Assimilation of Atmospheric InfraRed Sounder (AIRS) Profiles using WRF-Var

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ABSTRACT

A procedure to optimally assimilate Atmospheric Infrared Sounder (AIRS) thermodynamic profiles using WRF-Var is described. The paper focuses on the development of background error covariances and an optimal methodology for ingesting the AIRS profiles into an analysis by assigning separate land and water sounding error characteristics. The version 5.0 AIRS profiles contain information about the quality of each temperature layer, which is used to select the highest quality data at each profile location. Preliminary assessment of the impact of the AIRS profiles will focus on optimized tuning of the WRF-Var and comparison of analysis soundings to radiosondes.

1. INTRODUCTION

One challenge in numerical weather prediction is providing forecast models with an initial state that is a realistic description of the atmosphere. Observations from satellites are one valuable option to improve the model initial state, especially in data sparse regions. NASA's Atmospheric Infrared Sounder (AIRS)—a state-of-the-art atmospheric profiler—is one candidate to help overcome this forecasting challenge. AIRS radiances have been assimilated into global models yielding improvements in 500 hPa anomaly correlations out to 5-day forecasts (e.g. Le Marshall et al. 2006). However, for centers focusing on regional forecasting problems—such as NASA's SPoRT Center (Goodman et al. 2004)—assimilation of retrieved thermodynamic profiles is a logical first step to using AIRS. A methodology for assimilating AIRS thermodynamic profiles using WRF-Var is presented herein.

2. WRF-VAR IMPLEMENTATION

The WRF-Var is the three-dimensional variational (3DVAR) data assimilation component of WRF, which minimizes a cost function to estimate the true state of the atmosphere using a background from a previous forecast, observations, and their respective errors. These errors define the weighting of the background and observations such that larger background error for a variable will result in an analysis of that variable more closely resembling the observation (and vice versa). Observations are spread horizontally using a background error correlation length scale, which is a function of grid point separation. Observations are spread vertically using an empirical orthogonal function (EOF) decomposition of the vertical component of the background error (Barker et al., 2004).

The results herein use version 2.2.1 WRF-Var analyses with a 12-km (450 x 360) CONUS domain (see Fig. 1). The analysis contains 37 vertical levels with a top of 50 hPa. The background is a short-term Advanced Research WRF (ARW) forecast initialized with the North American Mesoscale (NAM) analysis at 0000 UTC and run to the AIRS observation time (selected as the mean time of the 2 easternmost AIRS swaths over North America).

2.1 Preparing the Observations

AIRS and the Advanced Microwave Sounding Unit (AMSU) form an integrated sounding system that can retrieve atmospheric profiles in clear and partly cloudy scenes. Due to its hyperspectral nature, AIRS can provide near-radiosonde-quality thermodynamic profiles that can resolve some small-scale vertical features. This superior vertical resolution and sounding accuracy make AIRS appealing as a complement to radiosonde measurements (Aumann et al. 2003). For this study, version 5.0 retrieved temperature and moisture profiles are used. These soundings contain 54 vertical levels below 100 hPa and have a spatial resolution of approximately 50 km at nadir.

Each profile contains level-specific quality indicators (QIs) that define a specific level below which data is of questionable quality. This level is generally consistent with clouds and land effects (Susskind et al. 2006). The QIs are used to select the optimal data from each profile for assimilation. A three-dimensional distribution of AIRS profiles for 21 January 2007 (as determined by the QIs) is shown in Figure 1.

Poorly-defined infrared emissivity due to inhomogeneous land type can lead to degraded

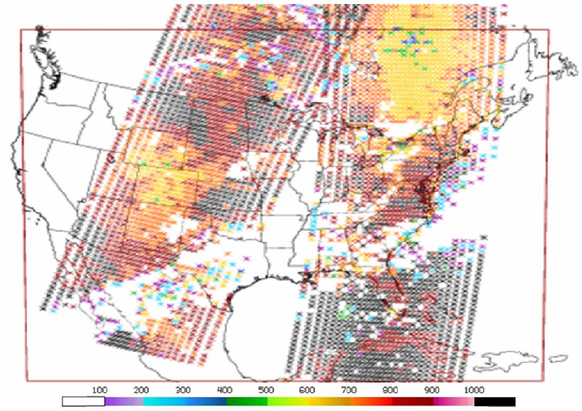

Fig. 1. Quality indicators for AIRS profiles assimilated at 0800 UTC on 17 January 2007. The black points represent the highest quality data, and each colored point denotes pressure level above which there is quality data. The red rectangle denotes the bounds of the WRF/ADAS domain.

