Ensuring the climate record: ocean vector wind measurements, 2003-2009"
(Reponse to RFI on Concepts for Science and Application Missions in the Post-2002 ERA)

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Summary

Understanding ocean-atmosphere coupling is crucial for modeling and predicting climate variations. Wind-forced baroclinic planetary waves with time scales of seasons to years are a key mechanism by which the ocean responds to, and propagates information about, changes in atmospheric circulation. However, recent space-based measurements and model studies have raised fundamental questions regarding the wind generation mechanisms, the influences of winds on planetary wave propagation (and thus the time scale of oceanic response to atmospheric forcing), and the importance of resonant, two-way, ocean-atmosphere interactions associated with oceanic planetary waves.

We propose acquisition of a continuous, consistent, 15-year time series of SeaWinds-class global ocean vector wind measurements, to be applied specifically to investigations of the roles of wind forcing and ocean-atmosphere resonance in the generation and propagation of baroclinic oceanic planetary waves. The proposed systematic measurement strategy involves flight of a combined active/passive microwave vector wind instrument to assure continuity and consistency between the end of the ADEOS-II/SeaWinds mission (2000-2003/4) and the start of the operational NPOESS constellation in 2009. The strategy allows for on-orbit direct test and refinement of passive microwave vector wind measurement technology without jeopardizing the continuity of the QuikSCAT/SeaWinds time series. The high accuracy, broad coverage, and continuous swath measurements will complement (and enhance the value of) the ESA/EUMETSAT ASCAT/METOP C-band scatterometer. High resolution backscatter data will have immediate additional utility for climatically important studies of vegetation, land- and sea-ice type and cover. The global ocean vector wind data will be available in near-real-time to satisfy NOAA requirements for operational numerical weather/climate prediction and modeling. The total 15-year set of wind forcing data will complement proposed and planned measurements of ocean dynamic response (from altimeters) and upper ocean thermodynamics (ie., sea-surface temperature from microwave and infrared radiometers), thus providing a comprehensive, statistically valid, systematic data set for climate investigations.

(1) Specific Scientific Rationale/Objective

It has long been known that baroclinic planetary waves are the primary mechanism by which the ocean adjusts to changes in atmospheric momentum input (Gill, 1982). Indeed, planetary waves with periods greater than a few hundred hours are ubiquitous in both conventional XBT and satellite altimeter data sets, with the spectrum dominated by variability in the seasonal-to-biennial band. Recent data and modeling analyses have raised fundamental questions about the role of wind forcing in the generation and propagation of these waves, and the influences of wave-induced sea-surface temperature perturbations on atmospheric circulation:

1) Are the observed levels of baroclinic planetary wave energy simply a passive ocean response to stochastic atmospheric forcing and day-to-day weather variability (Frankignoul et al. 1997)?

2) What is the role of two-way, resonant, ocean-atmosphere feedback in the generation and propagation of oceanic planetary waves, and their maintenance in the presence of (poorly understood) dissipative forces (White et al., 1998; Qui et al., 1997)? Do wave-induced SST perturbations cause anomalous tropospheric heating, surface wind convergence, and planetary vorticity advection by perturbing meridional winds (Palmer and Sun, 1985; White et al., 1998)?

3) Does wind forcing play a dominant role in the observed (nearly) factor of two increase in the celerity of nondispersive baroclinic planetary waves over that predicted by the classic, unforced theory (White, 1977; Kessler, 1990; Chelton and Schlax, 1996; and many others)?

The implications are profound. Faster planetary waves imply shorter basin-scale oceanic and climatic adjustment times. GEOSAT and ERS-1 propagating sea-level signals attributed by Jacobs et al. (1994) to the massive 1982-83 El Nino may in actuality have been generated by the later, smaller 1986-87 ENSO event. Free planetary waves may be excited poleward of the turning latitudes predicted by classic theory. If day-to-day weather forcing is dominant, accurate measurements of vector wind stress are critical, but coupled wave models may be simplified by neglecting wave-induced perturbations to the atmospheric circulation. Conversely, if oceanic planetary waves induce resonant perturbations in the atmosphere, climate models will require unanticipatedly accurate parameterizations of air-sea interactions and more detailed knowledge of the relative roles of atmospheric forcing and oceanic dissipation.

Ocean and coupled ocean-atmosphere models are presently unable to accurately represent the spectral shapes, total variances, and propagation speeds for seasonal-through-decadal planetary waves. Progress is hindered by the lack of sufficiently accurate, extensive, and lengthy measurements of surface wind forcing and upper ocean response. It is unclear whether poor model predictions result from inaccurate atmospheric forcing or inadequate and/or incorrect model physics. Existing data are unable to differentiate between competing explanations for observations and model results alike.

