Study of GOES Winds Impact in Eta Data Assimilation System

W. Paul Menzel [1] and Steven J. Nieman [2]

1 - NOAA/NESDIS
2 - Cooperative Institute for Meteorological Satellite Studies
1225 West Dayton Street
Madison, Wisconsin 53706

ABSTRACT

This paper presents the results of a case study into the sensitivity of the Eta data assimilation system (EDAS) to NESDIS operational observational wind data. Contributions from radiosonde observations (RAOB), Aircraft Communications Addressing and Reporting System (ACARS) wind estimates, GOES cloud drift (CD) winds, and GOES water vapor (WV) motions are studied in detail. Sensitivity reflects the root-mean-square difference over North America and surrounding waters for two verified quantities; 500 hPa geopotential height (Z500) and 300 hPa u-component of the wind (U300). Initial study indicates that the analysis and the 48 hour Eta forecast are very sensitive to radiosonde information, but that satellite winds also have significant impact.

1. INTRODUCTION

A case study was utilized to determine the sensitivity of the Eta data assimilation system (EDAS) (Black, 1994) to several observations of atmospheric motions. The EDAS was ported to a Silicon Graphics workstation at the Cooperative Institute for Meteorological Satellite Studies (CIMSS) with help from the National Centers for Environmental Prediction (NCEP). A control run of the EDAS utilized all of the wind data types, and one of the 4 wind data types (radiosonde observations, aircraft wind estimates, GOES cloud drift winds, and GOES water vapor motions) was denied for each experiment. Differences between the experimental and control runs are analyzed to demonstrate the sensitivity of the system to each data type.

2. EXPERIMENTAL DESIGN AND IMPLEMENTATION

In February 1998, three-dimensional variational analysis (3DVAR) (Parrish et al., 1997) became the data assimilation tool of the operational EDAS. Several other changes were made to the EDAS at this time, including an increase in horizontal resolution from 48 to 32 kilometers, an increase in the number of vertical levels from 38 to 45, and an increase in the number of soil moisture levels from 2 to 4. Procedures for utilizing EDAS forecasts as the first guess, thereby fully cycling the system, were also developed and implemented in operations in the summer of 1998. Details of the operational EDAS configuration can be found in the work of Rogers et al. (1997).

CIMSS acquired a Silicon Graphics Origin 2000 workstation in the summer of 1997 as a platform for EDAS research. The CIMSS Origin workstation has 2.0 Gigabytes of available memory and eight 195 MHz processors, although only four processors are typically used for EDAS research. A full 12 hour assimilation cycle for the EDAS, encompassing five assimilation steps and four 3 hour forecasts on the native grid requires approximately 1.25 hours at a resolution of 80 kilometers.

Since the CIMSS EDAS is not meant to be an operational forecast tool, this performance is acceptable. Due to computer constraints, NCEP scientists are accustomed to running 80 kilometer native grid parallels to diagnose changes in the system. The CIMSS EDAS is another resource for 80 kilometer parallel runs.

3. CASE STUDY DESCRIPTION

The EDAS analyses at 0000 UTC 8 October 1998 reveals two major weather systems. A large scale trough of geopotential height at 500 hPa just off the coast of British Columbia is poised to move slowly onshore (Figure 1). Several shortwaves are rotating around this trough. One of the more pronounced waves is crossing the coast and building a surface low pressure system in the lee of the Canadian Rockies. A second weather system involves a high amplitude trough of 500 hPa geopotential height stretching from Hudson Bay to the coast of Texas. The northern part of this system at the surface is a 990 hPa low pressure center just east of Hudson Bay. The central and southern parts of this system comprise a strong cold front stretching along the entire length of the upper-level trough. Strong low-level temperature gradients and convective precipitation are found along the front.

