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Far wake wind field comparison between satellite retrievals and microscale model results

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Introduction

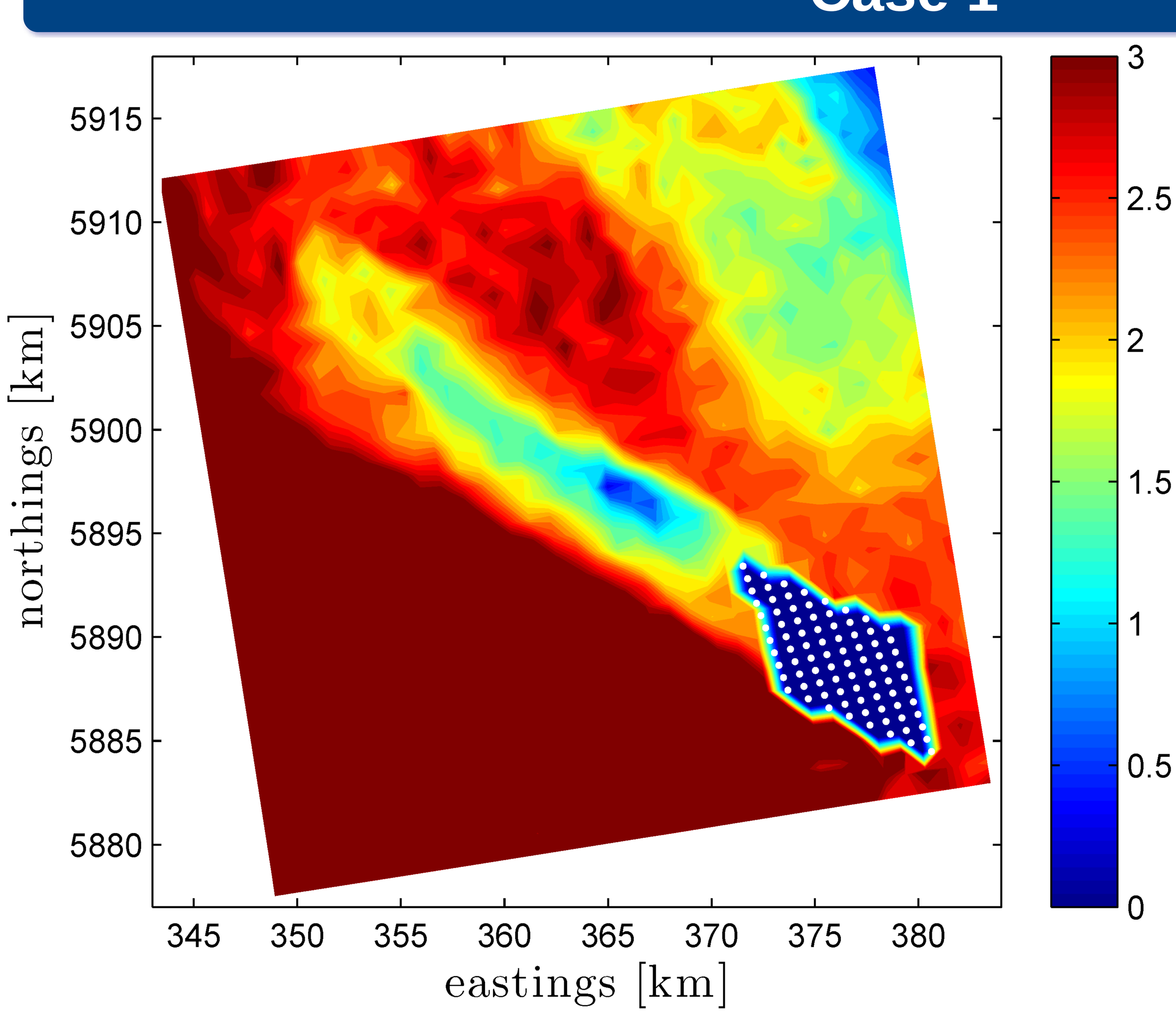
Clusters of offshore wind farms are becoming denser in the Northern European Seas. New offshore wind farms will be designed and planned so that they capture most of the energy available in the area, which in already current scenarios means that they will shadow the other offshore wind farms making wind projects economically less attractive. Satellite SAR images are of enormous advantage for planning offshore wind farms and clusters as wind-related measurements in offshore areas are scarce and very expensive. Synthetic Aperture Radar (SAR) can perform wind retrievals in extended offshore areas and we are already aware of the far wake effects of offshore wind farms based on previous SAR images collected from satellites. In this study we will directly compared new SAR wind retrievals for extended offshore areas where there are currently operating many of the largest offshore wind farms with the wake results from a microscale model. The microscale model is inherently not able to capture many of the effects of such large offshore wind farm clusters but we show that it can be used as part of the planning of wind projects.

