IMPACT OF SATELLITE TEMPERATURE, MOISTURE, AND WIND OBSERVATIONS IN THE ETA DATA ASSIMILATION SYSTEM OVER THREE SEASONS

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ABSTRACT

The seasonal impact of five satellite data types in the Eta Data Assimilation/Forecast System (EDAS) is studied. The five data types include two precipitable water data types, temperature data in a cloudy environment, and two cloud motion wind data types. The case studies chosen include 11-day periods during December 1998, April 1999 and July 1999. During these periods six EDAS runs were executed twice daily; they include a control run of the EDAS, which utilizes all 34 operational data types, and five experimental runs in which one of the five satellite data types is denied. The 00-hr sensitivity and 24-hr forecast impact of these data types in the EDAS are investigated. Evaluation of conventional meteorological parameters at mandatory pressure levels reveals modest positive forecast impact from all five of these data types in all three seasons. The cloud motion wind information has the largest positive forecast impact during the winter season, while the precipitable water information has the largest positive forecast impact during the summer and transition seasons.

1. Introduction

The seasonal impact of five satellite data types in the Eta Data Assimilation/Forecast System (EDAS) is studied. The five data types include three layer (GOESM, Menzel et al. 1998) and vertically integrated precipitable water (SSMI, Alishouse et al. 1990), temperature data down to cloud top (TOVCD, Reale et al. 1994), infrared cloud drift winds (GOESC, Nieman et al. 1997) and water vapor winds at cloud top (GOESW, Velden et al. 1997). Only reports over water were used.

The case studies chosen include 11-day periods during December 1998, April 1999 and July 1999. During these periods six EDAS runs were executed twice-daily. The six runs include a control run, which utilizes all operational data types used in the EDAS, and five experimental runs in which one of the five satellite data types is denied. Differences between the experimental and control runs are then accumulated during the 11-day periods and analyzed to demonstrate the 00-hr analysis sensitivity and 24-hr forecast impact of these data types in the EDAS. Conventional meteorological terms evaluated include geopotential heights, temperature, u-component of the wind, and relative humidity on five mandatory pressure levels.

If a data type does not affect the analysis, there are four possible explanations. First is that the data were too few in number. Second is that the data received too little weight. Third is that the environment sampled by the observation was already successfully depicted by the EDAS. Fourth is that the data may not have passed an assimilation quality control check. It is beyond the scope of this study to separate these possibilities.

2. Experimental Design and Implementation

Three-dimensional variational analysis (3DVAR) (Parrish et al. 1996) became the data assimilation technique of the operational EDAS in February 1998. Procedures for utilizing EDAS forecasts as the first guess, thereby "fully-cycling" the system on its own first guess, were also developed and implemented in operations during the summer of 1998. Details of the operational 3DVAR portion of the EDAS configuration can be found in the work of Rogers et al. (1997). The EDAS has since been updated (NWS 1999); experimental results presented here are generated with a May 1999 version of both 3DVAR and the Eta forecast model.

A total of 396 separate EDAS runs were required to isolate the extended length contributions from each of these five observational data types. An additional 220 EDAS simulations were performed to study conventional data denials during December 1998 and July 1999. Data used in the experiments reported here were obtained from an 80 kilometer, 38 level EDAS which was being executed at NCEP twice-daily "parallel" to the 32 kilometer operational EDAS. All 616 EDAS simulations performed herein are also run at 80 kilometers and 38 levels.

Sensitivity of the EDAS assimilation to the five data types is only evaluated at 00-hr, meaning after a complete 12-hr 3DVAR assimilation. The Root Mean Square (RMS) sensitivity **S** is defined as

$$S = \sqrt{\frac{\sum_{i=1}^{N} (D_i - C_i)^2}{N}} \quad , \qquad (1)$$

where **C** is the control assimilation containing all the data types, **D** is the assimilation containing all but the one denied satellite data type and **N** is the total number of grid points on the isobaric level being evaluated. Since (1) only contains two analyses and does not contain an independent verification, the sensitivity diagnosed by (1) does not indicate whether the 00-hr analysis is better or worse with the denied satellite data type. Seasonal sensitivity statistics are only presented at 00-hr.

The RMS forecast impact **FI** of an individual data type is evaluated as

$$FI = \sqrt{\frac{\sum_{i=1}^{N} (D_i - A_i)^2}{N}} - \sqrt{\frac{\sum_{i=1}^{N} (C_i - A_i)^2}{N}} \qquad (2)$$

In (2) **N** has the same meaning as above. The variables **C** and **D** are the 24-hr control and denied forecasts, respectively, and **A** is the 00-hr EDAS control analysis valid 24-hrs after the forecast began. Unlike (1), (2) directly evaluates whether the 24-hr forecast is closer to or farther away from the EDAS analysis valid at the same time as the 24-hr forecast. In (2) the first term can be considered the error in the denied forecast. The second term in (2) can be considered the error in the control forecast.

Both the 00-hr sensitivity and 24-hr forecast impact diagnostics are delayed one day after the start of each 11-day seasonal period. This delay in evaluating the statistics allows more time for the impact of the denied data to be removed from the initial first guess, and reduces the 11-day time periods to 10 days diagnostically.

Each of the 616 EDAS simulations consisted of the complete 12-hr assimilation cycle and a 48-hr forecast cycle. Data were assimilated via 3DVAR at T-12, T-9, T-6, T-3, and T-0, using 3-hour Eta model forecasts between each assimilation step. At each assimilation time, all data within ± 1.5 hours are included. In this study, SSMI typically contributed about 3000 reports, GOESM about 20000, TOVCD about 20000, GOESC about 5000, and GOESW about 4000. Errors assigned to the observations in the EDAS (Table 1) influence the weighting each report gets. The result of the 12-hr assimilation cycle is the complete analysis before the Eta model's forecast cycle begins.

