P3.20 ASSIMILATION OF MODIS RETRIEVALS WITH THE MM5/3DVAR SYSTEM IN AN ARCTIC EXTREME RAIN EVENT

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1. INTRODUCTION

A continuing difficulty with respect to the improvement of regional weather and climate model simulations relates to the fact that the input observational information is limited and inaccurate, especially in observationally sparse areas such as large oceans and remote polar regions. Although there are more conventional observation stations in most inland and populated areas, the number of observations is still not enough to fully characterize complicated weather systems, especially most extreme events.

Satellites provide the capability to monitor weather systems from outer space, and satellite data has been incorporated in numerical weather predictions through various data assimilation approaches. The three-dimensional variational data assimilation (3DVAR) approach has been used to improve objective data analysis and numerical model conditions in weather/research centers throughout the world (e.g., Rogers et al., 1996; Courtier et al., 1998; Lorenc et al., 2000). The 3DVAR system developed by the National Center for Atmospheric Research (NCAR, Barker et al., 2004) is used in this study along with the Fifth Generation Penn State University (PSU)/NCAR mesoscale model (MM5, Stauffer and Seaman, 1990) to conduct assimilation studies of satellite data during an extreme rain event.

The MM5/3DVAR system has previously been applied in the study of polar meteorology, such as in an Arctic reanalysis study and an Arctic extreme weather study presented in two companion papers in this volume, Tilley et al. (2005) and Fan et al. (2005). In the Arctic reanalysis study, Tilley et al. (2005) present their results on the applications of 3DVAR in the Arctic region through four generic case studies, one from each season. Fan et al. (2005) study the application of the MM5/3DVAR system in the simulation of an extreme rain event. The resolution sensitivity results are presented therein. Their results show that increasing the model horizontal resolution from 45 to 15 km produces better simulations/forecasts for all the experiments conducted and that the 3DVAR analysis shows some limited benefits over the MM5 control and nudging runs. The two major problems observed through the study of Fan et al. (2005) were determined to be: 1) the current background error covariance data is obtained from a global model which is not necessarily representative of the mesoscale MM5 model background error; 2) the observation data assimilated is sparse over the study domain, implying that utilization of new data sources remains a high priority in data assimilation and reanalysis efforts. The latter problem will be the focus of this study.

For the polar regions, the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments onboard the NASA Earth Observing System (EOS) satellites *Terra* and *Aqua* provide frequent, high density observations, including vertical profiles. The MODIS level 2 data are available at 5 km resolution on 20 vertical pressure levels. The MODIS-retrieved variables that are assimilated as a new observational data source into the MM5/3DVAR system include temperature, dew point temperature (humidity), geopotential height (or pressure), and total precipitable water. Numerical experiments have been conducted for the purposes of investigating the feasibility of assimilating MODIS data via 3DVAR, as well as its effect on the simulation of an extreme rain event.

The extreme rain event which occurred in the month of July 2003 is used as our case study. This event produced more than 8 cm (e.g., 15 cm in Fairbanks) of rain in a 24-hour period over parts of Interior Alaska, resulting in local flooding. A detailed description of the event can be found in Fan et al. (2005).

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2. ASSIMILATION SYSTEM

The same MM5/3DVAR data assimilation system is used here as in the companion paper by Fan et al. (2005). Since the emphasis of this study is on the introduction of a new observation data type (MODIS-retrieved profiles) into the 3DVAR system, most of the MM5/3DVAR configurations follow Fan et al. (2005) except for the preprocessing of the MODIS data. The global background error for MM5 is created by NCAR; adjustments of the variance scaling factors and the length scalings are applied following Fan et al. (2005).

3. MODIS DATA PROCESSING

3.1 Observation Error

The first thing which must be done in order to introduce a new observational data type into the 3DVAR system is to determine the observational error, i.e. just how accurate are the observations to be input? To this end, we used a statistical no-bias assumption on conventional sounding data, and compared MODIS-retrieved temperature, dew point temperature, relative humidity, geopotential height, and precipitable water with radiosonde data in order to determine the approximate observational error for the MODIS data for each of these variables.

