Satellite based estimation of atmospheric wakes downstream offshore windparks using a new objective technique

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Introduction

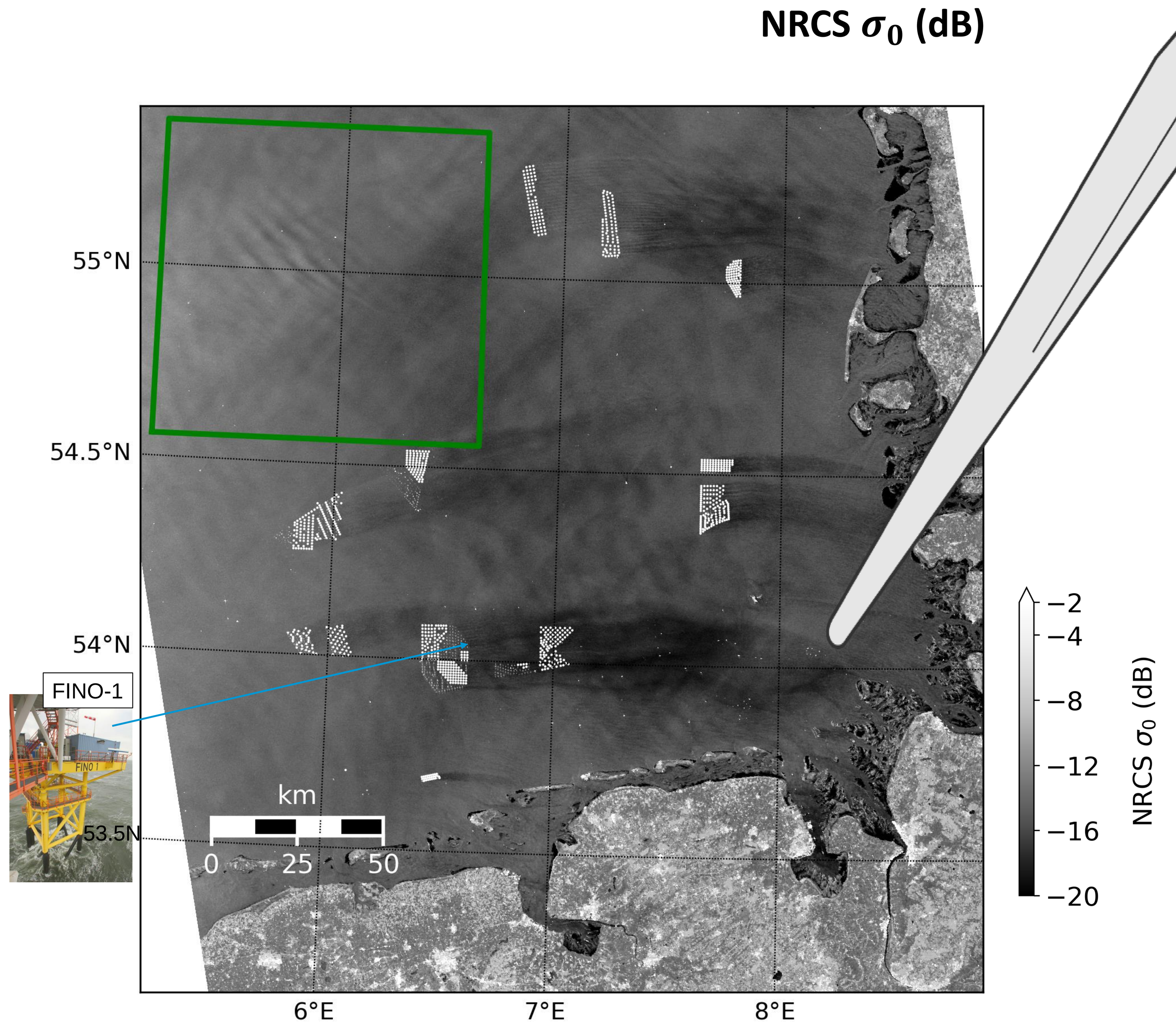
Synthetic Aperture Radar (SAR) satellite showed evidence of wakes longer than 20 km. However, the analysis of SAR satellite data for the estimation of the wind speed deficit behind offshore wind farms is complex. The main difficulty is related to the fact that an undisturbed reference wind field for the time of the SAR overflight is usually unavailable. Only 1D velocity deficit could be computed from previous techniques that include manual intervention with some degree of arbitrariness.

- A need of an alternative and automated approach that uses the wind direction and the characteristics of the wake is important to limit the impact of arbitrariness on the results.
- This enables a systematic error analysis of SAR based wind deficit estimation. The spectral analysis of the background wind is therefore usueful.

