Application of Coincident Sub-Footprint Scale Winds to Observe the Effect of Surface Vorticity on the RapidScat Scatterometer Ku-Band NRCS and Retrieved Winds

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Abstract

This study combines very high resolution wind vectors measured in the Gulf of Mexico with satellite observation of the normalized radar cross section (NRCS) of the sea surface, and the retrieved winds. The NRCS and associated products are provided by the RapidScat Ku-band scatterometer mission on the International Space Station. One topic of interest is observing how calculations of the vorticity and divergence using different spatial scales from two wind products, are related to the radar backscatter for each of the two radar polarizations. The two wind products are the satellite-based Level 2B wind vectors and an in-situ based, higher resolution product, with close proximity in time. Vorticity and divergence are key ocean forcing parameters. In the one example analyzed and discussed here the time difference between the satellite overpass and the surface wind product is less than 30 minutes.

The winds in regions near atmospheric fronts usually display very large directional diversity on scales smaller than a radar footprint. One goal of this project is to assess the sensitivity of the curl of the wind to different scales of wind resolution that are used to calculate it, and to consider its relation to the behavior of the NRCS in that region. Included in these comparisons are the collocated calculations of the NRCS using the JPL Ku-band NRCS model function with this wind product, and its response to a variety of vorticity conditions. It will be seen that the higher resolution winds are able to resolve interesting features better than the lower resolution product.

Introduction

Spatial derivatives of the wind fields are very important for atmospheric boundary-layer processes, upper ocean forcing, and deep ocean forcing. These quantities are inherent in the curl of the ocean vector winds, which is usually referred to as the vorticity. Another important and related quantity is the divergence, which is also presented herein. We are using two different wind products, each with a large number of data points across wide swaths so it is possible to observe a variety of conditions and processes. Our approach is to study both the radar measurements and wind data from different points of view.

The sub-footprint winds are from a relatively new, high-resolution, hourly wind vector product (2.5 km horizontal resolution) that covers the continental US. This is the Real Time Mesoscale Analysis (RTMA), from NOAA-NCEP. This wind product is based on multiple sensors, surface and space-based. It also assimilates NEXRAD (ground based) rain observations.

We are comparing the RapidScat PO.DAAC NRCS products (Level 2A) and the Level 2B 12.5 km wind product to the values estimated from this higher resolution wind product. It is also possible to estimate the sea surface backscatter, using the RapidScat geophysical model function (GMF), provided by colleagues at JPL. Rain monitoring, when desired, is available through a special RScat "RadRain" product created by Remote Sensing Systems (REMSS) for this mission, using a variety of collocated, coincident satellite radiometer sensors. In addition higher resolution rain measurements are available via the NASA IMERG data resource, provided by the NASA Precipitation Measurements Mission.

RapidScat and Data

The International Space Station (ISS) RapidScat mission is a time-series continuation mission to fill the gap created by the loss of data from the NASA QuikSCAT mission. RapidScat was launched from Cape Canaveral, Florida on 15-September 2014. ISS flies at an altitude approximately one-half that of QuikSCAT, which allows RapidScat to retrieve wind vectors in an asynchronous orbit with respect to the sun. This daytime/nighttime asynchronicity enables RapidScat to retrieve winds at the same location at variable times of the day which can provide two distinct advantages over a sun-synchronous platform: 1) more precise temporal co-location between multiple remote sensing spacecraft and 2) observation of diurnal processes. From the launch date above until the unfortunate drop in the echo power signal on 15 August 2015, there are over 10 months of full system functionality and nominal data.

The standard data products that will be used here are the normalized radar cross sections (σ_0) Level 2A (L2A), both the 25 km and 12.5 km resolution versions. The estimated winds in the L2B 12.5 wind vector cells (WVC) will also be used. This product has been enhanced by methods to correct for rain [Rcciardulli, 2016].

Objectives

We seek to observe and assess the effect of rapid (small scale) changes in wind magnitude and direction on the measured NRCS (for H-pol and V-pol), that is collected by the RapidScat scatterometer. It is expected that these wind dynamics will translate into corresponding features in the spatial distribution of vorticity and divergence that is calculated from the level 2B wind product. And the vorticity and divergence will also be derived from the NCEP RTMA surface wind product, and compared with what is derived from the scatterometer product.

