High-resolution Surface Winds in the Coastal Transitional Zone from SAR Satellite Imagery and MC2 Weather Prediction Model

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EXTENDED ABSTRACT

In complex regions, the high-resolution wind fields can not be captured correctly by an interpolation of sparse observations such as from masts and buoys or from large-scale meteorological analysis. Observations distant by more than a hundred kilometres are generally poorly correlated in coastal environments where important transitions between land and sea occur in topography, surface roughness and temperature. On the other hand, wind field information on a regional basis with a very good resolution is provided by Numerical Weather Prediction (NWP) model and Synthetic Aperture Radar (SAR) satellite methods. At least two questions follow: a) how accurate are these two methods and b) can these complementary approaches help each other.

NWP models have been used since long ago for weather forecasting applications. These complex numerical models solving the Navier-Stokes equations with different schemes for physical processes and surface properties were not intended, at first, for surface wind purposes but focused mainly on describing correctly the temperature, clouds and rain precipitations. Anyhow, the state-of-the-art Mesoscale Compressible Community (MC2) model [1] [2], developed by Environment Canada, has shown high wind prediction capabilities [3]. It was used to produce the Canadian national wind atlas at a resolution of 5 km (www.windatlas.ca). With the satellite imagery approach, many instruments derive winds from a snapshot of the sea surface roughness: altimeter, passive microwave imager, scatterometer and SAR. The benefits of these wind retrievals have already been recognized, for example the ECMWF center includes the QuikSCAT scatterometer winds (spatial resolution ~ 25 km) in their analysis. SAR scenes have the advantage of giving realistic wind speed patterns with much more details (spatial resolution < 1 km) and closer to the coastline.

In the present study, 14 synoptic situations with near-stationary atmospheric conditions over the St. Lawrence River (Quebec, Canada) are analyzed. On the one hand, the SAR images are acquired from the C-band RADARSAT-1 satellite operating in horizontal polarization. A geophysical model function, CMOD-IFR2 [4], is applied to transform the normalized radar cross section into the 10 m height wind speed using a polarization ratio [5] $PR = \frac{\sigma^0_{HH}}{\sigma^0_{VV}} = \frac{(1+\alpha\tan^2(\theta))^2}{(1+2\tan^2(\theta))^2}$ with α=1 [6]. In our case, the 'a priori' information on wind directions necessary to invert the CMOD is obtained by an interpolation of local observations and measurements from the QuikSCAT scatterometer. On the other hand, the meteorological fields are computed on a 3D staggered grid by the MC2 model in self-nesting mode for grid-point spacing of 24, 4 and 1 km. The six-hour Canadian Meteorological Center (CMC) analyses are used to pilot the model for the coarse resolution runs.

In the coastal region of the St. Lawrence River and Gulf (Figure 1), the offshore wind features assessed by the SAR and MC2 approaches are well resolved. An overall comparison of the surface winds between these two methods gives a root mean square error (RMSE) of 2.07 m/s with a bias of 0.13 m/s for the wind speeds at a 4 km grid size. For the wind directions, we get a RMSE of 16.3° and a bias of –5.7°. It should be reiterated that the wind directions used in this comparison for the SAR methods came from local observations and the QuikSCAT scatterometer. We found out that using the MC2 data instead of *In situ* and QuikSCAT data as the source of wind directions to invert the CMOD function within the SAR method did not improve the overall statistics. A validation of the surface winds derived by the SAR imagery or predicted by the MC2 model against the measurements of a buoy and the QuikSCAT scatterometer shows that both methods have a similar accuracy. Previous studies were done at a coarser resolution of approximately 100 km and had found a wind speed RMSE ranging between 2.1 m/s and 4.0 m/s [7][8][9]. The high-resolution computations of the SAR and MC2 methods enable to better resolve the topographic and surface roughness effects that influence the surface wind fields in coastal regions.

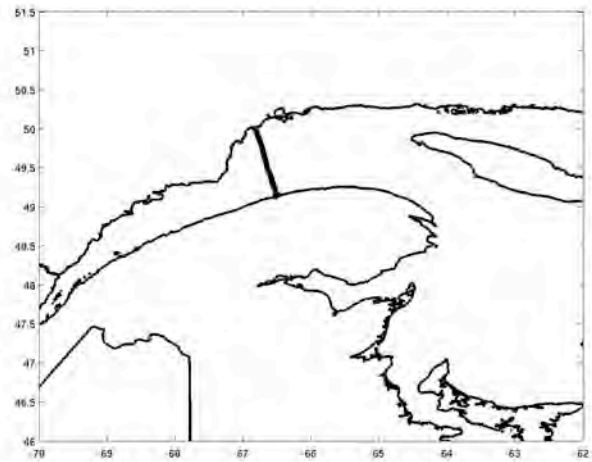

Figure 1. Map of the St. Lawrence River and Gulf region (Quebec, Canada) with the transect starting at the Cap-Chat station (south shore).

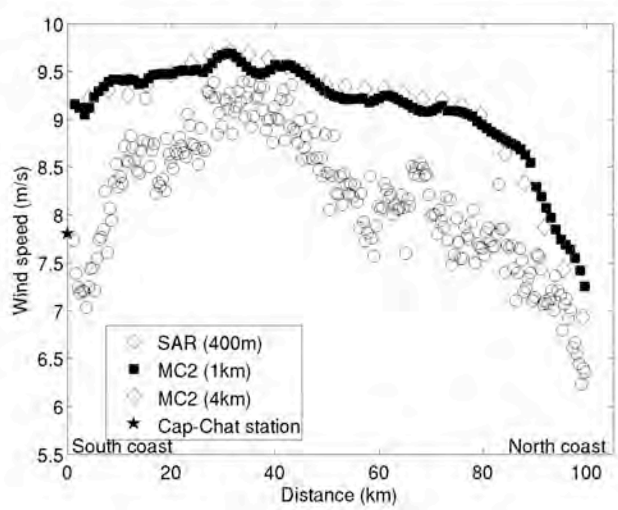

Figure 2. Average of SAR and MC2 wind speeds along a transect perpendicular to the coast, starting at the Cap-Chat station (south shore).

A more detailed analysis of the local differences is performed by looking at wind speeds along a transect perpendicular to the coastline. The mean wind speed estimated by the SAR and MC2 methods for the 14 scenes are reasonably close along this transect (Figure 2). While approaching the coast, the wind speed drop-off is clearly sensed by both methods. The intensity of winds is much greater 20-30 km offshore than onshore. However, local differences are non-negligible and can reach up to 1.5 m/s near the Cap-Chat station. On a single case basis, important local deviations can be expected between SAR and NWP winds [10]. Calculating the mean wind speed over several cases averages out these large deviations. Even at a microscale resolution, the MC2 winds at a 1 km grid-point spacing are more steady than the inhomogeneous winds assess by the SAR imagery. The turbulent nature of the surface winds arises more clearly from the SAR snapshots, which also contain some noise produced by the speckle effect and radiometric error for instance. Moreover, the MC2 model computes the Reynold's-averaged Navier-Stokes equation and discontinuities of the meteorological values are not allowed. In conclusion, the SAR satellite imagery and the NWP models are reliable approaches to assess the detailed wind fields in coastal areas. Although none are absolutely perfect, they have the advantages of providing surface wind information with a good accuracy, a high resolution and a large coverage.

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