Background

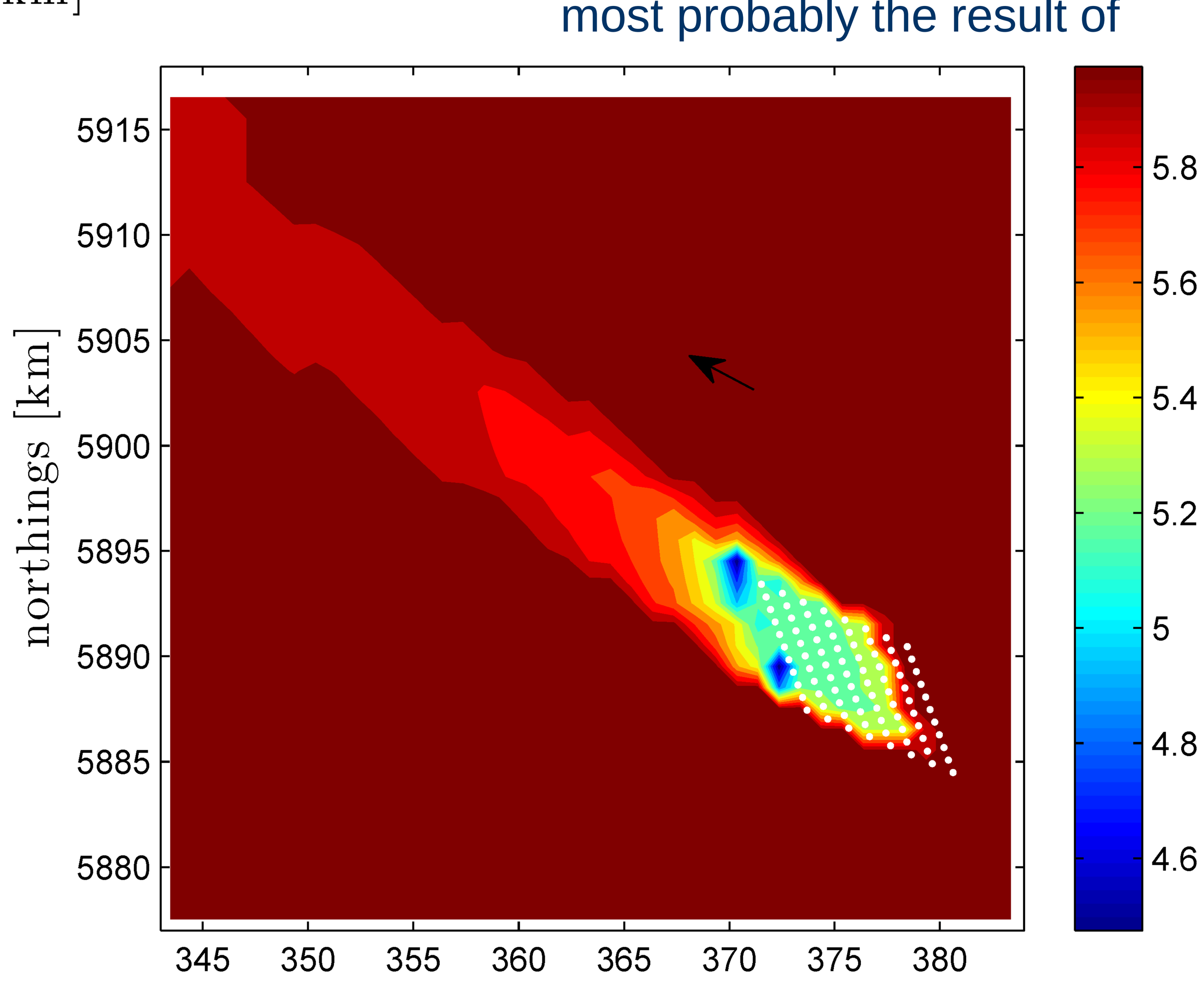
A modified version of the Park wake model (Katic et al. 1986) also implemented in the Wind Atlas Analysis and Application Program (WAsP) (Mortensen et al., 2007), is here used for wake calculations. The main difference between this modified version and that in WAsP is that the former does not take into account the effects of the 'ground reflecting back wakes' and so it only takes into account the shading rotors both directly upstream and sideways. The Park wake model is based on the wake deficit suggested by Jensen (1983), who derived a mass conservation-like equation for the velocity deficit behind a wind turbine. Katic et al. (1986) further suggested that the square of the total wake deficit should be the sum of the square of all contributing wake deficits and introduced the effect of the underground rotors.