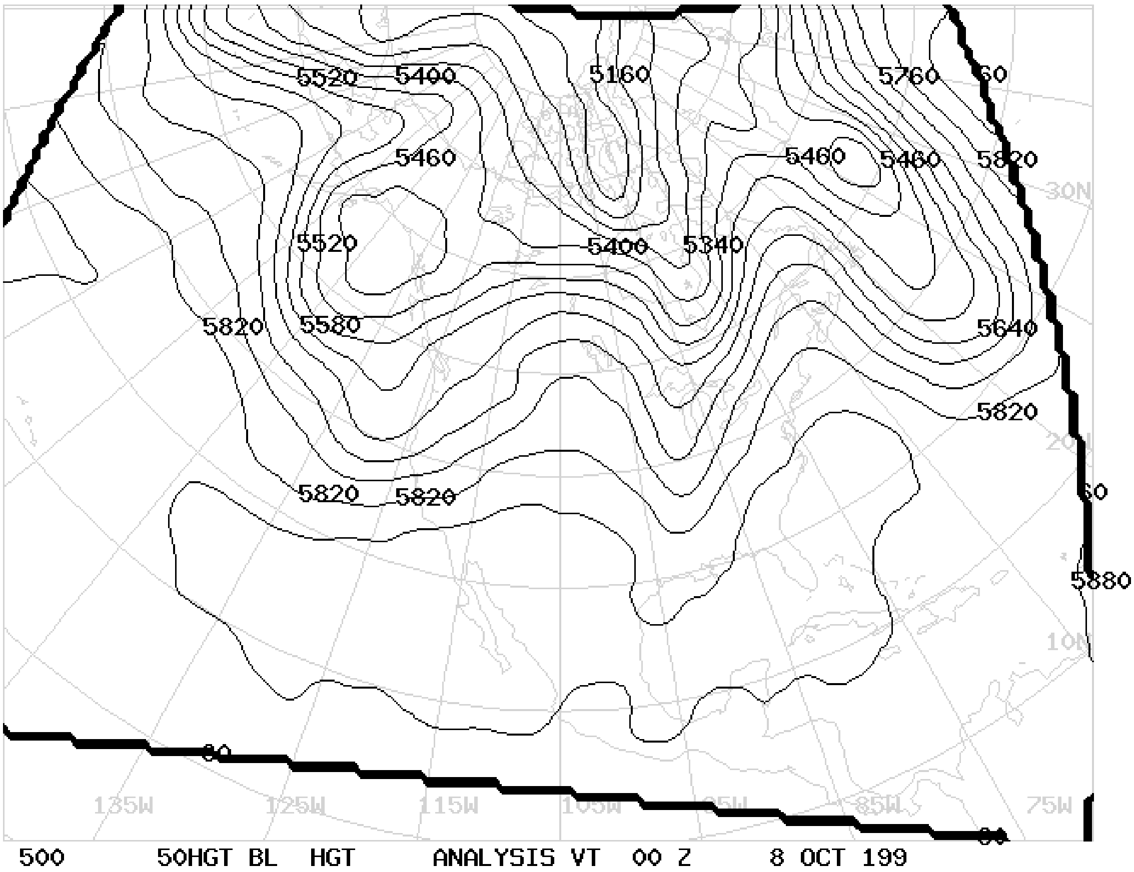

Figure 1: 500 hPa geopotential height at 0000 UTC 8 October 1998 revealing two major weather systems.

4. ANALYSIS AND DATA

The regional 3DVAR system is an evolution of the global analysis system used at NCEP (Derber and Wu, 1998). The analysis system minimizes an objective function of the form:

$$J = J_b + J_o + J_{bal}. \qquad (1)$$

The $\mathbf{J_b}$ term corresponds to the fit to a prior estimate of atmospheric conditions, or background. The $\mathbf{J_o}$ term represents the fit to all types of real observations. The explicit $\mathbf{J_{bal}}$ term in the objective function represents a weak balance constraint between the mass and velocity variables during minimization. When all three terms are expanded, the equation takes the form.

$$J = \frac{1}{2}\left[\left(x - x^b\right)^T B^{-1}\left(x - x^b\right) + \left(y^0 - Hx\right)^T R^{-1}\left(y^0 - Hx\right) + \left(x - x^b\right)^T H_{bal}^T B_{bal}^{-1} H_{bal}\left(x - x^b\right)\right]. \qquad (2)$$

This function is minimized at observation locations to yield the analysis. The resultant series of analysis values is represented by $\mathbf{x}$. The series of background values is given by $\mathbf{x^b}$. $\mathbf{B}$ is the background error covariance matrix. $\mathbf{R}$ is the observational error covariance matrix. The series of observations is given by $\mathbf{y^0}$. $\mathbf{H}$ represents the forward model, which is used to convert the NWP model variables to observational space and units. The forward model for the balance relationship, $\mathbf{H_{bal}}$, is a finite difference approximation to the thermal wind equation evaluated at each grid point. The magnitude of the error assigned to the balance relationship, $\mathbf{B_{bal}}$, determines the amount of balanced enforced during analysis.

