11A.4 **COMPREHENSIVE TEST-RIG FOR WRF DATA ASSIMILATION DEVELOPMENTS AT NCAR'S DATA ASSIMILATION TESTBED CENTER**

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1. INTRODUCTION

To apply the mostly recent developed data assimilation techniques and ingest new satellite observations into an operational system requires an end-to-end examination of the system and a thorough evaluation of the impacts of the new components on weather forecasts. By closely working with both research and operational communities, the Data Assimilation Testbed Center (DATC) at NCAR has been focusing on preparation, testing, and implementation of data assimilation systems, therefore, leveraging the efforts of the development teams and operational centers.

This paper provides a summary of the on-going work at the DATC to test the NCAR's WRF-ARW and WRF Variational Data Assimilation System (WRF-Var) and a preview of future plans as well.

2. TESTBED STRATEGY

The DATC has built a framework in which extended testing can be conducted. The strategy to ensure testing is performed thoroughly includes the following three-step procedure:

- Define a reference configuration related to model, namelists, testing period, testing suite scripts and verification package.
- Run "benchmark" defined by above reference configuration.
- Perform "sensitivity" tests by varying components of the reference configuration (typically only namelists are modified).

For current WRF-Var testing, an end-to-end model system available at the DATC includes: the WRF Preprocessing System (WPS); WRF-ARW; WRF-Var; and the WRF-Var based verification package. The whole system was run in either cold-start mode (using an independent analysis/forecast product as the first-guess for WRF-DA) or cycling mode (using a previous forecast as the first-guess) for an extended period of time so that the capability and stability of the whole system and the varying components of the system could be examined closely.

3. STATUS AND SOME RESULTS

Currently, the DATC has various project testbeds active in varying domains. Extended tests of the end-to-end system have been conducted in these domains to assess the impact of different observation types and different system configurations on short-range forecasts. Some results are briefly described in this paper.

3.1 AMSU-A RADIANCES

The AMSU instrument detects the Earth/atmosphere emitted radiation in the microwave portion of the electromagnetic spectrum. The AMSU-A (temperature sounder), a 15 channel passive radiometer, detects energy emitted by atmospheric molecular oxygen (a major atmospheric constituent) and is largely unaffected by the presence of clouds--from the emission source, through the atmosphere, to the sensor which resides on polar orbiting satellites.

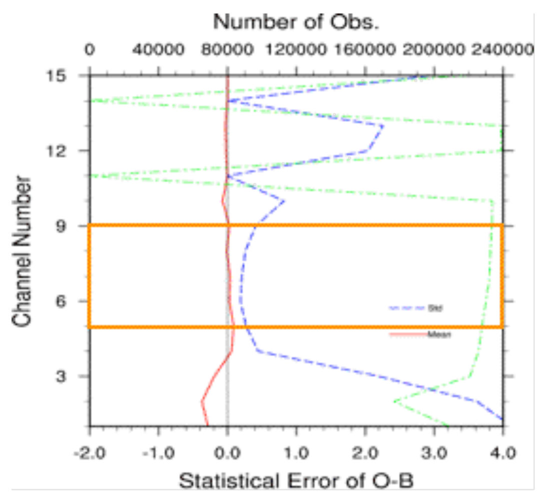

Fig. 1 Statistical bias (red, units: K), standard deviation (blue, units: K) and observation number (green) of AMSU-A brightness temperature observations in the southeast Asian domain for each of the 15 channels.

To evaluate the statistically significance of impact of AMSU-A data on forecasts, month-long experiments with and without AMSU-A data were conducted in two different domains: the Antarctic domain and the Southeast Asian domain. The AMSU-A data used in this study are BUFR formatted data from NOAA-15, 16, and 18. NCEP GFS analysis served as the first guess at the beginning of the cycling and lateral boundary conditions throughout the testing period. For the Antarctic domain, the testing period is October, 2006, which is the transition season of the area. For the Southeast Asian domain, it is August, 2007, the hurricane season.

Short of having the truth and collocated independent observations, the errors of the AMSU-A radiance data were estimated by comparing the observations with the analyses (as background) from the control experiment, GTS. Fig. 1 shows the statistical errors and the number of AMSU-A data in terms of brightness temperature in the Southeast Asian domain. Channels 5-9 have much smaller standard deviation values than most of the other channels and, therefore, were assimilated in the above-mentioned radiance data assimilation experiments.

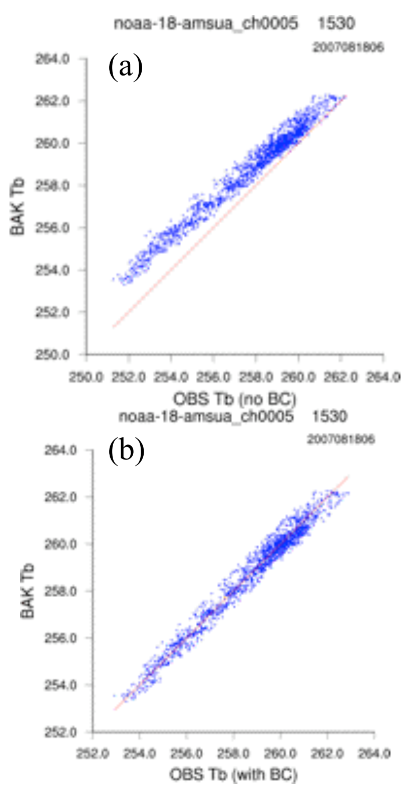

Fig. 2 Scatter plots of AMSU-A observations (x-axis) versus the background (y-axis) (a) before and (b) after BC.