We implemented the model in a Matlab script, which allows us to compute wake deficits in any given point and so results from the wake model can be compared to, e.g., satellite derived wind maps which contain information on a large area. Here we use a wake decay coefficient of 0.03 for the wake computations. The wind speed output of the model is at hub height and thus for comparison with the 10-m satellite winds the wind speed at any level can be extrapolated to 10 m and viceversa by assuming the wind follows the logarithmic profile with a constant roughness length of 0.0002 m

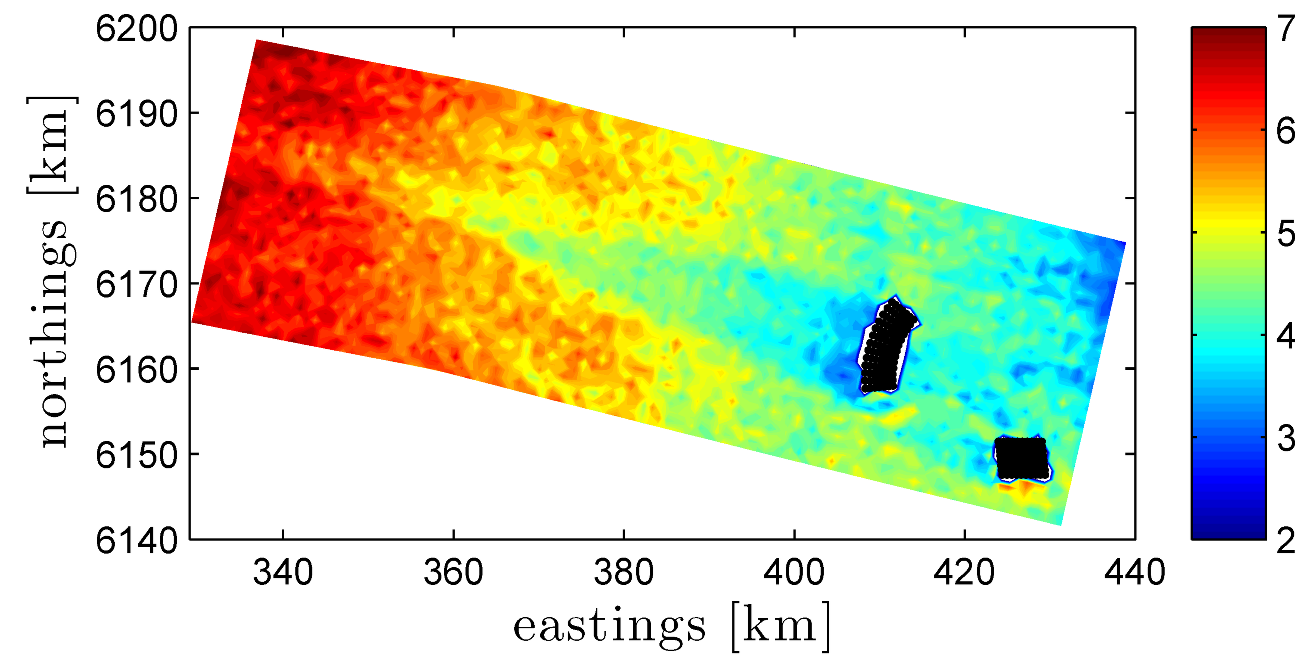
Case 1



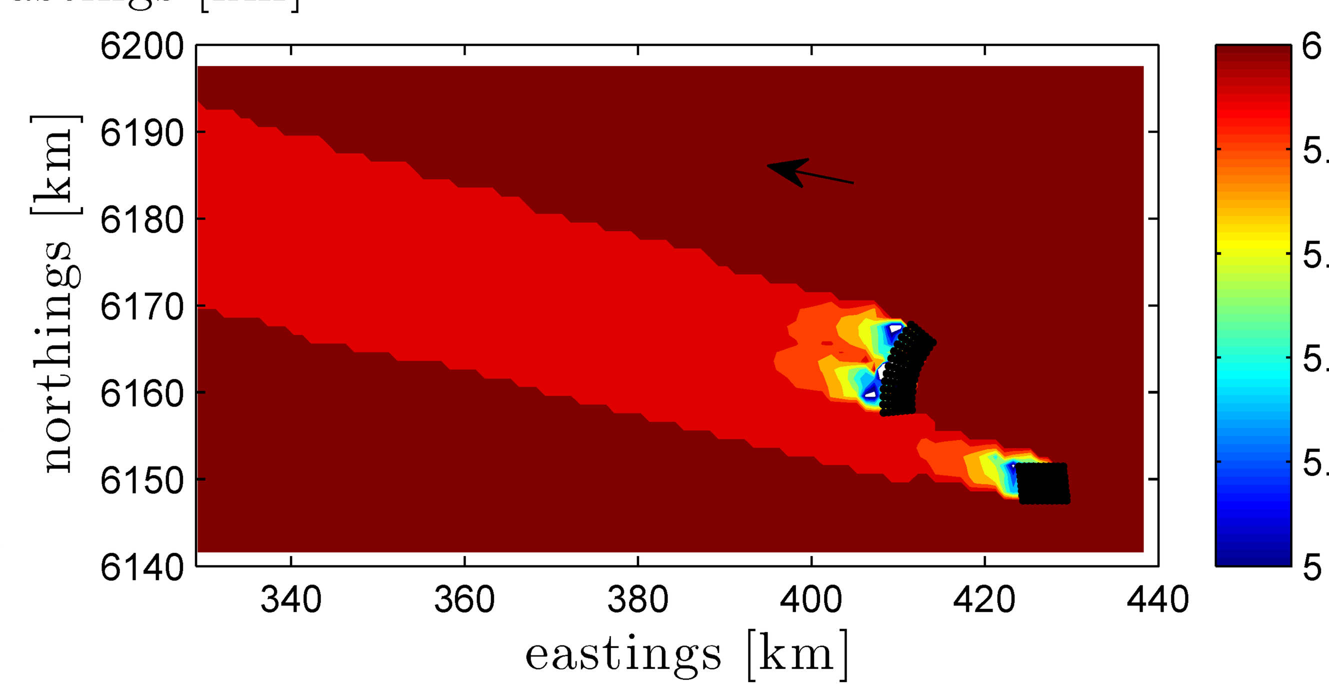
Three different satellite images (cases) are here analyzed. On the left plot of each case the SAR retrieval is displayed and on the right plot the wake results. Case 1 illustrates southeasterly winds at the Sheringham shoals wind farm. The maximum wind speed of the satellite grid points upstream the wind farm is about 3 m/s, which is approx. 3.58 m/s using the log profile. Turbines cannot operate under such wind speeds so the image is most probably the result of higher wind speeds met before at the farm. The wake model input is 6 m/s and 125° at 81.75 m. Here it is interesting to notice that although there are obvious differences between the results of the model and the SAR image, the wake spreads very similar in both cases, but as expected, the wake extends approx. 15 km in the simulation results, whereas it seems to extend up to 30 km in the SAR image



