Impact of METOP ASCAT Ocean Surface Winds on Global Weather Forecasts

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Abstract

An Observing System Experiment (OSE) has been conducted to study the impacts of assimilating the Advanced SCATterometer (ASCAT) surface winds product. The assimilation system and forecast model are a recent version of the National Centers for Environmental Prediction (NCEP) Global Data Assimilation/Global Forecast System (GDAS/GFS) at the current operational resolution. The impacts of assimilating the ASCAT surface wind products are assessed during two seasons by comparing the forecasts through 168 hours of control simulations utilizing all the data types assimilated into the operational GDAS with the experimental simulations using this new surface wind product. The forecast impact for the NCEP system will be compared to that of the U.S. Navy's global NAVDAS-AR (NRL Atmospheric Variational Data Assimilation System – Accelerated Representer) and NOGAPS (Navy Operational Global Forecast System) assimilation/forecast suite.

Several aspects of the assimilation of ASCAT will be discussed including Quality Control (QC) procedures, data thinning, and ambiguity tests which are necessary for improving NWP forecasts. Accept/reject quality control criteria based on sea surface temperature, to reject observations which may be contaminated by sea ice, and an innovation vector difference test (observation minus background) has been developed and incorporated into the ASCAT assimilation procedures. We will also show results from thinning the ASCAT data to different resolutions. A vector ambiguity test developed for ASCAT has been incorporated into the QC procedures and will be discussed.

Ongoing projects include additional evaluation the current quality control procedures and thinning routines (or superob generation) used for ASCAT as well as WindSat winds, and the development and testing of advanced QC and data selection methods for ASCAT and WindSat winds vectors. These enhancements will be tested in the Navy's global and mesoscale data assimilation systems and transitioned to the operational systems at Fleet Numerical Meteorology Oceanography Center.

INTRODUCTION

Sea surface wind vectors have been estimated with active remote sensing instruments, such as QuikSCAT (Yu and McPherson 1984), and with passive polarimetric microwave radiometery, such as WindSat (Bettenhausen et al., 2006), and have been proven to have a positive impact on NCEP global forecasts (Le Marshall et al., 2006, Zapotocny et al., 2008, Bi et al., 2009). The latest remotely sensed surface wind-measuring instrument is ASCAT (http://oiswww.eumetsat.org/WEBOPS/eps-pg/ASCAT/ASCAT-PG-0TOC.htm). ASCAT is one of several instruments on the Meteorological Operational satellite programme (MetOp) polar orbiting satellite launched by the European Space Agency (ESA) and operated by EUMETSAT. It is the first in a series of such instruments dedicated to provide routine surface wind observations over the global oceans. ASCAT is an active microwave sensor designed to retrieve ocean surface vector winds. The mission of ASCAT is to enhance the spatial and temporal resolution of surface winds observations at global and regional scales thereby allowing better characterization of the air-sea interaction process as well as ocean wind forcing.

ASCAT surface wind data are currently used in daily weather forecast operations at the European Centre for Medium-Range Weather Forecasts (ECMWF). Assimilation experiments of ASCAT surface wind vectors in the ECMWF analysis and forecast system have shown positive effects on forecast skill over the Southern Hemisphere (http://www.ecmwf.int/publications/newsletters/pdf/113.pdf).

In this study, two seasons of ASCAT data have been assimilated into NCEP GDAS/GFS, and their forecast impact assessed. This was accomplished by comparing the forecast results with and without assimilating the ASCAT winds through 168 hours for the months of August 2008 and January 2009. Quality control procedures required to assimilate the surface winds are discussed. The geographical distribution of the anomaly correlations are also presented.

QUALITY CONTROL AND DATA THINNING

Most of the quality control (QC) of the ASCAT data was accomplished in the retrieval process. Observations that failed the retrieval process or were flagged for rain, land, or sea ice contamination were omitted from the observations as outlined in (http://www.knmi.nl/scatterometer/publications/pdf/ASCAT_Product_Manual.pdf).

A thinning technique was used for ASCAT instead of the superob technique used operationally for QuikSCAT and WindSat. Tests were run to determine whether 150km, 100km or 50km thinning boxes were more effective. It was found that overall the 100km thinning box gave the best forecast results in terms of the anomaly correlation scores.

The preliminary statistical results from a short term 20-day test experiment indicated that there were problems in the Antarctica regions due to contamination by sea-ice. This suggested there were still some quality control problems with the observations after the retrieval process procedures were used. Based on the preliminary statistical results, a series of additional quality control procedures were added within GDAS/GFS. A Sea Surface Temperature (SST) check (SST > 273K) was used as a criterion to remove observations suspected of still containing sea ice. This routine rejects the observations during the thinning process to allow vectors in warmer regions of the thinning box to be used. An innovation vector difference test (observation minus background) was developed and incorporated into the ASCAT assimilation procedures. Through various trial and error tests it was determined that innovation differences greater than ~2.5 standard deviations, or 5m/s, for the U or V component were degrading the forecast and were rejected. Observations near coastlines were also not used.

