P1.4 THE IMPACT OF ASSIMILATING SATELLITE-DERIVED HUMIDITY ON MM5 FORECASTS

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1. INTRODUCTION

Due to the sparse nature of conventional observations, data assimilation methods and data sources are still areas of considerable research and development. Mesoscale weather forecasts are heavily influenced by the amount of observations.

Previous studies of an Alaska heavy rain event showed the benefits of both a Newtonian nudging scheme (NN; Tilley and Fan, 2001) and an intermittent data assimilation scheme using a Bratseth analysis technique (IDA; Fan and Tilley, 2001). However, some problems were revealed in the aforementioned studies, including terrain-associated wet biases and a lack of systematic domain-wide improvements in the forecasts. A primary contributing factor to the above problems may well be the sparse nature of available observational data. Available surface observations and upper air soundings are too sparse to give a good representation for meso- or micro-scale atmospheric structures, especially over areas of complex terrain.

High resolution AVHRR (Advanced Very High Resolution Radiometer) infrared data from NOAA polar-orbiting satellites has 4 km resolution, which can provide a wealth of information for application to mesoscale simulations and forecasts. In this study, the AVHRR infrared imaging data is utilized in an attempt to improve mesoscale cloud and precipitation representations.

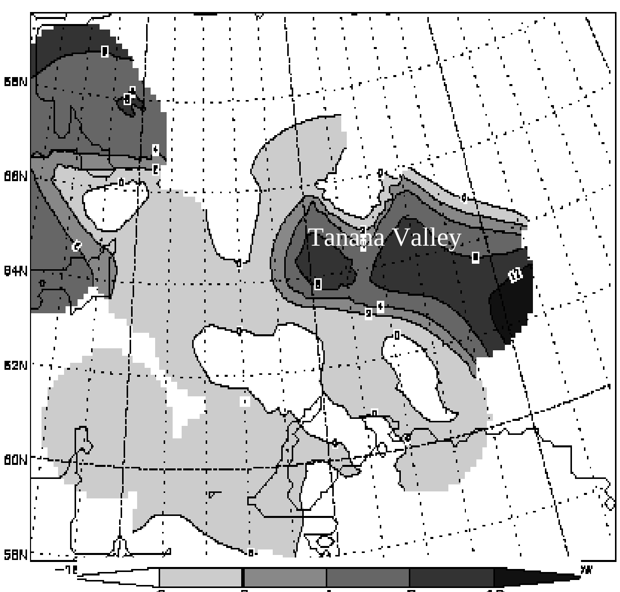

Figure 1. Station observed 24-hour accumulated rainfall (mm) at 12 UTC Aug. 12, 2000.

2. MODEL AND CASE

The MM5 model is configured with two nested domains with grid resolutions of 45 and 15 km, respectively. The dimensions of the two domains are 109x90 and 106x88. Both have 41 sigma levels vertically.

The Alaska heavy rain event of Aug. 11-13, 2000, described in detail in Tilley and Fan (2001), is studied here. Figure 1 shows the observed 24-hour accumulated rainfall within the 15km domain at 12 UTC Aug. 12, 2000.

3. METHODOLOGY

AVHRR data is used to derive cloud distribution both horizontally and vertically. As a result, cloud flag (i.e., clear or cloud) at each 3-dimensional grid point of the MM5 model can be obtained. Then the MM5 analyzed (for NN procedure) or forecasted (for IDA cycles) 3-dimensional specific humidity field is adjusted according to empirically derived relative humidity thresholds for cloudy or clear grid cells. The adjusted humidity fields is then used in both NN and IDA assimilation experiments.

3.1 *Satellite Data*

This study focuses on the impacts of satellite data on mesoscale forecasts. Satellite cloud imagery provides a visual representation of the cloud systems. Figure 2a shows the AVHRR channel 4 (10.3-11.3 μ) brightness temperature at 0008 UTC Aug. 12, 2000. However, in order to use them in numerical weather simulations, information on atmospheric variables must be derived. In this study, we choose to derive humidity from the AVHRR channel 4 brightness temperature through a simple method described below.

3.2 *Cloud Top and Base*

Under a one-layer cloud assumption, AVHRR channel 4 provides approximately the cloud-top brightness temperature where it is cloudy or the surface brightness temperature where it is clear. Using the MM5 analyzed 3-dimensional temperature field, we consider the model cloud top as being present at the level where the model temperature equals the channel 4 brightness temperature.