Case 2

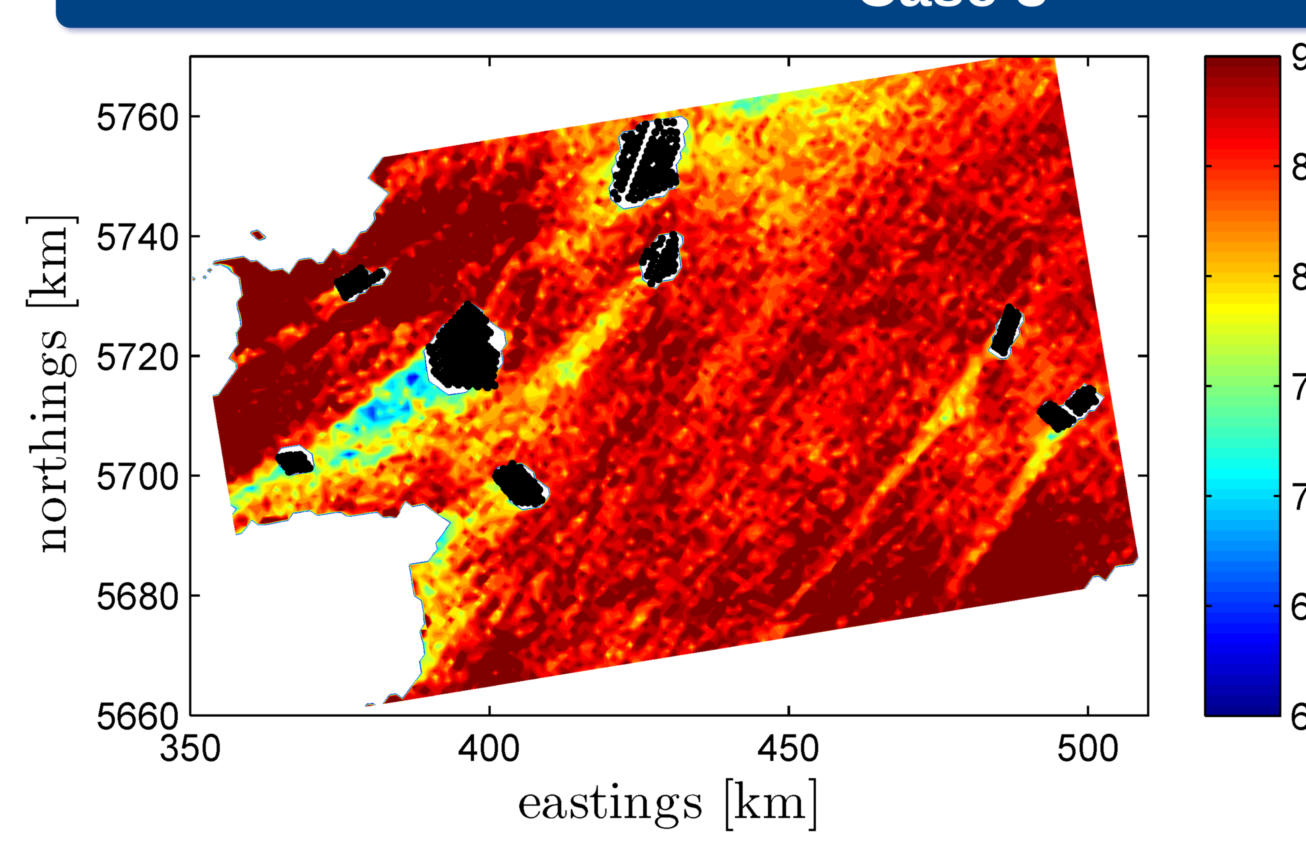


Here we have south-easterly winds at the Horns Rev I and II wind farms. The maximum wind sped of the satellite grid points upstream Horns Rev I is ~5 m/s, i.e. that at 80 m the wind speed is ~6 m/s which is the input to the model with a direction of 105°