AMBIGUITY QC

An ASCAT ambiguity QC procedure was also developed and tested for these experiments. The purpose was to identify those ASCAT vectors which are pointed in the opposite direction with respect to the GDAS/GFS background field. The ambiguity QC is based on comparing the vector difference of both retrieved wind vectors to the GFS model 6 hour forecast and determining which direction had the smallest vector error.

Two ambiguity QC scenarios were tested to determine which produced the better forecast. The first scenario removed observations where the vector difference of the originally selected vector is larger than its pair. The second scenario used the same criteria but replaces the originally selected vector with its pair. Removing the suspect observations generally produced a better forecast. Less than 2% of the observations were identified as being suspect by this ambiguity check.

DIAGNOSTICS

Several diagnostics were performed using the Control and ASCAT experiment analyses and forecasts. The anomaly correlation statistics were recorded using the traditional NCEP algorithms (NWS 2006) which are commonly used by NWP centers worldwide. The computation of all anomaly correlations for forecasts produced by the GFS are completed using code developed and maintained at NCEP. NCEP (NWS 2006) provides a description of the method of computation while Lahoz (1999) provides an interpretation for the anomaly. The reanalysis fields from the National Center for Atmospheric Research (NCEP/NCAR) (Kistler 2001) are used for the climate component of the anomaly correlations. This reanalysis was run at a resolution of T62L28. The output grids were reduced to 2.5^o by 2.5^o horizontal resolution and to rawinsonde mandatory levels. To calculate anomaly correlations the output grids from both the control and experiment were reduced to this 2.5^o by 2.5^o horizontal resolution using NCEP's GFS post processor. The fields being evaluated using anomaly correlations are truncated to only include spectral wave numbers 1 through 20. These fields are also limited to the zonal bands of 20^o-80° in each Hemisphere and to a tropical belt within 20° of the equator (20°N to 20°S).

In addition to the traditional AC statistics, geographic distributions of the AC for the 1000hPa and 500hPa geopotential height fields are performed. The fields being evaluated using geographic AC distributions are not limited to the zonal bands or the tropical belt. Following the expressing for computing the commonly used anomaly correlation statistics, the geographic AC distributions are calculated using the following expression:

$$ACC = \frac{\sum\{[(Z_F - Z_C) - \overline{(Z_F - Z_C)}][(Z_V - Z_C) - \overline{(Z_V - Z_C)}]\}}{\sqrt{\sum[(Z_F - Z_C) - \overline{(Z_F - Z_C)}]^2 \sum[(Z_V - Z_C) - \overline{(Z_V - Z_C)}]^2}} \quad (1)$$

Here suffix F denotes forecast, suffix C denotes climatology and suffix V stands for verifying analysis. The over bar is the time mean and Z is the geopotential height (1000hPa or 500hPa in our case).

ANALYSIS STATISTICS

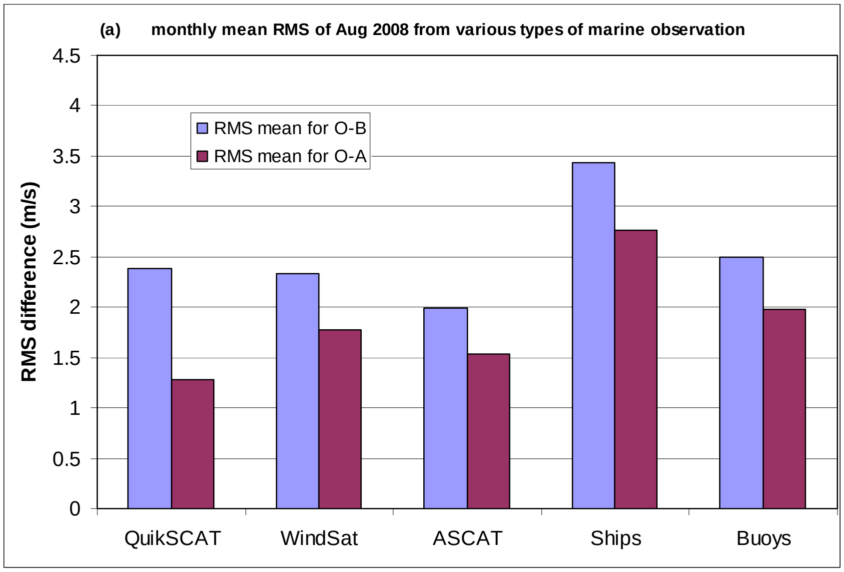
Figure 1 shows the monthly mean RMS difference of O-B and O-A for various types of marine observations used in operational NCEP GDAS/GFS for the month of August 2008 (Fig. 1a) and January 2009 (Fig. 1b). Ship data typically have the worst fit to the model background and analysis, WindSat, QuikSCAT and ASCAT have a very similar fit among these various types marine observations. Comparing QuikSCAT, WindSat and ASCAT wind vectors, ASCAT typically has a better fit to the model background but does not fit the model analysis quite as well as QuikSCAT for both seasons.

