IMPROVEMENT OF SCATTEROMETER WIND VECTORS — IMPACT ON HURRICANE AND COASTAL STUDIES

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1. INTRODUCTION

Spaceborne scatterometers have an advantage over numerical weather prediction (NWP) models in providing more detailed structures of ocean surface wind fields [Liu et al., 1998]. In the past decade, the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA) have launched four scatterometers with continuous improvement to the coverage and the spatial resolution of ocean surface wind vectors. The improvements made possible observations of new processes of ocean-atmosphere interaction.

Hurricane and coastal studies have strong human impacts and they are the two areas benefited from the new capability. Hurricanes out at sea are hazards to shipping, and hurricane landfall is devastating to human livelihood. Large population lives near the coast, and coastal oceans are the most productive part of global oceans. Hurricanes are driven by strong winds, and the nutrients in coastal oceans are controlled by wind-driven upwelling. The wind fields around hurricanes and over coastal ocean have strong temporal and spatial variability that cannot be sufficiently resolved by NWP.

2. SCATTEROMETER MISSIONS

Historically, ESA scatterometers used C-band (5 GHz), but the NASA prefers Ku-band (14 GHz). Ku-band is more sensitive to wind variation at low winds but is more subjective to rain contamination. The European Remote Satellite (ERS)-1 and -2 provided nine years of continuous wind data starting 1991, covering 40% of the global ocean daily. The backscatters measured have 50-km spatial resolution but are sampled at 25 km. The NASA Scatterometer (NSCAT) covered 77% of global ocean at 25-km resolution daily. The unexpected destruction of the solar array caused the early demise of NSCAT in June 1997, after returning 9 months of data. NASA launched QuikSCAT in 1999. It covers 93% of the global ocean in a single day. The standard wind product has 25-km spatial resolution, but special products with 12.5-km resolution for selected regions have been produced. Instead of the fan-beam antennas used by all the scatterometer before, QuikSCAT uses pencil-beam antennas in a conical scan and has a continuous 1,800-km swath. In one decade, daily wind vector coverage increases from 41%, to 77%, then to 93%, and spatial resolution improves from 50km, to 25 km, and to 12.5 km.

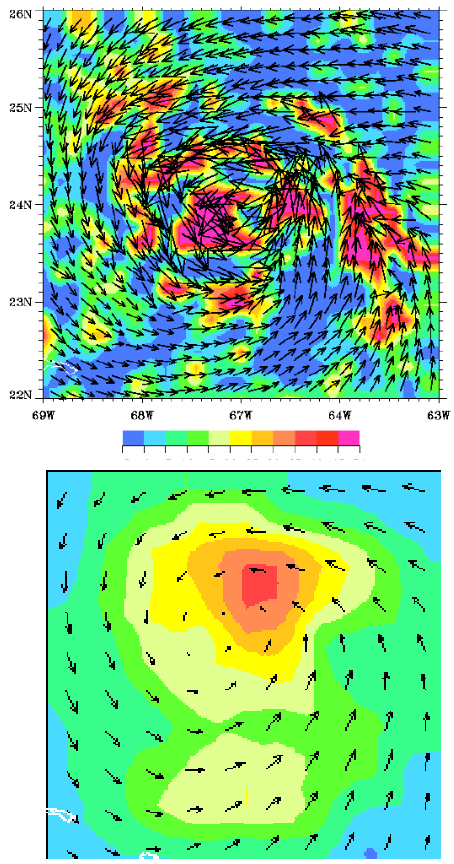

Figure 1. Hurricane Floyd on September 13, 1999. Black arrows representing wind vectors are superimposed on color image of wind convergence, derived from QuikSCAT (upper), and from Eta model (lower).