The model analyzed surface temperature T_g and temperature profile are used in the determination of cloud base. However, there often exist temperature inversions in high latitudes. In such instances we also utilize the maximum temperature of a vertical column,

T_m. Following the cloud detection algorithm of Garand and Nadon (1998) and considering the lifting condensation height, we consider the cloud base to be present at the level where the temperature (in °C) equals the larger of the quantities (T_g-3) and (T_m-4). If there is more than one solution, the height of the second closest solution to the surface is assigned as the cloud base. The rationale for this is that when a single inversion is present, the profile is statically stable below the inversion. The situation differs when there are three or more solutions (elevated inversion case); in this event, the lowest part of the profile is well mixed and clouds are likely to be present above this mixed layer.

3.3 *Humidity Adjustment*

The MM5 analyzed humidity field is adjusted according to the cloud field. A series of relative humidity (*RH*) thresholds (denoted by RH_{cld} and RH_{clr}) at different sigma levels have been empirically derived for both cloud and clear conditions based on statistics of relative humidity distributions. (More information on these thresholds will be presented at the conference.) The adjusted relative humidity will be set to RH_{cld} if $RH<RH_{cld}$ and it is cloudy or set to RH_{clr} if $RH>RH_{clr}$ and it is clear.

Experiments for testing these *RH* thresholds were conducted in which the adjusted humidity field was used to start up the model. The cloud-top temperature field after an hour of integration is shown in Figure 2b. Figure 2c shows the cloud-top temperature after a similar integration utilized the unadjusted humidity. By comparison with the AVHRR brightness temperatures in Figure 2a, it is clear that the cloud field is improved with the humidity adjustment scheme.

3.4 *NN and IDA Assimilation Approaches*

Two assimilation approaches are used in this study. The first is the Newtonian nudging (NN) approach (e.g., Simpson and Stauffer, 1996). Tilley and Fan (2001) investigated its usage over high latitudes. Their results have shown that nudging to different variables or with different nudging coefficients has significant impact on the simulation. Using both observation nudging and analysis nudging produced better simulations, consistent with the previous studies of Stauffer and Seaman (1990).

The second approach is an intermittent data assimilation with Bratseth analysis (IDA), which has been studied for the high latitude heavy rain event mentioned above (Fan and Tilley, 2001). During the IDA cycles, the model simulation is stopped when new data sources are available and a reanalysis is done before the model forecast is resumed. The model evolution is