Though for this case we were primarily interested in the accuracy of the MODIS measurements over the Arctic region in the summer, due to the relative paucity of radiosonde data in this part of the world we used soundings from the entire northern hemisphere over a one month period (July 2002), along with all available MODIS profile data from this same time in order to estimate the observational error. For each available radiosonde profile, we determined the difference between the MODIS-derived and in-situ measurements for the previously stated variables. This was done for the reported standard pressure levels which coincide with the 15 levels used for observation error in the 3DVAR preprocessor. Non-standard levels were disregarded in order to avoid introducing additional errors via interpolation. For each radiosonde, the closest MODIS data point was chosen for the comparison, provided it was located within 50 km. All told, this procedure resulted in a data set of ~1000 error values for variables at levels low in the atmosphere, with decreasing numbers higher up. We then averaged these differences over the entire Northern Hemisphere for each variable and level in order to determine the mean error, which was then used as the observational error input to the 3DVAR system.

3.2 Thinning

A problem which must be addressed with regard to the assimilation of very high resolution satellite data is the degree to which is must be pared down to prevent it from overwhelming the background as well as other, less concentrated observational types. The standard 3DVAR preprocessor contains an option to thin the satellite data types which it can accommodate, by default picking out one observation per model grid cell. After trying a similar approach for the assimilation of MODIS profiles, we discovered that the analysis increments generated were still undesirably large over the portions of the domain containing satellite data, which in turn led to disappointing model results. Through experimentation with different levels of thinning, we finally settled on using a thinning increment of one profile per 10 model grid points in both the x and y directions. With our model grid resolution of 15 km, this results in including one profile per $(150\ \text{km})^2$ region. This compares favorably with the distribution of conventional sounding data, and analysis increments generated over the satellite coverage areas were of similar magnitudes as those calculated from a typical set of radiosonde data.

4. ASSIMILATION EXPERIMENTS

In order to investigate the assimilation of MODIS data and easily perform comparisons, four experiments have been conducted. Two 3DVAR experiments using MM5 analysis (NCAR/NCEP reanalysis data enhanced by surface and upper-air observations via objective analysis) and forecast data (cold start mode and cycling mode, respectively) as background have been performed which are denoted by “3DVARic” and “3DVARc”. These two experiments did not include MODIS data. The final two experiments performed incorporate MODIS data assimilation, and are based on the first two. The indicator “MOD” is added to the notations of the previous two experiments to represent the two new runs, “3DVARicMOD” and “3DVARcMOD”.

5. RESULTS

As a part of our serial study, and following the companion paper by Fan et al. (2005), here we extend the verification and focus specifically on the impacts of MODIS data assimilation via the MM5/3DVAR system. Since our goal is the assimilation of relatively high resolution MODIS data, the higher resolution (15 km) experiments are the focus of the investigation below.

5.1 Impacts on 3DVAR Increment

For a given model analysis/forecast time, MODIS observations that fall into a ±30-minute window are assimilated. For example, the 6:20 am MODIS observations (shown in Figure 1 where cloud top temperature is used to illustrate the satellite coverage) are included at model time 6:00. After thinning, 136 MODIS profiles from the satellite pass shown in Figure 1 are assimilated.