TABLE 1. Errors assigned to observations in the EDAS at six pressure levels. The data type, description and units are shown at left. Rawinsonde (RAOB), aircraft (ACAR) and GMS errors are included for later discussion.

ID	Description	1000	850	700	500	300	200
RAOB1	Temperature (K)	1.2	0.8	0.8	0.8	0.9	1.2
ACAR1	Temperature (K)	1.5	1.1	1.0	1.0	1.0	1.0
TOVCD	Cloudy temperature (K)	7.6	7.1	6.6	6.6	7.0	6.7
RAOB1	Specific humidity (%)	5.0	7.0	10.0	20.0	20.0	20.0
SSM/I	Marine precip. water (mm)	8.0	8.0	8.0	8.0	8.0	8.0
GOESM	Marine precip. water (mm)	8.0	8.0	8.0	8.0	8.0	8.0
RAOB2	Winds ($m\ s^{-1}$)	1.4	1.5	1.6	2.1	3.0	2.7
ACAR2	Winds ($m\ s^{-1}$)	2.5	2.5	2.5	2.5	2.5	2.5
GOESC	IR Cld drft winds ($m\ s^{-1}$)	1.8	1.8	1.9	2.1	3.0	3.0
GOESW	Cld top water wapor ($m\ s^{-1}$)	1.8	1.8	1.9	2.1	3.0	3.0
GMSLO	IR/VIS Cld drft winds ($m\ s^{-1}$)	1.8	1.8	1.9	2.1	4.6	5.0

3. Results

Sensitivity diagnostics include time-summed RMS differences over the entire model domain for four quantities (Z, T, u and R.H.) on five mandatory pressure levels (1000, 850, 700, 500, and 300 hPa). Differences between the various experimental 12-hr assimilation runs and the control 12-hr assimilation run provide a measure of the sensitivity of the EDAS to each individual data type for these three extended length time periods. Similarly, time-summed differences between the 24-hr experimental forecasts and the 24-hr control forecast provide a measure of the positive or negative forecast impact of each data type in the Eta model.

The 00-hr bar chart sensitivity results (Figs.1-3) presented below have the same vertical scale by data type and time period. The 24-hr forecast impact results (Figs. 4-6) have the same vertical scale with respect to each other, but a different vertical scale than the 00-hr sensitivity results.

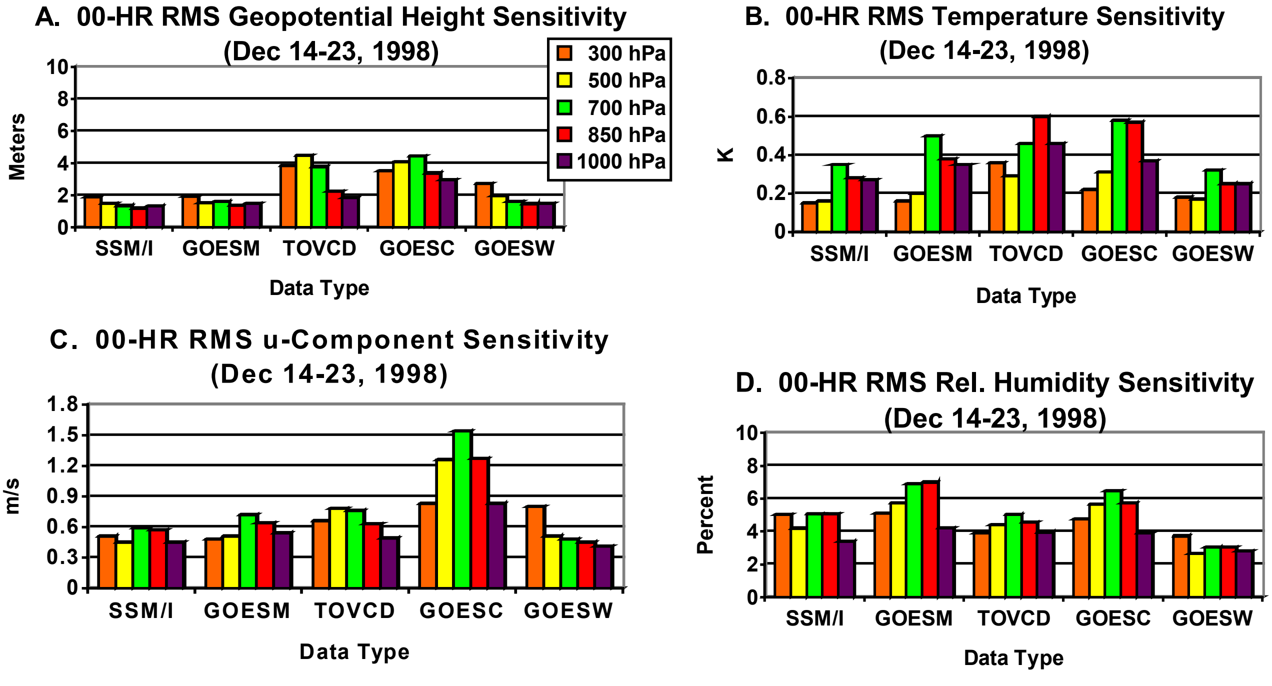

Fig. 1. Sensitivity of the five satellite data types after a complete 12-hr 3DVARassimilation. These results are formed by summing over time the results of (1) for each period from 0000 UTC 14 December 1998 through 1200 UTC 23 December 1998. The units of each field are listed on the y-axis.