Figure 2 displays a comparison of the bias, standard deviation, wind speed histogram and wind speed innovation histogram for ASCAT. Figures 2 (a-d) show the analysis statistics for August and figures 2 (e–h) show the analysis statistics for January. The green curve represents the observation minus background (O-B) and red curves represents the observation minus analysis (O-A). While there are relatively large biases for ASCAT observed wind speeds less than 2ms^{-1} during both seasons, these observations only account for less than 5% of the total number of observations (Figs. 2c and 2g). Figures 2 (a and e) show that there are also large biases and standard deviations for ASCAT observed wind speeds greater than 20ms^{-1} and in some cases the bias and standard deviation for O-A are even higher for O-B, again these observations account for less than 1% of the total number of observations (Fig. 2c and 2g) only. Figures 2c and 2g show that the majority of the counts are located within the wind speed range of 5-10 ms^{-1}. In

Figures 2d and 2h, the O-B histograms are slightly skewed to the left for both seasons which suggests ASCAT speeds are a little slower than the model background.

Figure 3 displays the geographic distribution of bias for wind speed at 10 meter height for ASCAT, WindSat and QuikSCAT for O-B (left) and O-A (right) from August 2008. The January 2009 results are not shown here since they are very similar. For ASCAT, the largest speed biases with respect to the background are found in the tropical Western Pacific, and in bands extending west from the Mexican coast to the central Pacific and to the east-southeast south of Central America (Fig. 3a). The overall speed bias for ASCAT is generally negative and within the range of [-0.5 0.5] ms^{-1}. For WindSat, the overall bias is generally positive and within the range of [-0.5 1.2] ms^{-1}, the largest biases were found over the Pacific and Indian Ocean south of 30^0N (Fig. 3b). The overall speed bias for QuikSCAT is also positive and is around [0 1.0] ms^{-1} with largest biases found in the tropical Western Pacific.

The biases are significantly reduced in most regions after assimilating the data (Figs. 3d, 3e and 3f). ASCAT continues to have negative bias albeit reduced. WindSat, continues to have positive biases in the Antarctic region and negative biases in Northern Pacific (Fig. 3e). The QuikSCAT bias becomes mostly neutral after the assimilation (Fig. 3f).



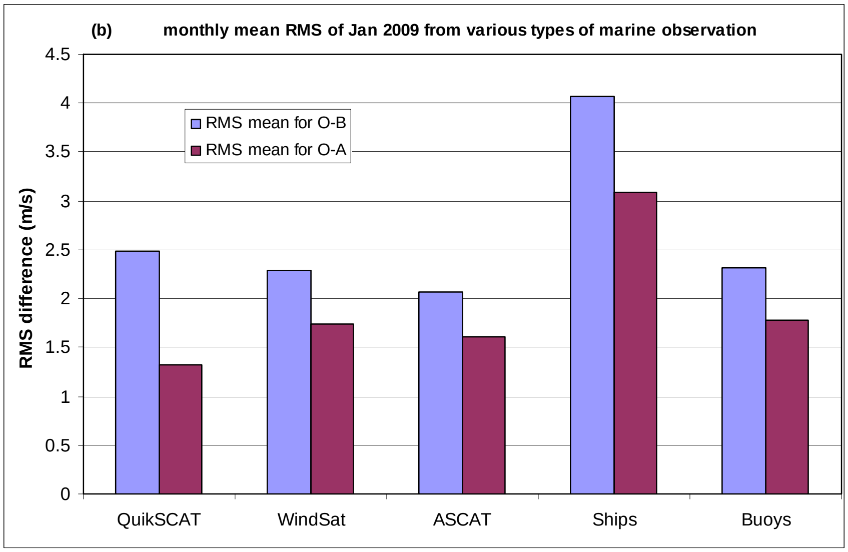


Figure 1. **Monthly mean RMS difference of O-B and O-A from various types of marine observation from August, 2008 and January, 2009.**