This proposal focuses on assuring the acquisition of a continuous, consistent 15-year set of global ocean vector wind measurements, allowing calculations of Ekman pumping and associated atmospheric forcing of the upper ocean, and diagnosis of surface wind response to oceanic planetary waves. Although solution of the complete problem requires simultaneous 15-year data sets of sea-surface height (to derive mean and time-varying upper ocean circulation) and sea-surface temperature (to obtain accurate air-sea energy fluxes), we assume that these other measurements will continue to be obtained with appropriate accuracy, resolution, frequency, and coverage from 1999 to 2014. The vector wind measurements proposed below follow the first-series QuikSCAT and SeaWinds missions and provide accurate, high-resolution, broad-swath, all-weather measurements to bridge the gap between those missions and the first planned NPOESS operational satellites in 2009. As discussed below, the proposed measurement approach will allow on-orbit direct comparisons of passive microwave vector wind measurements with those of the proven active scatterometry technique, without jeopardizing the continuity or consistency of the full data set in the event that the passive approach does not meet science specifications.

The radar backscatter measurements and vector wind measurements will also be used in a variety of other scientific and operational applications. Techniques have been developed to extract high (4-6 km) resolution backscatter information from the basic scatterometer measurements. These data have been used for vegetation classification and to examine decadal deforestation in climatically sensitive areas such as Amazonia; to provide high resolution ice mapping; and to examine seasonal and interannual changes in ice type and water content in glaciers and polar ice cap regions. The swath vector wind measurements are uniquely valuable for marine meteorology and operational weather prediction. As with NSCAT and QuikSCAT/SeaWinds, vector wind data will be made available to operational meteorological agencies in near-real-time. The NSCAT data were used operationally by marine forecasters at NCEP and the Joint Typhoon Warning Center, with great impact. The measurements enabled forecaster to analyze cyclones and fronts over the ocean with unprecedented accuracy.

Numerical forecast experiments demonstrated that asynchronous assimilation of NSCAT data resulted in improved global and regional forecasts. Both the coverage and vector nature of the NSCAT data were crucial – although SSM/I wind speed data have greater coverage, their impact was limited because of a lack of directional information. The impact of ERS-1/2 data was limited by the small coverage of the single-swath instrument and the lack of directional accuracy for winds below 5 m/s. NOAA has a documented requirement for ocean vector wind measurements that can only be achieved using multiple broad-swath instruments (Helen Wood, NOAA/NESDIS, personal communication).

(2) Specific Objectives and Measurement Approach

It is proposed to acquire all-weather, near-surface vector wind measurements over the global oceans for at least a 15-year period, in conjunction with precision measurements of sea-surface height and SST. The vector wind measurements must be consistent and contiguous with those previously obtained by the QuikSCAT/SeaWinds missions, and must extend in time to overlap (and allow cross-calibration with) the operational NPOESS microwave vector wind data set. Key attributes of the proposed vector wind data set are outlined and justified below:

1) *The vector wind measurements must cover the entire ice-free global oceans.* Significant geographical differences in planetary wave amplitudes and celerities have been observed. Numerical models of planetary waves and atmospheric forcing exhibit variable accuracy with latitude and ocean basin.

2) *The wind measurement time series must be continuous and consistent for at least 15 years.* The spectrum of upper ocean planetary wave variability is dominated by motions with time scales from hundreds to thousands of days. A 15-year series (~5500 days) is required to allow minimal statistical significance. Spatial averaging is not possible due to the spatial variability.

3) *The vector wind measurements must have sufficient accuracy, precision, and space/time resolution to allow accurate calculation of Ekman forcing and detection of resonant atmospheric perturbations.* Determination of Ekman forcing requires knowledge of wind stress curl on scales smaller than a planetary wavelength (in the present case, smaller than a few degrees), and hence measurements of surface wind components on similar scales. White et al. (1998) suggest that properly phased air-sea couplings resulting in meridional wind speed anomalies of ~1 m/s and wind stress curl anomalies of 10^(-8) Nt/m^(-3) can cause oceanic planetary wave celerity increases of up to a factor of 2, and wave amplitude doubling times of 4-6 months in the absence of dissipation. These accuracies on a few-day and –degree time and space scales exceed those of present operational surface wind analyses (Liu et al., 1998). *Component* accuracies of ~0.5 m/s for scales of 4 days and 2 x 2 degrees are required for the meridional wind and curl analyses. Instantaneous measurements with NSCAT-class accuracies of ~1.5 m/s rms speed errors, component standard deviations of ~1.25 m/s, and unity gain (Freilich and Dunbar, 1998) and with QuikSCAT/SeaWinds-class coverage (~1600 km continuous swaths, >90% daily coverage) can be used to construct fields with the required accuracy on planetary wave time and space scales. C-band scatterometers have been shown to yield lower (~2.5 m/s component rms) accuracy (Freilich 1997) and both the NSCAT- and ASCAT dual-swath instruments have lower coverage, leading to increased sampling errors in derivative quantities such as wind stress curl.

