INTERNATIONAL SCATTEROMETER TANDEM MISSIONS AND POTENTIAL SYNERGISM

W. Timothy Liu and Xiaosu Xie
Jet Propulsion Laboratory, California Institute of Technology
Pasadena, CA 91109, U.S.A
liu@pacificic.jpl.nasa.gov

ABSTRACT

Three scatterometers will be launched by Europe, India, and China in the next few years and they will fly in tandem with QuikSCAT of the United States. The potential improvement in coverage will open up new operational and research applications.

KEY WORDS: Scatterometer, Wind-stress, Climate-changes, Ocean-circulation

1 SCATTEROMETER MISSIONS

QuikSCAT has provided global coverage of ocean surface wind/stress vectors and other terrestrial and cryospheric measurements since 1999 [Liu, 2002]. Data with improved spatial resolutions have recently been produced and validated [Tang et al., 2004]. Three scatterometers will be launched in the next few years, providing much improved coverage and synergism in research and operational application. They will be launched on the European Meteorology Operational Platform (METOP), the Indian Oceansat-II, and the Chinese Haiyang-2 satellites. The essential parameters of the three future missions, as currently known, are compared with those of QuikSCAT in Table 1.

2 POTENTIAL COVERAGE

Figure 1 shows that QuikSCAT will cover 90% of the Earth in 24 hours. The Indian Oceansat-II is assumed to fly in a slightly lower orbit but will have slightly narrower swath and will provide the similar coverage as QuikSCAT. The Chinese Haiyang-2, with a higher orbit and a narrower swath than QuikSCAT will cover 75% of the Earth in 24 hours, and will take 36 hours to cover 90% of the Earth. ASCAT on European METOP has two swaths, each 550 km wide, will cover only 60% of the Earth in 24 hours and will take 48 hours to cover 90%.

Combining QuikSCAT and ASCAT, we will be able to cover 90% of the world ocean in 18 hours. Adding either Haiyang-2 or Oceansat-II, we will be able to achieve 90% coverage in less than 12 hours.

3 OPERATIONAL APPLICATIONS

Near-real-time (NRT) measurements of ocean surface vector winds from QuikSCAT have been widely used in operational forecasting and warning activities. They have been incorporated into daily operations by theTropical Prediction Center/National Hurricane Center of the National Oceanographic and Atmospheric Administration (NOAA), and Joint Typhoon Warning Center of the Department of Defense in the United States (US).

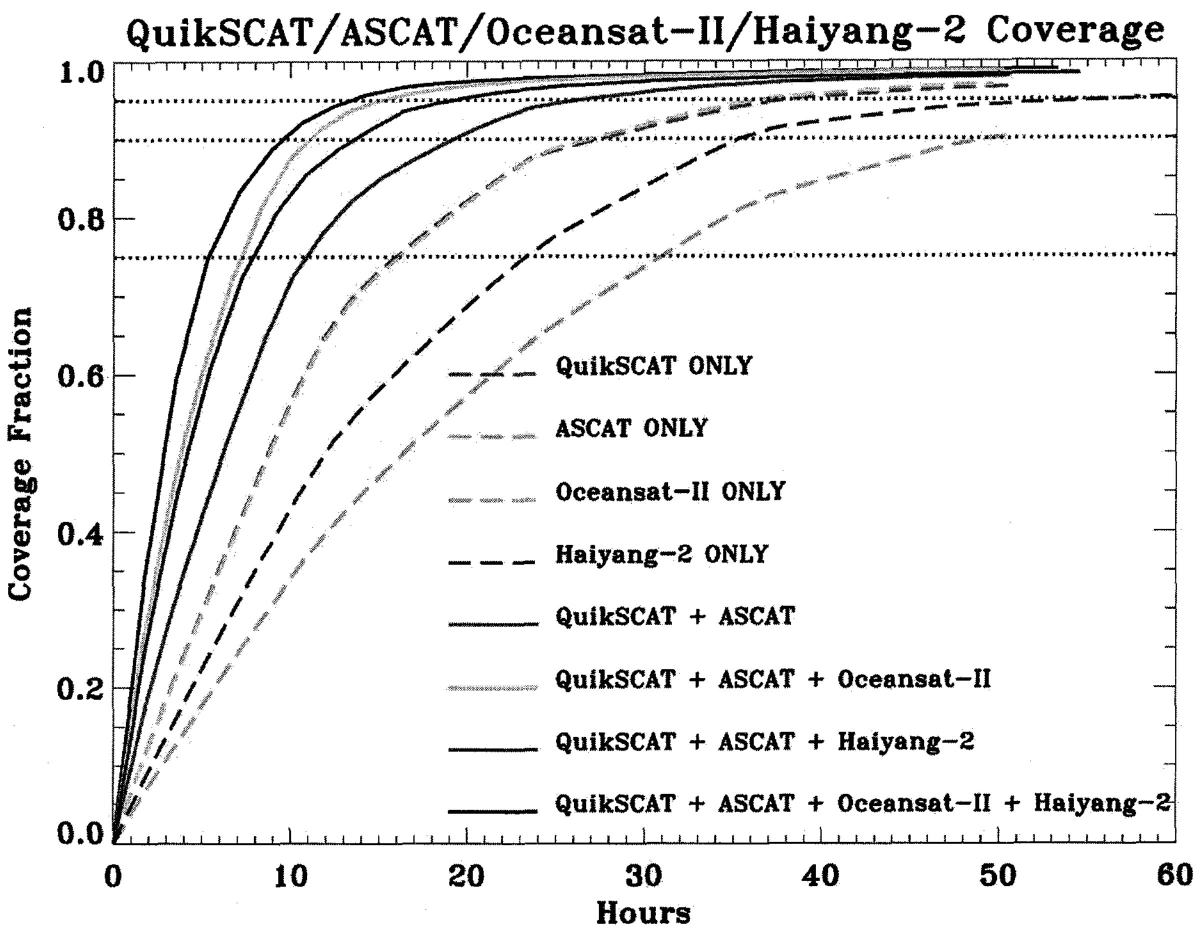
QuikSCAT NRT data have also been routinely assimilated into numerical weather prediction in major centers, including the National Center for Environmental Prediction of NOAA, the European Center for Medium Range Weather Forecast, the United Kingdom Meteorology Office, and the Japanese Meteorology Agency.