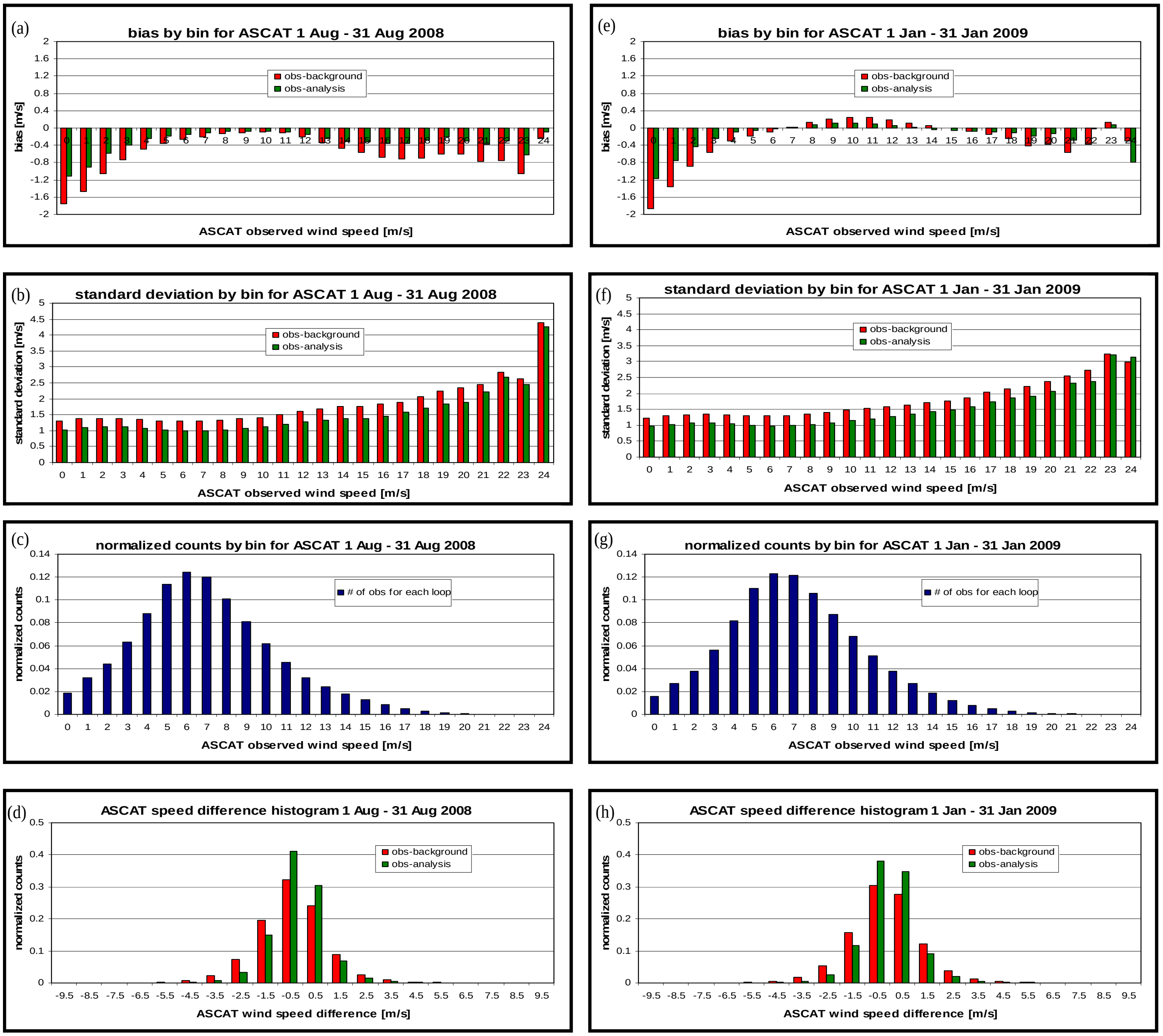


Figure 2. **A comparison of the bias, standard deviation, wind speed histogram and ASCAT wind speed difference histogram for ASCAT data. Panels (a) – (d) show the results from August 2008 and panels (e) – (h) show the results from January 2009.**

