Examining the Constellation of Scatterometers and Radiometers for Diurnal and Sub-Diurnal Wind Vector Variability

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*The constellation of satellite-based ocean surface wind and precipitation observations since 1999 consists of a diverse collection of both sun-synchronous and asynchronous orbiting satellite platforms, both wind vector-capable (*RapidScat, QuikSCAT, SeaWinds, ASCAT, OceanSat2, WindSat, RapidScat*) and speed-only radiometers (*TMI, GMI, AMSR, AMSR-2, SSMIS*). These data can be jointly examined for time-of-day variability over regions where the surface wind varies widely throughout the day, owing to various meteorological forcings, such as land/sea temperature differences near coasts, or possible variations associated with tropical convective precipitation. Early results of an analysis are described whereby multiple wind speed and wind vector products were jointly examined to investigate the diurnal (and semi-diurnal, in cases) ocean wind vector variability.*

Theory

The formulation follows the structure of *Gille et. al.* (2005) and later used by *Tang et. al.* (2014), by modeling the diurnal wind using an elliptical variability, with the addition of the speed-only radiometers, the sub-diurnal terms, the error variance, and the capability to examine each day over the 2003-current period (when at least two scatterometers were jointly operating). Assume we have n wind vector estimates from n wind vector-capable satellite passes, all of them during a given day over a given location. This number varies depending upon the time of year, location, and the satellites being considered. The daily and sub-daily u and v components can be expressed with an elliptical fit using a compact matrix formulation:

$$\begin{pmatrix} u_1\\ v_1\\ \vdots\\ u_n\\ v_n \end{pmatrix} = \begin{pmatrix} \overbrace{a_0+a_1\cos(2\pi t_1/24)+a_2\sin(2\pi t_1/24)}^{\text{daily}}+\overbrace{a_3\cos(4\pi t_1/24)+a_4\sin(4\pi t_1/24)}^{\text{sub-daily}}\\ b_0+b_1\cos(2\pi t_1/24)+b_2\sin(2\pi t_1/24)+b_3\cos(4\pi t_1/24)+b_4\sin(4\pi t_1/24)\\ \vdots \\ a_0+a_1\cos(2\pi t_n/24)+a_2\sin(2\pi t_n/24)+a_3\cos(4\pi t_n/24)+a_4\sin(4\pi t_n/24)\\ b_0+b_1\cos(2\pi t_n/24)+b_2\sin(2\pi t_n/24)+b_3\cos(4\pi t_n/24)+b_4\sin(4\pi t_n/24) \end{pmatrix} \qquad \vec{x}=\left(a_0\,a_1\,a_2\,a_3\,a_4\right)^T \quad \vec{y}=\left(b_0\,b_1\,b_2\,b_3\,b_4\right)^T$$