Using the error statistics, the system bias in AMSU-A observations was corrected for each channel and satellite. As an example, Fig. 2 shows the scatter plots of the observations from Channel 5 of the AMSU-A onboard NOAA-18 versus the background (forecasts from GTS) before and after the bias correction (BC) in the Southeast Asian domain.

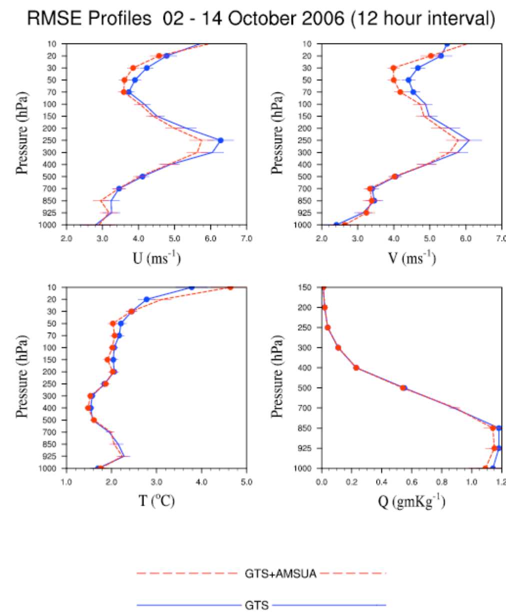

Fig. 3 vertical profiles of 36 hour forecasts from the control experiment (GTS) and the experiment with AMSU-A radiance data assimilated as an addition (GTS+AMSUA) verified against the conventional observations in the Antarctic domain.

In the Southeast Asian domain, the assimilation of AMSU-A radiance observations over ocean reduces the bias of the u and v-component of wind forecasts around 250-100 mb significantly. The impact on the forecasts of the other variables (u, T and q) was marginal. The root-mean-square errors (RMSEs) of these variables from the experiments are also very close.

The impacts of AMSU-A data assimilation on forecasts in the Antarctic domain are positive or neutral. Fig. 3 shows vertical profiles of 36 hour forecasts from the control experiment (GTS) and the experiment with AMSU-A radiance data assimilated as an addition (GTS+AMSUA) verified against the conventional observations in this domain. The assimilation of AMSU-A radiance observations over ocean reduces the RMSEs of wind forecasts through most of the vertical layers and moisture forecast at lower levels. The impact on the forecasts of the temperature was marginal mostly except for being negative close to the model top at 10mb.

3.2 AIRS RADIANCES

The Atmospheric Infrared Sounder (AIRS) is a high spectral resolution spectrometer with 2378 bands in the thermal infrared (3.7 - 15.4 μm) and 4 bands in the visible (0.4 - 1.0 μm). These ranges have been specifically selected to allow determination of atmospheric temperature with an accuracy of 1°C in layers 1 km thick, and humidity with an accuracy of 20% in layers 2 km thick in the troposphere.

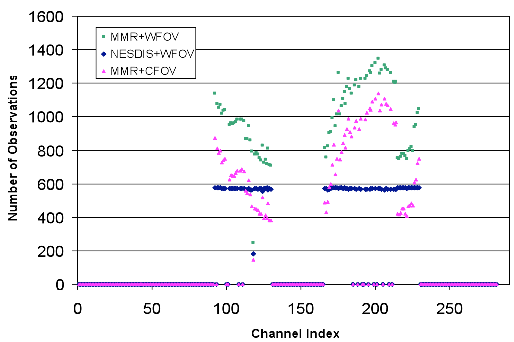

Fig. 4 MMR and Warmest FOV schemes increased assimilated observation number at 2007082606 compared with the default cloud detection and thinning schemes (Center FOV) in WRF-Var.

In this task, there are two sets of month-long experiments conducted at both 45km and 15km resolution grids in a tropical domain: The first is the control run, GTS, a full update cycling experiment with all available conventional data assimilation every 6 hours (excluding QSCAT and radiance retrievals); The second, GTS+AIRS, is the same as the GTS run, with AIRS radiance data (over both land and ocean) assimilated as an addition.