3. HURRICANE FLOYD

The coverage of QuikSCAT makes it the best instrument to provide the synoptic view of wind field over the global oceans. The high spatial resolution of its data also provides detailed descriptions of small and intense weather systems, like Hurricane Floyd, [Liu et al., 2000]. Fig. 1 shows that the 12.5-km spatial resolution allows the delineation of surface wind convergence associated with the multiple rain bands of Hurricane Floyd. The winds from the Eta model are not even close to being able to resolve such rain bands. Eta is a regional NWP model producing operational wind products with the highest available spatial resolution (40-km). The National Hurricane Center declared Floyd as a tropical depression on September 7, 1999. QuikSCAT data were available to track the surface vortex all the way back to African coast on September 2, 1999, opening debates on cyclogenesis [Liu and Hua, 2000; Ritchie et al., 2001]

3. CATALINA EDDY

When the normal winds from the northwest along the Southern California coast are stronger than normal, particularly during spring and summer, they interact with the local coastal topography to form an atmospheric cyclonic vortex off Los Angeles, called Catalina Eddy [Mass and Albright, 1989]. The gentle winds of the Eddy may direct the offshore marine layer toward the Los Angeles Basin. The cooling oceanic influence of the Eddy is often described as nature's purifier or air-conditioner. The Eddy is only 100 km in diameter; it is actually too small to appear in the present weather forecast models and is too shallow to have a strong influence on the cloud structure viewed by weather satellites. The high resolution (12.5 km) capability of QuikSCAT allows the visualization of the complete circulation of this "elusive eddy (Fig. 2). The effect on the ocean is little known. Local ocean upwelling caused by such transient vortex is often obscured by cloud cover, and cannot be detected by spacebased visible-infrared sensors, and the wind field with sufficient resolution has not been available to forced realistic simulation by ocean general circulation model (OGCM).

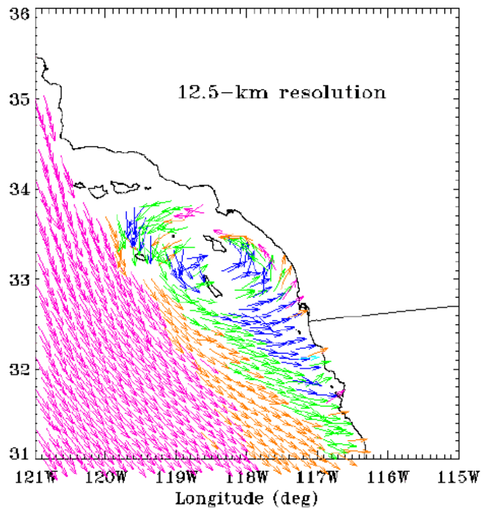

Figure 2. Catalina Eddy observed by QuikSCAT on March 13, 2000.

3. COASTAL UPWELLING

The wind jets through the mountain gaps of Tehuantepec and Papagayo in Central American have been revealed by NSCAT [Bourassa et al., 1999; Chelton et al., 2000]. They are too narrow to be resolved by operational NWP models These jets should have profound effect on upper-ocean temperature and nutrients through upwelling. Song et al. [2000], using high resolution QuikSCAT winds, were able to simulate the upwelling through a coastal OGCM (Fig. 3). The lowering of sea surface temperature (SST), the lifting of the thermolcline, and the increase in vertical velocity, together, indicate Ekman pumping driven by the intense surface wind stress.

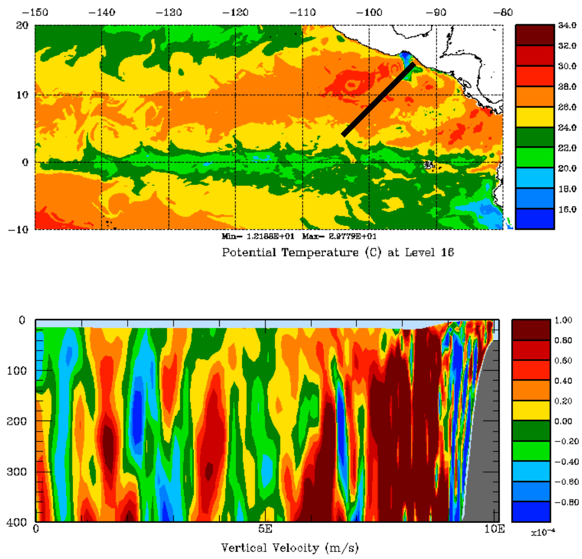

Figure 3. Model simulation of SST map (upper) and cross-section of vertical vector velocity along the black line in SST map (lower)