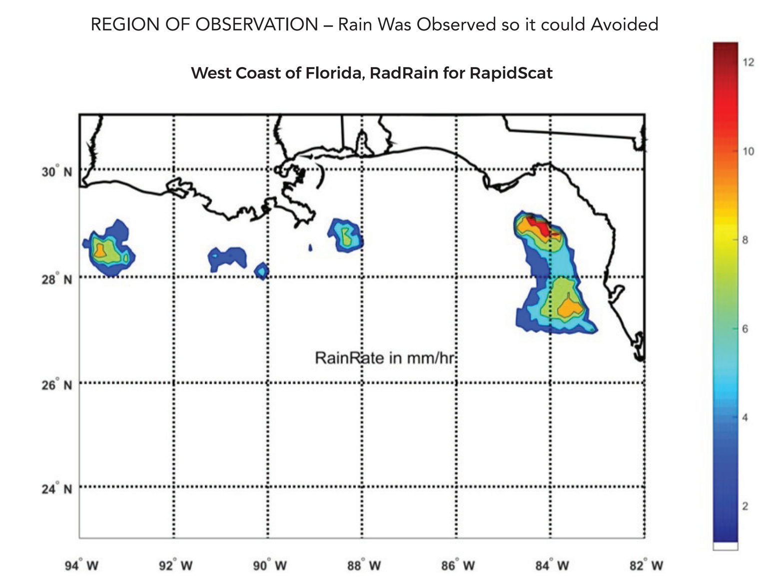


Figure 1. Rain conditions across the region of observation by the RapidScat scatterometer, on Aug. 3, 2015. Rain estimates are from the REMSS Radiometer Rain Collocations (RadRain) with RScat L2B Swath Grid. The data from orbit 4881 spanned almost all this area, with some exceptions in the northeast corner. Our analysis below focuses on the region south of Latitude=28° and west of Longitude=85 W.

NOAA-NCEP High Resolution Wind Product

The Real-Time Mesoscale Analysis (RTMA) is a NOAA/NCEP high-spatial and temporal resolution analysis/assimilation system for near-surface weather conditions. (http://nomads.ncep.noaa.gov/txt_descriptions/RTMA_doc.shtml). Its main component is the NCEP/EMC Gridpoint Statistical Interpolation system applied in two dimensional variational mode to assimilate conventional and satellite derived observations [Pondeca. et al, 2011]. The RTMA was developed to support the National Digital Forecast Database (NDFD) operations and provide field forecasters with high quality analyses for nowcasting, situational awareness, and forecast verification purposes. The system produces hourly analyses at 5 km and 2.5 km resolution for the Conus NDFD grid, 6 km for the Alaska NDFD grid and 2.5 km for the Hawaii, Puerto-Rico and Guam NDFD grids.

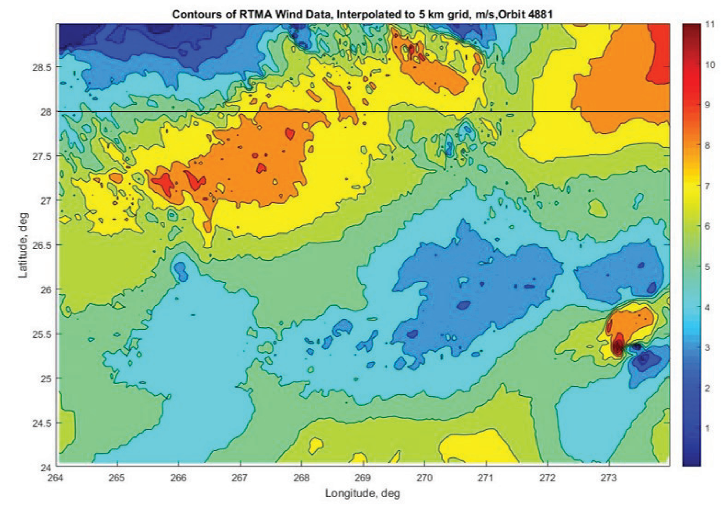


Figure 2. RTMA Wind magnitude, m/s, across region of interest, 5 km resolution. This is an hourly product that is based on an accumulation of multiple surface and space sensors. This image is within 25 minutes of RapidScat orbit 4881. The horizontal line at Latitude=28° demarcates a region to the north which is likely to be affected by rain.

