DEVELOPMENT OF A NEW CROSS-CALIBRATED, MULTI-PLATFORM (CCMP) OCEAN SURFACE WIND PRODUCT

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ABSTRACT

A new set of cross-calibrated, multi-satellite ocean surface wind data sets is described. The principal data set covers the global ocean for the period beginning in 1987 with six-hour and 25-km resolution and is produced by combining all ocean surface wind speed observations from SSM/I, AMSR-E, and TMI, and all ocean surface wind vector observations from QuikSCAT and SeaWinds. An enhanced variational analysis method (VAM) performs quality control and combines these data with available conventional ship and buoy data and ECMWF analyses. The VAM analyses fit the data used very closely. Comparisons with withheld WindSat observations are very good. The effect on monthly and annual average wind fields of the rain induced data sampling patterns for the microwave data sets is described.

Index Terms—variational methods, ocean surface wind, microwave radiometry, data processing

1. INTRODUCTION

July 1987 marks the beginning of an unprecedented period of remote sensing over the global oceans. Beginning with the launch of the DMSP SSM/I F08 satellite, the remote sensing coverage of the global oceans in a 6-hour period increased from 20% in 1987 to nearly 70% in 2004. From 1987 to 2007, over a dozen satellites became operational including both passive microwave sensors and scatterometers. See Fig. 1 for the temporal extent of the data sets analyzed in this work. We previously described a variational analysis method (VAM) [1] that was used to combine wind speeds derived from the DMSP SSM/I satellites into a consistent global analysis at 1 x 1 degree resolution [2]. Under the NASA funded REASoN project, this work was significantly expanded. Cross-calibrated data sets produced by Remote Sensing Systems (RSS) and derived from SSM/I (F08 – F15), TRMM TMI, QuikSCAT, SeaWinds and AMSR-E were combined to create a consistent, long-term (1987 – 2007), global data set of ocean surface winds at high resolution (6 hours, 25 km). The new data products are currently available for interested

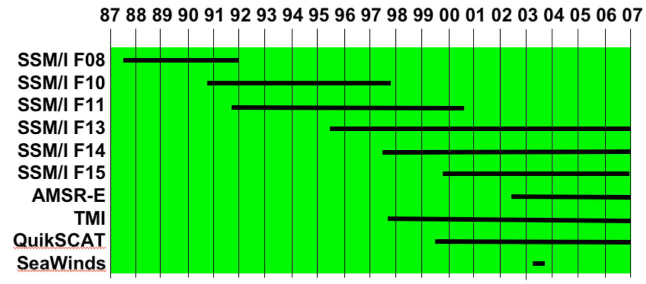

Fig. 1. Time availability of satellite surface wind data sets analyzed by the VAM. The SSM/I instruments are denoted F08 through F15; SSM/I is the Special Sensor Mircrowave/Imager; AMSR-E is the Advanced Microwave Scanning Radiometer-E; TMI is the TRMM microwave imager; QuikScat and SeaWinds are scatterometers; the other instruments are microwave radiometers.

investigators. Here we summarize the methodology, describe the data assimilated by the VAM, and introduce the products available for meteorological and oceanographic applications. Monthly and annual climatologies based on "satellite-only" data show significant differences relative to reanalysis climatologies. Applying the satellite data masks to the reanalysis demonstrates that the rain-induced data sampling that affects all microwave satellite ocean surface wind observations can cause the differences seen in the climatologies.

2. METHODOLOGY

The VAM [1] that was previously used for the assimilation of SSM/I wind speeds has been enhanced for the assimilation of data from multiple platforms at high resolution. The VAM analysis is defined to be the global grid of vector winds that minimizes

$$J = \lambda_{\mathrm{CONV}} J_{\mathrm{CONV}} + \lambda_{\mathrm{SCAT}} J_{\mathrm{SCAT}} + \lambda_{\mathrm{SPD}} J_{\mathrm{SPD}} + \lambda_{\mathrm{VWM}} J_{\mathrm{VWM}} + \lambda_{\mathrm{LAP}} J_{\mathrm{LAP}} + \lambda_{\mathrm{DIV}} J_{\mathrm{DIV}} + \lambda_{\mathrm{VOR}} J_{\mathrm{VOR}} + \lambda_{\mathrm{DYN}} J_{\mathrm{DYN}}$$

Here the λ are the weights, and the J are the individual cost function terms defined in Table 1.