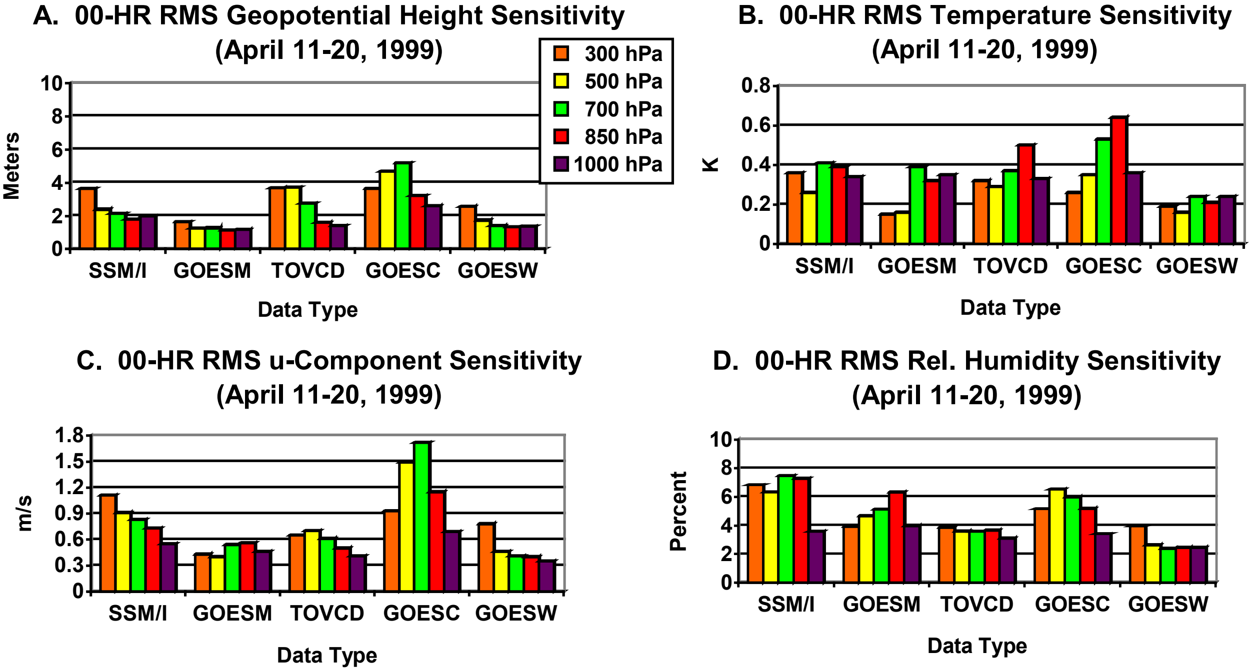

Fig. 2. Same as Fig. 1 except for the period 0000 UTC 11 April 1999 through 1200 UTC 20 April 1999.

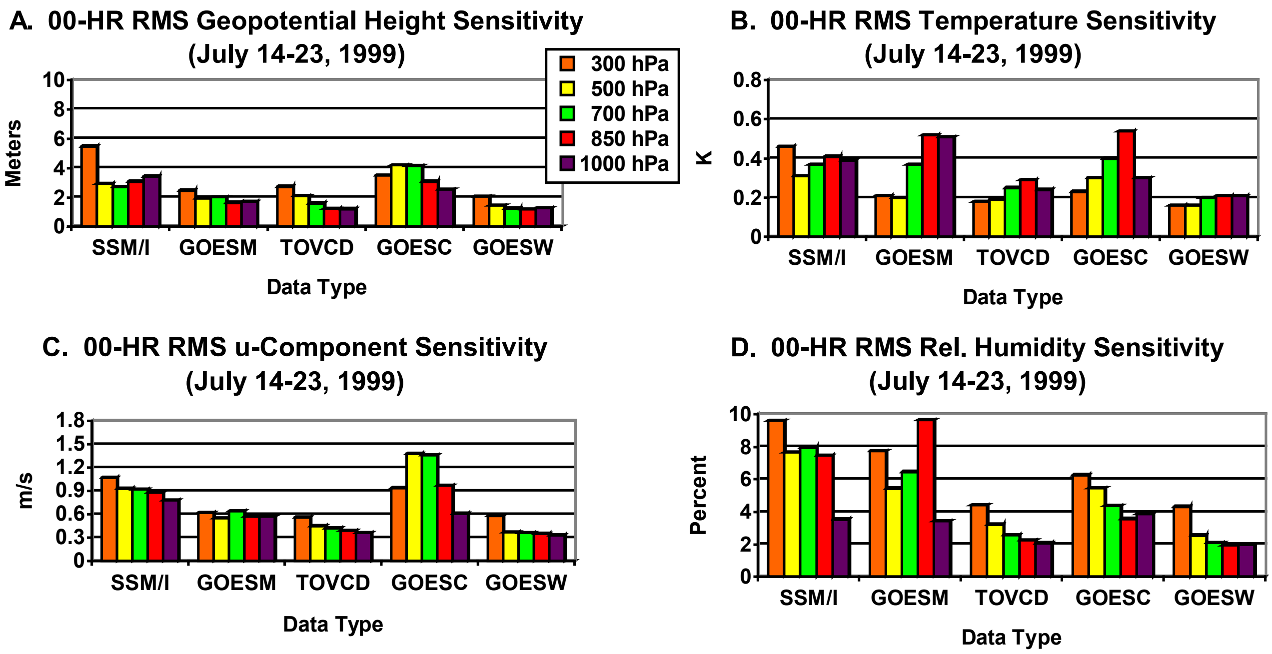

Fig. 3. Same as Fig. 1 except for the period 0000 UTC 14 July 1999 through 1200 UTC 23 July 1999.