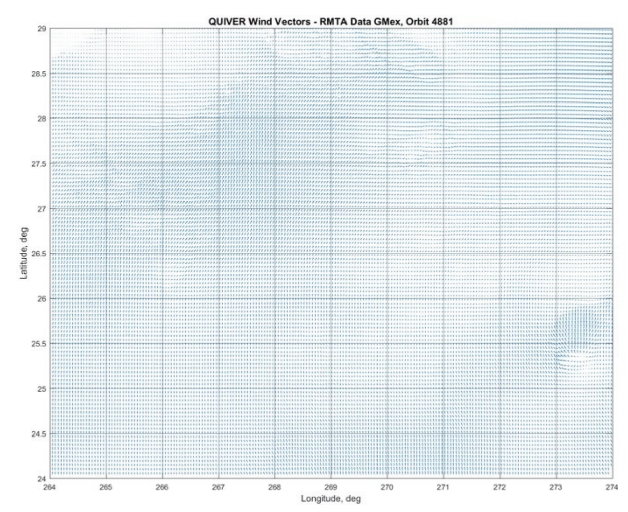
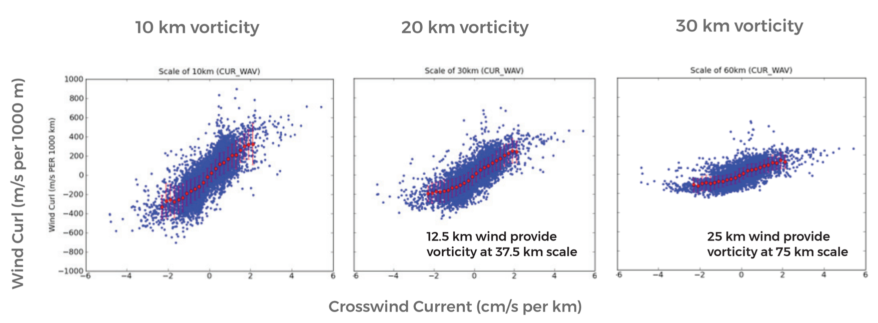


Figure 3. Wind speed vectors (magnitude and directions) associated with RTMA winds in Figure 2. The length of the arrows are scaled to represented wind magnitudes. Figures 2 and 3 indicate a wide range of conditions, including several areas with rapid changes in wind speed and direction, that will display distinct features of vorticity and divergence.

The Spatial Scale of the Vorticity Calculation Matters



Oceanography applications are very sensitive to the curl of the wind (vorticity). In the above example, the apparent relationship between curl and current changes depending on the scale at which vorticity is calculated. With much weaker coupling seen if the vorticity is calculated over too large an area. Therefore, we need high resolution wind vectors.

Winds and surface currents are from a coupled ocean/wave/atmosphere model (Shi, 2018), run at 3.3 km resolution using the COAWST model. Current features are small in scale, so resolution matters in the coupled earth system. We expect the weather associated with atmospheric fronts to generate large horizontal shear in currents along with strong curl in winds. This curl is very important for ocean forcing, upwelling, and biological productivity.

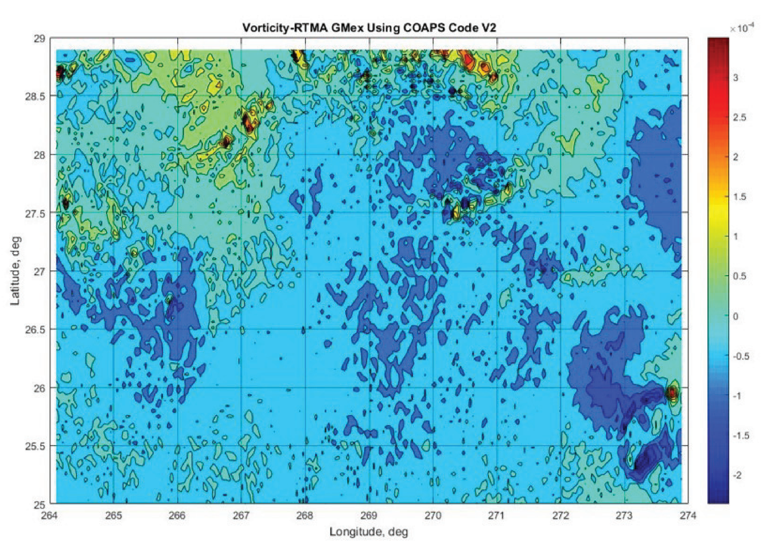


Figure 4a. The vorticity calculated from the RTMA wind vectors in Figure 3. The units of vorticity are inverse seconds, sec-1. The strong features here can be traced to the wind changes in Figure 3.