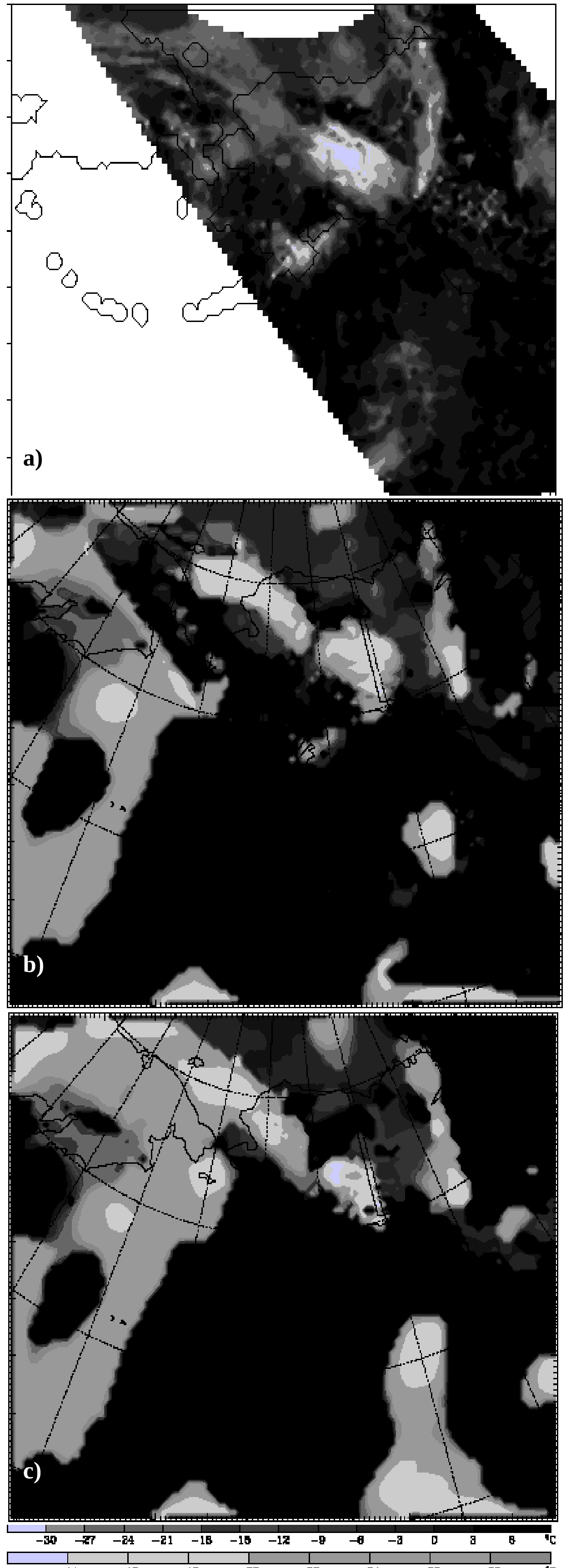

Figure 2. Cloud top temperatures from a) AVHRR Ch. 4 brightness temperature at 0008 UTC 12 Aug 2000; b) 1-hour MM5 simulation using adjusted humidity; c) 1-hour simulation using unadjusted humidity. Temperatures in °C

redirected toward the observations by reanalyzing the new observations into the model states.

4. EXPERIMENTS AND RESULTS

For the purpose of studying the impacts of AVHRR derived humidity on mesoscale forecasts via the two assimilation approaches, two control runs (Ctrl1 and Ctrl2) are designated in this study. Ctrl1 uses both observation nudging and analysis nudging on variables of temperature, wind, and mixing ratio at 6-hour intervals. Ctrl2 does intermittent data assimilation at 6-hour intervals using the Bratseth analysis scheme to ingest new data during the assimilation cycles. Table 1 gives the description of the experiments.

Table 1 Experiment design

Experiment	Assimilation Approach	AVHRR
Ctrl1	NN, observation + analysis nudging of temperature, wind, mixing-ratio at 6-hour interval	No
Ctrl2	IDA/Bratseth at 6-hour interval	No
A_NN6	Same as Ctrl1	Yes
A_NN3	Same as Ctrl1 except at 3-hour interval	Yes
A_IDA6	Same as Ctrl2	Yes
A_IDA6_NN3	Combination of A_IDA6 and A_NN3	Yes

Experiment A_NN6 uses the adjusted humidity instead of the MM5 analysis for the humidity nudging variables for 6-hour NN intervals. Figure 3 shows the simulated 24-hour accumulated precipitation at 12 UTC Aug. 12, 2000 and its difference from Ctrl1 in the fine domain. Two benefits of assimilating AVHRR information are shown here: more precipitation in the Tanana Valley rain centers, and reduced terrain-associated wet biases.

Given that the assimilation of AVHRR data has improved the simulation in Exp. A_NN6, it is worth trying to ingest more information. Experiment A_NN3 ingests 5 more time periods of AVHRR data for nudging at 3-hour intervals. Results (not shown) indicate a similar pattern of improvement, with the magnitude of the differences from Exp. Ctrl1 much larger than for Exp. A_NN6.

Experiment A_IDA6 utilizes AVHRR data at 6-hourly intervals via the IDA approach. Figure 4 shows the simulated 24-hour accumulated precipitation at 12 UTC Aug. 12, 2000 and its difference from Ctrl2 in the fine domain. The result indicates that this experiment produced more precipitation in the Tanana Valley than Ctrl2, though amounts were overforecasted in this area as well as near the Canadian border. The wet biases over high terrain are also reduced.

To examine the timing of the precipitation events, station precipitation time series can be examined. Figure 5 shows an example for station Big Delta (64.0N, 145.7W), which is close to the heavy rain center. It is shown that NN methods produce a better average trend