(3) Mission Type

This proposal is for a critical component mission as one part in a systematic measurement program designed to yield a 15-year consistent vector wind times series, starting with the QuikSCAT/SeaWinds missions and continuing through the NPOESS time frame. As discussed below, significant scientific and programmatic benefits would be gained by adding polarimetric radiometer channels to the existing instrument design, thereby demonstrating the accuracy and viability of a new, possibly more efficient measurement technique without jeopardizing the existing time series.

(4) Measurement Technique

A vector wind measurement instrument based on the broad-swath, Ku-band, dual pencil beam QuikSCAT/SeaWinds active microwave scatterometer, with effective overall swath width of ~1600 km provides one means of achieving the accuracy and resolution rquirements. The NSCAT mission demonstrated the accuracy of the Ku-band measurements and model function, the QuikSCAT/SeaWinds instruments achieve the broad contiguous swath and required coverage, and the QuikSCAT design demonstrates that such instruments can, if necessary, be flown on small spacecraft.

While active microwave scatterometry can meet the basic science requirements, the NPOESS program has chosen at present to acquire operational vector wind measurements using a passive polarimetric radiometer technique that has not been tested in space or quantitatively characterized over the global range of weather and cloud conditions. However, accurate and consistent vector wind measurements are required in the NPOESS period (2009-2014) to complete the measurement series. The proposed DoD/NRL Windsat mission may fly a passive vector wind radiometer with ~54 deg. incidence angle prior to NPOESS. However, aircraft experiments show that wind direction cannot be measured accurately at this incidence angle for wind speeds below 5-7 m/s. Thus, in addition to not providing direct comparisons with collocated scatterometer measurements, Windsat may not adequately test the full potential of the passive technique.

We therefore suggest that the SeaWinds class active scatterometer instrument proposed here be augmented to include a multi-frequency passive radiometer wind measurement system at incidence angles of ~45 or ~65 deg. Preliminary engineering studies show that this is feasible from an accommodation and design standpoint, without major cost impact to the existing SeaWinds design. The acquisition of fully collocated active and passive vector wind measurements will allow direct tests of the new passive technique over the full range of global conditions without the need for a completely separate mission. In addition, the radiometer channels will allow full rain flagging and correction of the scatterometer backscatter for atmospheric attenuation. The approach of combining proven and evolving measurement technologies in science-driven research missions was used (for example) on the TOPEX/Poseidon mission, where a new GPS-based precision orbit determination experiment was flown with the standard microwave and laser-ranging instrumentation, and an advanced solid state altimeter shared resources with the TOPEX dual-frequency instrument.

(5) Mission Characteristics

The proposed instrument could be accommodated on a QuikSCAT-class spacecraft or as an instrument on a larger platform such as the proposed NASDA ADEOS-III mission. Coverage and resolution require a sun-synchronous orbit at ~800 km altitude. Maximum science benefit would be achieved by coordinating the orbit with that of METOP to gain even better sampling characteristics. Pointing requirements (3 sigma) are nominal: control < 0.3 deg, knowledge < 0.05 deg, stability , 0.08 deg.sec.

Approximate Instrument/Data Characteristics

Mass:	200 kg	Power:	200 W
Data Rate:	80 kbps	Size:	100 cm diam. dish
Duty Cycle:	100 %		32 x 46 x 34 cm CDS assy
Rot. Rate:	18 rpm		81 x 91 x 43 cm SES assy
Scatt. Freq:	13.4 GHz (H,V)	Rad. Freqs:	18-19, 22, 35 GHz (18/19, 35 full polar.)
Scatt Inc.:	47, 55 deg.	Rad. Inc.:	~35 or ~65 deg.
Eff. Swath:	1600 km (cont.)	Backscatter Resolution:	
6-25 km			
Daily Cov.:	> 90% global ocean	Vector Wind Resolution:	25 km

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