Using Surface Pressure to Validate Tropical Cyclone Surface Wind Retrievals from SAR

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LONG-TERM GOALS

The goal of this study is to develop a new method for validating surface wind and stress retrievals from oceanic synthetic aperture radar (SAR) imagery of tropical cyclones through the use of surface pressure data. The reason for using surface pressure measurements is that they are comparatively more reliable than wind measurements in extreme wind conditions. Surface winds are a key parameter in the exchange of momentum, heat and water vapor between the atmosphere and ocean, and the relative surface flux magnitudes play an important role in the intensity of tropical cyclones. Surface winds are notoriously difficult to measure in high wind and high sea state conditions and high resolution surface wind fields derived from SAR imagery have great potential for improving our understanding of air-sea interaction near the core of tropical cyclones. However, SAR wind retrieval techniques in such environments are in their infancy compared to those in standard use for more typical meteorological conditions. This is largely because there is little data in the high wind regime (> ~20 m s^{-1}) for calibration and validation of the geophysical model functions that relate microwave backscatter to the surface wind vector. Presently the best available in situ wind observations in tropical cyclones are from GPS dropsondes. However, these only provide infrequent point-wise information. A second possible source of surface winds data are the remotely sensed winds from the airborne stepped frequency microwave radiometers. These provide a narrow swath of surface winds underneath aircraft penetrations, which are routine only in the Atlantic basin.

OBJECTIVES

SAR backscatter in the Bragg scattering regime is modulated by both the relative viewing geometry and the magnitude of the surface stress. Direct backscatter measurements for known viewing geometries and wind speeds have allowed the construction of geophysical model functions (GMFs) that predict the radar backscatter as a function of the neutral equivalent wind speed, which is a proxy for surface stress, the radar beam incidence angle and the relative angle between the beam and the wind vector. The incidence angle is known and the backscatter is measured. SAR only provides a

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14. ABSTRACT

The goal of this study is to develop a new method for validating surface wind and stress retrievals from oceanic synthetic aperture radar (SAR) imagery of tropical cyclones through the use of surface pressure data. The reason for using surface pressure measurements is that they are comparatively more reliable than wind measurements in extreme wind conditions. Surface winds are a key parameter in the exchange of momentum, heat and water vapor between the atmosphere and ocean, and the relative surface flux magnitudes play an important role in the intensity of tropical cyclones. Surface winds are notoriously difficult to measure in high wind and high sea state conditions and high resolution surface wind fields derived from SAR imagery have great potential for improving our understanding of air-sea interaction near the core of tropical cyclones. However, SAR wind retrieval techniques in such environments are in their infancy compared to those in standard use for more typical meteorological conditions. This is largely because there is little data in the high wind regime (> ~20 m s?1) for calibration and validation of the geophysical model functions that relate microwave backscatter to the surface wind vector. Presently the best available in situ wind observations in tropical cyclones are from GPS dropsondes. However, these only provide infrequent point-wise information. A second possible source of surface winds data are the remotely sensed winds from the airborne stepped frequency microwave radiometers. These provide a narrow swath of surface winds underneath aircraft penetrations, which are routine only in the Atlantic basin.

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single line-of-sight for any given patch of sea surface and the same backscatter could be measured for very different viewing geometries and wind speeds. Thus, a direct inversion from a single backscatter measurement to the corresponding surface stress vector is not possible and ancillary information or analysis techniques are needed to determine the wind direction. The GMFs are considered accurate between ~2 m s^{-1} and 20 m s^{-1} and reasonable accurate between 20 m s^{-1} and 30 m s^{-1}. Our interest is improving the accuracy and/or confidence in wind speed retrievals above 30 m s^{-1}.

The surface stress field that is impressed on the sea surface is the net result of the downward flux of momentum from the interior flow above the boundary layer. Because the pressure gradient force is a dominant term in the momentum budget, the imprint of the surface stress field can be used to estimate the surface pressure gradient field through the use of a diagnostic boundary layer model. Our standard boundary layer model also includes stratification and thermal wind corrections and an iterative gradient wind correction in strong storms and tropical cyclones. The gradient wind correction captures some of the effects of the nonlinear accelerations that dominate the high gradient regions.

We have developed, and plan to improve during this research, new boundary layer models that include the include all of the important nonlinear advection and curvature accelerations that dominate tropical cyclone boundary layer dynamics in the high wind cores. We expect that the use of such improved boundary layer models will be a significant improvement over the ad hoc gradient correction.

