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Toward Improved Use of GOES Satellite-Derived Winds at the National Centers for Environmental Prediction (NCEP)

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1. Introduction

Satellite derived winds have been used in the NCEP global data assimilation system since 1979. These winds provide valuable information for numerical model initialization over regions where conventional observations are not available. For example, the European Center for Medium-Range Weather Forecasts (ECMWF) (Tomassini et al., 1999, Kelly et al., 2000), U.K. Met. Office (Butterworth et al., 2000), and Australian Bureau of Meteorology (Le Marshall et al., 2000) found a positive impact from satellite-derived winds on routine operational forecasts. Some studies have reported a positive impact on hurricane track forecasts (Soden et al., 2000, Bhatia et al., 2000, Evans, 2000, Le Marshall, 2000). However, the imperfect wind data have the potential to degrade the quality of model forecasts. For example, the ECMWF and U.K. Met. Office found satellite winds had a negative impact on forecasts when they switched from assimilating low density to high density winds (Butterworth et al., 2000, Kelly et al., 2000). Various quality indicators have been developed and are distributed along with the observations as the guides to select better quality data in the data assimilation system. The Recursive Filter Flag (RFF), developed by Cooperative Institute for Meteorological Studies (CIMSS) (Hayden and Purser, 1995), is currently used as a quality mark in the satellite winds produced at the National Environmental Satellite, Data & Information Services (NESDIS). The Quality Indicator (QI), developed by European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) (Holmlund, 1998), is currently used as a quality mark in the satellite wind data produced at EUMETSAT. These quality marks can be used to select which data are used in the analysis system. For instance, ECMWF and U.K. Met Office used QI to filter EUMETSATE satellite wind data (Kelly and Rohn, 2000; Butterworth and Ingleby, 2000). Holmlund et al. (2000) use a combination of the RFF and QI to filter GOES satellite winds and have shown some improvements in the forecast skill. With satellite winds, it is not only necessary to account for random error, but also spatially correlated errors. When clusters of winds are derived from similar cloud systems by the same tracking technique, spatially correlated errors are likely. These problems have stimulated many efforts toward making better use of the data and reducing correlated errors, especially for the high density winds. Both the ECMWF and the U.K. Met. Office try to reduce correlated errors in the winds by thinning the data (Kelly and Rohn, 2000; Butterworth and Ingleby, 2000). The results from Kelly and Rohn (2000) showed that thinning high density EUMETSAT satellite wind data (based on higher QI values) improved model forecast skill. However, the results from Butterworth and Ingleby (2000) showed that high density EUMETSAT satellite winds have a negative impact on the forecast regardless of thinning. In this study, we use two NCEP low resolution (T62L28) and one higher resolution (T170L42) assimilation systems in a study of thinning algorithms for high density GOES cloud-drift infrared and cloud-top water vapor winds. In the following sections, we will describe the satellite wind data quality, the thinning algorithms, and the experimental results.

2. Evaluation of GOES satellite winds

GOES high density infrared and water vapor satellite winds are produced at NESDIS using procedures described in Nieman et al (1997) and Velden et al (1997), respectively. Data are produced for the region spanning 60S to 60N and 160E to 350E using images taken every 30 minutes. Most GOES high density infrared cloud-top wind observations are found in the 1000-700 hPa (35%) and 400-100 hPa (57%) layers, while water vapor winds (including cloud top and deep layer) are mostly located between 400 and 100 hPa (94%). The data used in this study were produced every half hour and distributed every three hours in Binary Universal Form for the Representation of meteorological data (BUFR). These BUFR files contain final wind information including wind speed and direction, height, and RFF values as well as intermediate information including the wind speed and direction derived from the first and second image pairs, and the original (before quality control) winds and heights. The availability of the intermediate information makes it possible to calculate additional quality flags such as QI and to make a more complete evaluation of the data quality.

The data quality assessment is performed using a variety of methods. First, the satellite wind observations are compared against colocated rawinsondes and NCEP global aviation analyses (Tables 1-2, respectively) for a one year period. In Tables 1 and 2, satellite water vapor winds include cloud-top and clear sky water vapor winds. Table 1 also includes a comparison of radiosonde to the forecast winds used in the creation of the NESDIS-processed winds. It should be noted that the NESDIS-processed forecast winds differ from those used in NCEP data assimilation system (Fig. 1).