3A. 00-hr sensitivity results

The time-summed 00-hr sensitivity results of geopotential heights, temperature, u-component of the wind and relative humidity for the 13-23 December 1998 time period are presented for five mandatory pressure levels in Figs. 1A-D, respectively. Largest overall wintertime geopotential height sensitivity (Fig. 1A), which represents a vertically integrated effect, is to TOVCD and GOESC. Both these data types provide up to a 4.5 meter change in the middle troposphere. The other three data types (SSM/I, GOESM, and GOESW) are in general near a 2 meter impact on all five isobaric levels.

Larger relative variation by isobaric level and data type is noticed in the 00-hr wintertime temperature sensitivities (Fig. 1B). The TOVCD and GOESC data types again provide the largest overall impact, up to 0.6 K in the lower to middle troposphere. However, other data types such as GOESM at 700 hPa also prove to be nearly as significant (0.5 K). In general the temperature sensitivities are larger in the lower to middle troposphere than aloft. For the most part this is an expected result, since the gradients of temperature in the wintertime hemisphere are largest at lower altitudes.

During this extended time period in December 1998, the 00-hr u-component analysis is clearly most sensitive to GOESC data at nearly all levels (Fig. 1C). For this period GOESC provides an impact of 1.5 m s^{-1} at 700 hPa. The 300 hPa GOESW, 500 and 700 hPa TOVCD and 700 hPa GOESM sensitivities have the next largest contributions, but these are all less than 0.9 m s^{-1}. Other data types, such as SSM/I and the remaining levels of GOESW show sensitivities less than or equal to a 0.6 m s^{-1} impact in the time-summed December 1998 results.

The 00-hr wintertime relative humidity sensitivities (Fig. 1D) demonstrate the most uniformity of the four standard meteorological fields presented here, at least when comparing data type to data type and level to level. Except for GOESW the 00-hr sensitivity provided by these data types average between 4 and 6%, with GOESM approaching 7% at 700 and 850 hPa. The GOESW sensitivities are 4% or less and the smallest for all levels by data type. A 7% relative humidity sensitivity seems like a much larger impact than a 0.6 K temperature or 1.5 m/s u-component sensitivity.

The 10-20 April 1999 and 13-23 July 1999 sensitivities are presented in Figs. 2 and 3, respectively. The April and July sensitivities are examined by comparing the time summed impact of these data types with their December counterpart. Concentration will focus on the precipitable water data types, which should logically have the largest impact in July and the smallest impact in December.

Comparing the relative humidity sensitivities during December 1998 and July 1999 (Figs. 1D and 3D respectively) clearly indicates that the impact of SSM/I data at all levels and GOESM data at 850 and 300 hPa is more significant in July (Fig. 3D) than December (Fig. 1D).

While relative humidity shows a larger 00-hr impact in July than December, the same cannot be said about the sensitivity of GOESC and GOESW cloud motion data types. Considering each of these two data types, their average impact might be slightly larger in winter than summer, but in general their impact remains fairly constant from season to season regardless of the field examined. (Compare GOESC and GOESW for all four fields within Figs. 1 and 3.) The only data type to show a significant drop in sensitivity from December to July is TOVCD. For this data type the July values are in some cases less than one-half the magnitude of their corresponding December values.

During the transition month of April (Fig. 2D) SSM/I has more impact on the analysis than GOESM, in contrast to what was seen in December (compare Figs. 1D and 2D). On the whole, April relative humidity sensitivities from SSM/I and GOESM are somewhat closer to their December values than their July values.

3B. 24-hr forecast impact results

Figures 4A-D show the 24-hr forecast impact for the same four fields presented above during the December 1998 time period. An examination of the four fields indicates that each of the five satellite data types cumulatively have a positive impact. GOESC clearly has the most positive forecast impact for the geopotential heights and u-component, and shows the largest positive impact when all four data types are combined. On the other hand, GOESW is the smallest contributor to nearly all fields, with cumulative results for the four fields producing only a slightly positive impact. The other three data types (SSM/I, GOESM and TOVCD), while not as positive overall as GOESC, each produce a cumulative positive forecast impact for the four fields added together.