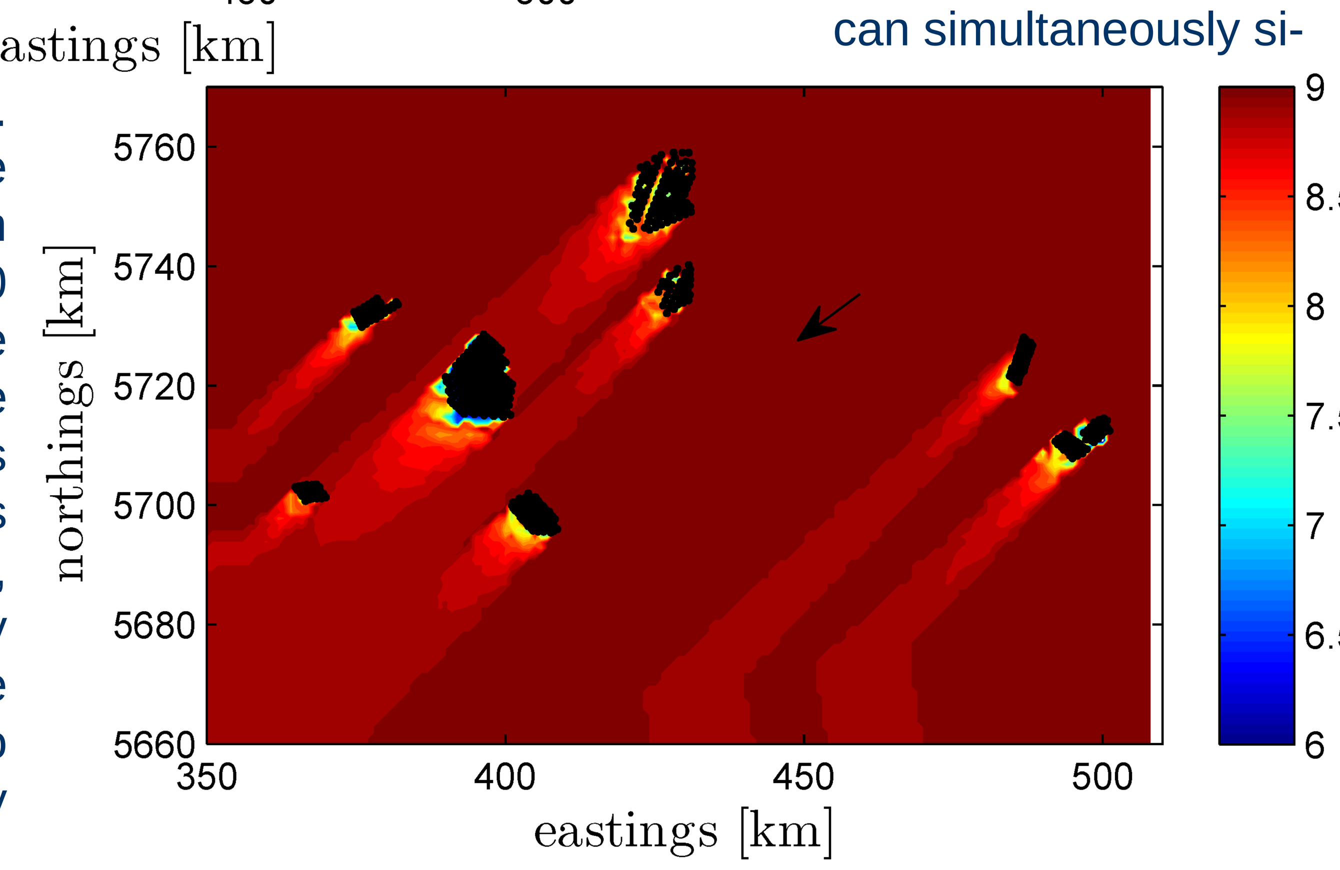


The wind speed variability in the SAR wind retrieval is very high (most probably due to the strong coastal wind gradient). The image shows a wake behaving with a cone-like shape not shown in the simulation results. However, close to and downstream the wind farms, particularly within the first 5-10 km northwest of Horns Rev II, the wake pattern is very similar between the SAR and the wake model results showing two distinctive zones of high speed deficits, which is the result of the wind farm wake pattern for this particular direction.

Case 3



The conditions here are unique because we observe wakes in the satellite image for a number of wind farms distributed in a large area of the North Sea and because the wind speed and direction do not seem to largely change over such extended area so we can simultaneously simulate all wind farms. Model results are shown for the condition of 9 m/s and 40° at 70 m. The SAR image shows that most of the wind variability comes from the wake deficits downstream the farms, which extend many tens of kilometers. The speed deficits seem to be well reproduced by the wake model.



Conclusions

- SAR images are useful for studying the effects of offshore wind farm clusters
- Microscale models can be used for understanding the inter-effect of offshore wind farms and clusters
- Wake results from microscale models (in terms of wake deficits, extension and spreading) are comparable with wind retrievals from satellite SAR

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