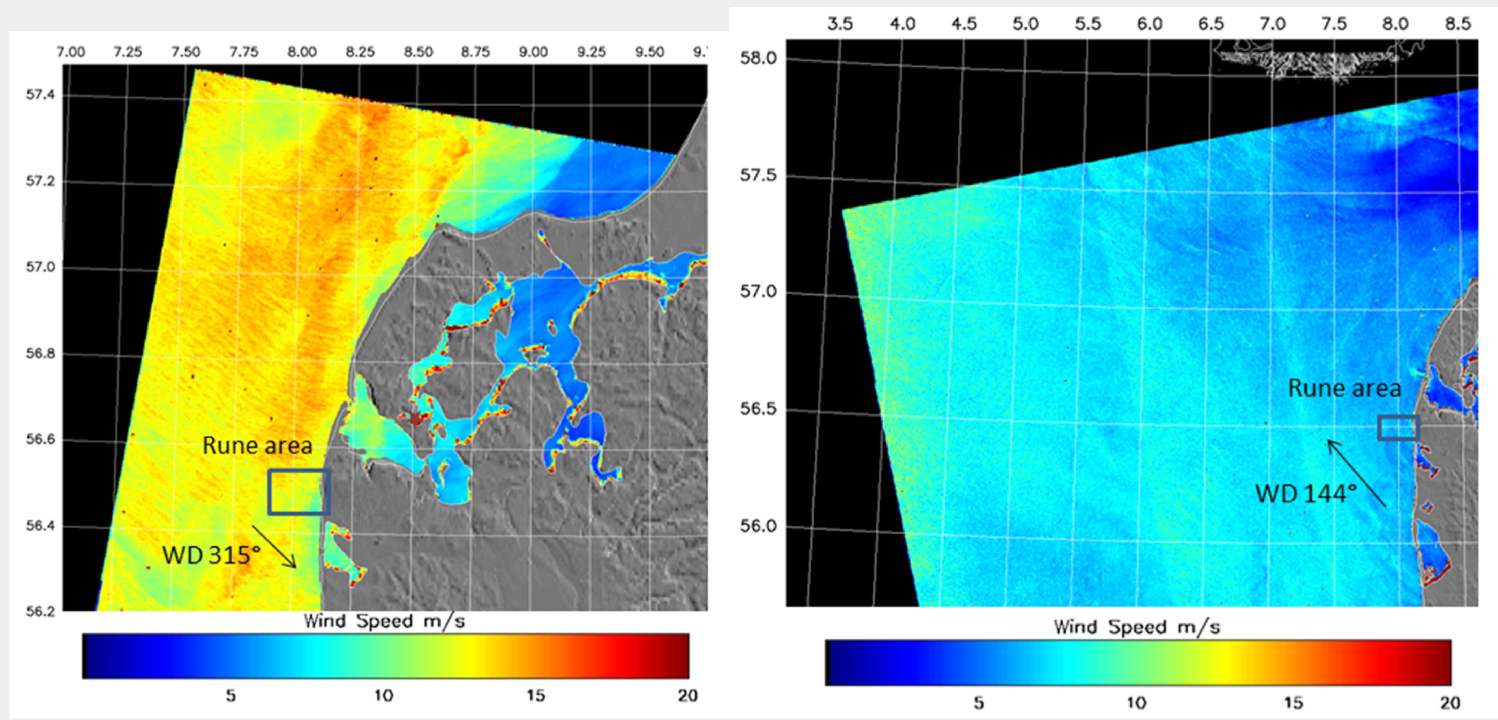

Figure 3: SAR wind fields from Sentinel-1A with constant wind direction.