Table 1.1 Statistics for satellite infrared winds (NESDIS processed NCEP model forecast winds) vs. colocated radiosonde winds from July 2, 2000 to July 2, 2001. Absolute direction difference represents the average of absolute difference between two wind direction.

Layer	wind vector RMS (m/s)	Speed Bias(m/s)	Absolute Direction Difference(deg)	Mean Speed(m/s)	Sample size
>700 hPa	3.42(3.24)	-0.05(-0.53)	14.73 (14.86)	9.88(9.40)	42684
400-700 hPa	4.77(4.32)	-1.10(-1.10)	13.31(13.48)	15.67(15.67)	55039
100-400 hPa	5.76(5.67)	-0.10(-1.01)	11.96(12.37)	23.49(22.57)	242548

Table 1.2 Satellite water vapor winds vs. radiosonde.

Layer	RMS (m/s)	Speed Bias(m/s)	Absolute Direction Difference(deg)	Mean Speed(m/s)	Sample size
400-700 hPa	6.55(5.68)	-2.24(-1.33)	13.53(13.62)	20.40(21.30)	12562
100-400 hPa	5.95(5.43)	-0.31(-1.23)	12.60(12.89)	22.41(21.49)	220654

Table 2.1 Statistics for satellite infrared winds vs. NCEP aviation analyses from July 2, 2000 to July 2, 2001.

Satellite winds	RMS (m/s)	Speed Bias(m/s)	Absolute Direction Difference(deg)	Mean Speed(m/s)	Sample size
>700 hPa	1.86	0.19	7.60	10.07	2687255
400-700 hPa	3.38	-0.09	10.23	15.30	579005

100-400 hPa	4.00	0.07	9.62	21.12	3748023

Table 2.2 Satellite water vapor winds vs. NCEP aviation analyses.

Satellite winds	Wind vector RMS (m/s)	Speed Bias(m/s)	Absolute Direction Difference(deg)	Mean Speed(m/s)	Sample size
400-700 hPa	4.82	-0.76	12.74	18.41	207600
100-400 hPa	4.39	0.18	10.83	20.63	3857408

The forecast winds used in the NESDIS processing of the satellite winds are created by NESDIS from 6 or 12-hour NCEP global forecast system (GFS) post-processed fields. The winds used in the NCEP data assimilation system are interpolated directly in time and space from the model's sigma surface and Gaussian grid using 3, 6 and 9 hour forecasts to the observation location. The difference between the NESDIS-processed and the NCEP data assimilation values can reach more than 10 m/s, with a root-mean-square (RMS) vector difference of 3.64 m/s and an absolute speed difference of 2.00 m/s. The impact of the forecast value differences at the observation location is unknown.

The absolute values of the statistics in Tables 1-2 vary slightly over different periods, but the general statistical tendency is similar throughout the year (see http://orbit-net.nesdis.noaa.gov/arrad/ftdt/index.html for more statistics). The root mean square (RMS) wind vector difference values of satellite infrared winds versus rawinsondes increase with mean wind speed and height, while RMS values for satellite water vapor winds versus rawinsondes remain fairly constant, at least for two levels. The absolute direction differences between satellite winds (infrared or water vapor) and rawinsondes decrease with height, possibly because the wind field is more uniform with height. The satellite wind speeds are slower than rawinsondes, especially at mid-levels. The statistics of NESDIS-processed forecast winds versus rawinsondes show that the NESDIS forecast winds have a smaller RMS, larger mean bias, and larger absolute direction difference. NESDIS forecast winds are slower than colocated rawinsondes. The comparisons of satellite winds to the NCEP analysis are similar to the rawinsonde comparisons, except for a reduction in the absolute values of the differences.