Used tools and observations

- One important source of information for the analysis of atmospheric wakes behind offshore windparks is satellite synthetic aperture radar (SAR). These data are not affected by daylight and cloud conditions and provide information on the small scale roughness of the sea surface, which can be related to near surface wind conditions. SAR scenes as acquired by the European Sentinel-1A/B satellites provide large coverage (e.g., 200x200 km) and high resolution (e.g., 20x20 m).
- Wakes behind offshore wind turbines cause very characteristic features on SAR images (dark streaks). 10-m wind speeds can also be retrieved from SAR data through a so called geophysical model function (GMF). This enables the estimation of some quantities such as the velocity deficit.

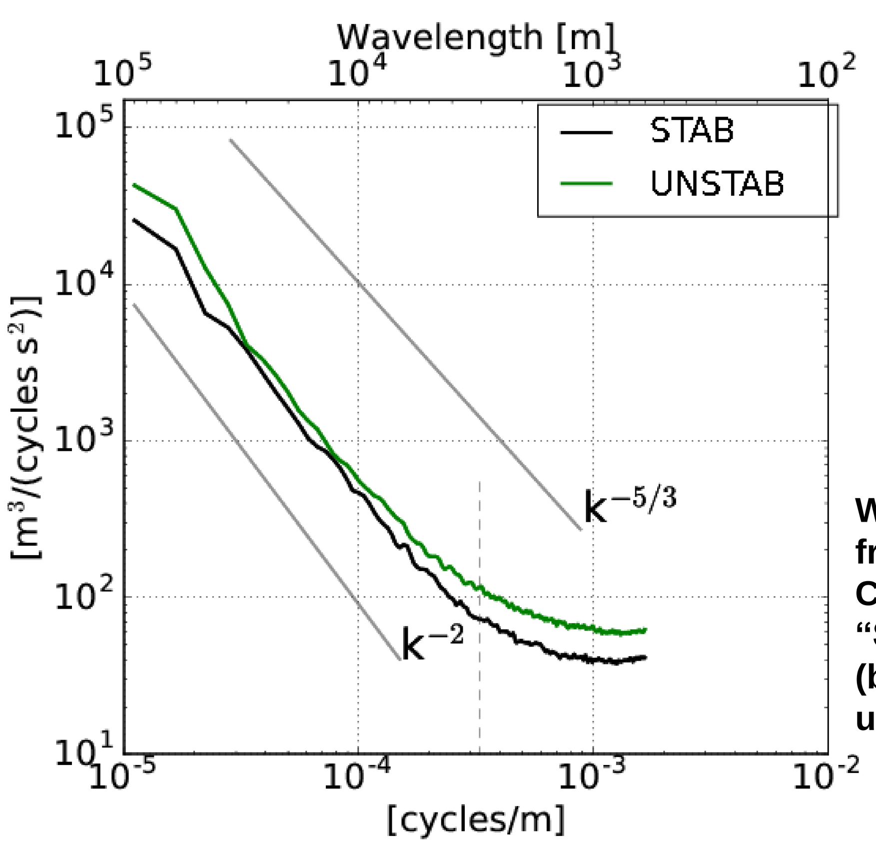
NRCS σ_0 (dB)



SENTINEL-1 SAR images acquired on M60 June 2019 at, 17:16 UTC showing wakes of more than 70 km length (dark streaks). The green box represents the domain of the computation of wavenumber spectrum

Horizontal wavenumber spectra

Wavenumber spectra are computed in the green box using the 10 m-wind derived from SAR that are collected from September 2016-December 2017. Wind field data were classified considering the stability conditions based on the thermal stratification from FINO1 data. It is found that the slope is quite close to k−5/3 power law. However, the spectral power of unstable conditions is higher than the spectral power of stable conditions.



Wavenumber spectra computed from 10-m wind field derived from Copernicus Sentinel-1 data. "STAB" stands for stable cases (black curve) and "UNSTAB" for unstable cases (green curve).