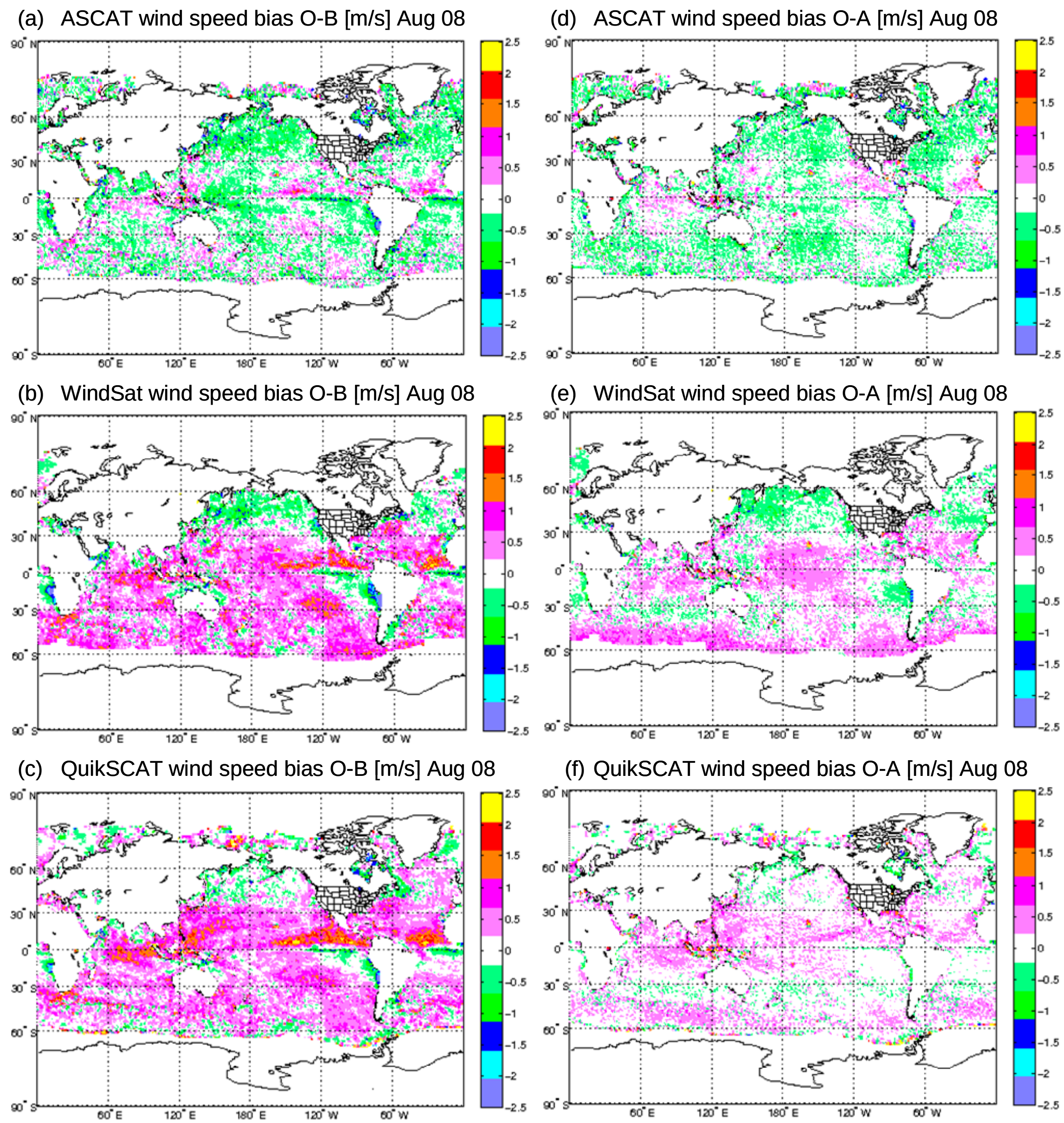


Figure 3. **A comparison of the geographic distribution of bias (for both O-B and O-A) for ASCAT, WindSat and QuikSCAT from August 2008. Panels (a) – (c) show the results from O-B statistics and panels (d) – (f) show the results from O-A statistics.**

GEOGRAPHIC DISTRIBUTION OF ANOMALY CORRELATION

Figure 4 is a bar chart of Anomaly Correlation Scores for day 5 forecasts without ASCAT (control) and with ASCAT (ASCAT) data for 500hPa and 1000hPa heights in the Northern and Southern Hemisphere during both seasons. During August 2008 (Fig. 6a), improvements in AC scores for 500hPa and 1000hPa heights are noted in the Southern Hemisphere. The 1000 hPa and 500hPa AC scores for the day 5 forecast of geopotential heights increased from 0.80 to 0.815 and 0.825 to 0.841 respectively by assimilated ASCAT winds. In the northern hemisphere, the AC scores for Control and ASCAT experiment are mostly neutral. For January 2009 (Fig. 6b), there are slight improvements for 500hPa and 1000hPa in the Southern Hemisphere and neutral in the Northern Hemisphere.