To further evaluate the GOES winds, we compared the GOES winds directly with NCEP GFS winds at the observation location interpolated from the 3, 6 and 9 hour forecast times (Fig. 2). The scatter plots in Figure 2 show only the infrared cloud-top satellite wind comparisons, as the results for cloud top water vapor winds are quite similar. The data were sampled from four assimilation cycles on 31 May 2000, at 00, 06, 12, and 18 UTC. Each cycle covers 6 hours; 3 hours before and 3 hours after each cycle hour, using satellite winds within ±1.5 hours. The sample size of 57271 observations is sufficient to produce statistics which are stable for longer periods. The dominant relationship between satellite winds and model guess is linear, as expected, with correlation coefficients of 0.999998 and 0.999996 for the u and v components respectively. However, the retrieved satellite wind u and v wind component values are higher than the model guess winds, especially for the larger u and v values. Overall, the mean speed of the satellite wind samples is slightly higher than that of the model guess winds (14.60 vs. 14.34 m/s). A similar study by Tomassini (1999) compared satellite winds with ECMWF forecasts, including satellite winds from different satellites (GOES, MET, GMS, and INSAT) . Those RMS wind vector differences between satellite and model winds were larger than the ones in this study. This may be because the NCEP model forecast is used as a first guess for the satellite winds and is used in the height assignment.

Two quality marks, QI and RFF, are currently used to estimate retrieved wind quality. RFF mainly measures the certainty of the height assignment, while QI primarily addresses internal consistency during the retrieval process. Colocation statistics for satellite winds versus rawinsondes for different RFF ranges were produced by Holmlund et al. 2000. They found that the wind vector difference RMS values decrease with larger RFF values, but the speed bias tends to increase. The study conducted by Holmlund (1998) showed that the normalized RMS values of satellite versus ECMWF model winds decreased as QI values increased. Figure 3 shows the relationship between RFF and QI for the May 31, 2000 sample. The relationship between these two is not simple, but there is a general increase in QI as the RFF increases. This correlation should be expected, since both quality indicators contain contributions from a measure of the fit of satellite winds to model first guess winds and both are intended to measure the quality of the observations.

The vector differences between satellite and model winds generally decrease as RFF and QI increase (Table 3), but there are significant differences in the characteristics of the two quality measures. The wind speeds tend to increase as QI increases while speeds decrease as RFF increases. Also, there are significant numbers of observations where the QI value is low while RFF is high, and vice versa.

Table 3.1 RMS, NRMS, and SWS for satellite vs. model winds for different RFF categories. RMS represents wind vector root-mean-square (RMS) difference between satellite and model, NRMS represents normalized RMS (RMS/mean wind speed), and SWS represents mean satellite wind speed for the category.

RFF	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	>90
RMS(m/s)	6.2	4.9	4.1	3.4	2.9	2.3	1.8	1.6	1.4
NRMS	0.31	0.24	0.19	0.16	0.13	0.11	0.09	0.09	0.07
SWS(m/s)	17.3	16.8	16.1	15.2	14.2	12.2	10.6	9.9	10.2
No	4127	6173	8766	9814	9536	8638	5803	1426	199

Table 3.2 RMS, NRMS, and SWS (as in Table 3.1) for QI instead of RFF.

QI	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
RMS (m/s)	5.6	4.9	4.6	4.2	3.4	4.0	3.8	2.6
NRMS	0.41	0.33	0.30	0.23	0.17	0.20	0.16	0.08
SWS(m/s)	8.5	9.5	10.4	11.9	13.1	13.1	14.7	18.5
No.	1285	2258	3596	5679	7628	6544	11071	18604

3. Data thinning and experiment design

Experiments have shown (Butterworth et al., 2000, and Kelly et al., 2000) that the use of all available high density winds in the assimilation system produces inferior results. The speculation is that the inferior results occur because of spatially correlated errors in the observations. One solution to minimize the effects of the correlated error is to thin the winds. The experiments described in this section are various attempts at thinning strategies for the GOES wind data.

The basic technique in all thinning methods is to divide the atmosphere into three dimensional boxes and produce one observation per box according to a particular algorithm. We chose thirteen vertical layers, 50 or 100 hPa deep, centered at 850, 800, 750, 700, 600, 500, 400, 350, 300, 250, 200, 150, 100 hPa, to define the vertical component of the boxes. Three horizontal resolutions, 1x1, 2x2, and 2.5x2.5 degrees were tested for the horizontal component. The thinning strategies tried for each box include RANDOM thinning which randomly selects one observation per box, AVERAGE thinning which averages all the observations in a box, RFF thinning which picks the observation with highest RFF value, QI thinning which picks the observation with highest QI value, and QI+RFF thinning which chooses the observations with highest QI+RFF value. In addition, CONTROL and NOSAT experiments were performed which used all available high density data and no satellite winds at all, respectively.