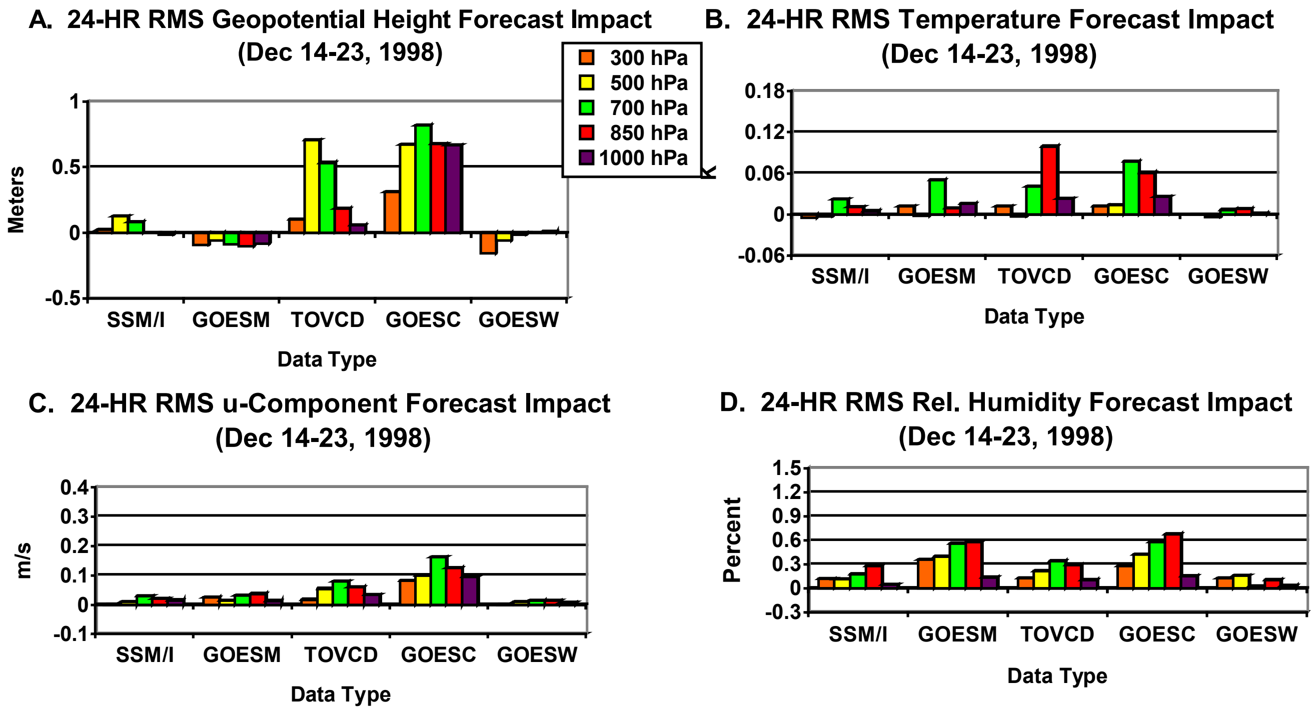

Fig. 4. Forecast impact of the five satellite data types after 24-hrs of Eta model integration. These results are formed by summing over time the results of (2) for each period from 0000 UTC 14 December 1998 through 1200 UTC 23 December 1998. The units of each field are listed on the y-axis.

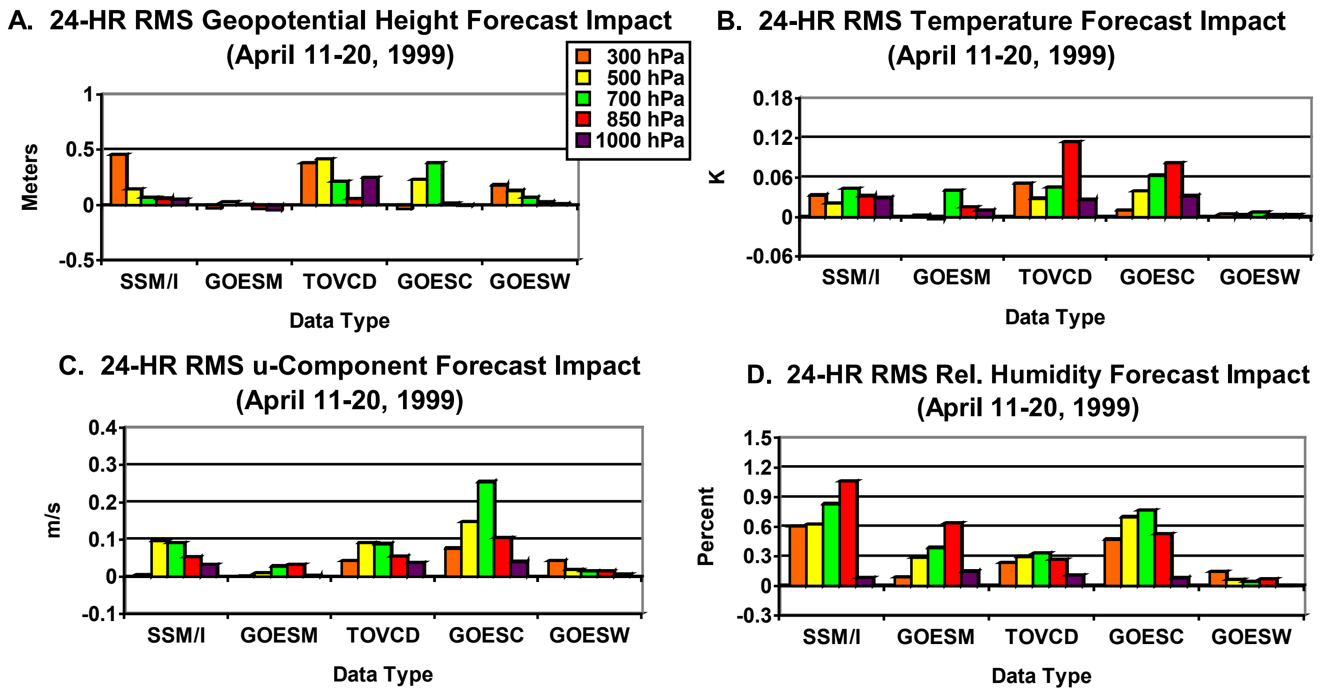

Fig. 5. Same as Fig. 4 except for the period 0000 UTC 11 April 1999 through 1200 UTC 20 April 1999.