A new 2D velocity deficit computation

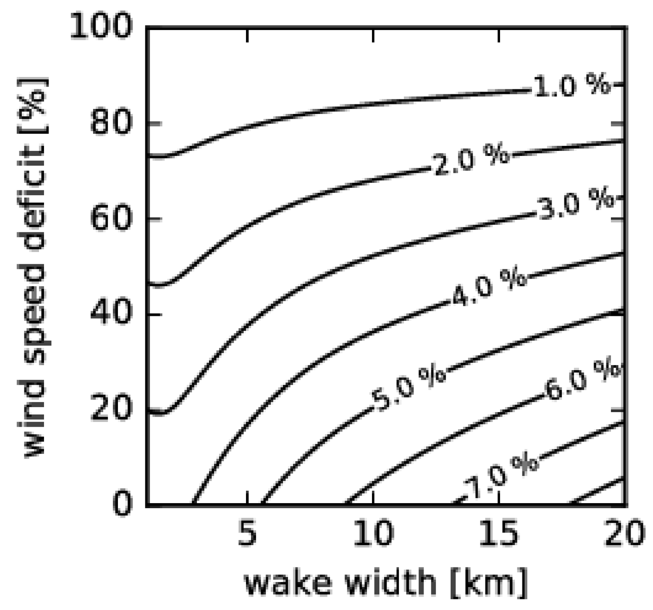
The computation of the velocity deficit of wakes behind the offshore windparks requires the better knowledge of the undisturbed or freestream wind field. The estimation of the background wind field is performed using the undisturbed wind fields on both side of the wake area through filtering method (e.g. Kaiser window K_ξ). It takes into account the **width** of the wake (ξ) and the **wind direction**. **The background wind $\mathbf{V_{freestream}}$** is obtained though the **convolution** of the filter and the original SAR wind field. This procedure enhances the wind speed in the wake areas. Finally, the velocity deficit $\mathbf{V_d}$ is estimated without any manual intervention. The filter emphasizes visually the 2D view of the wake.

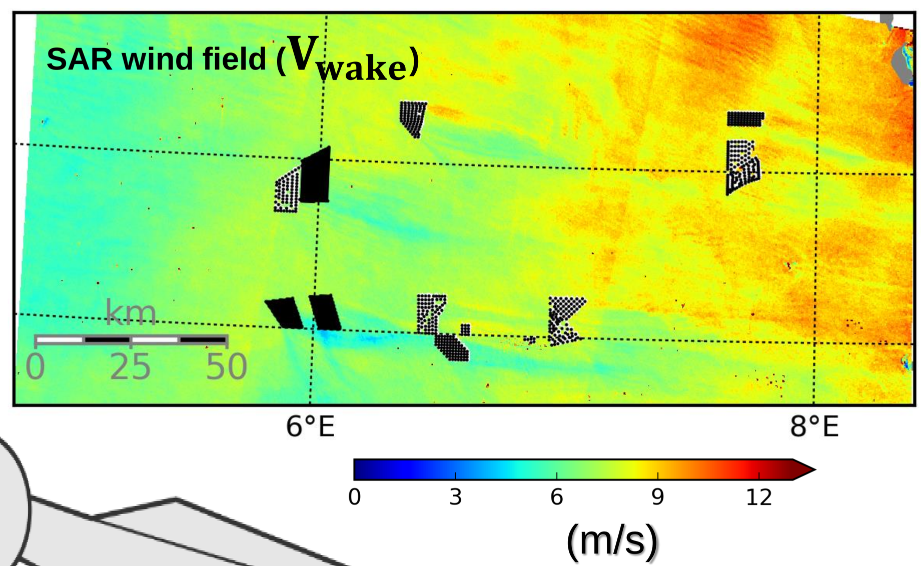
$$V_d = 100 * \frac{V_{freestream} - V_{wake}}{V_{freestream}}$$

Estimation of $V_{freestream}$ by 2D convolution of the SAR wind field with taylored filter

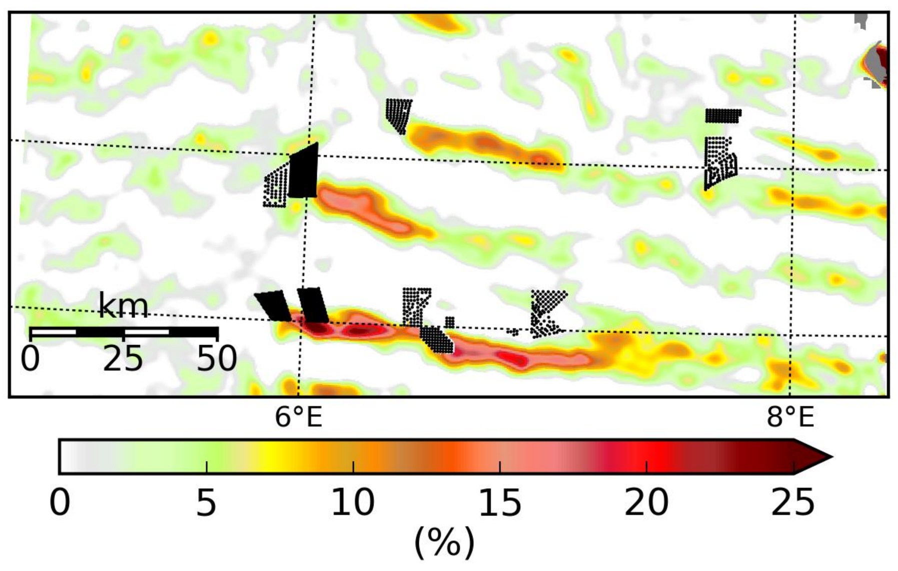
$$K_\xi(x) = \begin{cases} \dfrac{I_0\left(\alpha\sqrt{1-(2x/\xi)^2}\right)}{I_0(\alpha)}, & |x| < \xi/2 \\ 0, & |x| \geq \xi/2 \end{cases}$$