The experiments were conducted using different versions (Systems-A, -B, and -C) of the NCEP global assimilation and forecast model systems that were used operationally before October 2002. The data assimilation system in the experiments is based on the three dimensional variational (3D-Var) scheme described in Derber et al. (1991), Parrish and Derber (1992), and McNally et al. (2000).

System-A is a reduced resolution (T62) version of the NCEP T170 system operational from January to October 2000. System-B is a reduced resolution (T62) version of the T170 NCEP model operational from May 2001 to October 2002. The 2001-2002 operational model upgrade included the addition of prognostic clouds, a shortwave radiation calculation modified to take advantage of a directly predicted cloud condensate path, a new aerosol scheme, a modified convective parameterization scheme, and a new USGS orography dataset to define the model orography. Systems-A and -B use a 192x94 Gaussian grid and 28 vertical levels from surface to 3 hPa. There are also several changes in the analysis system from System-A to System-B. The analysis system was changed to include: new satellite data (NOAA-16 AMSU-A/B and NOAA-15 AMSU-B microwave radiances), minor changes in the usage of satellite radiances, improved rawinsonde data quality control, modification of the saturation vapor pressure calculation, and changes to the moisture constraint. System-C is identical to System-B except for the horizontal and vertical resolution; it is a T170 model and has a 512x256 Gaussian grid and 42 layers from surface to 2.0 hPa.

The experiments with System-A were run with data from August 1-31, 2000. The experiments with System-B were run for the System-A test period, and for the period of January 15-February 20, 2001. The experiments with System-C were run for September 1-30, 2002. The System-A experiments compared all the candidate thinning algorithms (using a 2x2 degree box) to determine the best algorithm. The experiments for System-B and System-C used the best System-A algorithm (at different box resolutions) to compare the results with and without thinned satellite data. In addition, in the System-C experiment the EUMETSAT satellite winds were switched from the low density used in the System-A and System-B experiments to high density.

4. Results

Table 4 Skill scores from System-A for the period of August 1-31, 2000. NH-500 and SH-500 represent Northern and Southern Hemisphere 500 hPa geopotential height anomaly correlation coefficients (%); TR-850 and TR-200 represent the tropical RMS wind vector difference against its own analysis of 850 and 200 hPa (m/s). CONTROL represents the case with all satellite winds currently used operationally; RANDOM, AVERAGE, RFF, QI, and RFF+QI represent the different thinning algorithms. NOSAT represents the case without any satellite winds. All the cases use a 2x2 degree thinning box.

		2-day	3-day	4-day	5-day
	CONTROL	94.7	88.6	79.4	67.0
	RANDOM	94.7	88.6	79.3	66.8
	AVERAGE	94.7	88.6	79.4	67.0
NH-500	RFF	94.7	88.6	79.3	66.7
	QI	94.7	88.6	79.3	67.1
	RFF+QI	94.6	88.4	79.0	66.1
	NOSAT	94.7	88.6	79.7	68.1
	CONTROL	95.0	89.0	83.0	75.2
	RANDOM	95.0	89.2	83.1	75.0
	AVERAGE	95.0	89.1	82.9	74.9
SH-500	RFF	95.0	89.2	83.2	75.2
	QI	95.0	89.2	83.2	75.1
	RFF+QI	94.9	89.1	82.8	74.4
	NOSAT	95.0	89.4	82.8	73.9

	CONTROL	3.910	4.560	5.051	
	RANDOM	3.916	4.583	5.068	
	AVERAGE	3.911	4.571	5.052	
TR-850	RFF	3.903	4.567	5.049	
	QI	3.882	4.541	5.033	
	RFF+QI	3.884	4.556	5.028	
	NOSAT	3.952	4.627	5.151	
	CONTROL	7.066	8.348	9.373	
	RANDOM	7.019	8.352	9.297	
	AVERAGE	7.040	8.368	9.327	
TR-200	RFF	7.005	8.304	9.290	
	QI	6.971	8.358	9.327	
	RFF+QI	6.952	8.287	9.263	
	NOSAT	7.105	8.452	9.394	

The five thinning algorithms (Table 4) showed small differences in both the 500 hPa geopotential height anomaly correlation scores and vector RMS winds. The largest difference in the mid-attitude 500 hPa geopotential height anomaly correlation scores and tropical vector RMS winds is 1.5% between Northern Hemisphere (NH-500) QI and QI+RFF on forecast day-5 and 1% between AVERAGE and RFF+QI on day-3 forecast at 200 hPa in the tropics (TR-200). Overall, the QI-thinning produced the best results. However, when compared with the control run, even QI thinning showed tropical wind vector RMS error improvements of only 1% (at most) and a negligible improvement in the mid-latitude geopotential heights.