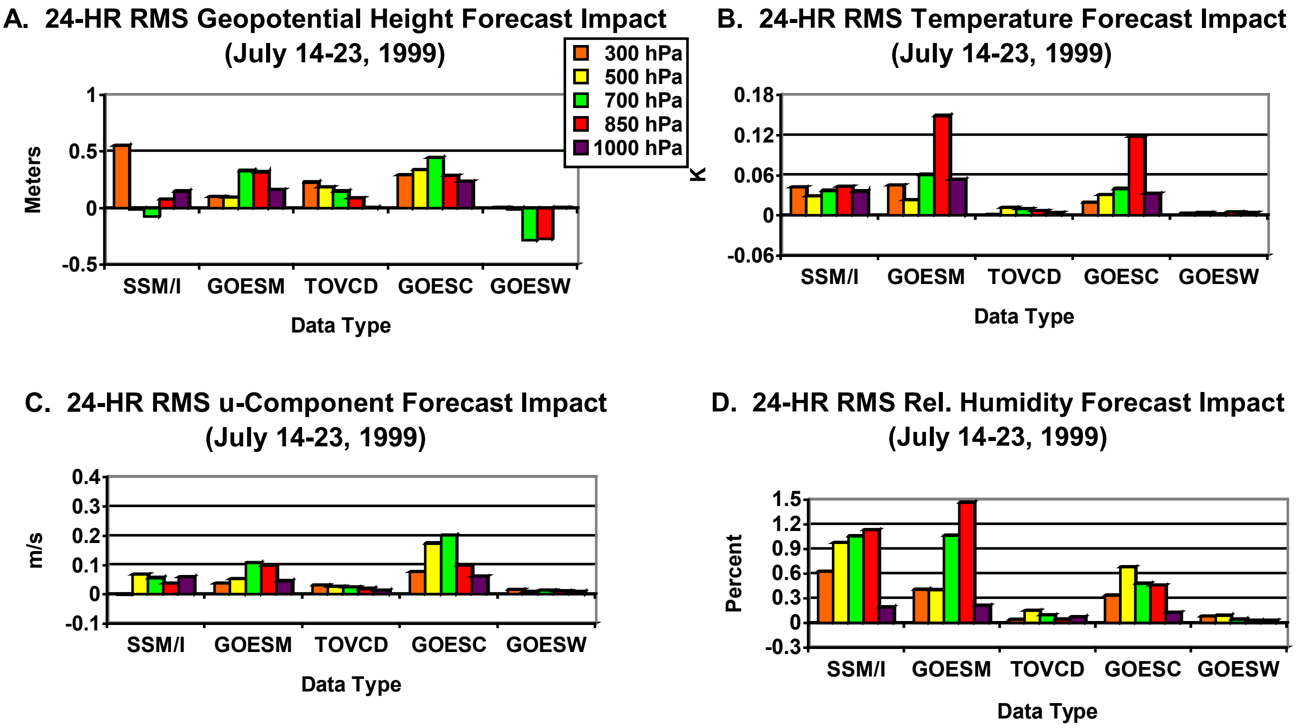

Fig. 6. Same as Fig. 4 except for the period 0000 UTC 14 July 1999 through 1200 UTC 23 July 1999.

The 24-hr April and July 1999 forecast impact results are displayed in Figs. 5 and 6, respectively. Comparing the SSM/I and GOESM precipitable water data types from December 1998 (Fig. 4) and July 1999 (Fig. 6) indicates that, a larger atmospheric moisture content in July nearly always translates to a larger positive forecast impact in July than December for all four fields presented. In fact, by July the precipitable water data sets provide some of the largest positive forecast impacts, even for fields not intrinsically related to moisture (see GOESM at 850 hPa in Fig. 6B and SSM/I at 300 hPa in Fig. 6A). The negative impact of GOESM in geopotential heights in December 1998 (Fig. 4A) has also reversed and is neutral by April (Fig. 5A) and modestly positive by July 1999 (Fig. 6A).

With respect to the non-moisture data types, a December 1998 and July 1999 comparison indicates that the impact of GOESC and TOVCD is positive for virtually every level and field in December, and for all levels and fields in July (compare Figs. 4 and 6). However, similar to the 00-hr sensitivities, the overall magnitude of the positive forecast impact for these two data types decreases somewhat from winter to summer, especially TOVCD impacts. Furthermore, while GOESW is modestly negative in the lower and middle troposphere in terms of geopotential heights in July (Fig. 6A), its overall impact remains slightly positive during all three 11-day periods when cumulatively examining all four fields.

3C. The importance of several conventional data types

The impact of several conventional data types were also be examined. The five data types are rawinsonde temperature and moisture observations (RAOB1), Aircraft Communications Addressing and Reporting System (ACARS) temperature data (ACAR1), rawinsonde wind observations (RAOB2), ACARS wind observations (ACAR2), and Geostationary Meteorological Satellite low-level infrared/visible cloud drift wind observations (GMSLO).

