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Synthetic aperture radar satellite data for offshore wind assessment: A strategic sampling approach

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ABSTRACT

Many studies have shown that the synthetic aperture radar (SAR) approach is an adequate tool for wind assessment and mapping in coastal and offshore areas. However, a large SAR scene sample is required to precisely calculate wind statistics. The proposed sampling algorithm, called strategic sampling, is based on a long term data series (e.g. QuikSCAT) from a nearby location to accurately evaluate the wind statistics with a reasonable number of wind observations (<45). Strategic sampling methodology relies on the complementarity of two databases: the SAR satellite RADARSAT-1 and the QuikSCAT scatterometer were chosen. Random sampling, on the other hand, requires 75 and 225 wind observations to estimate, respectively, the average wind speed and mean power output of a modern wind turbine, with an error less than 10% for a 90% confidence level. This represents a difference of at least two to seven times more SAR scenes for random sampling than for strategic sampling. The SAR sample selected via strategic sampling at a specific offshore location can then be used for wind predictions in neighboring regions. Finally, the strategic sampling algorithm is used to estimate the minimum number of SAR images for a coastal region located in eastern Canada.

1. Introduction

Offshore areas are expected to play an important role in wind power development. Since winds are usually stronger and steadier there, several offshore wind power projects are already planned in Europe and in North America. For instance, the 300 GW European wind power target for 2030 is half onshore and half offshore (EWEC conference, 2007). Unfortunately, sea wind measurement improvements are still needed, especially in proximity to complex coastal conditions. Wind can be measured directly by anemometers and vanes put on buoys, masts and ships or indirectly by weather balloons and rawinsondes. But these methods cannot be applied to map large sea areas with high spatial resolution. In practice, only two approaches can meet these needs: numerical weather prediction (NWP) models and synthetic aperture radar (SAR) satellite imagery.

NWP models can generate wind statistics from simulations of the atmospheric flow by solving Navier–Stokes equations. NWP models are largely used for wind resource mapping. Wind atlases have been produced from NWP model simulations for several regions and countries (for Canada, see www.windatlas.ca). The accuracy of these numerical models is closely linked to the available meteorological data that serve as initial conditions as well as the model grid scale for adequately resolving variations in topography and surface roughness.

In the last five years or so, many studies showed that synthetic aperture radar (SAR) satellite imagery may also be useful for two purposes: (a) NWP result validation and improvement, and (b) as the main approach for wind assessment in coastal waters and offshore areas (Beaucage et al., 2008). The SAR satellite method provides measurements of sea surface winds derived from a snapshot of the sea surface roughness. Analyzed at a high-resolution scale, Beaucage et al. (2007) showed that wind speed accuracies estimated by the SAR approach are quite comparable to those of mesoscale NWP models. However, the ability to provide reliable wind statistics from remotely sensed data depends on the density of the SAR image database.

The basis of this study is to find an efficient sampling method for remotely sensed data in order to obtain a precise estimation of wind resources with a small number of observations. In other words, the goal is to limit the cost of wind mapping. The work of Pryor et al. (2004) has demonstrated that a minimum of 75 and 175 wind observations is required to accurately estimate the Weibull scale and shape parameters, respectively, using random sampling. They also showed that these numbers can drastically increase

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according to the Weibull fitting method used to characterize wind speed distribution. In this study, we introduce a new sampling method, called strategic sampling, based on a long term data series gathered from a nearby area, in order to make an accurate evaluation of wind statistics from a small subset of the whole remote sensing dataset. This relatively small sample selected via strategic sampling at a specific offshore location can then be used for wind predictions in neighboring regions. Thus, the strategic sampling algorithm allows the wind mapping of a wide coastal region with a reasonable number of SAR images. We will also show that it is more efficient in terms of sample size to estimate the mean power output produced by a modern turbine than the wind power density.

This paper presents three sampling methods: the first is based on random sampling, the second is called strategic sampling and the third is a combination of the two. In the methodology section, database and models available for the region of study are introduced. A description of the wind distribution and the methodology to estimate the Weibull parameters follows. The average wind speed and mean power output of a modern turbine is also presented. In the results section, the estimation of the Weibull parameter, average wind speed and mean power output are presented using random sampling, strategic sampling and a combination of the two. The next section shows how the strategic sampling results can be extrapolated to neighboring locations in order to estimate the minimal SAR image number necessary to map a large region. Finally, the last section presents the limits of each method as well as the errors associated to the parameter estimations.

2. Methodology

2.1. Database and models

In this study, we focus on the wind resources of the St. Lawrence Estuary (see Fig. 1) near the tip of the Gaspé Peninsula in eastern Canada. Three types of long term data series are available: scatterometer wind data, SAR satellite wind-derived images and a wind atlas generated from NWP model simulations. The wind speed histogram is characterized by a classic Weibull distribution. The average wind speed and mean power output of a modern turbine are calculated for several specific sites. To compare with the lowest level of the atlas (30 m height), the wind speed measurements of QuikSCAT and RADARSAT-1, representing equivalent neutral winds at a 10 m height, are extrapolated to 30 m height using the logarithmic wind profile assuming neutral atmospheric conditions.