Many factors influence the sensitivity of the variational analysis to a specific data set. The amount of observational data, represented by the length of all series in equation 1, is important. Every observation at a given level is considered to be a separate report, accounting for the existence of about 9200 radiosonde wind reports at T-12 and about 6700 at T-0 over North America. ACARS data number about 5000 every three hours, except T-12 where only 820 reports show up. Cloud drift winds number at about 3000 every three hours while water vapor motions peak near 11000 at T-9 and reduce to near 5000 at T-6 and T-3. Table 1 summarizes the wind measurements that where available in the 8 October 1998 case study. Real-time constraints on forecast generation can lead to somewhat fewer reports at T-0 than are routinely found at T-12.

Table 1. The number of wind measurements from each of the four observation systems at every three hours during the 12 hour assimilation cycle.

	CD	RAOB	ACARS	WV
T-12	2892	9186	820	121
T-9	2899	42	5633	10996
T-6	3119	837	4610	4551
T-3	3162	11	5109	5359
T-0	5140	6733	4957	0

However, the operational 3DVAR system also takes steps to reduce the volume of data by considering only one observation per model grid point. In the “superob” procedure, all data types for a given variable are considered equivalently, regardless of their observational error, proximity to analysis time, or total number within the grid cell. That datum representing the median of all observational values at a given grid cell is chosen, and all others are not used. Since all data types have different temporal and spatial coverage, the superob procedure limits the effectiveness for some types more than others. At each assimilation time, all data are included from within 1.5 hours.

The relative weight of each data set is typically inversely proportional to its observation error. Table 2 shows the observation error estimates assumed in the Eta for wind data at five pressure levels. All winds are weighting roughly the same.

Table 2. Error estimates used in the Eta for wind data at five pressure levels in m/s

	CD	RAOB	ACARS	WV
1000 hPa	1.8	1.4	2.5	1.8
850	1.8	1.5	2.5	1.8
0	1.9	1.6	2.5	1.9
500	2.1	2.1	2.5	2.1
300	3.0	3.0	2.5	3.0

Sensitivity of the variational analysis to data is also dependent on the accuracy assigned to the model forecast which is used as a background during analysis. Error statistics compiled from 100, 80 kilometer, 17 level, 24-36 hour forecasts of the Eta model are used to estimate the quality of the background in the vertical. This vertical distribution of background error is then modified to be dependent on latitude and filtered to produce the three-dimensional background error covariance (**B**). Data has the best chance of influencing the analysis in regions where the background error is relatively large. Further research is being done to incorporate regional estimates of model accuracy into the variational analysis.

If a data set does not affect the analysis there are two possible explanations. One is that the data either was too few in number or received relatively little weight as compared to the weights assigned to the background and other data through estimated errors. The other is that the environment sampled by the observation was already successfully depicted in the EDAS. It is not possible to separate these two possibilities in this study.

5. RESULTS

The EDAS was run 5 times on this case study. The control utilized all of the data, and one of the 4 data sets was denied for each experiment. Each run consisted of the complete 12-hour assimilation cycle. Data was assimilated via 3DVAR at 1200 UTC 7 October 1998 (T-12), 1500 UTC 7 October (T-9), 1800 UTC 7 October (T-6), 2100 UTC 7 October (T-3) and 0000 UTC 7 October (T-0), using 3-hour Eta model forecasts between each assimilation step. The result of the 12-hour assimilation cycle is the complete analysis before the Eta model’s forecast cycle. Differences of the various experimental run analyses with the control run analysis yield a measure of the sensitivity of the EDAS to each individual data set for this case. Root-mean-square (rms) differences were computed for various quantities at three levels in the atmosphere (850, 500, and 300 hPa). These statistics were computed over a region defined roughly by the GOES-8/10 satellite image; the results for winds are summarized in Figure 2 and for geopotential heights in Figure 3.