AIRS retrievals over land (Borbas 2007). Thus, over land soundings will have larger errors than those over water. In this study, both land and water profiles are assimilated, so they are treated as two separate observation types in the analysis process. To accomplish this task, the WRF-Var source code was altered to accommodate an AIRS-land and an AIRS-water data set. Observation errors used for the AIRS profiles are based on estimates cited by Tobin et al. (2006). The over water soundings are assigned errors based on Tropical Western Pacific (TWP) validation, and the over-land soundings are assigned errors based on Southern Great Plains (SGP) validation (Fig. 2.).

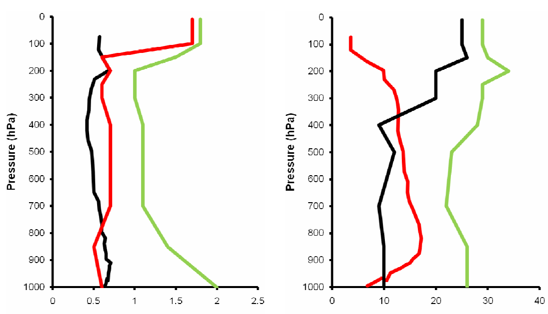

Fig. 2. Background errors (black) and observation errors (red: AIRS-water, green: AIRS-land) for WRF-Var analysis. It is the ratio of the background and observation errors that controls the magnitude of the analysis increment during the assimilation process.

*2.2 The **B** Matrix*

Correct use of the background error covariance matrix (**B** matrix) is important in determining the appropriate weighting between the background and observations, as well as how information contained in observations is spread horizontally and vertically. Optimal analysis configuration desires background errors that are consistent with the domain/grid spacing, the model used for the background, and the season. A **B** matrix was calculated using the National Meteorological Center (NMC) method of averaged forecast differences (Parrish and Derber 1992) using the “gen_be” program in the WRF-Var package. Short-term WRF forecasts for a two-week period (17 to 31 January 2007) were used to run the NMC method. The background length scale and eigenvectors, which describe the horizontal and vertical spread of the observations, are shown in Figures 3 and 4 respectively. The average background error over the entire domain is shown in Figure 2. The **B** matrix provides a temperature and relative humidity length scale

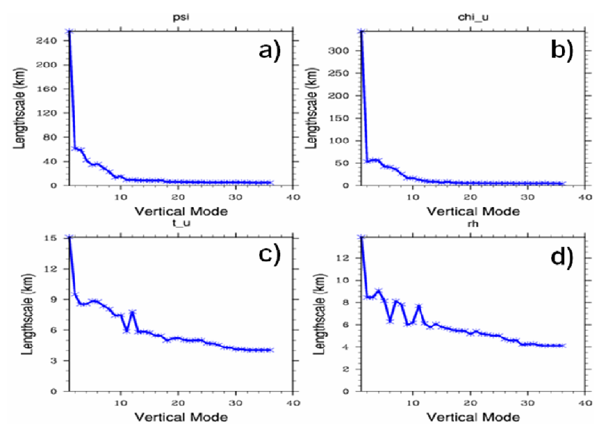

Fig. 3. Length scale for each control variable—a) streamfunction, b) velocity potential, c) temperature, and d) relative humidity—for WRF-Var analysis. The length scale controls the horizontal spread of the observations during the assimilation process.