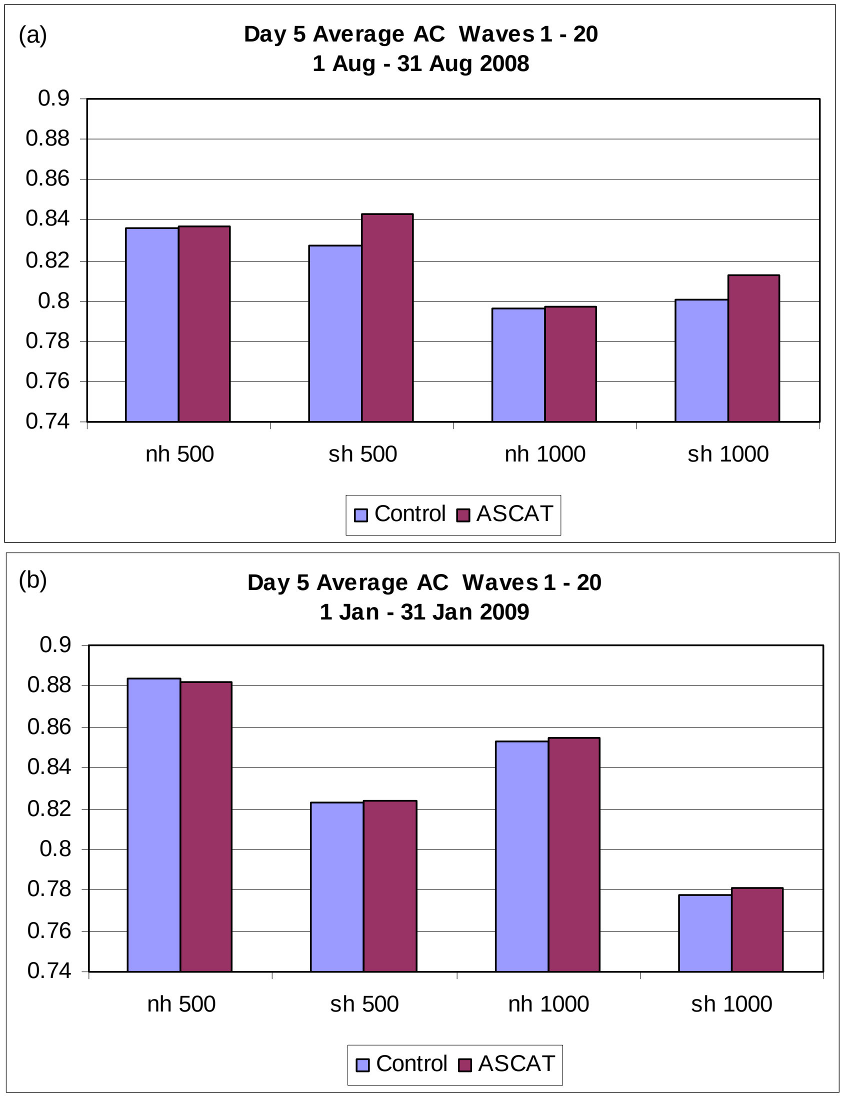


Figure 4. **Anomaly Correlation Scores for day 5 forecasts without ASCAT (Control) and with ASCAT (ASCAT) data for 500hPa and 1000hPa heights in the Northern and Southern Hemisphere from August 2008 and January 2009.**

Global distribution of 1000hPa geopotential height anomaly correlations is presented in Figure 5. Heights determined to be underground were not used. The geographic AC distribution for the Control and ASCAT experiments (Figs. 5a and 5b) show similar pattern with small AC (0.5-0.7) realized in the Arctic, North Atlantic and part of North Pacific. The anomaly correlation difference distribution for August (Fig. 5d) has the largest negative differences over northern Canada, off the east coast of the United States, and a band off the west coast of the United States extends to the central Pacific. The largest positive differences for Fig 5d are scattered mainly in the West Pacific and Arctic. The die off curve (Fig. 5c) indicates that the control simulation AC scores are close to ASCAT experiment AC until day 3, then the ASCAT experiment shows greater forecast skill from day 4 through day 6. By day 7 the forecast skills become similar. Large negative differences are noted near Arctic, Northwest of Atlantic Ocean for 1000hPa. In the Southern Hemisphere, large positive difference patterns are seen southeast of Australia for 1000hPa. There are also several isolated small positive difference patterns along Indian Ocean. The tropics look noisy as expected. Figures 5e shows the geographic distribution of 1000hPa geopotential height standard deviation using ASCAT experiment analysis fields for the month of August 2008. Heights determined to be underground were not used. The standard deviation in the tropics of 1000hPa is very small with values less than 15m. Relatively large monthly mean standard deviations are realized in the 50^0-60^0 S band with maximum values around 105m. Consistent with what we have seen in the 500hPa geopotential height standard deviation plot, in the winter hemisphere, the standard deviation of the geopotential height of 1000hPa is much stronger than the summer hemisphere. The tropics have the smallest standard deviations while largest standard deviations are again realized in the winter hemisphere.