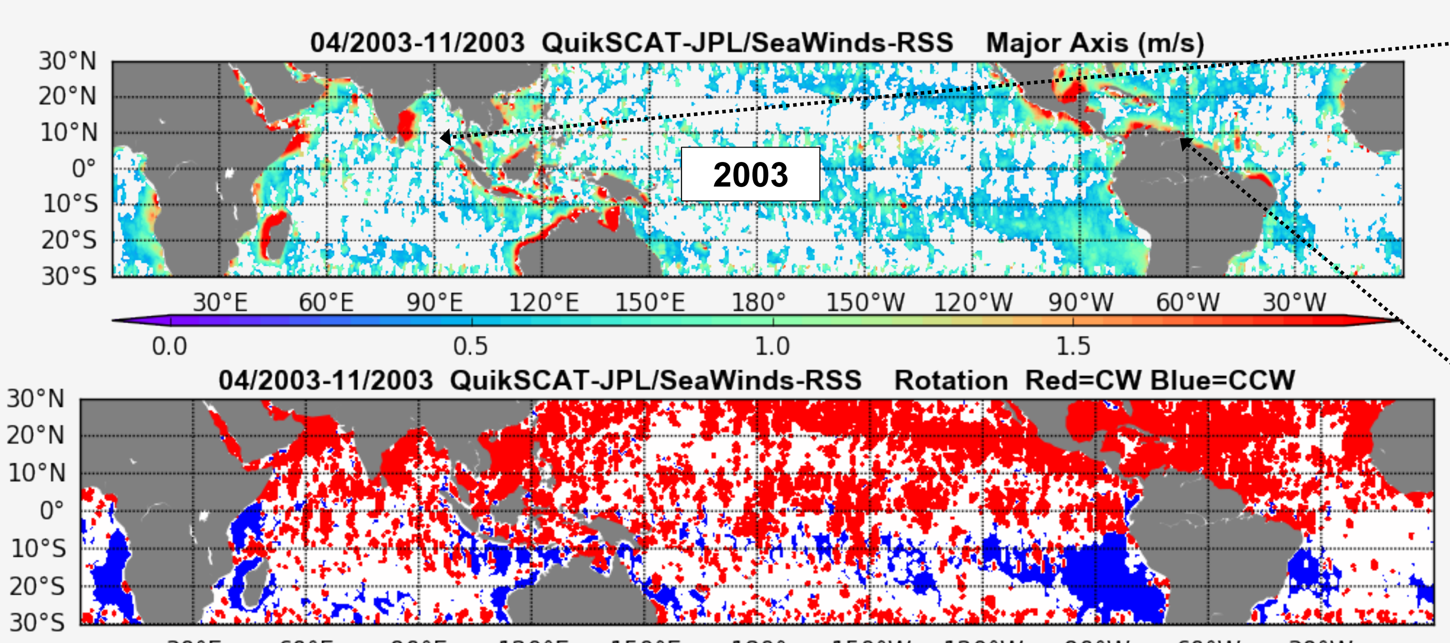
$$[A]=\begin{pmatrix} 1 & \cos(2\pi t_1/24) & \sin(2\pi t_1/24) & \cos(4\pi t_1/24) & \cos(4\pi t_1/24)\\ \vdots & \vdots & \vdots & \vdots & \vdots\\ 1 & \cos(2\pi t_n/24) & \sin(2\pi t_n/24) & \cos(4\pi t_n/24) & \cos(4\pi t_n/24) \end{pmatrix} \qquad \hat{\vec{x}}=\left(A^T D_u^{-1} A\right)^{-1} A^T D_u^{-1} U \quad \hat{\vec{y}}=\left(A^T D_v^{-1} A\right)^{-1} A^T D_v^{-1} V$$

For the speed-only (w) radiometers, since the relation between w and the u and v components is non-linear, hypothetical vectors are created by varying the directions one degree at a time (e.g., for one radiometer):