The 3DVAR increment fields are the first place that assimilation of MODIS data will show its impact. In both the 3DVARic and 3DVARicMOD experiments, for example, the MM5 analysis is used as background and all the available conventional observations are assimilated. The only difference between the two experiments is that 3DVARicMOD includes assimilation of MODIS profiles. When the MODIS data from the pass shown in Figure 1 is assimilated, the 3DVAR increments of temperature, wind, pressure, and mixing ratio have all been affected. For example, Figures 2a and 2b show the 3DVAR increments of the lowest sigma level temperature before (in 3DVARic) and after (in 3DVARicMOD) the MODIS data is ingested, respectively. Assimilation of MODIS data has introduced clear differences in the temperature increments. In contrast to the increments that are created by the assimilation of solely conventional data in Figure 2a, Figure 2b shows that including the MODIS data seems to have amplified the increments in some areas (e.g., northwest Canada) and created new features elsewhere (e.g., Kenai Peninsula). The negative increment minimum in northwest Canada has been amplified from -2.0 C to -3.4 C. On the other hand, the positive increment maximum on the Alaska-Canada border has been increased from 0.71 C to 0.89 C. Along with the presence of the amplified negative increments in southwestern Alaska, the horizontal gradient of the increment field has been enlarged in the orthogonal direction of the satellite path (see Figure 1). The domain-

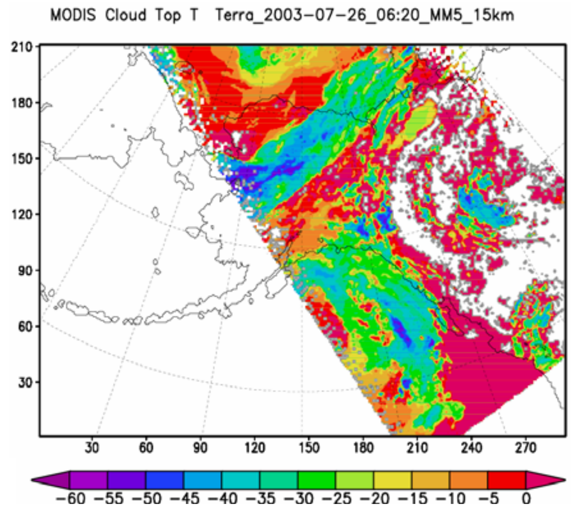

Figure 1 MODIS cloud top temperature from satellite *Terra* valid at 6:20 am UTC 26 July 2003.

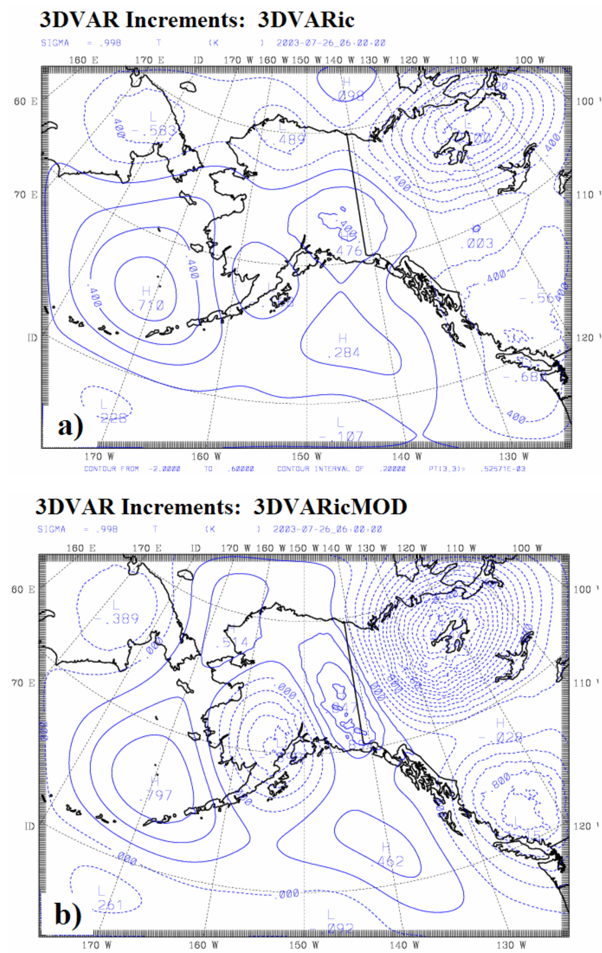

Figure 2 3DVAR increment in the lowest sigma level temperature for 1) experiment 3DVARic in which only conventional observations are assimilated; and 2) experiment 3DVARicMOD in which both conventional observations and MODIS profiles are assimilated.