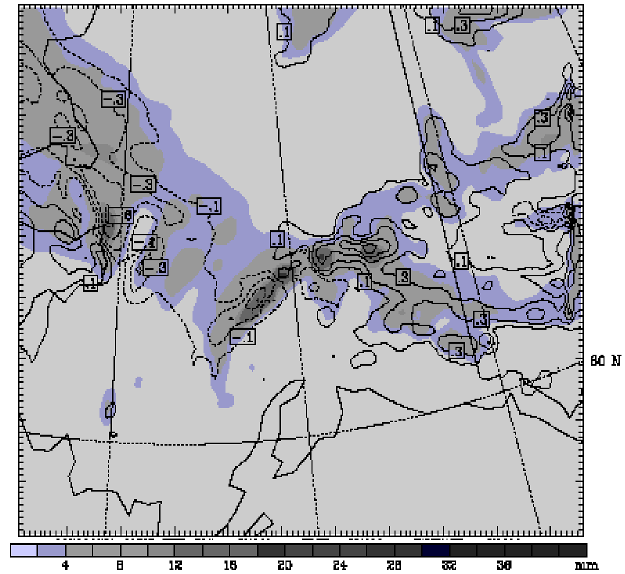

Figure 3. 24-hr accumulated precipitation (mm, gray scale) of A_NN6 and its difference (contour) from Ctrl1, at 12 UTC Aug. 12, 2000.

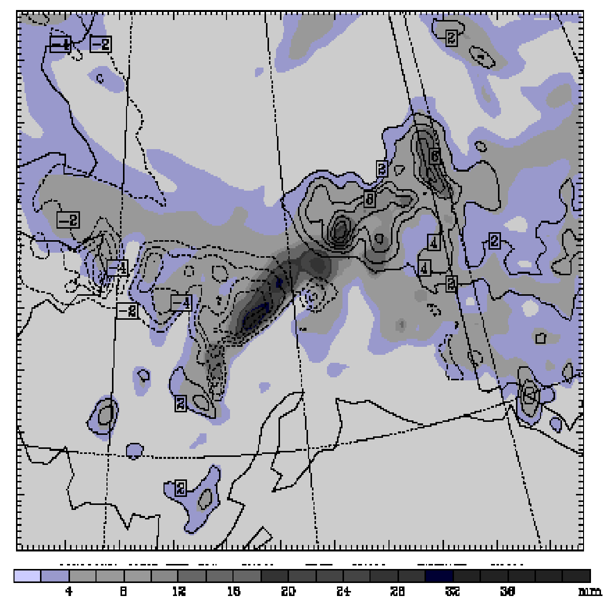

Figure 4. 24-hr accumulated precipitation (mm, gray scale) of A_IDA6 and its difference (contour) from Ctrl2, at 12 UTC Aug. 12, 2000.

while IDA approaches produce stronger peak rain rates (e.g., 06 UTC 12 August). This may be the reason behind the overforecast areas seen in Figure 4.

Based on the above results, experiment A_IDA6_NN3 was conducted, in which the IDA approach is conducted at 6-hour intervals and while 3-hourly nudging is applied during each IDA cycle. Figures 6a and 6b show the results in terms of differences from the results of Exps. Ctrl1 and Ctrl2. Figure 6a indicates that more precipitation has been

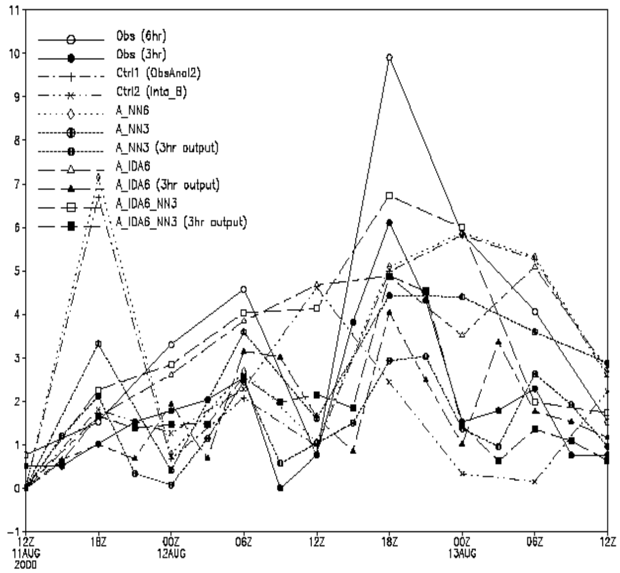

Figure 5. Time series of observed and simulated precipitation at station Big Delta (64.0N, 145.7W).

produced in interior Alaska and less in western Alaska in comparison with exp. Ctrl1. The comparison with Ctrl 2 (Figure 6b) shows a similar pattern to that seen in Figure 4, but without the overforecasting of precipitation seen there and noted in the discussion of Exp. A_IDA6. The time series of this experiment (Figure 5) also indicates improvement over the other simulations.