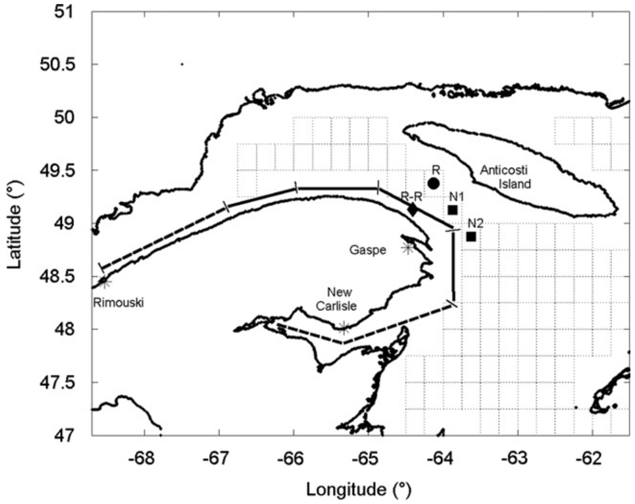

Fig. 1. Map of the St. Lawrence River and Gulf region with the QuikSCAT reference site (R), the two neighboring QuikSCAT sites (N1, N2),the Rivière-aux-Renards (R-R) offshore site and the Gaspé mast (Gaspe). The coastal waters of the Gaspé peninsula are divided into six zones for wind resource mapping. The dotted rectangles correspond to the 0.25° × 0.25° QuikSCAT grid.

Firstly, scatterometers like QuikSCAT or ASCAT (onboard METOP-A) and passive microwave radiometers (TMI, SSMI, AMSR-E and WINDSAT) located on satellites can provide sea surface wind fields at a relatively coarse resolution of approximately 50 km on a twice-daily basis. The QuikSCAT scatterometer (JPL, 2001) started operating in mid-July 1999 and allows to generate a wind climatology. The QuikSCAT wind data are processed automatically by the Jet Propulsion Laboratory and are freely available on the NASA PO.DAAC web site. We chose a reference site located at 49.375°N 64.125°W (see Fig. 1) because it coincides with the location of most of the SAR images in our dataset. From 1999 to 2006, a total of 2525 rain-free QuikSCAT data are available at this location based on the rain flag algorithm of JPL (2001) and Huddleston and Stiles (2000). Rainfall contaminates the wind speeds derived by QuikSCAT because it attenuates and scatters the radar signal in the atmosphere as well as modifies the sea surface roughness thereby reducing the accuracy of measurements (Contreras and Plant, 2006; Tournadre and Quilfen, 2003; Portabella and Stoffelen, 2001). The wind speed accuracy obtained from the QuikSCAT scatterometer is around 1–1.5 m/s (Ebuchi et al., 2002; Bourassa et al., 2003; Pickett et al., 2003; Chelton and Freilich, 2005). However, the 25 km grid size of the wind vector cells does not allow QuikSCAT to gather reliable wind data near the shore.

Secondly, SAR satellites (e.g. RADARSAT-1, AMI-SAR on ERS-2, ASAR on Envisat) retrieve the surface winds at a microscale resolution from a snapshot of sea surface roughness in a way similar to scatterometers. The large virtual antenna of synthetic aperture radar, produced by taking into account the Doppler frequency shift of the electromagnetic pulses scattered back to the radar, generates images with a resolution ranging from a few meters to 100 m. The Canadian RADARSAT-1 satellite has been operating since 1995. Since image acquisition is done upon request, the number of archived RADARSAT-1 images varies from one region to another. Furthermore, SAR satellite passes over the same location are less frequent due to a lower area coverage compared to spaceborne scatterometers and radiometers. The RADARSAT-1 revisit time is once a day in high latitude using large beam coverage (ScanSAR mode), and less than once every five days at the equator (RSI, 1995). In the St. Lawrence River and Gulf region, we initially possessed 104 RADARSAT-1 images (1996–2005 period) in various beam modes from standard to ScanSAR Wide. However, only 62 RADARSAT-1 images fully covered our reference location. The SAR-derived wind maps are produced using in-house software in a semi-automatic fashion depending on the source of wind directions used. Currently, an automatic and user-friendly software is being developed at the Risø Centre (Hasager et al., 2007). In the present study, we used the same methodology to transform SAR scenes into wind maps as is described in Beaucage et al. (2007). The SAR-derived winds usually have an accuracy of approximately 1.5 m/s (Vachon and Dobson, 1996; Wackerman et al., 1996; Monaldo et al., 2001; Choisnard et al., 2004; Hasager et al., 2005) compared to in situ measurements, and the retrieved wind fields are reliable even close to the coastline (Beaucage et al., 2007).

Thirdly, the Canadian Wind Energy Atlas was generated using the Mesoscale Compressible Community (MC2) model (Benoit et al., 1997; Tanguay et al., 1990) which was initialized with the NCEP/NCAR (National Centers for Environmental Prediction/National Center for Atmospheric Research) reanalysis (Kalnay et al., 1996) for the 1958–2000 period. The wind speed histograms and wind