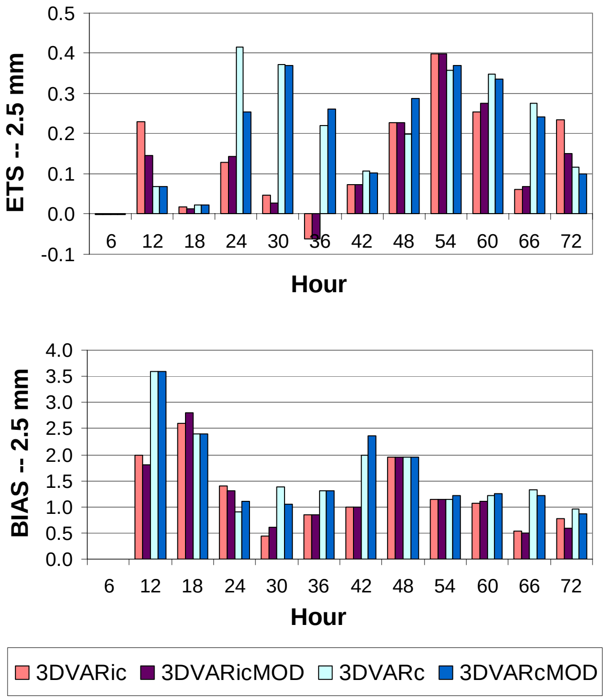

Figure 3 Equitable Threat Score (ETS) and Bias for the 2.5 mm precipitation threshold for the experiments in the legend.

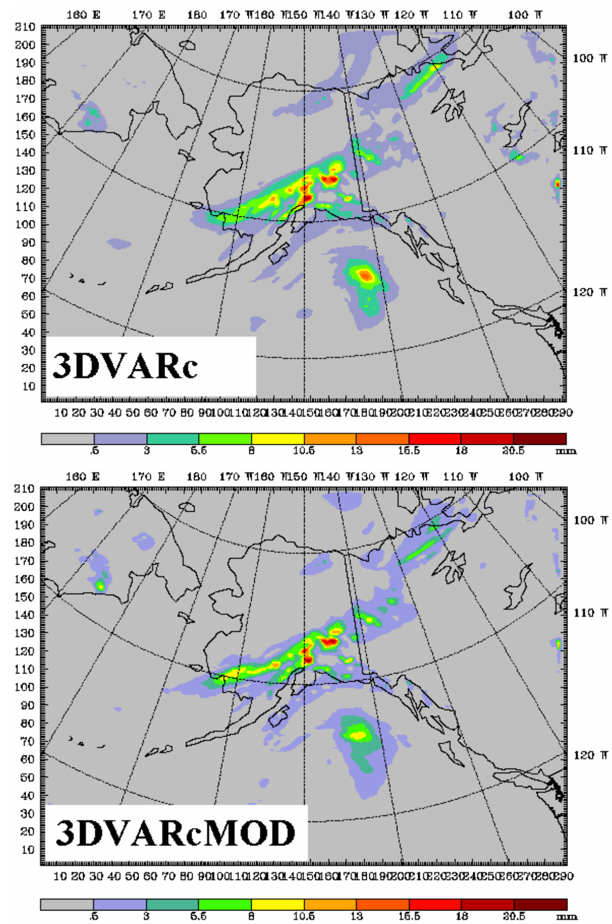

Figure 4 Model forecasted 6-hour accumulated precipitation (mm) valid at 12 UTC 28 July 2003 for high resolution (15 km) experiments without (3DVARc) and with (3DVARcMOD) the MODIS data assimilated.

wide mean increment has been changed from -0.137 C to -0.145 C, and the root-mean-square increment from 0.42 C to 0.7 C.

