TROPICAL CYCLONE WIND ESTIMATION USING SYNTHETIC APERTURE RADAR

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1. INTRODUCTION

In the last decade several synthetic aperture radar (SAR) images of tropical cyclones have been acquired by the European satellite ENVISAT, as well as the Canadian satellite RADARSAT-1. These SAR data provide a unique opportunity to investigate the utility of SAR data for estimation of extreme winds as well as other parameters useful for the improvement of tropical cyclone forecast.

2. METHODS AND RESULTS

We have investigated various SAR images of tropical cyclones, which were acquired by the SAR aboard the satellites ENVISAT and RADARSAT-1 at different polarizations and incidence angles, using a similar approach as suggested by Horstmann et al., 2005 [1]. The resulting SAR-retrieved wind fields are compared to results of high-resolution numerical models as well as in situ measurements collected by aircrafts and buoy data.
Uncertainty estimates are retrieved with respect to the local wind as well as imaging geometry. Furthermore, limitations of SAR wind retrieval at high wind speeds, in particular of the geophysical model functions (GMF) for retrieving wind speeds, will be addressed and discussed. These investigations show the influence of sea state (in particular of swell) and heavy rain on the NRCS and therefore on the wind speed retrieval as well as the limitations due to sensors.

2.1. Wind Speed Ambiguity

Under strong surface wind conditions, the normalized radar cross section (NRCS) tends to go into saturation and under certain incidence angles and wind direction starts to decrease again with increasing wind speed. This leads to two possible wind speed solutions at certain NRCS. An approach to remove wind speed ambiguities in case of tropical cyclone winds and wind systems was suggested by Shen et al. 2009 [2], but a general solution is still lacking. We propose a different methodology for wind speed ambiguity removal. A preliminary test is presented using a modeled wind field available from the Hurricane Research Division (HRD) wind analysis system (Powell et al. 1998 [3]) together with a Radarsat-1 SAR image of Hurricane Katrina acquired on August 28, 2005. Using the wind speed information from the HRD (Fig. 1 a) together with the wind directions extracted from the SAR as well as the SAR retrieved incidence angles the NRCS are computed using the GMF Cmod5. These NRCSs are then used as input to the Cmod5 to retrieve wind speeds, which result in some regions in a lower and upper wind solution (Fig. 1 b1 and b2). Based on the geographical points where the two solutions are about coincident, which are also the points where a significant noise is visible in the upper solution (Fig. 1 b1), some cluster and morphological operations are defined, which result in the mask shown in Fig. 1 c. Based on this mask it is possible to reconstruct the original HRD wind field with very low noise (compare Fig. 1 a and d). This procedure will be investigated under different incidence angle and wind conditions and applied to real SAR image.