The operational requirement of ocean surface wind vector in revisit time is often put as 6-12 hours, which could only be achieved by scatterometers on a constellation of

Table 1. Platform and sensor parameters of the four scatteerometer missions

Satellite	Orbit Inclination (degree)	Orbit Period (min)	Swath Width (km)	ECTAN (local time)	Orbit Height (km)
QuikSCAT	98.722	101.05	1900	5:54 am	803
ASCAT	98.7	101.346	2x550	9:30 am/pm	817
Oceansat-II	98	99.303	1840	12:00 pm	720
Haiyang-2	99	124.83	1700	6.00 am/pm	965

ECTAN - equatorial crossing time of ascending node



satellites at low orbits, as demonstrated in Figure 1.

4 RESEARCH APPLICATIONS

4.1 Ocean Inertial response

Two-dimensional wind-stress vector field from QuikSCAT has been used to compute the divergence and curl that control the vertical mixing and bring short-term momentum and heat trapped in the surface mixed layer into the deep ocean where they are stored over time, and bring nutrients and carbon stored in the deep ocean to the surface where there is sufficient light for photosynthesis.

In the midlatitude storm-track regions of both hemispheres, the inertial resonance mixing process depends on synchronous rotations of the surface stress vector on local inertial time scales. In the North Pacific, about 10% of the wind forcing due to inertial resonance leads to an estimate of as much of 70% of the seasonal cooling due to ocean mixing [Milliff et al., 2001]. Sampling of surface wind forcing must be sufficiently frequent to resolve local inertial periods in order to account for this important ocean mixing process.

4.2 Ocean Ecology and Carbon Cycle

As described in Section 4.1, surface wind stress is a key aspect of the forcing that regulates the productivity of oceanic ecosystems. In nutrient-limited areas of the ocean, wind-driven upwelling and mixing are important mechanisms of nutrient supply. Lin et al. [2003] demonstrated that wind forcing by typhoon increases not only the local chlorophyll but significantly affects carbon cycle. Time series of the air-sea difference in the partial pressure of carbon dioxide at monitoring sites reveal tremendous variability on very short time scales [Bates and Merlivat, 2001]. Because of the nonlinear relationship between wind speed and the gas transfer coefficient of carbon dioxide [Carr et al., 2002], the high-frequency fluctuations can have a dramatic impact on the mean flux [Liu, 2003].

4.3 El Nino

The models and theories for predicting El Nino Southern Oscillation (ENSO) have advanced considerably in the past decade. One of the remaining issues is whether atmospheric transient forcing, such as the 30-60 day Madden Julian Oscillation (MJO) and short-duration (5-20 days) westerly wind bursts (WWB) contribute to the irregularity of ENSO, limiting its predictability. The generation of WWB is triggered by northerly cold surges from East Asian that last for 2-3 days. Their development over the tropical western Pacific is observed to be associated with the organized high-frequency super cloud clusters (SCC) embedded in MJO. Diurnal cycles provide important forcing mechanisms modulating SCC over the warm pool through evaporation and sensible heat [Sui and Lau, 1992].

Although the operational Tropical Atmosphere Ocean moorings are able to record high-frequency wind forcing at a few locations near the equator, sufficient geographical coverage monitoring can be achieved only by spacebased scatterometers [e.g., Liu et al., 1996; Yu et al.,2002; Han et al. 2006]. The high frequency wind vectors provided by future scatterometer missions flying in tandem with QuikSCAT will contribute to the understanding of these multiscale interactions that affect ENSO.