EDAS wind analyses are most sensitive to GOES cloud drift winds at 300 and 850 hPa and conventional radiosonde observations (RAOB) at 500 hPa. ACARS wind information is important at 300 hPa. Water vapor winds show some impact at 300 hPa, but little at lower levels (as would be expected from the GOES water vapor spectral band). EDAS geopotential analyses are most sensitive to ACARS winds at 300 and 850 hPa and GOES cloud drift winds at 500 hPa. RAOBS show the least significance of the four wind data types at all levels. Geographical influences are not shown but can be summarized as follows: ACARS influence the EDAS except in the northeastern Pacific, GOES cloud drift winds influence the EDAS over the oceans including the northeastern Pacific, GOES water vapor drift winds are ubiquitous but influence the EDAS minimally, and RAOBs have the largest influence on the EDAS in Canada.

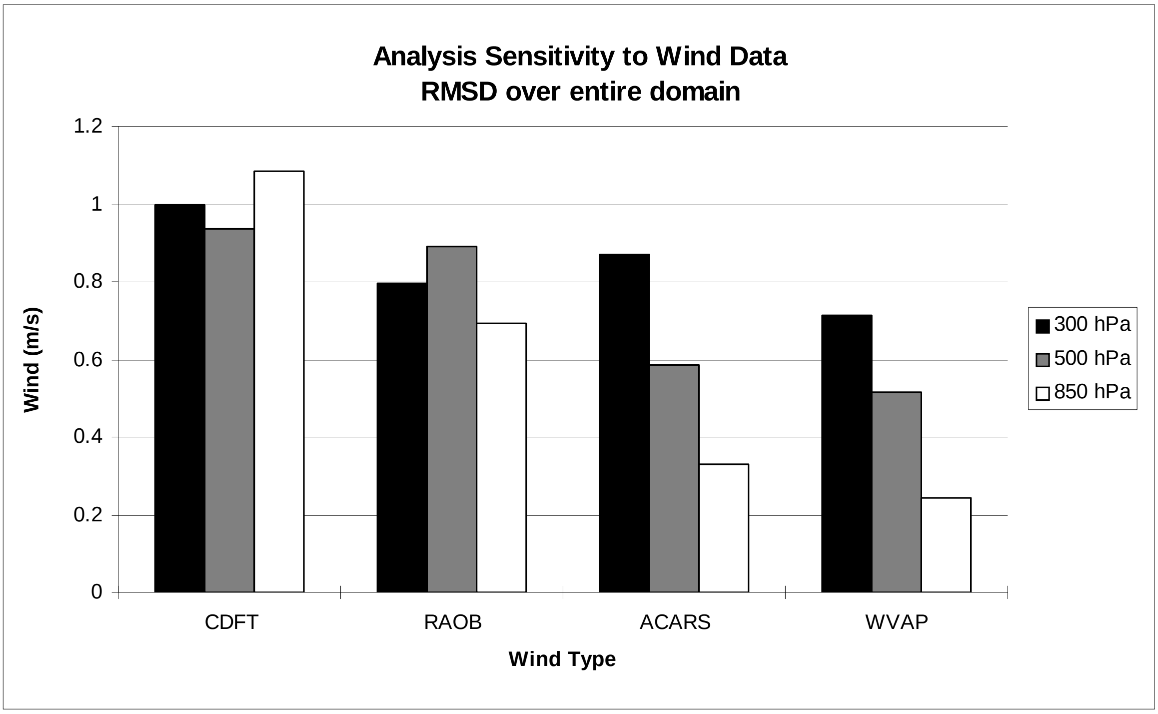

Figure 2: Root-mean-square (rms) wind differences at three levels in the atmosphere (850, 500, and 300 hPa) caused by denial of a given wind type during the assimilation cycle.