Table 1. Observation functions and background constraints used in the VAM.

Term	Expression	Description of constraint
		Observation Function for the
J_{CONV}	$\sum(\mathbf{V}_A - \mathbf{V}_O)^2$	• wind vectors
J_{SCAT}	$\sum(\mathbf{V}_A - \mathbf{V}_O)^2$	• wind vectors
J_{SPD}	$\sum(\lvert\mathbf{V}_A\rvert - \lvert\mathbf{V}_O\rvert)^2$	• wind speeds
		Background Constraints on the
J_{VWM}	$\int(\mathbf{V}_A - \mathbf{V}_B)^2$	• vector wind magnitude
J_{LAP}	$\int[\nabla^2(u_A - u_B)]^2 + \int[\nabla^2(v_A - v_B)]^2$	• Laplacian of the wind components
J_{DIV}	$\int[\nabla^2(\chi_A - \chi_B)]^2$	• divergence
J_{VOR}	$\int[\nabla^2(\psi_A - \psi_B)]^2$	• vorticity
J_{DYN}	$\int(\partial\zeta_A/\partial t - \partial\zeta_B/\partial t)^2$	• vorticity tendency

REASoN products were assimilated at 25-km resolution on a 1/4 x 1/4 degree latitude-longitude grid. For comparison, a 1 x 1 degree grid was used for the previous SSM/I Pathfinder data set [2]. As spatial resolution is increased, temporal scales must be resolved more accurately. The VAM was modified to perform the analysis at the observation times. Recognizing that data far from the analysis time is less valuable because of the assumption of linear in time variation of the wind components, the FGAT procedure was enhanced to effectively de-weight the data as the time difference between the observation and the analysis increases.

3. DATA

The VAM requires a background (first guess) analysis of gridded *u* and *v* winds. Analysis increments are added to this background to arrive at the final analysis. The 10-meter winds from the ERA-40 Reanalysis were used as a background for the period July 1987 to December 1998. Beginning in 1999, the ECMWF Operational analysis provides a higher quality choice for a background.

Satellite surface wind data were obtained from RSS under the DISCOVER project (Distributed Information Services: Climate/Ocean Products and Visualizations for Earth Research). Figure 1 shows the availability of satellite ocean surface wind products from RSS.

4. PRODUCTS

We produce three standard data sets, designated as level 3.0, 3.5 and 2.5. The primary data set, denoted Level 3.0, contains 6-hourly gridded VAM analyses. These analyses are time averaged over 5-day and monthly periods to derive the Level 3.5 data set. Only those grid points containing observations that passed quality control are used in the average to produce a “satellite-only” climatology. Because the VAM analysis fits the satellite data so closely (see Section 5) we refer to the Level 3.5 product as satellite-only. Finally, directions from the VAM analyses are assigned to the wind speed observations for each passive microwave sensor to derive the Level 2.5 data set. All data sets share the same 25-km latitude-longitude grid.

5. VALIDATION

The RMS wind speed difference between the VAM analysis and the assimilated satellite wind speeds is approximately 0.5 m/s for the entire 21-year period (Fig. 2). This is a 1-1.5 m/s improvement over the ERA-40 and ECMWF operational backgrounds. The RMS wind speed difference versus Windsat—data not used in the VAM analysis—is also significantly improved, with a reduction of approximately 1 m/s (Fig. 3). Overall, the VAM winds are unbiased relative to the satellite speeds (Fig. 4). This is a significant improvement over the background wind field, which has a persistent low wind speed bias. The RMS direction difference of the VAM analysis versus the assimilated scatterometer winds (Quikscat and SeaWinds) is approximately 5 degrees, a nearly 10 degree improvement over the background (Fig. 5).

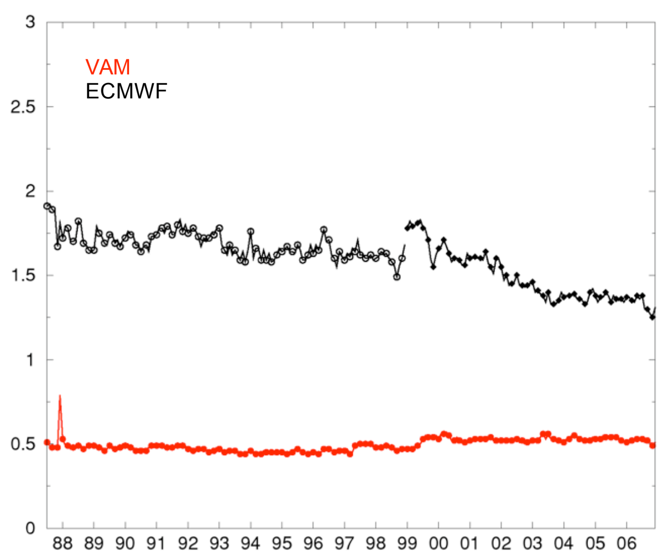

Fig. 2. RMS wind speed fit (m/s) versus the assimilated satellite wind speeds.