5. SUMMARY

A simple technique has been developed to derive cloud and humidity from AVHRR. The derived information has been assimilated into MM5 via two economic approaches, Newtonian nudging (NN) and intermittent data assimilation with Bratseth analysis (IDA). A high latitude heavy rain case has been studied. The results show the following conclusions:

- Clouds and humidity derived from AVHRR adds value to the precipitation forecast.
- In assimilating AVHRR derived humidity, the NN approach produces better trends while the IDA approach produces better peak rain rates.
- The combination of NN and IDA approaches in assimilating AVHRR derived humidity improved the precipitation significantly.

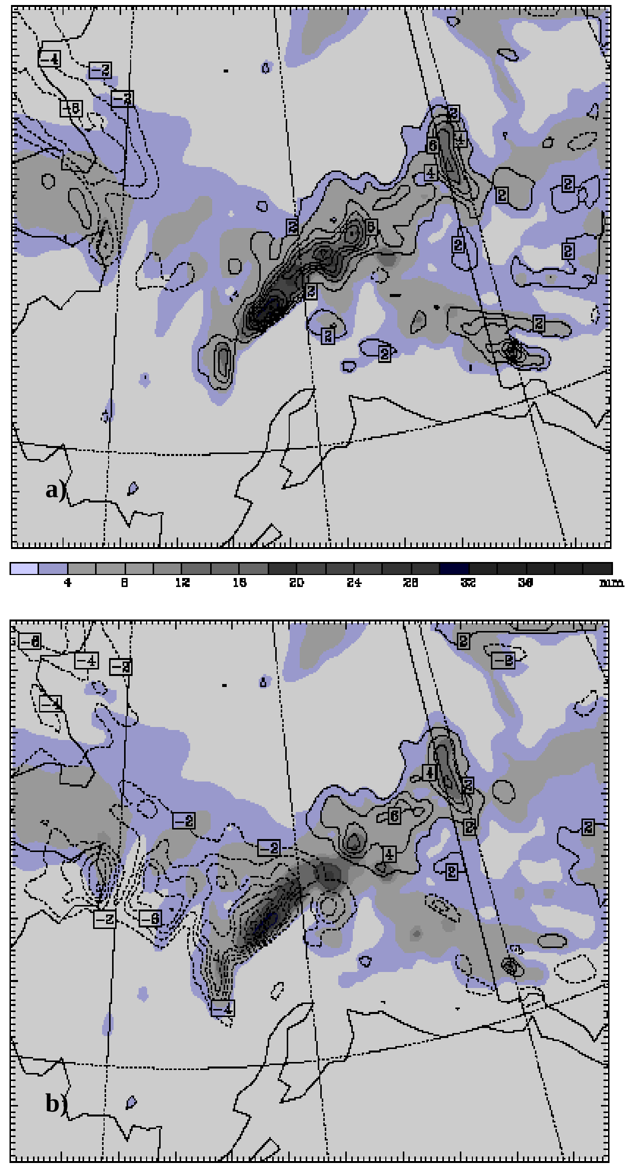

Figure 6. 24-hr accumulated precipitation (mm, gray scale) of A_IDA6_NN3 and its differences (contour) from (a) Ctrl1 and (b) Ctrl2.

REFERENCES

Grand, L and S. Nadon, 1998: High-resolution satellite analysis and model evaluation of clouds and radiation over the Mackenzie Basin using AVHRR data. *J. Climate*, **11**, 1976-1996.

Fan, X., and J. S. Tilley, 2001: Application of the Bratseth Scheme for High Latitude Intermittent Data Assimilation Using the PSU/NCAR MM5 Mesoscale Model. Preprint, *14th Conference on Numerical Weather Prediction*, AMS, Ft. Lauderdale, FL, J139-143.

Simpson, J. D. and D. R. Stauffer, 1996: Assimilation of SSM/I precipitable water data for improving extended-range dynamic analysis of the tropical Pacific. Preprint, *11th Conference on Numerical Weather Prediction*, AMS, Norfolk, VA, 270-272.

Stauffer, D. R. and N. L. Seaman, 1990: Use of four-dimensional data assimilation in a limited-area mesoscale model. Part I: Experiments with synoptic-scale data. *Mon. Wea. Rev.*, **118**, 1250-1277.

Tilley, J. S., and X. Fan, 2001: Revisiting the utility of Newtonian nudging for four-dimensional data assimilation in high latitude mesoscale forecasts. Preprint, *14th Conference on Numerical Weather Prediction*, AMS, Ft. Lauderdale, FL, J144-149.