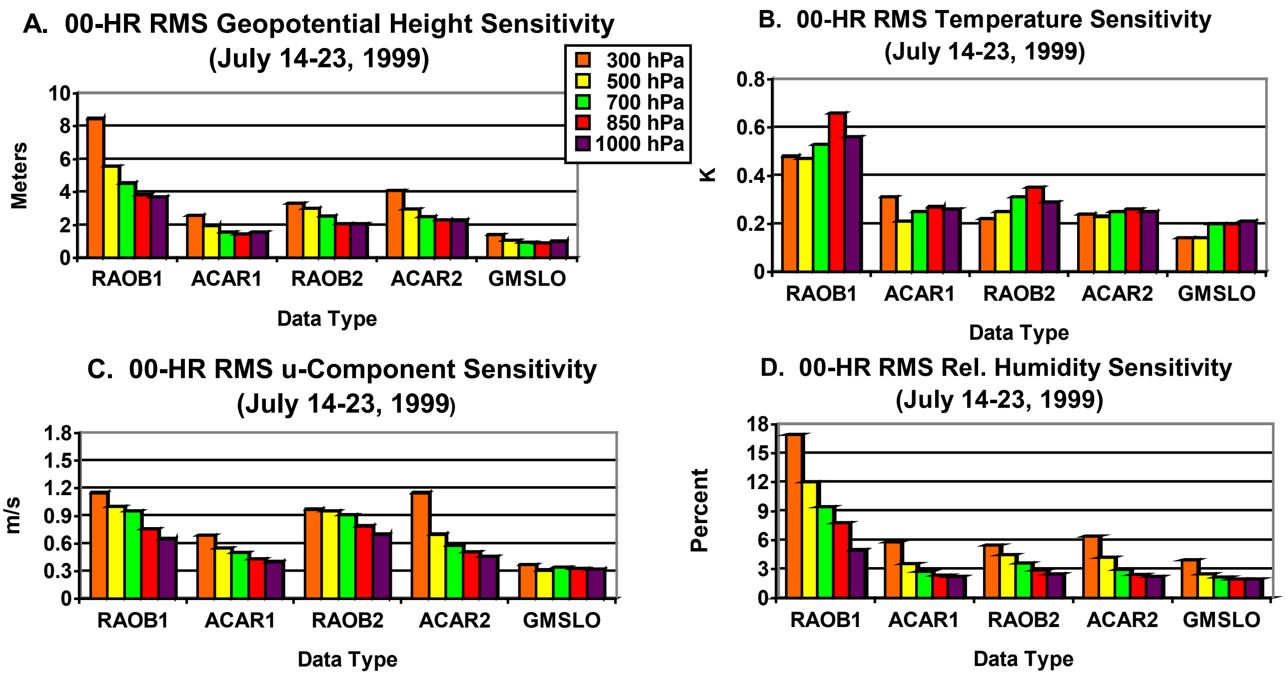

Fig. 7. Sensitivity of four more conventional data types as well as cloud drift wind information from GMS after a complete 12-hr 3DVAR assimilation. These results are formed by summing over time the results of (1) for each period from 0000 UTC 14 July 1999 through 1200 UTC 23 July 1999. The units of each field are listed on the y-axis.

Figure 7 displays the 00-hr sensitivities of these five new data types during the July 1999 time period. Note that the vertical scale is the same as the previous sensitivity figures, except for relative humidity where the vertical axis has been expanded from 10% in section 3A to 18% here. Inspection of these four fields reveals that the EDAS has the largest sensitivity to RAOB1 data for all four fields, especially geopotential height, temperature and relative humidity. The remaining three conventional data types (ACAR1, RAOB2 and ACAR2) all demonstrate a nearly equal sensitivity with each other, and as little as one-half the overall RAOB1 sensitivity. The GMSLO sensitivity is clearly the smallest for all four fields. Another interesting aspect of these results is that the sensitivities are in general larger in the upper troposphere than in the lower troposphere. This is especially true for the geopotential height, u-component and relative humidity sensitivities (Figs. 7A, C and D) and different than the satellite data types of Fig. 3, which appear somewhat more random with height.

Comparing satellite and non-satellite data sensitivities reveals several interesting features. With respect to geopotential height, the RAOB1 sensitivities are clearly the largest at all five isobaric levels (compare Figs. 3A and 7A). RAOB1 is also the largest at every level for temperature sensitivity, although the 850 and 1000 hPa GOESM, 850 hPa GOESC and 300 hPa SSM/I sensitivities come in a close second (compare Figs. 3B and 7B). GOESC provides the largest overall u-component sensitivity, especially at both 500 and 700 hPa where values approach 1.4 m s^{-1}. RAOB1, RAOB2 and SSM/I provide the second largest sensitivities and are of nearly equal importance (compare Figs. 3C and 7C). RAOB1 is also the most important for overall relative humidity sensitivity, and is particularly important at 500 and 300 hPa (compare Figs. 3D and 7D, noting the different y-axis scales).

Figure 8 displays the 24-hr forecast impact of these five new data types during the July 1999 time period. Similar to the five July satellite data types presented in Fig. 6, these more conventional data types also provide a positive impact for nearly all fields and levels. GMSLO impact is small due to the lack and location of these observations within the EDAS model domain.