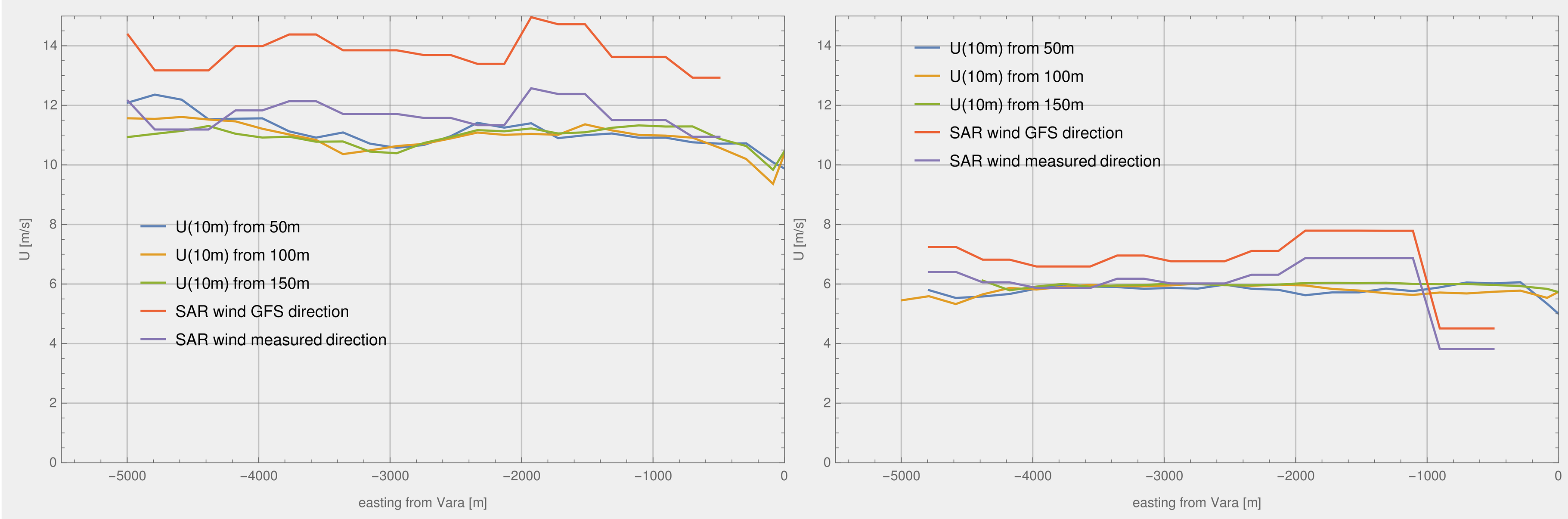

Figure 4: 10m wind speed derived from the three transects and SAR winds retrieval with GFS wind direction input and constant wind direction from dual Doppler measurements.

