International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 32, No. 1, March 2022, pp. 81–86; https://doi.org/10.17736/ijope.2022.aj11
http://www.isope.org/publications

Comparison of Simulated Offshore Wind Farm Wakes and SAR Images

Henning Heiberg-Andersen, Heidi Ytterstad Hindberg, Jørn Havås Mæland, Harald Johnsen,
Torleif Lothe and Leonid Vasilyev
Norwegian Research Centre AS (NORCE), Bergen, Norway

Offshore wind farms are usually located remotely from meteorological stations, and access to wind measurements in the farms and immediate surroundings is therefore limited. Spaceborne Synthetic Aperture Radar (SAR) is a promising instrument for observation of wind farm wakes due to its high spatial resolution and large coverage. The wakes are manifested in the SAR backscattering intensity images as elongated areas with lower backscattering intensity. Good agreement between images from SAR and Doppler radar measurements has recently been reported for the wake of the Westermost Rough wind farm in cases without stable atmospheric stratification. Inspired by this first-of-its-kind comparison of ground-based Doppler radar and SAR images of wind farm wakes, in this work we compare SAR images and simulations of the two interacting wakes of the Sheringham Shoal and Dudgeon wind farms off the east coast of England. The wakes are simulated by the Weather Research and Forecasting (WRF) code, a state-of-the-art regional meteorological code that has a simple built-in wind farm model. The normalized radar cross section (NRCS) is estimated from the Sentinel-1 IW GRD products by averaging the intensity pixels to the output resolution of the model (i.e., 500 m). To study the impact of atmospheric stability on the agreement between 10-m wind speeds derived from SAR images and WRF simulations, we select two cases of land breeze and two cases of sea breeze. A sea breeze is characterized by a more stable marine atmospheric boundary layer, so the best agreement between SAR wind fields and simulated wind fields is expected for the land breeze cases, according to the comparative measurements from the Westermost Rough wind farm. All four selected cases have wind speeds above 10 m/s to promote clear wind farm wakes in the SAR images. For the wind industry, we expect relations between SAR images and hub height conditions to be of interest, and we make a first attempt to establish a robust relationship between the turbulence intensity at hub height and the SAR backscattering intensity in the centers of the wind farm wakes. In accordance with the reported results from Westermost Rough, we find better agreement between simulations and wind fields from SAR images for unstable than for stable atmospheric conditions. For stable atmospheric conditions, there appears to be no systematic relationship between SAR backscattering intensity and turbulence intensity at hub height in the wake region.

INTRODUCTION

Sentinel-1 is an operational C-band Synthetic Aperture Radar (SAR) earth observation mission consisting of two satellites in polar orbit. It was developed by the European Space Agency (ESA) for the Copernicus initiative and has a free and open data policy (www.copernicus.eu). SAR satellites do not depend on solar illumination and can penetrate clouds and thus can generate daily observations over large areas at higher latitudes. SAR ocean images are basically a “fingerprint” of the lower atmosphere on the ocean surface and to first order a measure of surface stress. Thus, traditional SAR wind is “wind” modified to be consistent with the surface stress, i.e., equivalent neutral wind. Neutral transfer coefficients that can be used to convert the satellite wind to kinematic surface stress for assimilation into numerical weather prediction models have been developed (e.g., see Bourassa et al., 2019, and references therein).

Offshore wind farms are clearly visible in SAR images as collections of bright points of strong backscattering from the metallic surfaces of the wind turbines. The wakes downwind of the farms are characterized by increased turbulence and reduced wind speed. The ambient atmospheric turbulence generally constrains the extension of the wake by mixing surrounding air of higher speed into the wake. Since the atmospheric turbulence is typically lower over the ocean than over land, offshore wind farms typically create longer wakes than onshore wind farms. At wind speeds above 10 m/s, we observe clear wake effects behind offshore wind farms in the SAR images for both stable and unstable atmospheric conditions.

The recent work of Ahsbahs et al. (2020) showed good agreement between images from SAR and Doppler radar measurements at the Westermost Rough wind farm in cases without stable atmospheric stratification. Land and sea breezes provide most of the energy harvested by wind farms in coastal regions, which makes accurate 24-hour power forecasts for trading and grid operation challenging. It is worth examining whether the information contained in the freely available SAR images can improve the understanding of wakes under land and sea breezes and eventually lead to better operational forecasts. A land breeze is characterized by increased turbulence and vertical air motion over the sea surface, while a more stable marine atmosphere characterizes a sea breeze. Thus, according to the findings of Ahsbahs et al. (2020), SAR images of the wind farm wakes should typically be more reliable during a land breeze than during a sea breeze.

In this work we compare simulated wakes to SAR images taken during land and sea breezes at wind speeds above 10 m/s. The wind farm wakes are simulated by the Weather Research and Forecasting (WRF) model (Skamarock et al., 2008), an atmo-

Received October 11, 2021; updated and further revised manuscript received by the editors December 6, 2021. The original version (prior to the final updated and revised manuscript) was presented at the Thirty-first International Ocean and Polar Engineering Conference (ISOPE-2021), Rhodes, Greece (virtual), June 20–25, 2021.
KEY WORDS: Wake simulation, offshore wind farm, SAR.