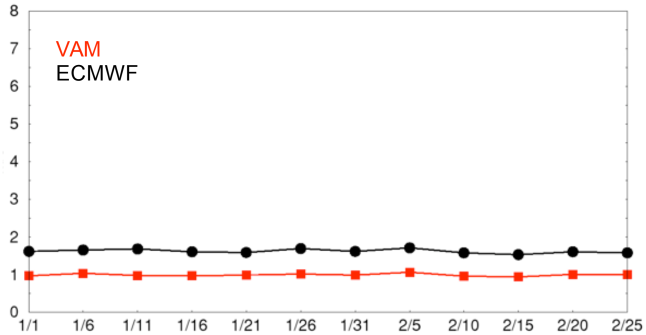

Fig. 3. RMS wind speed fit (m/s) versus Windsat for a 2-month period in 2004 (grouped into 5-day bins).

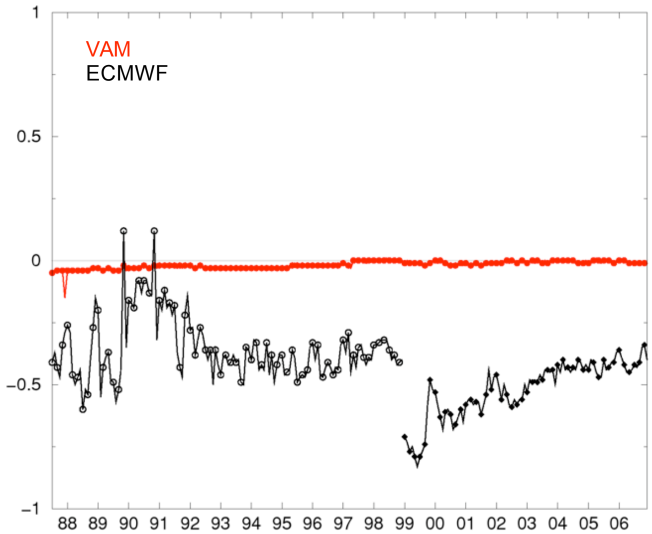

Fig. 4. Mean speed difference (m/s) versus the assimilated satellite wind speeds.

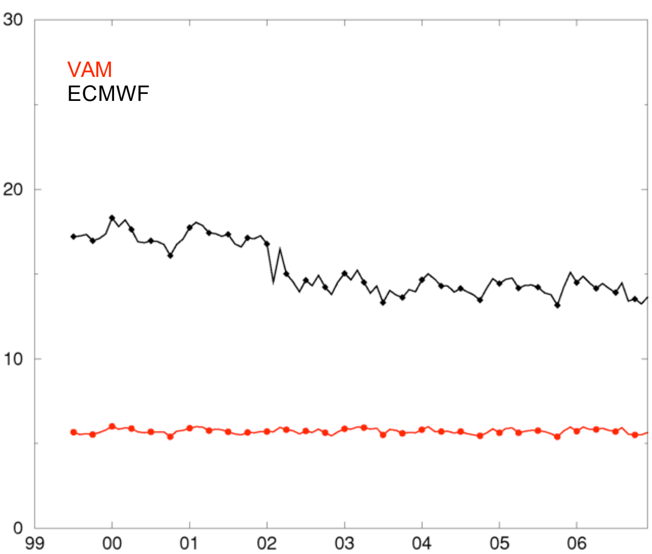

Fig. 5. RMS direction fit (degrees) to the assimilated scatterometer winds.

6. EARLY RESULTS

The VAM blends all available surface wind observations with the best estimate of the starting wind field. The result is a comprehensive surface wind analysis that better represents the true wind by intelligently combining all assets. The benefit of using the VAM blended products is very evident when deriving surface wind climatologies.