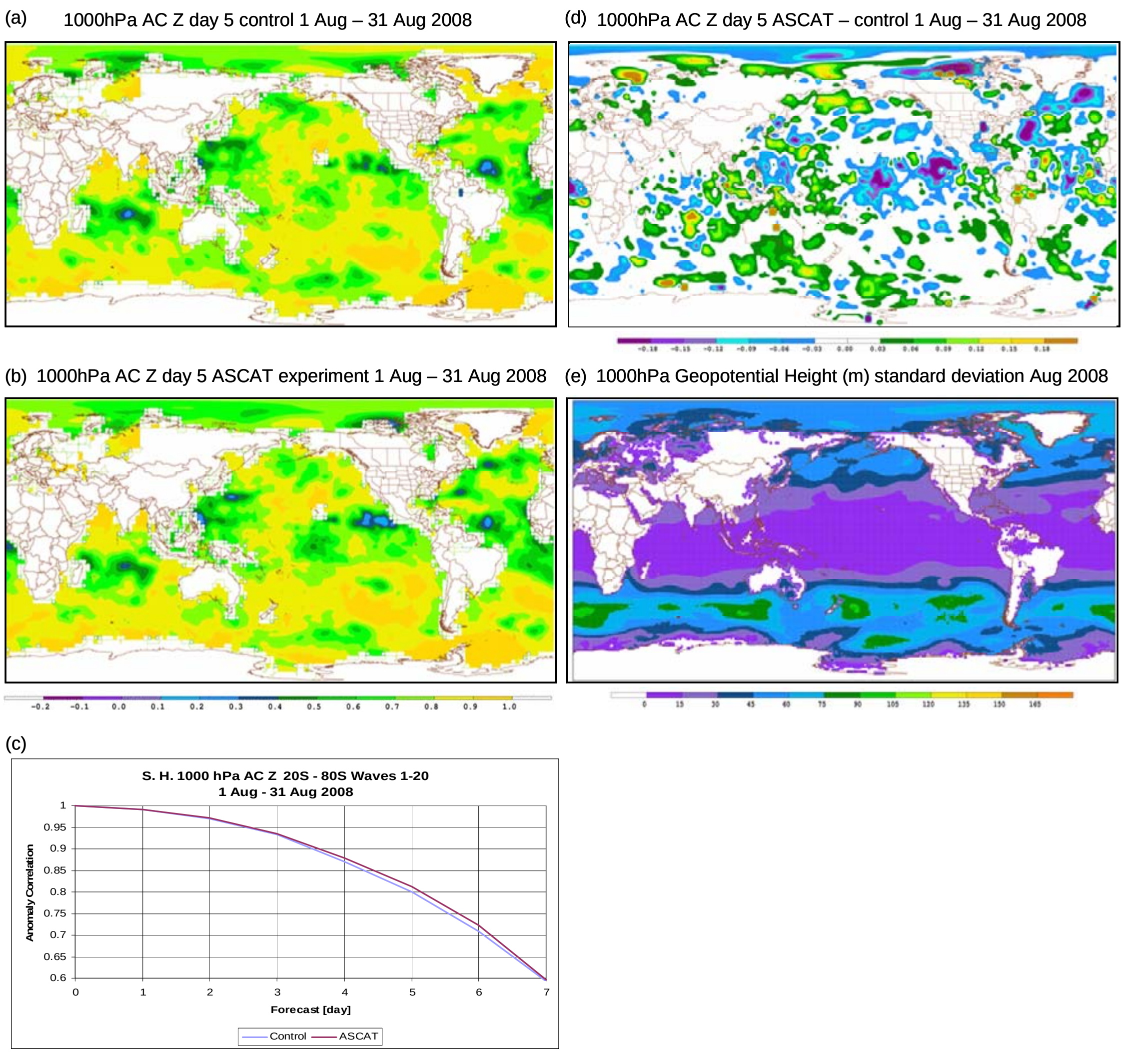


Figure 5. **Panels (a) and (b) show the geographic distribution of anomaly correlation of day 5 for 1000hPa geopotential height from the control experiment and ASCAT experiment from August 2008. Panel (c) shows the anomaly correlation for days 0 to 7 for 1000 hPa geopotential height in the regions 20°-80° in the Southern Hemisphere. For panels (c) the results have been truncated to only show results for waves 1 - 20. Panel (d) shows the difference between panels (a) and (b) using ASCAT minus control. Panel (e) shows the geographic distribution of standard deviation of August 2008 from ASCAT experiment analysis fields for 1000hPa geopotential height**

Figure 6 shows the comparison of 72 hr forecast track from different ASCAT horizontal thinning resolution experiments vs. best track. In this study, the tropical cyclone (TC) track forecasts of the Navel Research Laboratory Atmospheric Variational Data Assimilation System/Coupled Ocean/Atmosphere Mesoscale Prediction System (NAVDAS/COAMPS) and the Navy Operational Global Atmospheric Prediction System (NOGAPS) were evaluated for a number of data assimilation experiments conducted from 1 August – 30 August, 2009. The case shown here is an eastern Pacific case hurricane Felica. To evaluate the impact of different horizontal resolutions for different types of satellite observations on the NAVDAS/COAMPS and NOGAPS TC track forecasts, several experiments were performed. These experiments includes: (1) Control experiment with surface winds turned off; (2) 0.5 degree thinning; (3) 1.0 degree superobing; (4) 1.0 degree thinning for both ASCAT and WindSat winds. The satellite observations assimilated in these experiments consisted of surface winds from WindSat and ASCAT, QuikSCAT, Special Sensor Microwave Imager (SSM/I) wind speeds, and European Remote Sensing Satellite-2 (ERS-2) scatterometer winds. The impact of the assimilation of WindSat, ASCAT, QuikSCAT, SSM/I wind speeds and scatterometer winds on the TC position track were positive through forecast length 72hr. Although not shown, there were no significant improvement/degradations on the TC intensity from the assimilation of the aforementioned satellite observation types.