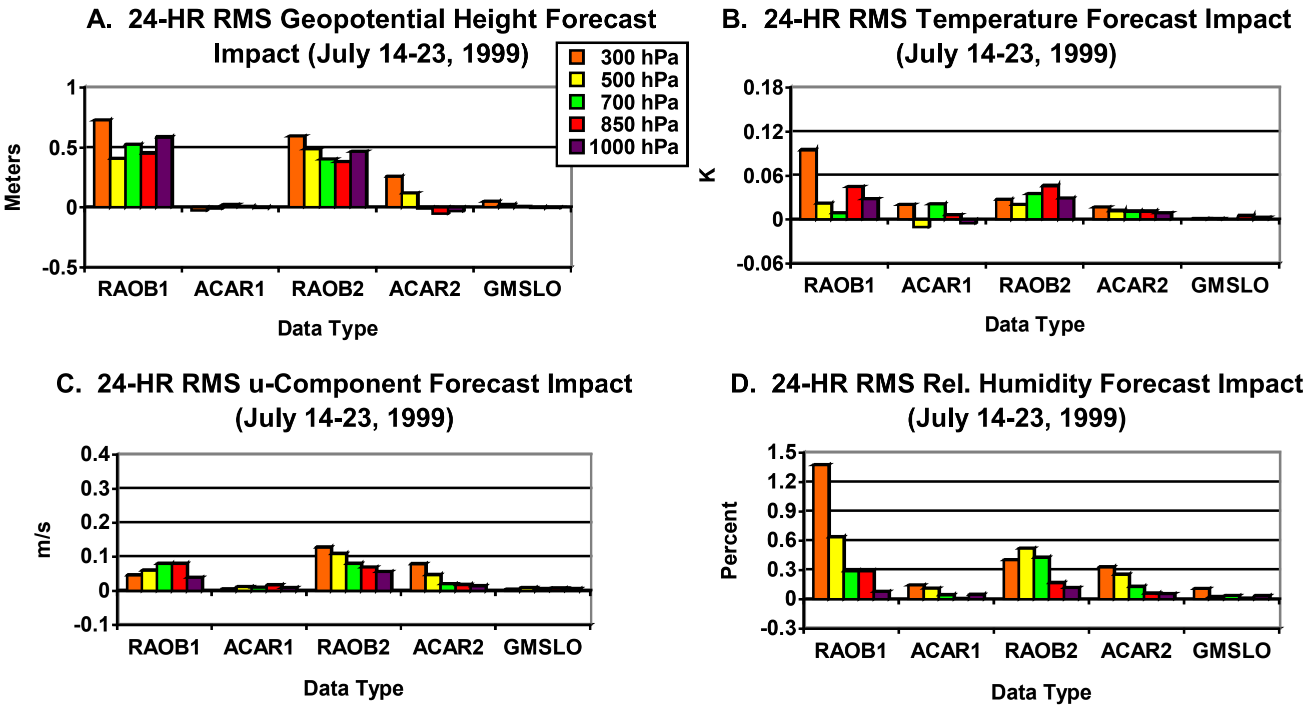

Fig. 8. Forecast impact of four more conventional data types as well as cloud drift wind information from GMS after 24-hrs of Eta model integration. These results are formed by summing over time the results of (2) for each model run from 0000 UTC 14 July 1999 through 1200 UTC 23 July 1999. The units of each field are listed on the y-axis.

The results from both RAOB and ACAR data types are not as easy to understand. These two data types are assigned relatively small errors to the observation (large importance), at least with respect to the satellite data types. However, when comparing Figs. 6 and 8, it is clear that the RAOB and ACAR data (Fig. 8) have generally speaking similar or smaller positive forecast impact than most of the five satellite data types (Fig. 6). Interestingly, ACAR1 forecast impact is very small for the four fields presented, even though its 00-hr sensitivity was as large as RAOB2. ACAR2 impact is still small but more significant than ACAR1 for both the u-component (Fig. 8C) and relative humidity (Fig. 8D) fields during the July 1999 time period. Of the five data types presented in this subsection, the RAOB1 and RAOB2 impacts are clearly the largest overall. However, in spite of what one might expect, their contributions are similar to or slightly smaller than many of the five satellite data types.

Several specific details about these summertime forecast impacts are now highlighted. First, with respect to geopotential height, RAOB1 and RAOB2 clearly provide the most positive forecast impact of the 10 data types presented for July (compare Figs. 6A and 8A). Second, with respect to temperature forecast impact, GOESM and GOESC have the largest overall positive contribution of the 10 July data types, due in large part to the significant positive impact at 850 hPa (compare Figs. 6B and 8B). Third, GOESC is the largest contributor to u-component forecast impact, RAOB2 is second most important (compare Figs. 6C and 8C). Fourth, the SSM/I and GOESM precipitable water data types are dominant with respect to overall positive forecast impact for relative humidity; however, RAOB1 has the largest positive forecast impact in the upper troposphere (compare Figs. 6D and 8D). Finally, the largest contribution of the five satellite data types is generally at 700 and 850 hPa, at least for the data types which have a significant impact (Fig. 6). On the other hand, the more conventional data types presented in this subsection tend to have their largest positive impacts at 300 and 500 hPa, especially RAOB1's relative humidity forecast impact (Fig. 8D).

4. Summary

This paper summarizes the 00-hr sensitivities and 24-hr forecast impacts of the EDAS to five satellite data types during 11-day periods in a winter, summer and transition season. The five satellite data types are SSM/I, GOESM, TOVCD, GOESC, and GOESW. The three 11-day periods are 13-23 December 1998, 10-20 April 1999, and 13-23 July 1999. Sensitivity and forecast impact statistics were presented for four standard meteorological fields, at each of five isobaric levels. The fields consisted of geopotential heights, temperature, u-component of the wind and relative humidity. While only the u-component statistics were presented, the v-component statistics for both sensitivity and forecast impact were found to be very similar to the u-component.

The 00-hr sensitivity results indicate that GOESC has nearly equal impact during all three time periods, while the precipitable water data types of SSM/I and GOESM have nearly twice as much impact in summer as winter. During the assimilation and forecast, most data types impact the fields they do not observe as much as the ones they do. For example, precipitable water data sets impact the u-component of the wind as much as GOESC cloud drift winds impact the relative humidity. Of the non-satellite data types, rawinsonde observations of temperature and moisture (RAOB1) were the most important of any data type in the 00-hr EDAS analysis.

The 24-hr forecast impact results indicate that all five of the satellite data types provide some positive impact. GOESC had the most positive overall forecast impact during the course of these simulations, at least when considering all fields examined during all three 11-day periods. The precipitable water data sets of SSM/I and GOESM had the most positive forecast impact during summer in terms of relative humidity, but their importance was reduced significantly during winter. GOESW had the smallest impact of all five satellite data types, with its overall contribution being just slightly positive. While the positive forecast impact is termed modest, it is important to note that very few negative forecast impacts were observed, either for the three 11-day periods as a whole (only 28 of 295 were negative), individual 11-day periods (16 of 100 were negative during July), or individual time periods. A separate investigation into the importance of more conventional data (both RAOB and ACAR) during winter and summertime established that their positive forecast impact was about the same or slightly smaller than the five satellite data types investigated, even though they were more important in the 00-hr sensitivities.

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