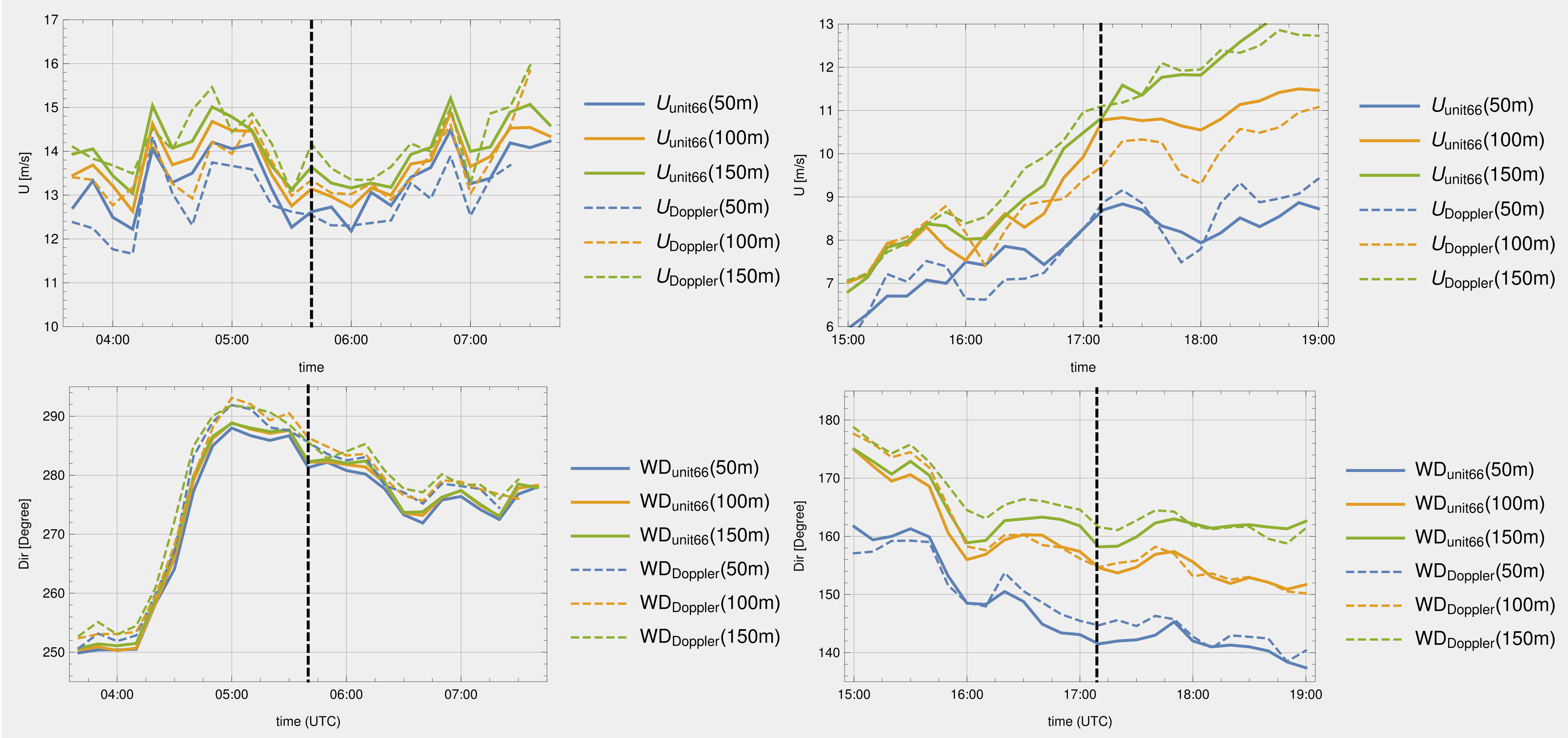

Figure 5: Time series of the wind speed and direction at 50m, 100m and 150m from unit 66 (onshore profiling lidar on the coast at 26.5m height.) and the dual Doppler 1.5km offshore. The black dashed line indicates the time SAR image.

6) Conclusions and Outlook

The two examples in Figure 4 show that SAR wind retrievals can give comparable results in the coastal zone compared with dual Doppler lidar wind observations. Assumptions about the wind profile are necessary to bring lidar wind profiles down to 10m for comparison. For onshore winds we expect SAR wind retrievals to work reasonably well because of the undisturbed fetch. For the presented offshore case the SAR winds agree well with the dual Doppler lidar as well. For both cases a constant wind direction input from the 50m dual Doppler lidar measurements improves the accuracy of the SAR wind speed retrieval.
The next step will be to use all available SAR scenes (107) for similar comparisons. Combining SAR images with measurements on land for information about the wind profile could help to make a SAR based near shore wind atlas. This approach can be tested with the 3 months of lidar data from the RUNE campaign.
The RUNE campaign also includes data from a scanning lidar. With a direction input from the dual doppler, reconstructions of the lidar wind field is possible. This would give the possibility to investigate if SAR wind retrievals can depict the instantaneous wind speed behavior in the coastal zone, also above 10m.

7) References & Acknowledgements

Acknowledgements go to ESA for Sentinel 1-A data, ForskEL for the RUNE project and APL/NOAA for the SAROPS system.

[1] Knut-Frode Dagestad et al. *Wind Retrieval From Synthetic Aperture Radar, an Overview*, Seasar 2012 Oceanography Workshop, 2013

[2] S. Jacobsen, *Joint Offshore Wind Field Monitoring With Spaceborne Sar and Platform-Based Doppler Lidar Measurements*, 36th International Symposium on Remote Sensing of Environment, 2015