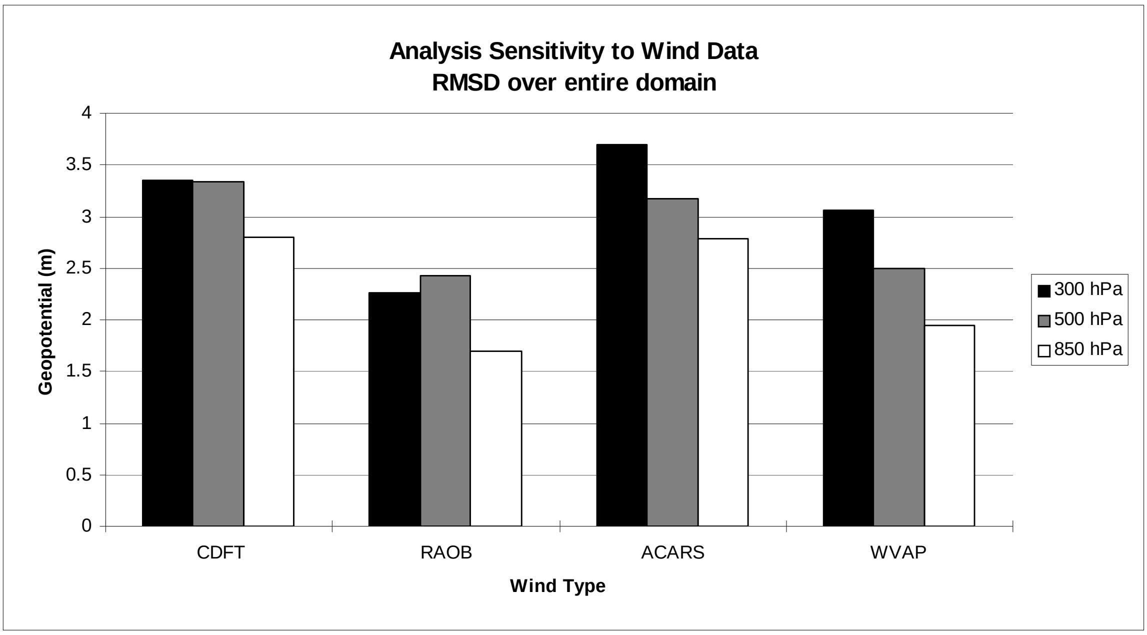

Figure 3: Root-mean-square (rms) geopotential height differences at three levels (850, 500, and 300 hPa) caused by denial of a given wind type during the assimilation cycle.

Figure 4a shows the horizontal plots of the EDAS analyses difference at 500 hPa height field due to removal of the GOES water vapor wind data; Figure 4b shows the same for the Eta 48 hour forecast. The EDAS analyses demonstrates a modest sensitivity to the removal of the water vapor winds near the short waves in the 500 hPa flow (see Figure 1). 48 hours later the forecast remains sensitive to the denial of water vapor winds in the region of the storm. Which forecast verifies better? Table 3 shows the validation of the 48 hour forecast against radiosonde observations; removal of water vapor winds detracts from the 500 hPa geopotenital height forecast the most even though they influenced the EDAS minimally.