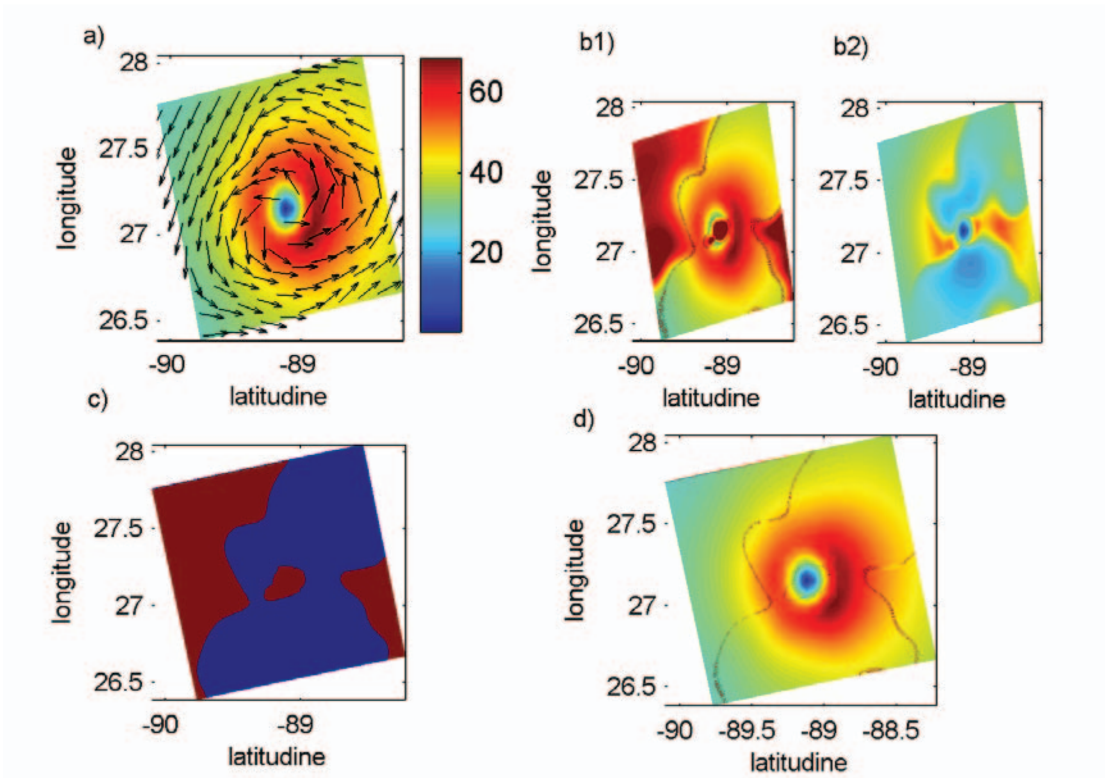

Figure 1. (a) HRD wind field (m/s) for hurricane Katrina on August 28, 2005 with superimposed wind directions retrieved from wind streaks visible in RADARSART-1 SAR image at 2350 UTC. (b1) Cmod5 upper solution from the simulated NRCS field (not shown) and (b2) Cmod5 lower solution. (c) Mask created from (b1) and (b2) wind geometry with an image "morphological" operation; purple and blue areas are the zones where the lower and the upper Cmod5 solutions must be taken, respectively. (d) Reconstructed wind field from (b1) and (b2).

2.2. Tropical cyclone eye-finder

The location as well as the shape and size of a tropical cyclone eyes are of great importance for numerical modeling and prediction of tropical cyclones as well as for the automated SAR wind direction retrieval. Therefore, a fully automated methodology was developed, that enables to extract tropical cyclone eyes from SAR images. We have found that the wind intensity map retrieved from the SAR image using the geophysical model function Cmod4 with a fixed wind direction of crosswind is very useful to highlight the location of the eye. Using these wind speed images a region is defined where the retrieved winds are greater than 25 m/s. This "open" region is closed using a morphological closing procedure on the SAR image, based on a disk like structuring element of about 100 km. On this selected region a polar transect algorithm has been defined based on the NRCS as well as on the wind intensity map obtained via Cmod4 and cross winds. Taking the centroid of this area as a starting point for polar transects the algorithm iterates to the mean of the points where there are local minima for both NRCSs and wind speeds, which satisfy predefined thresholds. The preliminary version of the eye detector has shown to detect tropical cyclone eyes in most of the SAR images tested (Fig. 2 a and b). However, it fails in cases, where the eyes are of very small size, i.e. less than 2 km (Fig. 2 c).

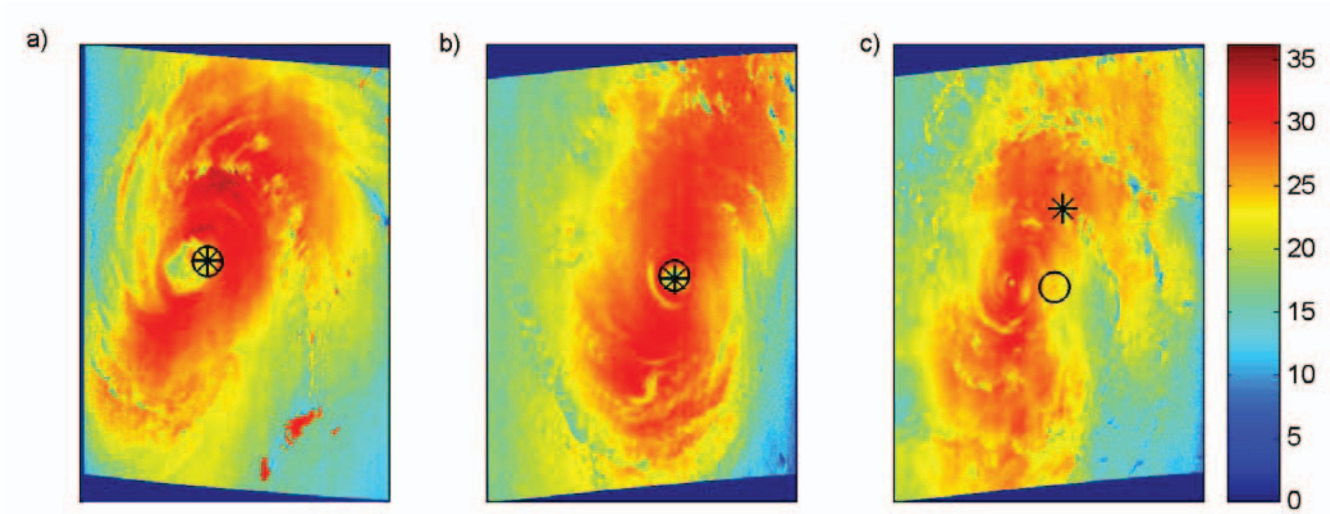

Figure 2. Location of tropical cyclone eyes (* and O) as detected by automatic cyclone eye finders. Color map are the wind speeds (m/s) retrieved from 3 SAR images acquired in the Pacific Ocean using a fixed cross-wind direction with respect to radar look direction and the Cmod4 algorithm.

The utility of SAR for estimating extreme winds as well as the automated detection of shape and size of the eyes of tropical cyclones will be discussed based on the above-presented analysis with respect to a large data set.

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