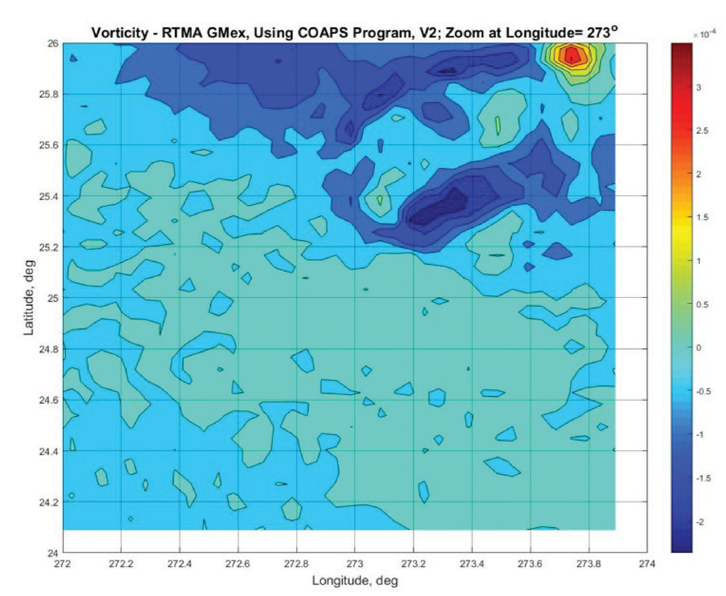


Figure 4b. This presents a "zoom" of an interesting vorticity feature in Figure 4(a), within a 2° by 2° square.

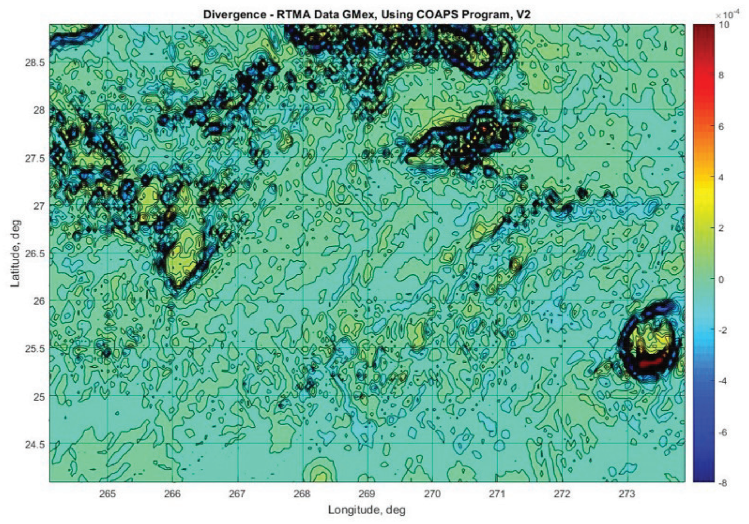


Figure 5a. Divergence of RTMA wind vectors shown in Figure 3.

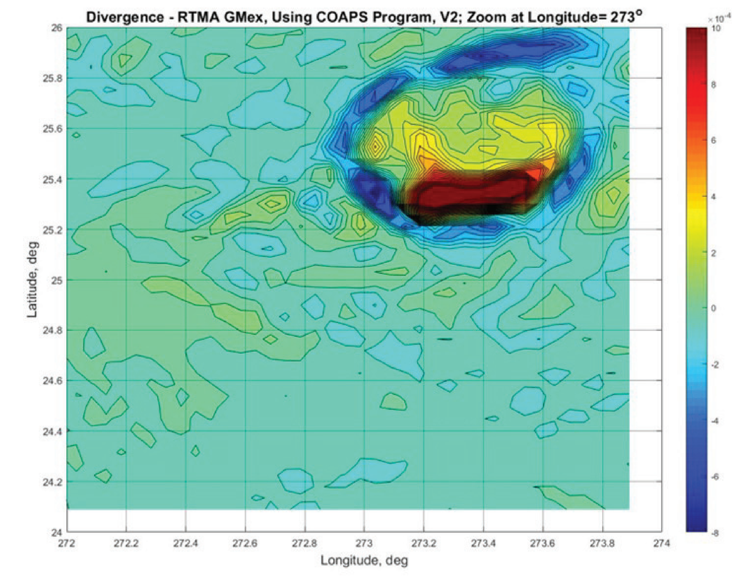


Figure 5b. This presents a "zoom" of the divergence in Figure 5(a), within a 2° by 2° square.