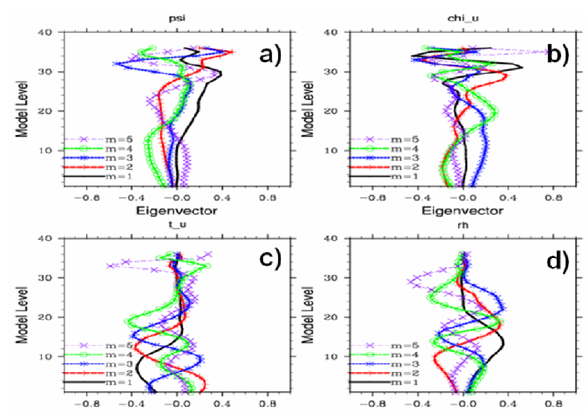

Fig. 4. Eigenvectors for each control variable—a) streamfunction, b) velocity potential, c) temperature, d) relative humidity—for WRF-Var analysis. The eigenvectors control the vertical spread of the observations during the assimilation process.

on the order of the analysis grid spacing. The first vertical mode, which analyzes large-scale features, is close to the grid spacing (Fig. 3 c and d).

3. ANALYSIS IMPACT

Analysis impact of AIRS profiles on 700 hPa temperature for 17 January 2007 is shown in Figure 5. Figure 5b shows the difference between the background and a Barnes analysis of the AIRS temperature profiles (innovations). AIRS temperatures are warmer than the background across the southeast US and cooler than the background across south Florida and the Great Lakes. AIRS profiles portray ±4°C differences from the background in some areas.

Figure 5c shows the analysis increment of temperature with the original length scale (length scale factor = 1). Since the estimates of background error length for higher vertical modes ($m \geq 2$) are smaller than the grid spacing (see Fig. 2c), the analysis tends to have a limited spread resulting in bull's eyes and stripping features. Tests were conducted using WRF-Var tuning factors, which adjust the spread of analysis variables by multiplying the length scale by the prescribed value. Subjectively, it was determined that a length scale factor of 1.5 and 2 for temperature and relative humidity, respectively, led to an optimal configuration that smoothed the bull's eyes and stripping without compromising analysis fidelity. Figure 5d shows the magnitude and horizontal spread of the AIRS profiles on the 700 hPa temperature analysis after the tuning is applied. The analysis increments depict ±3°C changes in a similar pattern to the innovations (Fig. 5b) emphasizing the impact of AIRS on the analysis. Moisture at 700 hPa (not shown) reveals a similar impact. The 700 hPa results are representative of results at most other levels.

To further illustrate the impact of the AIRS profiles, Figure 6 shows collocated 0800 UTC soundings near Greensboro, NC (GSO). The 0800 UTC radiosonde (green) is a linear interpolation of 0000 and 1200 UTC soundings. The background (black) is too cool and dry below 600 hPa compared to the radiosonde. The AIRS profile (blue) is warmer and much moister than the background. When AIRS observations are assimilated, the analysis (red) is warmer and moister than the background. For the temperature analysis, the inclusion of AIRS