The CONTROL, NOSAT and QI experiments were repeated using System-B for August 1-31, 2000 (Table 5) and January 15-February 20, 2001 (Table 6) . The System-B results from August show that the impact of using all the satellite winds is much smaller on the tropical vector RMS winds at 200 hPa (TR-200) when compared with System-A. There is a small negative impact on the tropical wind vector RMS at 850 hPa (TR-850) for the day-

2 and -3 forecasts.

Table 5 System-B scores for August 1 -31, 2000. QI-2.5, QI, and QI-1.0 represent the experiments with satellite winds for 2.5x2.5, 2.0x2.0, and 1.0x1.0 degree horizontal box thinning

		2-day	3-day	4day	5-day
	CONTROL	95.4	90.1	81.6	70.1
NH-500	QI	95.4	90.0	81.4	69.9
	NOSAT	95.4	89.9	81.2	69.9
	QI-2.5	95.4	90.0	81.5	69.8
	QI-1.0	95.4	89.9	81.0	69.3
	CONTROL	95.1	89.4	83.4	75.8
SH-500	QI	95.1	89.5	83.4	75.6
	NOSAT	95.1	89.6	83.8	76.7
	QI-2.5	95.1	89.4	83.3	75.4
	QI-1.0	95.2	89.6	83.6	75.6
	CONTROL	3.824	4.270	4.558	
TR-850	QI	3.845	4.301	4.596	
	NOSAT	3.798	4.255	4.575	
	QI-2.5	3.839	4.303	4.610	
	QI-1.0	3.849	4.298	4.603	
	CONTROL	7.158	8.157	8.903	
TR-200	QI	7.152	8.135	8.888	
	NOSAT	7.266	8.278	8.955	
	QI-2.5	7.137	8.103	8.871	
	QI-1.0	7.172	8.158	8.892	

The impact of satellite winds on the geopotential height forecasts is negligible except in the Southern Hemisphere at day five (75.8% (CONTROL) vs. 76.7% (NOSAT)) where the impact was negative. The impact of thinning is less clear with System-B than with System-A. The thinning has almost no impact on the geopotential height forecast field, a negative impact on the 850 hPa tropical wind vector RMS, and a slight positive impact on the 200 hPa tropical wind vector RMS.

When comparing the System-A and System-B experimental scores (Tables 4 and 5) for the August 2000 period, we see an overall improvement in forecast skill in both the mid-latitudes and tropics for System-B, except in the 2 day wind vector difference RMS values. Improvements increase with forecast length and are more than an order of magnitude larger than any improvements due to the use of the satellite winds.

The results of experiments using the 1x1 and 2.5x2.5 degree horizontal thinning boxes for satellite winds are also presented in Table 5. Compared to the 2x2 degree thinning box experiments, the 1x1 degree thinning box produces worse results. A comparison between the 2x2 and 2.5x2.5 thinning boxes produces mixed results, with larger wind differences at 850 hPa, smaller differences at 200 hPa in the tropics, and little difference at mid-latitudes.

Table 6 System-B scores (as in Table 5) using a 2x2 degree thinning box for January 15-February 20, 2001.

		2-day	3-day	4-day	5-day
	CONTROL	96.3	91.5	84.0	74.7
NH-500	QI	96.3	91.5	84.0	74.4
	NOSAT	96.3	91.6	84.1	74.5
	CONTROL	94.7	88.6	79.7	68.6
SH-500	QI	94.6	88.5	79.5	68.3
	NOSAT	94.7	88.6	79.6	68.2
	CONTROL	3.627	4.150	4.447	
TR-850	QI	3.638	4.149	4.555	
	NOSAT	3.611	4.138	4.465	