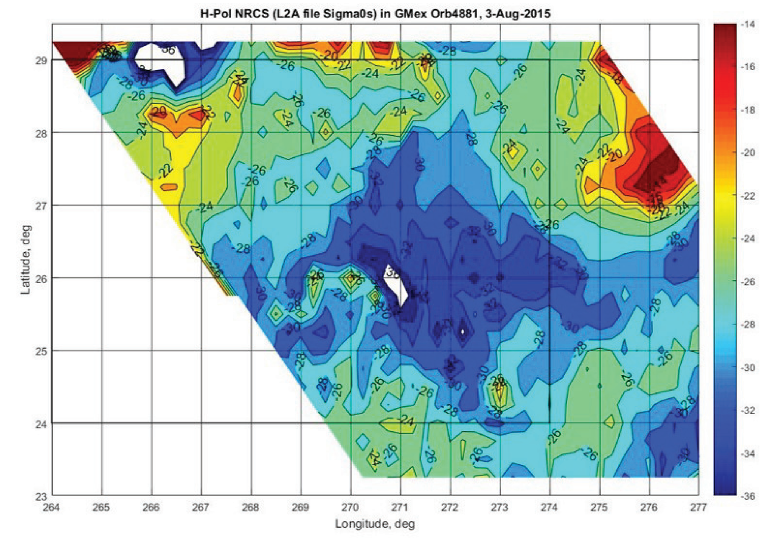


Figure 6. The RScat H-pol NRCS across region of interest. This is magnitude only, no look direction separation. The rectangle defined by the solid black line indicates a rain free zone that matches the wind map of Figure 2.

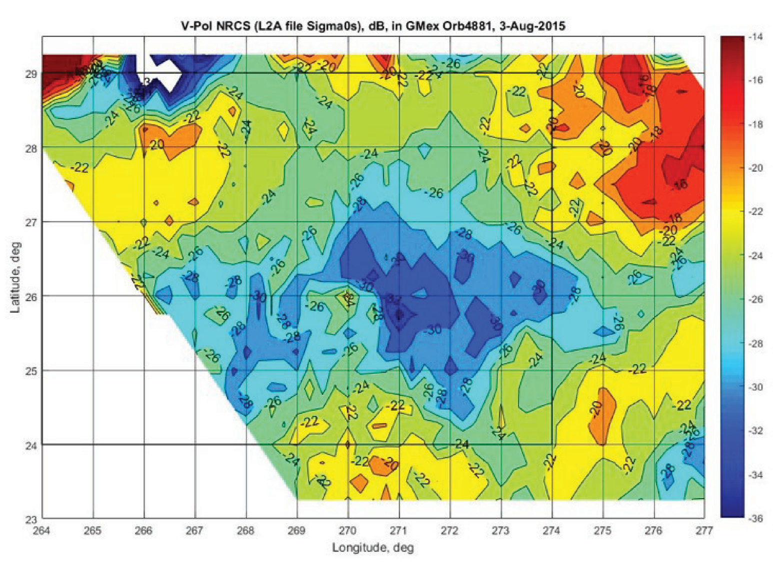


Figure 7. The RScat V-pol NRCS across region of interest. The rectangle defined by the solid black line indicates a rain free zone that matches the wind map of Figure 2.

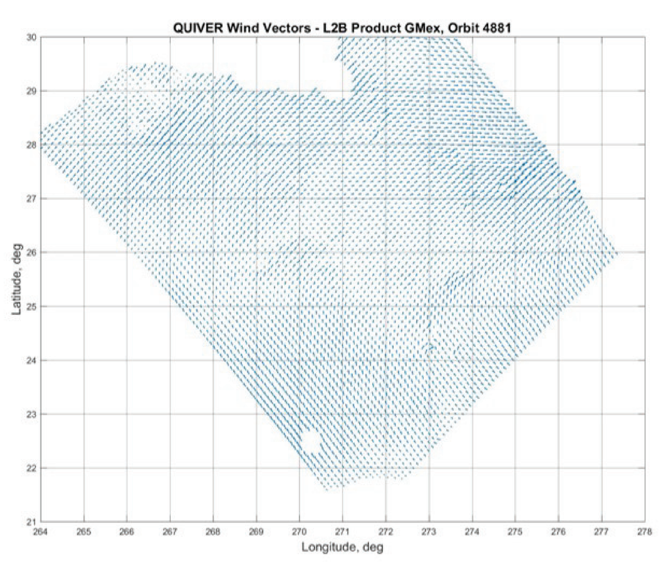


Figure 8. Map of the wind vectors for the JPL Level 2B Product. Correlations can be seen when comparing these results to the intensities and features seen in Figures 6 and 7.