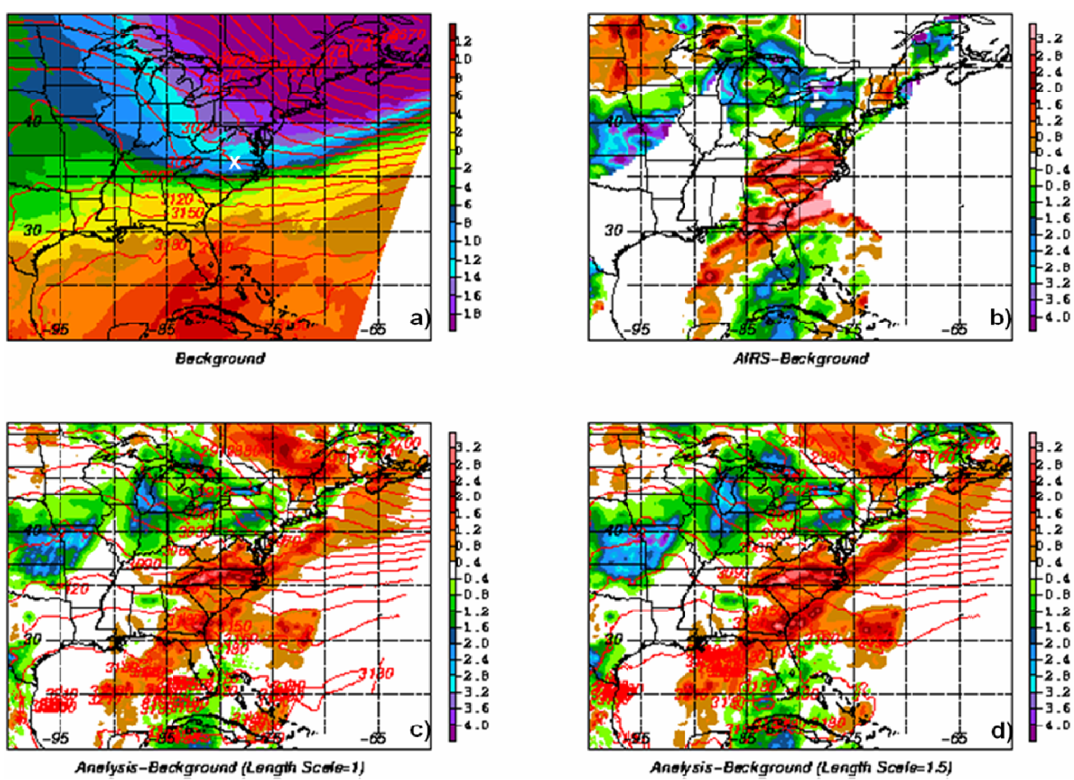

Fig. 5. Analysis impact of AIRS on 700 hPa temperature for 17 January 2007. The difference between the AIRS and the background is shown in b) resulting in the analyses in c) and d). The analysis with the original length scale resulting in bull's eyes and stripping (especially evident over KS and MO) is shown in c) while d) shows the impact of tuning the length scale to remove some of those smaller scale features. The "x" in a) denotes the location of the Greensboro, NC sounding described in Figure 6.

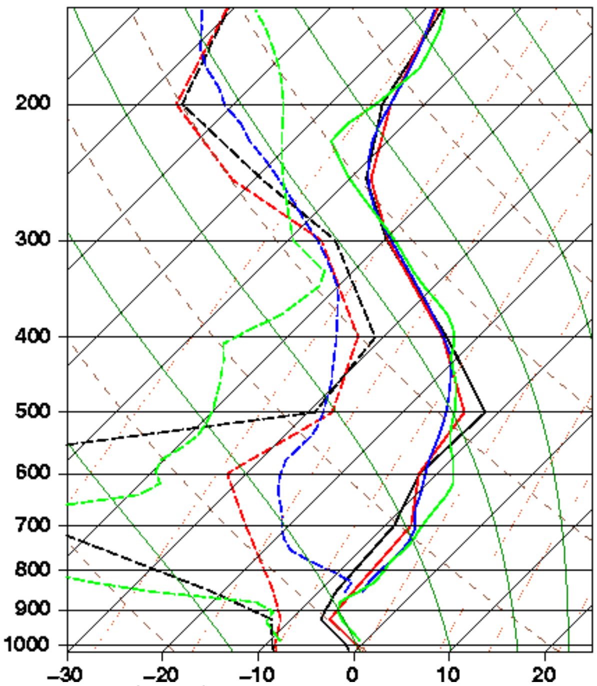

Fig. 6. Profiles of temperature (solid) and dew point (dashed) near Greensboro, NC (GSO) radiosonde location for 0800 UTC 17 January 2007. The background (black) and WRF-Var (red) profiles are for the nearest grid point. The AIRS profile (blue) is for the highest-quality retrieval closest to the grid point. The radiosonde (green) is a linear interpolation of the 0000 and 1200 UTC soundings to 0800 UTC.

produces a superior analysis to the background (compared to the radiosonde) below 600 hPa. AIRS pulls the moisture analysis in the correct direction at 700 hPa but moistens the analysis too much compared to the radiosonde.

4. CONCLUSIONS/FUTURE WORK

A methodology for assimilating version 5.0 AIRS thermodynamic profiles into WRF-Var has been presented. A short-term ARW forecast was used as the background for the analysis, and quality indicators were used to select only the highest quality AIRS data. The profiles were assimilated as separate land and water soundings due to their different error characteristics. Results indicate that AIRS profiles produce an analysis closer to *in situ* observations than the background, which should lead to improved initial conditions and better forecasts when used to initialize a model forecast. Future work will focus on conducting model simulations using the AIRS-enhanced initial conditions for short-term (0-48h) regional ARW runs. These forecasts will be verified against *in situ* observations, and if superior to control forecasts, AIRS-enhanced initial conditions will be transitioned to National Weather Service forecast offices for their local WRF runs.

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