Error of estimated deficit as a function of wake width and "true" deficit. The given % number are absolute errors defined as STD with respect to "true deficit" given in %



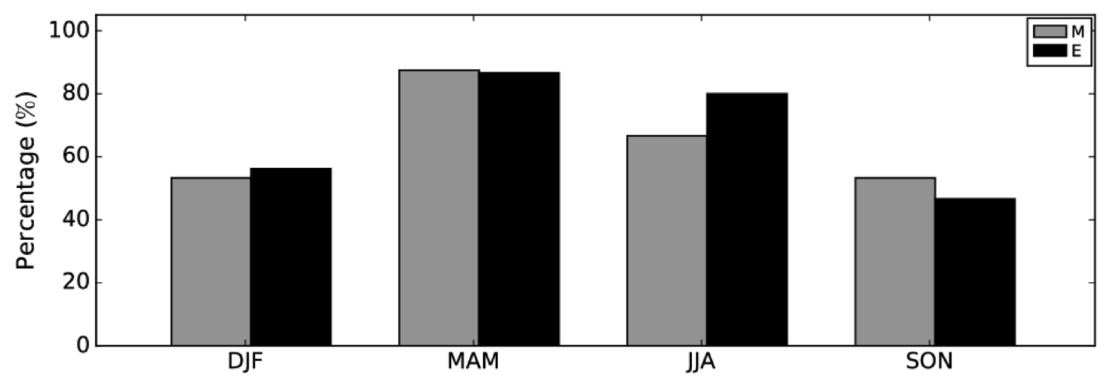


Velocity deficit derived with WISDEM technique

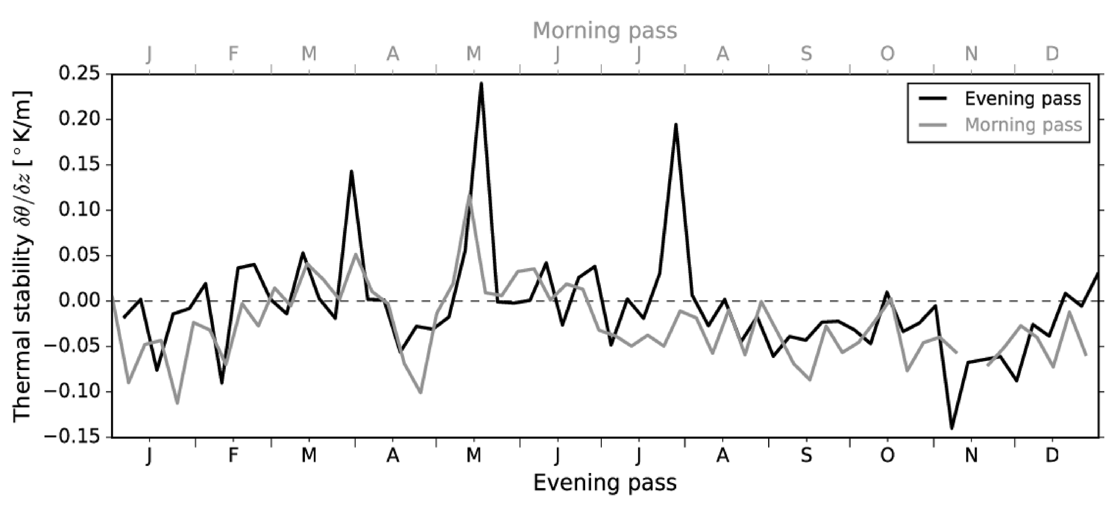


Statistical wake occurrence analysis

The velocity deficit computed from the filter technique is used as a tool to analyse the detection of wake behind any wind park in the German Bight in the year 2017. The statistics of appearance of wakes is based on the morning and evening SAR overflights for the same frame geometry. High percentage of wake is found from March-August (**62% / 59%) for** Evening/morning passes. This results correlate with the thermal stratification from FINO-1.



Percentage of Sentinel-1 wake appearance in 2017 for Morning (M) and evening (E) passes.



Thermal stability estimated from FINO-1 for morning and evening passes.

Conclusions

- The spectral analysis revealed that spectral slope of the wind field for all stability conditions are generally close to k-5/3. The spectral energy decreases with the atmospheric stability.
- The new filter method improves the 2D view and detection characteristics of wakes behind the windparks. This eases the estimation of the velocity deficit behind offshore wind parks from SAR imagery without any subjective and arbitrary manual interventions. It also allows error estimates for deficits based on spectral properties of the background wind field.
- Seasonal distribution of wake is displayed, which is coherent with the thermal stratification from FINO-1

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