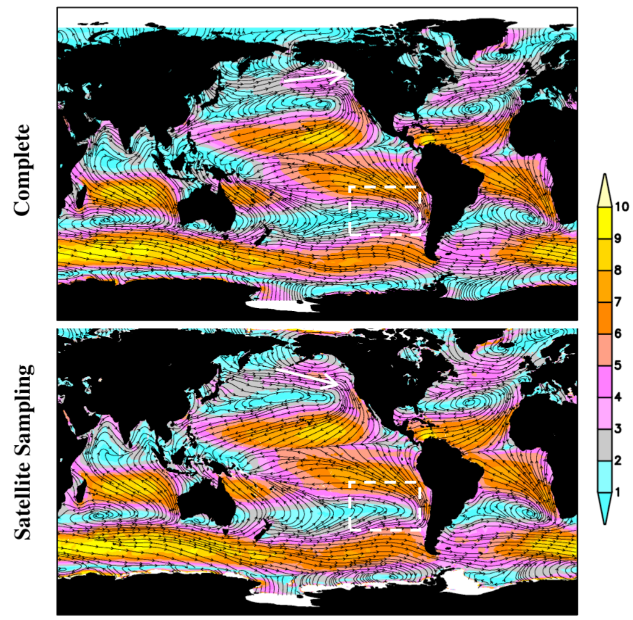

Fig. 6. Annual mean climatology for 2006 determined using complete sampling (top) and satellite sampling (bottom) as described in the text. Shown are streamlines in black and vector wind magnitudes in colors (m/s).

Microwave sensors cannot reliably retrieve ocean surface winds in the presence of rain. This introduces a fair weather bias in satellite-only derived wind climatologies. Figure 6 demonstrates this by comparing the annual mean of the VAM blended Level 3.0 products with and without satellite masking. The two plots are processed identically, except that in the bottom plot each VAM analysis is masked by the presence of satellite observations that passed quality control. Comparison of these two plots reveals significant differences in the depiction of the general circulation pattern. Anticyclonic circulation centers associated with the Hadley cell are less pronounced in the satellite-sampled climatology as can be seen for example in the boxed region. There is also an overall equatorward trend in the satellite-sampled climatology as is evident in the turning of the mean wind just south of Alaska. This can be explained by the overall reduction in cyclonic winds due to rain masking as is clearly demonstrated in the snapshot of SSM/I coverage of three cyclones in the North Pacific in Fig. 7. The elimination of poleward winds associated with cyclones creates the equatorward bias that we see in the satellite-sampled climatology and can misrepresent the overall general circulation pattern.

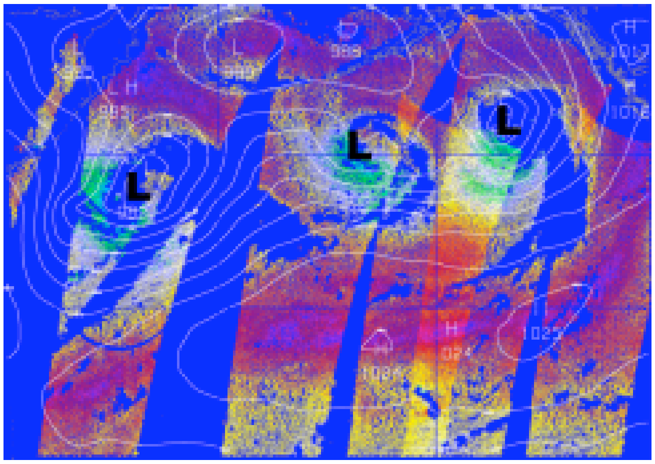

Fig. 7. Sample SSM/I data coverage of three cyclones in the North Pacific. Sea level pressure contours from an operational analysis are shown for reference.

The VAM is better able to represent these cyclones and to locate storms that are too weak or missing in the background wind field. Fig. 8 shows an example of a cyclone in the North Pacific. The background analysis depicts a single cyclone just south of the Kamchatka peninsula. The VAM analysis reveals a second more intense cyclone to the south that is consistent with the Quikscat winds. MODIS cloud imagery (not shown) confirms the existence of this second cyclone. In general, the VAM analysis of all data produces more intense cyclones that are often underrepresented in the background wind field.