4.5 Non-ocean Studies

While spacebased scatterometers were originally designed for wind retrieval over the ocean, their data have been proven useful for studies of land and ice. Tandem operation of spacebased scatterometters will benefit operational users who need more timely observations of the sea ice edge. Currently, 24-36 hours of QuikSCAT data are required to map the full ice edge. Tandem operations will improve this to less than 6 hours. The net mass balance of Greenland and Antarctica ice caps is considered a key indicator of global climate change. To measure the critical mass balance, ablation due to melting must be determined as well as accumulation [Drinkwater et al., 2001]. The accurate estimation of ablation requires measuring the melt intensity on timescales of fractions of a day, which can only be achieved through tandem operations of more than one sensor.

5 DISCUSSION

There are considerable sensor and science synergism between scatterometers and microwave radiometers, as described by Ebuchi and Liu [2005]. The Tropical Rain Measuring Mission (TRMM) Microwave Imager (TMI) and the Advanced Microwave Scanning Radiometer (AMSR) on Aqua have provided sea surface temperature under both clear and cloudy conditions, besides wind speed, water vapor, cloud liquid water and rain. The concept of combining both active and passive microwave into one sensor [Liu and Yueh, 2004] was proposed and engineering studies are being conducted.

The success of future scatterometers depends on calibration [Tsai et al., 1999]. Coincident measurements with QuikSCAT will provide the much needed cross-validation.

ACKNOWLEDGMENT

This study was performed at the Jet Propulsion Laboratory, Californian Institute of Technology, under contract with the National Aeronautics and Space Administration (NASA). It was supported by the Ocean Surface Vector Wind and Physical Oceanography Programs of NASA. Ke Xu, Vijay Agarwal, and Hans BoneKamp kindly provided information on the Chinese, Indian, and European missions.

REFERENCES

Bates, N.R. and L. Merlivat, 2001: The influence of short-term wind variability on air-sea CO2 exchange. *Geophys. Res. Lett.*, **28**(17), 3281-3284.

Carr, M.E., W. Tang, and W.T. Liu, 2002: CO2 exchange coefficients from remotely sensed wind speed measurements: SSM/I versus QuikSCAT in 2000. *Geophys. Res. Lett.*, **29**(15), doi:10.1029/2002GL015068.

Drinkwater, M.R., D.G. Long, and A.W. Bingham, 2001: Greenland snow accumulation estimates from scatterometer data. *J. Geophys. Res.*, **106**, 33935-33950.

Ebuchi, N., and W.T. Liu, 2005: Synergism of SeaWinds and AMSR. 33pp.

Han, W., W. T. Liu, and J. Lin, 2006: Impact of atmospheric submonthly oscillations on sea surface temperature of the tropical Indian Ocean. *Geophys. Res. Lett.*, **33**, L03609, doi:10.1029/2005GL025082.

Lin, I-I, W.T. Liu, C.-C. Wu, G. T.F. Wong, C.Hu, Z. Chen, W.-D. Liang, Y. Yang, and K.-K. Liu, 2003: New evidence for enhanced ocean primary production triggered by tropical cyclone. *Geophys. Res. Lett.*, **30**(13), 1718, doi:10.1029/2003GL017141.

Liu, W.T., 2002: Progress in scatterometer application, *J. Oceanogr.*, **58**, 121-136.

Liu, W.T., 2003: Scientific Opportunities Provided by SeaWinds in Tandem. *JPL Publication 03-12*. Jet Propulsion Laboratory, Pasadena, CA. 39 pp.

Liu, W.T. and S. Yueh, 2005: Water and Ocean Wind Sensor (WOWS). Concept proposal to National Research Council Decadal Survey. Jet Propulsion Laboratory, Pasadena, 10 pp.

Liu, W.T., W. Tang, and R. Atlas, 1996: Responses of the tropical Pacific to wind forcing as observed by spaceborne sensors and simulated by model. *J. Geophys. Res.*, **101**, 16345-16359.

Milliff, R.F., M.H. Freilich, W.T. Liu, R. Atlas and W.G. Large, 2001: Global Ocean Surface Vector Wind

Observations from Space, in *Observing the Oceans in the 21st Century*, C.K. Koblinsky and N.R. Smith (eds), GODAE Project Office, Bureau of Meteorology, Melbourne, 102-119.

Sui, C.-H, and K. M. Lau, 1992: Multi-scale phenomena in the tropical atmosphere over the western Pacific. *Mon. Wea. Rev.*, **120**, 407-430.

Tang, W., W.T. Liu, and B.W. Stiles, 2004: Evaluation of high-resolution ocean surface vector winds measured by QuikSCAT scatterometer in coastal region. *IEEE Trans. Geoscience and Remote Sens.*, **42**, 1762-1769.

Tsai, W.-Y., J.E. Graf, C. Winn, J.N. Huddleston, S. Dunbar, M.H. Freilich, F.J. Wentz, D.G. Long, and W.L. Jones, 1999: Postlaunch sensor verification and calibration of the NASA Scatterometer. *IEEE Trans. Goescience and Remote Sensing*, **37**, 1517-1542.

Yu, L., R.A. Weller, and W.T. Liu, 2003: Case analysis of a role of ENSO in regulating westerly wind bursts in the Western Equatorial Pacific. *J. Geophys. Res.*, **108**(C4), 3128, doi:10.1029/2002JC001498.