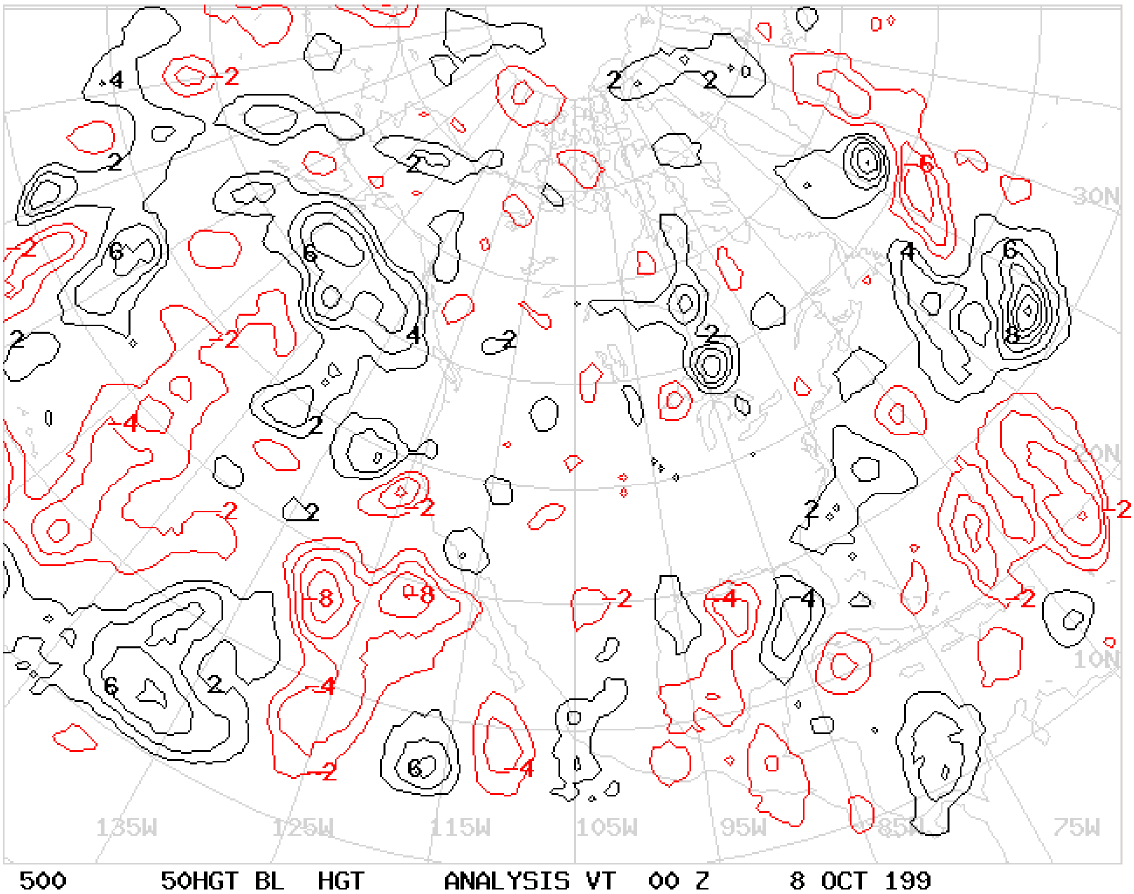

Figure 4a: EDAS analyses difference at 500 hPa height field due to removal of the GOES water vapor wind data during 12 hour assimilation cycle ending 00 UTC 8 October 1998.