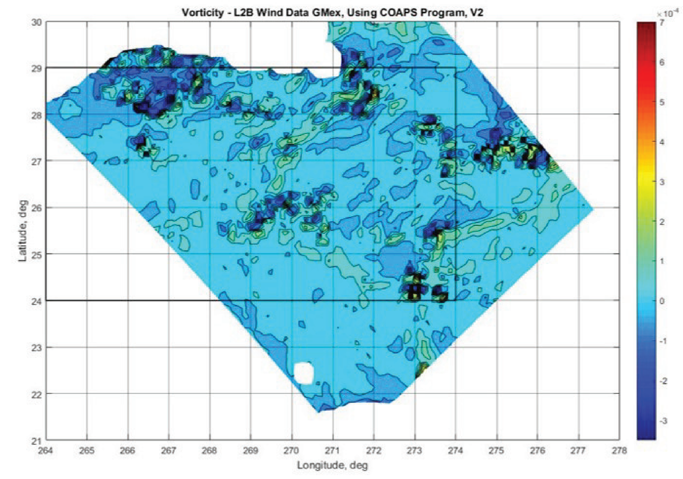


Figure 9a. The vorticity calculated from the RScat Level 2B wind vectors in Figure 8. Many general properties of this vorticity map agree well with those estimated from those calculated from the RTMA winds.

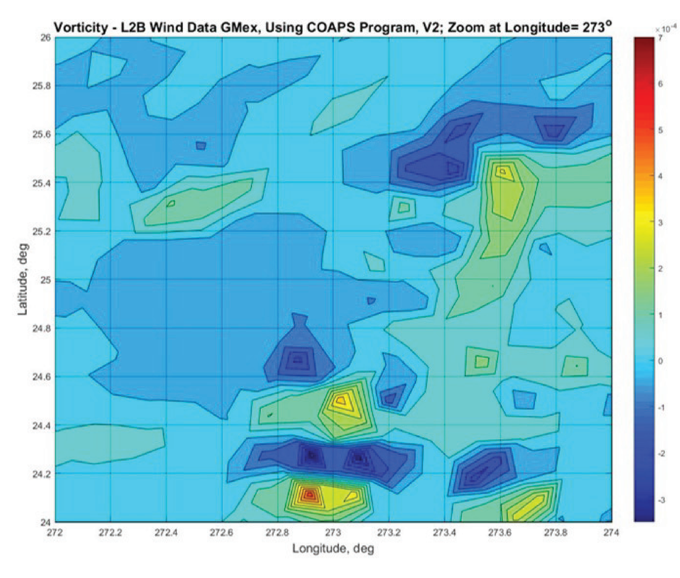


Figure 9b. This presents a "zoom" of the vorticity in Figure 9(a), within a 2° by 2° square.

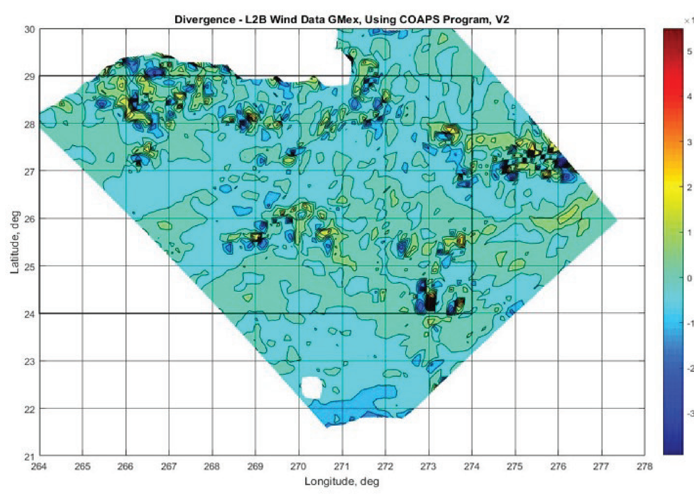


Figure 10a. The divergence calculated from the RScat Level 2B wind vectors in Figure 8.