TR-200 CONTROL	7.248	8.331	9.196	
TR-200 QI	7.246	8.331	9.154	
TR-200 NOSAT	7.526	8.701	9.418	

By comparing Tables 5 and 6, we can examine the stability of the statistics over different seasons. The Northern Hemisphere 500 hPa geopotential height anomaly correlation scores for the winter experiments (January 10-February 20, 2001) are slightly larger than for summer (August 2000), while the summer Southern Hemisphere 500 geopotential anomaly correlation scores (January 10-February 20, 2001) are slightly smaller than in winter (August). The differences are also reflected in the NCEP operational T170 system (and other operational systems), where the geopotential height anomaly correlation scores clearly show seasonal variations. The wind vector RMS values for January 10-February 20, 2001 are smaller at 850 hPa and larger at 200 hPa. The impacts of satellite winds on tropics are consistent for both periods. The experiments with QI data thinning for both periods show similar results during both seasons: a minor impact in the mid-latitudes, a slight negative impact at 850 hPa, and a very small positive impact at 200 hPa.

Table 7 System-C scores (as in Table 5) for September 1-30, 2002

	2-day	3-day	4-day	5-day
NH-500 CONTROL	97.8	94.3	88.3	78.2
NH-500 QI	97.8	94.6	88.7	79.2
NH-500 NOSAT	97.8	94.5	88.6	79.4
SH-500 CONTROL	96.7	93.0	86.9	79.1
SH-500 QI	96.9	93.6	87.7	80.3
SH-500 NOSAT	96.9	93.6	87.8	80.3

TR-850	CONTROL	3.413	3.911	4.262	
	QI	3.189	3.769	4.205	
	NOSAT	3.195	3.748	4.174	
TR-200	CONTROL	5.887	7.081	8.121	
	QI	5.699	7.041	8.180	
	NOSAT	5.731	7.037	8.156	

The results from the higher resolution System-C are different from the lower resolution models. The satellite winds have a negative impact on forecast scores that can be seen when comparing Table 7 with Tables 4-6. The different density of EUMETSAT satellite winds could be a possible reason; other centers had similar results when they switched from low density to high density EUMESAT satellite winds (Kelly et al., 2000, Butterworth et al., 2000). The results from thinning are comparable with no satellite winds in the mid-latitude height anomaly correlations, worse in the tropical RMS, and better than results from the control run.

Time series plots provide more detailed mid-latitude anomaly scores and tropical vector RMS for the experiments with System-B for August 2000 (Figs. 4-5). The differences between the experimental forecasts were larger for longer time periods. Thus to emphasize the results, Figsures 4 and 5 show the 5-day mid-latitude anomaly correlations and the 4-day tropical vector wind differences. The time series of the Northern and Southern hemisphere aomaly correlation scores confirm that the differences between the control run and QI-thinning are very small throughout the whole experiment period. However, the differences between control and no satellite winds (Fig. 4) are noticeable by the fifth day, especially in the Southern hemisphere (Fig 4b) where the differences are up to 10%. Scores from any one experiment are not uniformly greater than those of any other, showing the need to perform the experiments over longer time periods to produce average values which reflect the overall tendency. A notable feature of the Northern Hemisphere 500 geopotential height at forecast days-4 and -5 on August 24, 2000 is an anomaly correlation much lower than on other days. The same feature occurred in the T170 NCEP and the U.K. meteorological office operational system. The reason for this lower skill forecast is unknown.

The time series of tropical wind vector RMS differences at 850 hPa level (Fig. 5a) reveals that the difference between the CONTROL and NOSAT experiments is very small, except on August 18, 2000 when the difference reaches approximately 0.6 m/s. The larger RMS differences are persistent from forecast day-2 to forecast day-4, which verify on 18 August 2000. This difference makes the CONTROL mean 850 hPa tropical wind vector RMS value slightly greater than that of NOSAT. Since the larger forecast errors are in the CONTROL forecasts verifying on 18 August, this suggests that the verifying CONTROL analysis may have had significant errors. Also, The time series of tropical wind vector RMS at 850 hPa for experiments with RFF thinning (Figure 6 shows persistently larger wind vector RMS (for forecast vs. analysis) in the 18 August forecasts (2-day forecast valid on the 20th , 3-day forecast valid on the 21st, and 4-day forecast valid on the 22nd). Note that most of the differences were in the zonal wind results. Both the poor analysis in the CONTROL and the poor forecasts in the RFF results suggest that the quality of data on August 18th may have been below normal, and that the QI screening removed more of the bad data than the CONTROL (which used all the data) and the RFF.