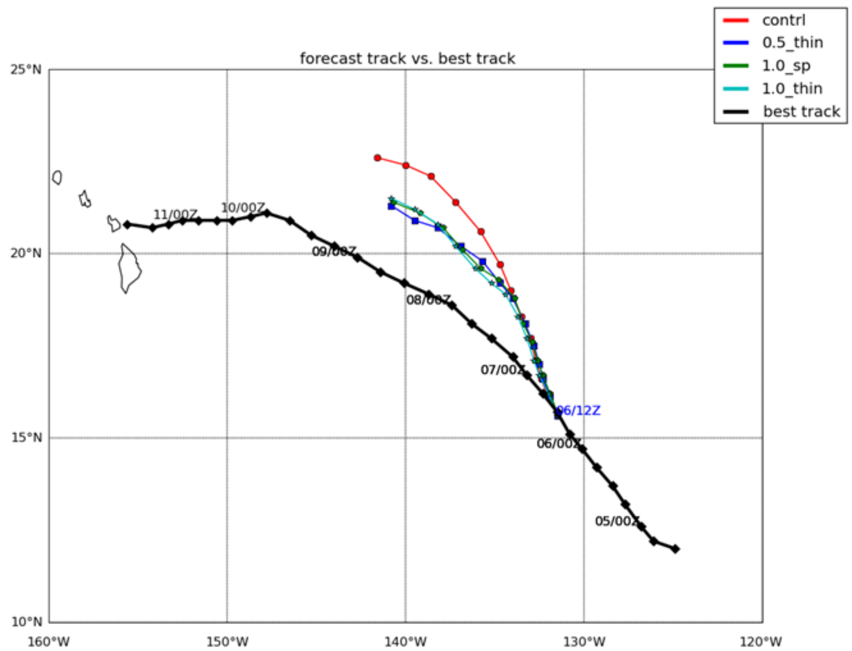


Figure 6. Comparison of forecast track from different ASCAT horizontal thinning resolution experiments vs. best track. The case showed here is hurricane Felica in eastern Pacific.

FUTURE PLANS

Ongoing projects include additional evaluation the current quality control procedures and thinning routines (or superob generation) used for ASCAT as well as WindSat winds, and the development and testing of advanced QC and data selection methods for ASCAT and WindSat winds vectors. These enhancements will be tested in the Navy's global and mesoscale data assimilation systems and transitioned to the operational systems at Fleet Numerical Meteorology Oceanography Center.

REFERENCES

Bettenhausen, M.H., C. K. Smith, R. M. Bevilacqua, N. Wang, P. W. Gaiser, and S. Cox, 2006: A Non-linear Optimization Algorithm for Wind sat Wind Vector Retrievals. *IEEE Trans. Geosci. Remote Sens.,* **44**, 597-610.

Bi, L., J. Jung, M. Morgan, and J. Le Marshall, 2009: A Two-Season Impact Study of the WindSat Surface Wind Retrievals in the NCEP Global Data Assimilation System. *Weather and Forecasting*. In press. DOI: 10.1175/2010WAF2222377.1

Kistler, R., E. Kalnay, W. Collins, S. Saha, G. Withe, J. Woollen, M. Chelliah, W. Ebisuzaki, M. Kanamitsu, V. Kousky, H. Van den Dool, R. Jenne and M. Fiorino, 2001: The NCEP-

NCAR 50-Year Reanalysis: Monthly Means CD-ROM and Documentation. *Bull. Amer. Meteor. Soc*, **82**, 247-267.
Lahoz, W. A., 1999: Predictive Skill of the UKMO Unified Model in the Lower Stratosphere. *Quart. J. Roy. Meteor. Soc.*, **125**, 2205-2238.
Le Marshall, J., Bi, L., Jung, J., Zapotocny, T. and Morgan, M. 2006: WindSat Polarimetric Microwave Observations Improve Southern Hemisphere Numerical Weather Prediction**.** *Aust. Meteor. Mag*. 56, 35-40.
NWS, cited 2006: NCEP Anomaly Correlations. [Available online from http://wwwt.emc.ncep.noaa.gov/gmb/STATS/STATS.html .]
Yu, T.-W., and R. D. McPherson, 1984: Global Data Assimilation Experiments with Scatterometer Winds from Seasat-A. *Mon. Wea. Rev.*, **112**, 368-376
Zapotocny, T., J. A. Jung, J. F. Le Marshall and R. Treadon, 2008: A Two-Season Impact Study of Four Satellite Data Types and Rawinsonde Data in the NCEP Global Data Assimilation System. *Wea. Forecasting*, **23**, 80-100.