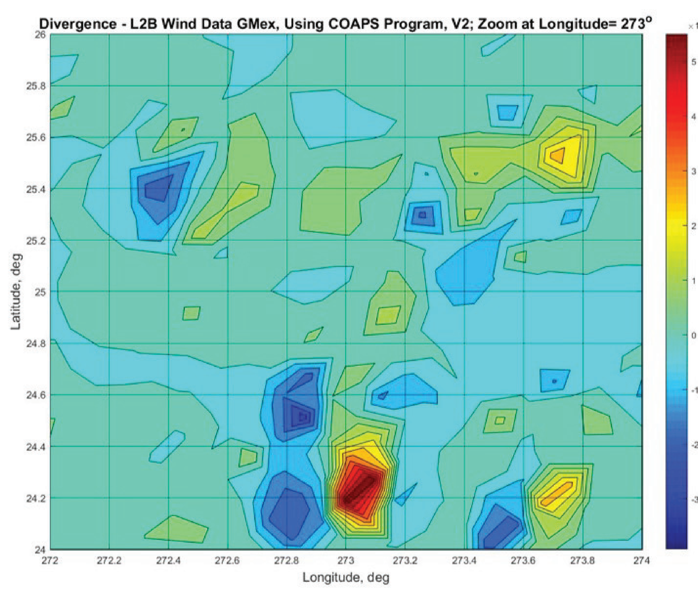


Figure 10b. This presents a "zoom" of the divergence in Figure 5(a), within 2° by 2° square.

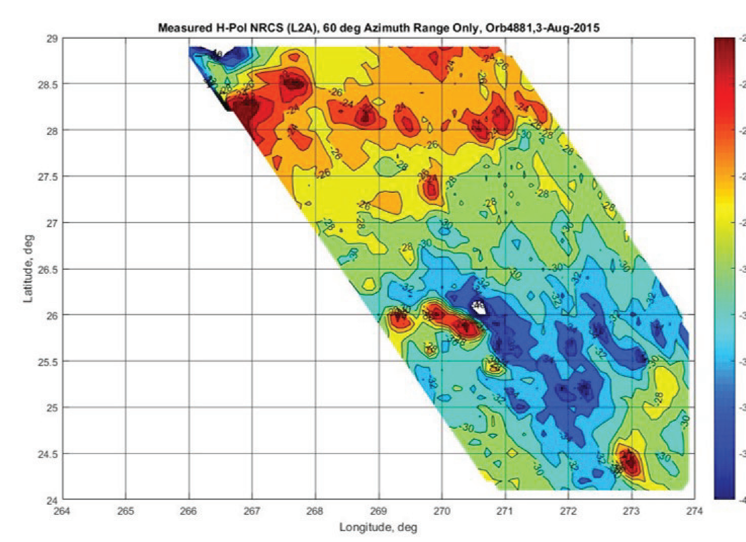


Figure 11. An azimuthally selective subset of the RScat H-pol NRCS shown in Figure 6, wherein only a 60° wide azimuth range was collected. This angular selectivity helps provide strong wind gradients with better visibility and resolvability.

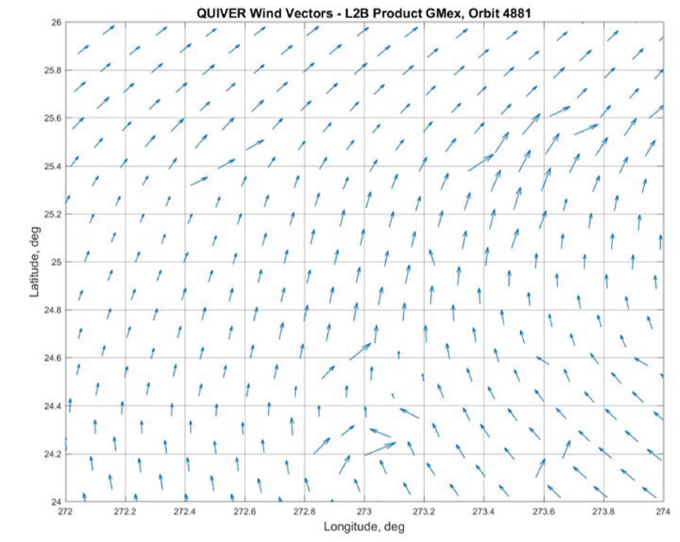


Figure 12. A subset ("zoom") section from Figure 8 to focus on an area with strong variations wind speed and direction that are identified in Figure 11.