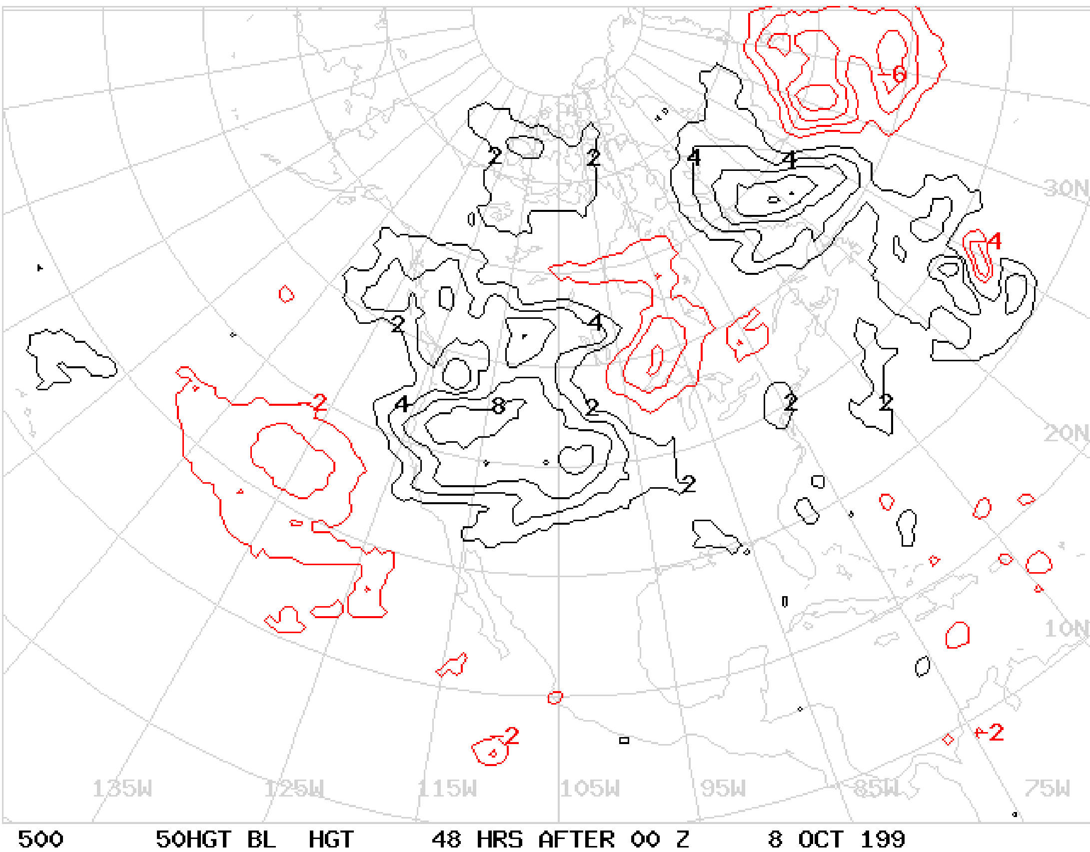

Figure 4b: Eta 48 hour forecast (valid time 00 UTC 10 October) difference in the 500 hPa height field due to removal of the GOES water vapor wind data during the assimilation cycle.

Table 3. Validation of 300 hPa u-component wind (m/s) and 500 hPa geopotential height (m) for the 48 hour forecasts of each of five runs. The control run utilized all of the data types, and the other four denied the data type listed. Statistics are RMSD versus radiosondes. The difference between the control and each experiment is shown as well.

	Control	CD	RAOB	ACARS	WV
300 hPa U	7.58	7.60	7.80	7.85	7.62
		-0.02	-0.22	-0.26	-0.04
500 hPa Z	24.29	24.19	24.45	24.46	25.53
		0.11	-0.16	-0.17	-1.24

6. SUMMARY

This initial case study reports on the sensitivity of the EDAS analysis and the 48 hour Eta forecast to four operational wind data types. We do not propose that the results are representative of all synoptic regimes or seasons. However, the case does demonstrate that various satellite wind observations can have a significant influence on the EDAS analysis over oceanic regions that subsequently affect the 48 hour Eta forecast over the continental United States. Aircraft winds, GOES cloud drift winds, GOES water vapor drift winds, and radiosonde wind observations all have a contribution to make. A further understanding of how to utilize these data, and future data types like them, could lead to improvements in forecast accuracy, especially on the west coast of the United States.

The results presented here also demonstrate the usefulness of the CIMSS EDAS as a research tool for evaluating the usefulness of various data types within the system. Future work will concentrate on longer term studies involving the understanding of the usefulness of current types of operational satellite data, the investigation of the impact of new sources of satellite data and products, and better characterization of observational errors and forward models.

ACKNOWLEDGEMENTS

The authors wish to thank their NCEP collaborators Eric Rogers, David F. Parrish, Geoffrey J. DiMego, and Michael Baldwin for invaluable assistance with this study. In addition CIMSS colleagues Timothy J. Schmit, J. P. Nelson III, William Raymond, and Robert Aune helped to provide GOES data and visualization and verification tools.

REFERENCES

Black, T. L., 1994: The new NMC mesoscale Eta model: Description and forecast examples. *Wea. Forecasting*, **9**, 265-278.

Derber, J. C. and W.-S. Wu, 1998: The use of TOVS cloud cleared radiances in the NCEP SSI analysis system. Accepted by *Mon. Wea. Rev.*

Parrish, D. F., J. C. Derber, R. J. Purser, W.-S. Wu, and Z.-X. Pu, 1997: The NCEP global analysis system: Recent improvement and future plans. *J. Met. Soc. Japan*, **75**, 249-255.

Rogers, E., M. Baldwin, T. Black, K. Brill, F. Chen, G. Dimego, J. Gerrity, G. Manikin, F. Mesinger, K. Mitchell, D. Parrish, and Q. Zhao, 1997: Changes to the NCEP Operational “Early’ Eta Analysis/Forecast System. *Tech Proc*., Bulletin **447**. NWS. Science Division, Silver Spring, MD.