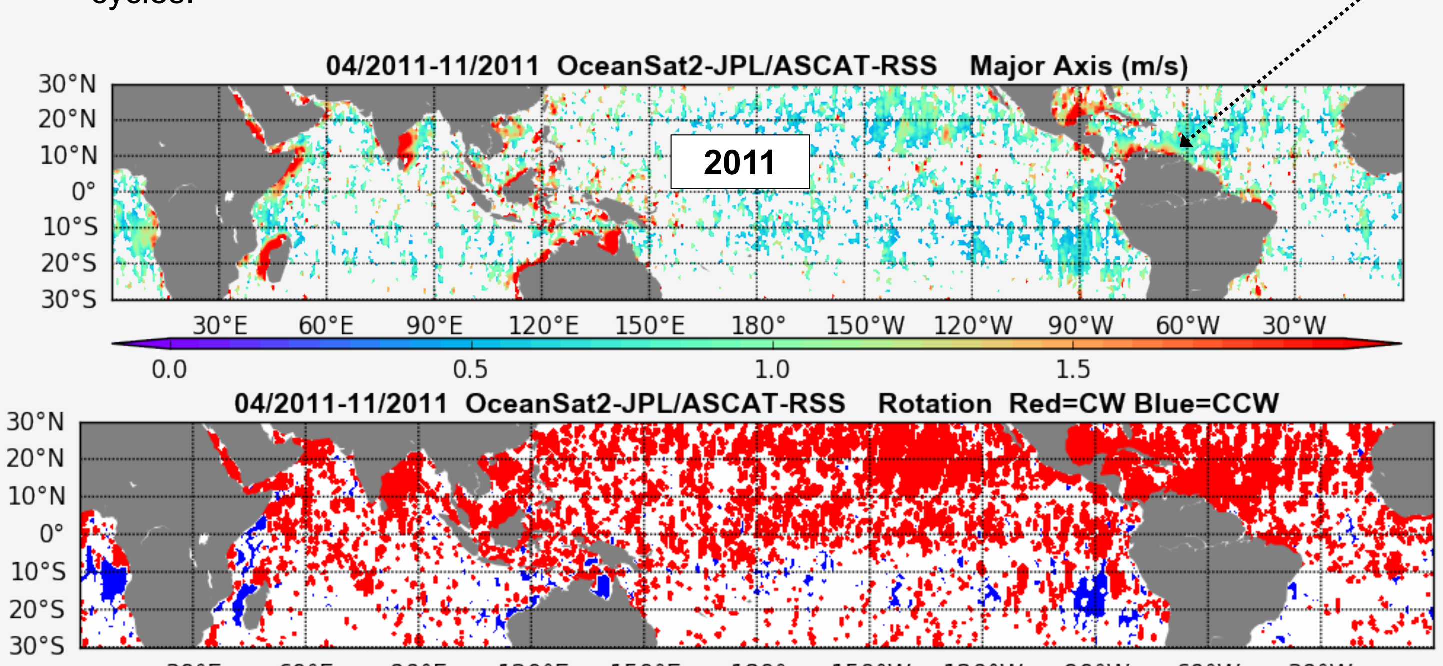
In either case, these expressions can be expressed in matrix form, where D_u and D_v are diagonal matrices with the variance of the u and v observations.

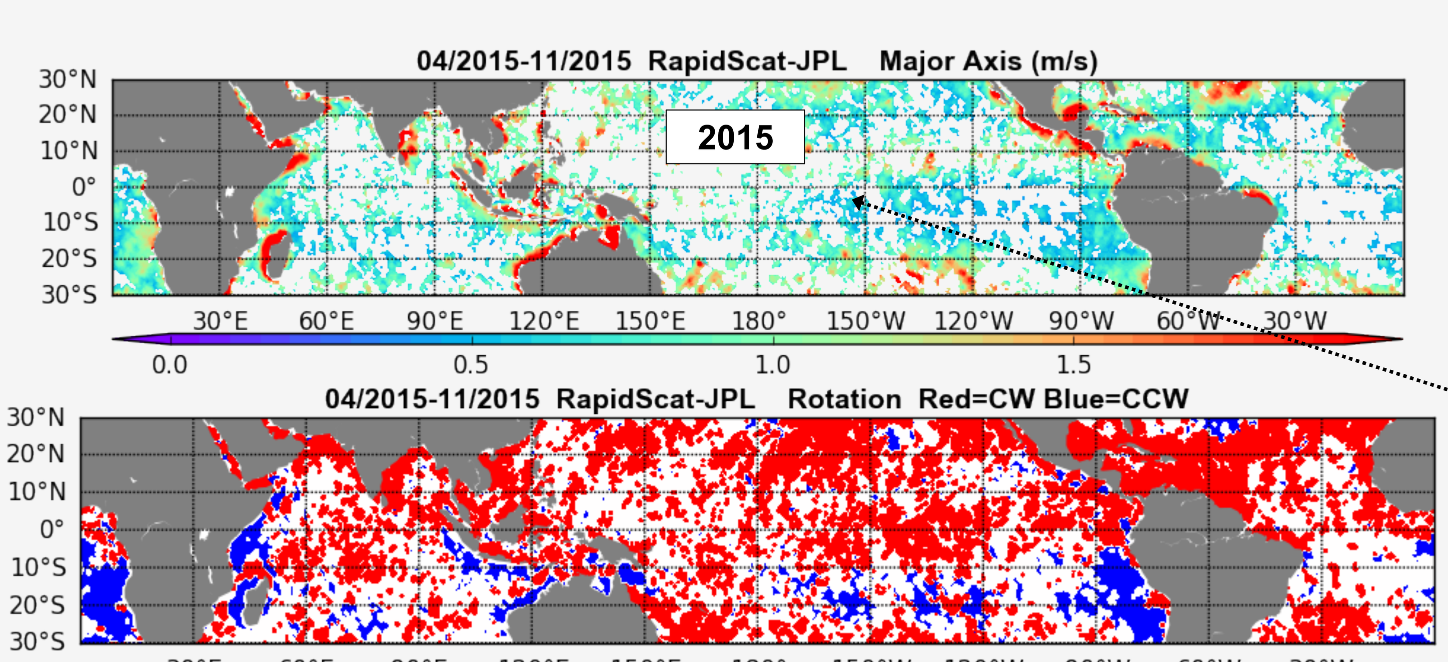
$$u_{n+1}=w\cos(\theta)=a_0+a_1\cos(2\pi t_1/24)+a_2\sin(2\pi t_1/24)+a_3\cos(4\pi t_1/24)+a_4\cos(4\pi t_1/24)$$
$$v_{n+1}=w\sin(\theta)=b_0+b_1\cos(2\pi t_1/24)+b_2\sin(2\pi t_1/24)+b_3\cos(4\pi t_1/24)+b_4\cos(4\pi t_1/24)$$
$$E(\theta)=\min\left(\sum_{i=1}^{n}\left(u_{n+1}-u_i\right)^2+\left(v_{n+1}-v_i\right)^2\right)$$