Once the pressure gradient fields have been obtained from the surface winds and the boundary layer model, a least-squares optimization technique is used to find the best-fit, zero-mean surface pressure pattern that matches the pressure gradient field. When pressure observations are available, the average difference between them and the zero-mean field is the optimal estimate of what is effectively the integration constant resulting from converting pressure gradients into a pressure field. It is important to emphasize that, *even without using ancillary data to set the absolute value of the pressure field, the bulk pressure difference between any two points in the SAR-derived pressure field is the optimal estimate of that pressure difference based on the field of SAR stress vectors.* Extensive analyses of scatterometer-derived pressure fields have shown them to be highly accurate and to contain more mesoscale information than ECMWF surface analyses. The premise of using pressure data for SAR wind Cal/Val is based on this fact.

We pose the Cal/Val problem as an optimization problem in which we seek the least adjustment to the surface vector field that will minimize the difference between the SAR bulk pressure gradients (BPG) between any combination of points and that derived from observations. Given a first-guess surface wind vector field we calculate a first-guess surface pressure field. Given two or more surface pressure observations within this field, e.g. from dropsondes, we can calculate corresponding observed BPGs within the image. The cost function to be minimized is the RMS difference between the SAR-derived BPGs and the observations along with constraints on the corrections to the wind field so that the optimization procedure does not impose unreasonable wind vector corrections. The cost function can be expanded to include surface wind observations such as from SFMR.

Each optimization step adjusts the surface wind vectors and recalculates the surface pressure field and the BPGs. The optimization treats the U and V components of the SAR winds separately since their error characteristics can be assumed to be independent and Gaussian. Each step in the optimization requires a new nonlinear surface pressure field in order to evaluate the cost function. Since the optimized surface wind field adjusts U and V separately, both the speed and direction can differ from the initial guess. It should be noted that since surface pressure fields are integral properties of the surface vector wind fields, wind adjustments must occur over a broad spatial region rather than just locally near the pressure data. Thus, even though we use point-wise pressure data, they imply wind corrections for a large number of wind vector cells. Previous experience with first-generation ERS scatterometer winds found effectively no effect on speed below 20 m s^{-1} and a 5% difference above.

APPROACH

Our approach is to make extensive use of existing SAR imagery of Atlantic basin hurricanes obtained during the CSA RadarSAT Hurricane Watch program. Ancillary and in situ data can be obtained from NOAA HRD and other sources. We plan both to generate surface wind fields using our existing software and to collaborate with Chris Wackerman (Veridian Systems) and Hans Graber (RSMAS, Univ. Miami) who routinely produce SAR wind analyses using independent techniques.

In the upcoming year, our focus will be to modify our existing scatterometer surface pressure retrieval code for SAR winds and to incorporate it into optimization software. We plan to extensively analyze the accuracy of SAR-derived surface pressures against the available data and to isolate the impact of the nonlinear dynamics missing in the basic boundary layer parameterization and how well their lack is ameliorated by the gradient wind correction. We plan a first set of optimization experiments using the gradient-wind pressure retrieval.

The new boundary layer model, which includes the important nonlinear accelerations, will be incorporated into the pressure retrieval code for use in the optimization experiments that are planned for Year 2.

In general, Foster is responsible for boundary layer model development and analysis and for development of the optimization programs. Patoux is responsible for development and maintenance of the pressure retrieval code and analysis of results against observations. Throughout the course of our research, we will keep in close contact with Wackerman and Graber (and others in the SAR winds community) so that the results of our research can be (1) independently assessed and (2) incorporated into their wind retrieval techniques.

WORK COMPLETED

We received our funding in September, 2008. So no significant work has been completed. Foster attended a Typhoon Impact DRI Modeling and Remote Sensing Meeting in Miami June 10-11, 2008. We have also begun re-coding the new tropical cyclone boundary layer model into a modular form for incorporation into the optimization codes.

RESULTS

We received our funding in September, 2008. So we have no results to report at this time.

IMPACT/APPLICATIONS

The primary result of our research will be the development of a new and unique method for calibration and validation of SAR wind retrievals in the wind regime. Depending on the outcome, there should be either increased confidence in the accuracy and limitations of SAR winds or improved model functions for wind retrievals.

RELATED PROJECTS

This project is related to “Analysis of Sub-Grid Boundary Layer Processes Observed by TODWL in Support of the Western Pacific Tropical Cyclone Structure 2008 (TCS-08) Experiment”, N00014-08-1-0247, Foster and G. David Emmitt co-PIs. This project will analyze boundary layer wind prifiles and boundary layer structure data obtained during the TCS-08. These data will be used to assess/improve the new tropical cyclone boundary layer model that will be incorporated into our pressure retrieval technique.