5.2 Impacts on Forecasts

Through verification against station observations of surface temperature, winds, humidity, and sea-level pressure, the MODIS data assimilation displays little impact on model forecasts in terms of absolute root-mean-square error and biases in the experiments conducted for this case study.

For the precipitation forecasts, the equitable threat scores (ETS) and biases are calculated. Figure 3 shows the ETS and bias at the 2.5 mm threshold. Again, no significant impacts from the inclusion of the MODIS data are seen. However, the cycling mode of 3DVAR shows better skill in precipitation forecasts than the cold mode of 3DVAR. A Student's t-test on the ETS score shows that the cycling mode 3DVAR with only conventional data improves ETS over the cold mode 3DVAR at a confidence level of 85%, while the cycling mode 3DVAR including both conventional and MODIS data results in a higher confidence level of 93%.

Figure 4 shows the simulated 6-hour accumulated precipitation valid at 12 UTC 28 July 2003 from experiments 3DVARc and 3DVARcMOD. Comparing the two plots in Figure 4, we can see that the changes caused by the assimilation of MODIS data are larger over the oceans than over inland areas. This provides further evidence that increased data assimilation benefits data-sparse areas the most and implies that observational data assimilation (of MODIS and other satellite data) in the Arctic and other oceanic areas has a significant benefit.

Figure 5 shows a time series of observed and modeled 6-hour precipitation at Fairbanks, AK for all four experiments. It is apparent that MODIS data has a very small impact for this inland station;

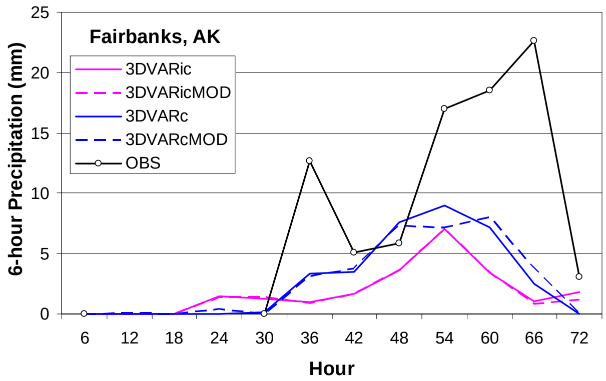

Figure 5 Observed and model 6-hour precipitation time series for the station Fairbanks, AK.

again, the cycling mode 3DVAR experiments (3DVARc and 3DVARcMOD) produced more realistic precipitation forecasts than did the cold mode 3DVAR experiments.

6. SUMMARY

The MODIS retrieved profiles of temperature, dew-point temperature, relative humidity, geopotential height, and total precipitable water have been successfully added as a new observation type into the MM5/3DVAR system. Observation error has been diagnosed for use in 3DVAR through verification against radiosonde data from the entire Northern Hemisphere. MODIS data assimilation via the MM5/3DVAR system has been studied for an extreme rain event. For this case, the MODIS data introduced additional increments to the 3DVAR analysis, and had a relatively larger impact on the precipitation forecasts over the ocean areas than inland. The impacts on surface temperature, surface winds and humidity, and sea-level pressure, though, were all relatively insignificant in the experiments conducted for this case.

However, the study presented in this paper is not the final word on the impact of MODIS data in the Arctic. More cases will need to be examined and other assimilation strategies to be considered. We are performing experiments for the four generic cases as described in Tilley et al. (2005), as well as two other extreme cases (a snow case and an Arctic cyclone case). More results and further conclusions will be presented at the conference.

Also, as we have discussed in two companion papers in this volume (Tilley et al., 2005; Fan et al., 2005), replacing the generic background error covariance which we have so far been using remains a critical step towards better performance in data assimilation via 3DVAR. We are presently working to produce customized background error statistics for our local MM5 model, which will be used in place of the global MM5 background error; results will be presented if complete.

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