The AIRS data used in this study were from the Aqua satellite available at 06 and 18Z. Only those observed from the NCEP 281-channel subset (Goldberg et al. 2003) were assimilated in GTS+AIRS. The data were first thinned to a 90km horizontal resolution by picking the warmest FOV within each thinning grid box to avoid data correlations. The Multivariate Minimum Residual (MMR) cloud detection scheme was used to remove the radiance observations from those channels below the detected clouds. Compared with the default "hole-identifying" cloud detection scheme and central FOV thinning scheme, the MMR and warmest FOV schemes increased assimilated radiance observation number. As an example, Fig. 4 shows the number of assimilated radiance data with different combinations of cloud and thinning schemes at 06Z, August 26, 2007. The system bias of AIRS observations assimilated in GTS+AIRS was corrected for each channel using the Variational Bias Correction Scheme (VarBC). The VarBC cycle period for this experiment was 24 hours to avoid potential diurnal variation of bias correction coefficients. Four bias predictors, the offset, the satellite scan position, the square of the satellite scan position and the cube of the satellite scan position, were used in this experiment.

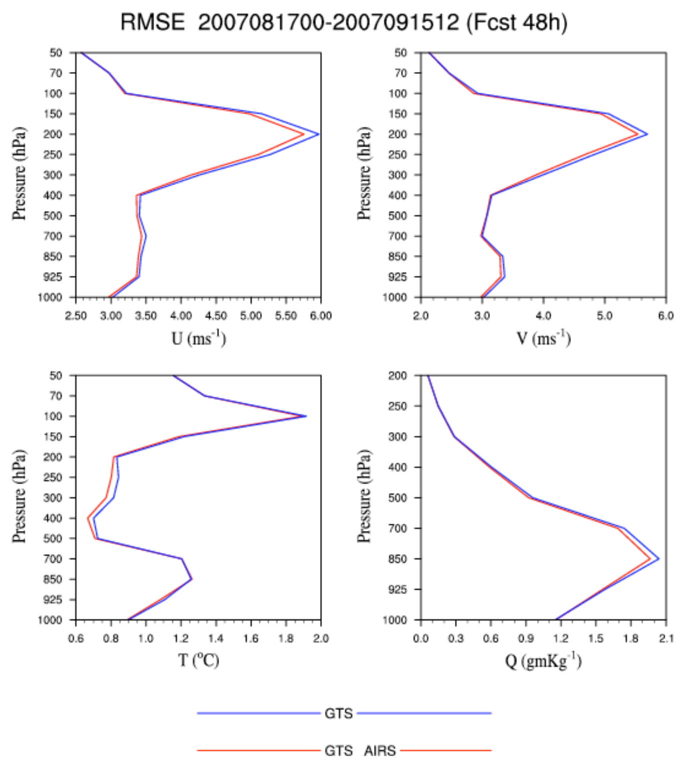

Fig. 5 Vertical profiles of the RMSEs of the 48 hour forecasts at 06Z and 18Z from GTS (blue) and GTS+AIRS (red) verified against ECMWF analyses: (a) u (m/s), (b) v (m/s), (c) T (K) and (d) q (g/kg).

As the AIRS observations assimilated in GTS+AIRS were only available at 06Z and 18Z, verifications were first made at 06Z and 18Z to access direct impacts on analyses and 6 hr forecasts. Assimilation of AIRS radiance data has small impacts on the biases of wind and temperature but relatively larger impacts on moisture in lower and middle atmosphere. The RMSEs of all four forecast fields were reduced with assimilation of AIRS data.

To be consistent with other experiments conducted at DATC, verifications were then made at 00Z and 12Z for analyses and 12-48 hour forecasts. The analyses at 00Z(12Z) from GTS+AIRS contain the information from both the conventional data assimilated at these times and the background, the previous 6 hour forecast at 06Z(18Z) which were made starting from the analyses with direct assimilation of AIRS radiances. That is, the impacts of AIRS data on forecasts at 00Z and 12Z are propagated from the previous forecasts and therefore indirect. Figure 5 shows vertical profiles of the RMSEs of the 48 hour forecasts. The RMSEs of wind and moisture analyses generated from GTS+AIRS are smaller than those from GTS. The RMSEs of temperature from these two experiments are similar ,with GTS+AIRS slightly better .

3.3 OTHER STUDIES

Besides radiance data impact studies, the DATC also reviewed other capabilities as part of the WRF-Var code and their impacts on analyses and forecasts. These capabilities include the observation tuning, ensemble based QC, outer-loop data QC, etc.

4. SUMMARY AND CONCLUSIONS

The DATC at NCAR performed a few month-long tests in various domains to assess the impacts of radiance data assimilation and other recent developments in the WRF-Var code. These extended pre-operational tests make it possible to understand the role of the new capabilities of the WRF-Var in improving weather forecasts over different geographical domains, and gain insights as to where and how the satellite data complement existing observation systems and whether and how recent developments in the data assimilation system to help improve the analysis and then forecasts.

In the coming year, the DATC will continue working on the existing testbeds and begin building new testbeds as required. We will test the impact of various capabilities through extended period testing. The DATC will also deliver testing reports to operational agencies and centers. These reports will include an impact assessment in terms of a) scientific verification and validation, b) computational performance, and c) potential technical changes required to implement upgrades.

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