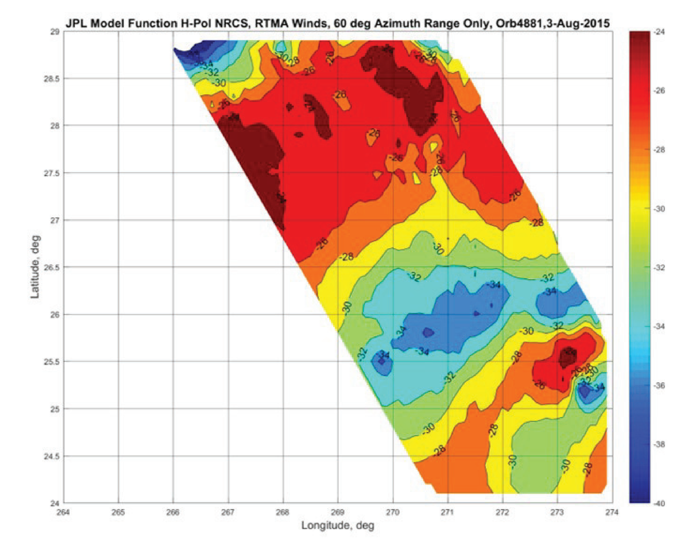


Figure 13. Estimates of the H-pol NRCS derived from the collocated wind vectors in Figure 3 and calculated using the JPL Model Function at the locations where RScat measurements were made using on a 60° azimuth window.

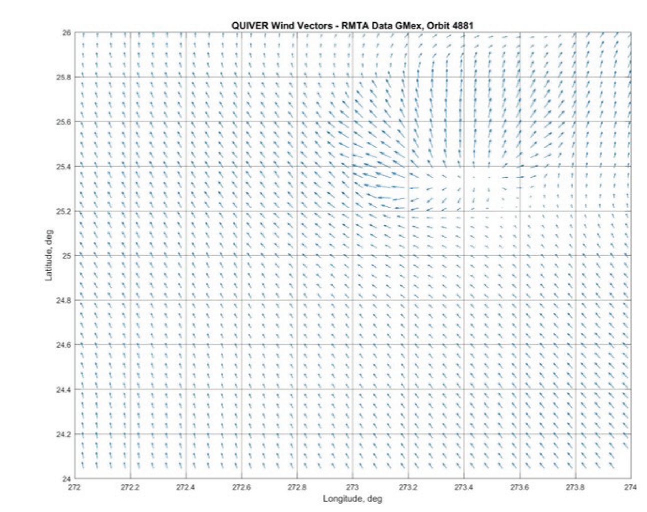


Figure 14. A subset ("zoom") area from Figure 3 that matches a feature in the model derived H-pol NRCS image in Figure 13, which displays strong variations in magnitude and direction.

Summary

This was a unique opportunity to use high resolution, near-coincident sea surface winds covering a wide area for comparison with the RapidScat K_u-band scatterometer radar cross section and wind products. The purpose of this study was to examine the ability of the scatterometer wind product to estimate the vorticity and divergence of atmospheric winds at the air-sea interface. While the event that was studied was a single orbit over the Gulf of Mexico, this region contained a wide range atmospheric conditions at that time. This dynamic range of wind speeds and directions provided us with laboratory like opportunities.

The results presented here gave evidence that the scatterometer can be very effective for this type of measurement with its current resolution capabilities. And it also indicated that improvements in spatial resolution of the scatterometer, in the future, would provide additional gains in its abilities, and new opportunities for research in physical oceanography.

Features in the L2B data that appear to be poor ambiguity selections appear in areas with a great deal of sub-footprint variability in speed and direction. This variability is poorly captured in the L2B product, but improved resolution, such as the resolution suggested for WACM (Winds and Current Mission), would capture this spatial variability in speed and direction. While such features appear to be rare and related to atmospheric fronts and convection, they are expected to have relatively great impart on ocean forcing and air-sea coupling.

Continuation of this effort, to take advantage of a significant volume of RapidScat data archives would be productive. This continuation would examine additional orbits and events, to include different weather, ocean temperature and seasonal conditions. This is likely to discover more interesting phenomena and interpretations of this combination of high resolution winds and RapidScat.

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