4. NEW OBSERVATIONS IN THE TROPICAL PACIFIC

The high quality winds derived from QuikSCAT and coincident all weather SST measurements by the microwave imager on the Tropical Rain Measuring Mission (TMI) reveal the coherent propagation of atmospheric and oceanic parameters associated with Tropical Instability Waves (TIW), the temperature front of the Pacific equatorial cold tongue. The phase differences infer that the wind-SST coupling is caused by buoyancy instability and mixing in the atmospheric boundary layer, as confirmed by wind profiles measured on a research ship [Liu et al., 2000]. The analysis was extended to the south of the equator and to the Atlantic Ocean by Hashizume et al. [2001]. Data from the scatterometer and the altimeter were also combined to study temperature advection in TIW by Polito et al. [2001].

Only the Hawaii Islands break the steady westward flow of the Trade Winds and North Equatorial Current in the tropical Pacific. According to conventional theories and observations, the wind wakes caused by the islands should dissipate within 300 km downstream, and should not be felt in the western Pacific. The fine resolution of QuikSCAT reveals a persistent wind pattern to the west, composed of alternate high and low winds streaks, and lines of positive and negative curl of wind stress. This pattern stretches a few thousand kilometers from the western side of the Hawaii Islands to beyond Wake Island in the western Pacific. The altimeter of Topex/Poseidon shows bands of positive and negative sea level changes, implying cyclonic and anticyclonic current gyres with an eastward geostrophic current between them at 19°N. TMI reveals a narrow band of warmer water and enhanced atmospheric convection (high cloud water) at the position of the geostrophic current deviations, probably resulted from heat advection from the west. QuikSCAT also observes surface wind convergence and vorticity associated with the warm water and convection. The long wake revealed by QuikSCAT may be sustained by positive feedback between the ocean and the atmosphere. This narrow gap amidst westward flowing wind and current that may have aided the ancient eastward migration of Polynesian across half of the Pacific has never been viewed a single system until QuikSCAT data were combined with two other microwave sensors by Xie et al. [2001] and Liu [2001].

5. FUTURE MISSIONS AND NEW TECHNOLOGY

Quikscat will be followed by an identical scatterometer on ADEOS-2 scheduled to be launched in February 2002. If there is sufficient overlap between the operations of the two identical scatterometers, the importance of high-frequency wind forcing on the ocean can be demonstrated. ESA is planning to launch a series of C-band dual-swath advance scatteroemter (ASCAT), on their operational platform METOP, starting in December 1995. NASA is planning to launch a polarimetric scatterometer on the Japanese Global Change Observation Mission (GCOM), so that two wide-swath scatterometers will provide continuous time series of high frequency wind forcing.

One of the drawback on scatterometer is the wind-direction ambiguity. The backscatter is a cosine function of the azimuth angle (angle between radar beam and wind direction). In a recent experiment, it was demonstrated the correlation between copolarized and cross-polarized backscatter are sine function of azimuth angle. By adding receiver of cross polarizied backscatter to the scatterometer on QuikSCAT, the directional ambiguity problem can be eliminated. Although QuikSCAT has a continuous scan, the azimuth angles are too close together at the outer swath and too far apart near nadir, hampering selection of wind direction. With polarimetric scatterometer, we can achieve uniform retrieval accuracy across the entire swath. Polarimetic scatterometer can separate rain effect in the atmosphere from that at the surface, and perhaps can improve the accuracy of retrieving wind under rain. Polarimetric scatterometer also does not require full circular scan to get the azimuth angles, and will ease accommodation problem on spacecraft. We strive to infuse new technology to extend applications and to ease transition into operational spacecraft, while preserving the continuity of high quality wind-vector measurements.