The wind vector RMS vertical profiles (satellite vs. control run analysis) averaged over the tropics August 2000 and for August 18, 2000 are shown in Figure 7. The 18 August RMS differences are much larger than August average values (3-4 times), especially at 06z. These results support the theory that the satellite winds on August 18 may have been of poorer quality. The poor quality satellite winds may be the result of navigation problems, which usually occur near 06z. The 18 August vs. August average daily observation number, averaged over the tropics, is plotted in Figure 8. The data samples from August 18 are consistently smaller than the average, except at 18z. This may be due to heavy data quality control. The smaller amounts of satellite wind observations on 06 and 12z, possible poor quality observations at 06z also point towards the possibility of navigation problems on August 18th. However, we were not able to acquire any records indicating the presence or absence of navigation problems during this period.

The largest consistent positive impact from the satellite winds is in the 200 hPa tropical winds (Figure 5). The time series of tropical wind vector RMS (CONTROL vs. NOSAT) at 200 hPa shows that satellite winds improve the forecast most of the time. However, the wind vector RMS differences for the NOSAT are sometimes smaller than those for control run experiments, especially later in the period. QI data thinning produced better forecasts than the CONTROL experiment (Fig. 5), but the differences between these two are very small (less than 0.5 m/s).

5. Summary

The impact of satellite winds and satellite wind thinning on forecasts, using different versions of the NCEP global data assimilation and forecast system, were evaluated in this study. The results show that the impact of satellite winds on forecasts is system dependent. This dependency can come from the quality of the forecast model, the data used, or the details of the data assimilation system. As seen when comparing results between System-A and System-B, improving a data assimilation and model forecast system can reduce the impact of satellite winds.

The NCEP data assimilation system assumes that observation errors are spatially uncorrelated, which is not appropriate for satellite winds. A common strategy to reduce the effect of spatially correlated errors of satellite winds is to thin the data. Overall, the thinning with QI index shows a little more skill than other thinning algorithms. Comparing the forecast scores of the control experiment with thinning experiments showed mixed results with strong system dependency. For example, improvements from thinning the forecast wind vector in the tropics are seen at both lower (850 hPa) and higher (200 hPa) levels in the older System-A. In the more recent System-B with T62 resolution, the improvements are only seen at higher levels and degradation is found at the lower levels. For the higher resolution System-C, most of the impacts of thinning were positive, however, satellite winds had a negative impact on the forecast scores. More experiments are needed to investigate the causes, and further analysis is needed to explore the problems of improving satellite wind usage in the NCEP operational data assimilation and forecast system. Future improvements in the use of satellite winds should come from better satellite wind quality assessment (e.g., detecting and monitoring navigation problems), improved satellite winds (e.g., improved height specification and use of the forecast field), and better data assimilation techniques (e.g., inclusion of correlated errors and improved specification of forecast errors).

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Figure Captions

Fig. 1. NESDIS processed model forecast winds used in deriving satellite winds (Un,Vn) versus model forecast winds used in NCEP global data assimilation system (Um,Vm). Sample size is 57271 from 31 May 2002 (+/- 1.5 hours around 00,06,12,18UTC).

Fig. 2. Same as Fig. 1 except final NESDIS derived satellite winds (Us,Vs).

Fig. 3. RRF versus QI flags for 31 May 2002.

Fig. 4. Five day 500 hPa Northern Hemisphere (a) and Southern Hemisphere (b) geopotential height anomaly correlations for 05 Aug. - 31 Aug. 2000. Forecasts are verified against their own analysis.

Fig. 5. Four day 850 hPa (a) and 200 hPa (b) RMS vector differences for 05 Aug. - 31 Aug. 2000. Forecasts are verified against their own analysis.

Fig. 6. RMS vector wind differences between 2 (a), 3 (b) and 4(c) day forecasts for CONTROL, RFF and NOSAT experiments from 05 -31 Aug. 2000. Forecasts are

verified against their own analyses.

Fig. 7. RMS vector wind differences between satellite observations and analyses at 00 UTC, 06 UTC, 12 UTC , and 18 UTC 18 Aug. 2000 (dashed) and for average from 1-31 Aug. 2000. Differences are from CONTROL analysis.

Fig. 8. Same as figure 6 except average number of observations.