7. SUMMARY

We used an enhanced variational analysis method (VAM) to combine the latest RSS cross-calibrated, multi-satellite data sets of ocean surface wind. In this way we uniformly combine all available surface wind speed observations from SSM/I, AMSR-E, and TMI, and all ocean surface wind vector observations from QuikSCAT and SeaWinds with the best ECMWF analyses. The VAM analyses cover the global ocean for the period beginning in 1987 with six-hour and 25-km resolution. The analyses fit the data used very closely. Comparisons with withheld WindSat observations are also very good. The VAM analyses are used to assign directions to the microwave radiometer wind speed data sets. Pentad and monthly average data sets are also available. The impact of satellite sampling induced by the effect of rain on the microwave instruments can be a substantial disadvantage and must be considered in any analysis based on "satellite-only" data. For most purposes the VAM analyses should be used because these fit the microwave surface wind data very closely where such data are available and can improve upon the ECMWF analysis of cyclonic winds.

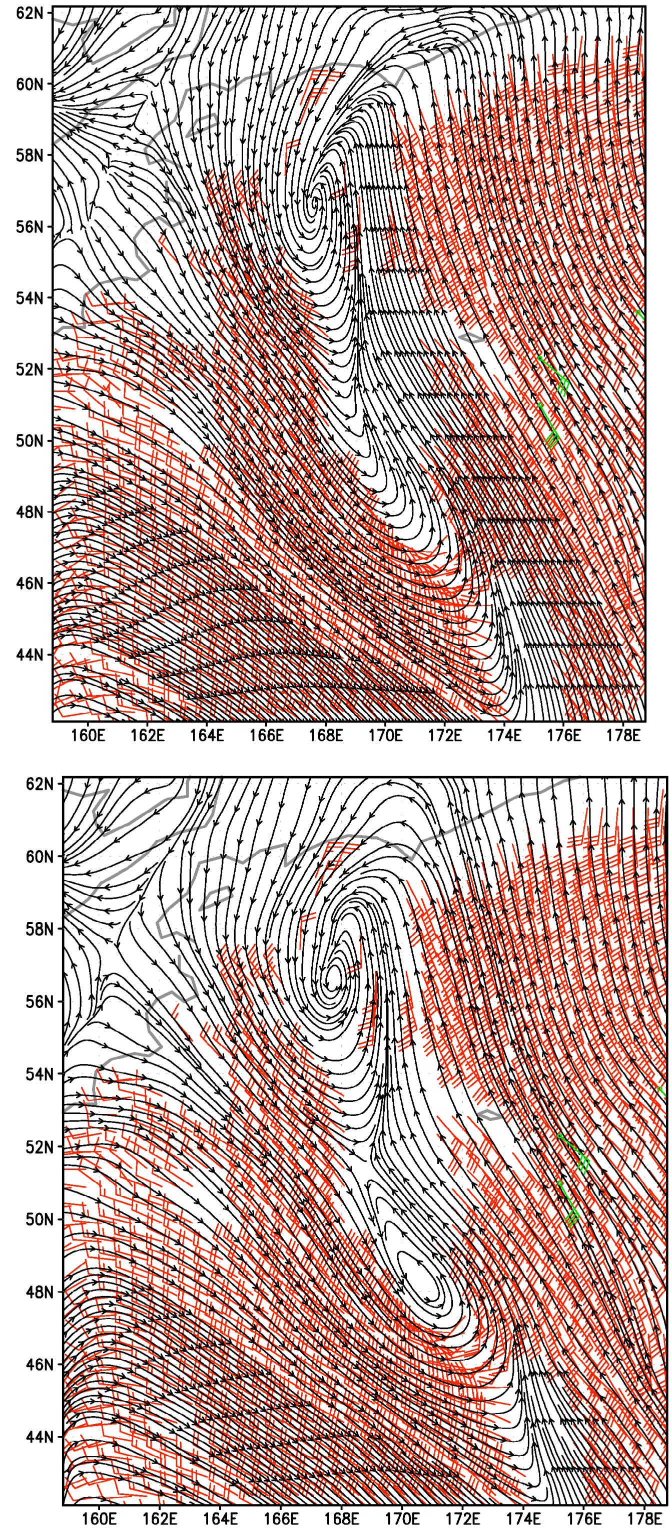

Fig. 8. Streamlines for the ECMWF (top) and VAM analysis (bottom) for 0600 GMT 2 Jan 2004. Quikscat winds are shown as red wind barbs.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

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