And locating the directions θ that best agree with the observed vectors.



The **top** panel shows the global map of the diurnal ellipse major axis (m s^{-1}) and the direction of the ellipse rotation (red=CW, blue=CCW), derived from the April-November 2003 QuikSCAT-SeaWinds tandem mission (n=4 day^{-1}), which agrees closely with Fig. 1 of *Gille et. al.* (*2005*). This same analysis was repeated using the same months of 2011 with OceanSat-2-JPL and MetOp-A ASCAT-RSS (Version 2.1) (**middle**), and during same months during 2015 using only RapidScat-JPL (**bottom**). While there are slight differences in the areas of small diurnal magnitude over open ocean and in the southern hemisphere ellipse rotation direction, the patterns in general show good agreement. This suggests that RapidScat can be used for examining daily wind variability in places where the phenomena underlying the daily wind variability is sustained and captured over several RapidScat local time repeat cycles.





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References

Gille, S.T., et. al. (2005). Global observations of the land breeze. *Geophys. Res. Letters*, 32.
Tang, W., et. al. (2014). Detection of diurnal cycle of ocean surface wind from space-based observations. *Int. J. Rem. Sens.*, *35*, 5328-5341.

Thirteen-Year Analysis (April 2003-Feb 2016)
The maps on the lower left show mean values over limited 7-month periods. To examine the day-to-day variability over a long term, all products listed on the left side were examined for the April 2003-Feb 2016 period (when at least two scatterometers were functional), over specific "target areas" where the major axis exceed 2 m s^{-1}. Both the daily-only (three **a** and three **b** coefficients estimated each day), and daily+sub-daily analysis (five **a** and five **b** coefficients estimated each day) was done, to examine the the persistence of the daily-only variability, and to further analyze for the presence of any sub-daily variability. Days are included only when the magnitude of the diurnal u and v components sufficiently exceeded the variability (twice the standard deviation) in the estimated regression coefficient terms.

Referencing to Common Sensor
In this study, the asynchronous orbiting TRMM-TMI V7 0.25-degree wind speed products are used as a wind speed reference from 1999-2014, and GPM-GMI from April 2014-current, both produced by RSS (eight-month overlap period between TMI and GMI). Per-pixel coincidences within ±5-min between TMI (or GMI) and each of the 15 other different wind speed or wind vector (depending upon sensor type) datasets were collected over the Nov 1999-Mar 2016 period. Mean bias correction lookup tables were generated for each 0.5 m s^{-1} wind speed bin of the reference sensor. These were applied to adjust the speed each of the non-reference sensors, prior to any qualitative analysis.