6 DATA AVAILABILITY

Objectively interpolated and near real time surface ocean winds can be viewed and downloaded on-line through http://airsea-www.jpl.nasa.gov/seaflux. Uniformly gridded surface winds from NSCAT AND ERS-1 can also be accessed from the same website.

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REFERENCES

Bourassa, M., L. Zamudio, and J.J. O Brien, 1999: Noninertial flow in NSCAT observation or Tehuantepec winds. *J. Geophys. Res.,* **104**, 11311-11319.

Chelton, D.B., M.H. Freilich, and S.K. Esbensen, 2000: Satellite observations of the wind jets off the Pacific coast of Central America. Part I: Case studies and statistical characteristics. *Mon. Wea. Rev.*, **128**, 1993-2018

Hashizume, H., S-P Xie, W.T. Liu, and K. Takeuchi, 2001: Local and remote atmospheric response to tropical instability waves: a global view from space. *J. Geophys. Res*., **106**, 10173-10185.

Mass, C.F., and M.D. Albright, 1989: Origin of the Catalina Eddy, *Mon. Wea. Rev*., **117**, 2406-2336.

Liu, W.T., 2001: Wind over troubled waters. *Backscatter,* **12, No. 2**, 10-14.

Liu, W.T., and H. Hu, 2000: Spacebased scatterometer in studies of tropical cyclones in the past two decades. Presented at the Fall 2000 Meeting of the Amer. Geophys. Union at San Francisco.

Liu, W.T., H. Hu, and S. Yueh, 2000: Interplay between wind and rain observed in Hurricane Floyd. *Eos, Trans. of AGU*, **81**, 253 & 257.

Liu, W.T., W. Tang, and P.S. Polito, 1998: NASA Scatterometer provides global ocean-surface wind fields with more structures than numerical weather prediction. *Geophys. Res. Lett***., 25**, 761-764

Liu, W.T., X. Xie, P.S. Polito, S. Xie, and H. Hashizume, 2000: Atmosphere manifestation of tropical instability waves observed by QuikSCAT and Tropical Rain Measuring Missions. *Geophys. Res. Lett*., **27**, 2545-2548.

Polito, P., J.P. Ryan, W.T. Liu, and F.P. Chavez, 2001: Oceanic and Atmospheric Anomalies of Tropical instability Waves., *Geophys. Res. Lett*., **28**, 2233-2236.

Ritchie, E., J. Simpson, W.T. Liu, C. Veldon, K. Brueske, and J. Halvorsen, 2001: A closer look at hurricane formation and intensification using new technology. *Coping with Hurricanes*. Chapter 12, R. Simpson, M. Garstang, and R. Anthes (eds.), Amer. Geophys. Union.

Song, Y.T., W.T. Liu, and W. Tang, 2001: Applications of QuikSCAT wind to coastal and regional oceans. Unpublished manuscript.

Tsai, W.-Y., S. Nghiem, J. Huddelstgon, M. Spencer, B. Stiles and R. West, 2000: Polarimetric scatteromometer: a prmising technique for improving ocean surface measurements from space. *IEEE trans. Geosci. Remote Sensing,* **38**, 1903-1921.

Xie, S.P., W. T. Liu, and Q. Liu, and M. Nonaka, 2000: Far-reaching effects of the Hawaiian Island on he Pacific Ocean-Atmosphere. ***Science***, June 15.

Yueh, S. H., W. J. Wilson, and S. Dinardo, 2001: Polarimetric radar remote sensing of ocean surface wind. *Proc. IGARSS 2001, IEEE*, in press.