Demonstrating the Operational Value of Thermodynamic Hyperspectral Profiles in the Pre-convective Environment

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1. Introduction

The Short-term Prediction Research and Transition Center (SPoRT; Goodman *et al.* 2005) is a collaborative partnership between NASA and operational forecasting partners, including a number of National Weather Service (NWS) Weather Forecasting Offices (WFO). As a part of the transition to operations process, SPoRT attempts to identify possible limitations in satellite observations and provide operational forecasters a product that will result in the most impact on their forecasts.

One operational forecast challenge that some NWS offices face, is forecasting convection in data-void regions such as large bodies of water (*e.g.* Gulf of Mexico). Vertical profiles of the atmosphere are important to analyze when forecasting convection because it gives a good depiction of instability. Instability is an important measurement forecasters look at when forecasting convection. Currently, there are no regular land-based type soundings taken over the water.

The Atmospheric Infrared Sounder (AIRS) is a sounding instrument aboard NASA's Aqua satellite that provides temperature and moisture profiles of the atmosphere. Using these profiles is one way to supplement land-based upper air soundings to address this forecast challenge. However, satellite derived profiles may show unrealistic-looking sharp gradients or appear overly smooth compared to land-based soundings that forecasters are more accustomed to viewing. Thus, SPoRT has determined the best approach to mitigate possible poor forecaster reaction to a couple of lower quality profiles to create an analysis tool to act as a proxy for the individual retrieved profiles. This is accomplished by blending the retrieved profiles with a model first guess from the Advanced Research Weather Research and Forecasting (WRF-ARW) model.

AIRS profiles are unique in that they give a three dimensional view of the atmosphere that is not available through the current rawinsonde network. AIRS has two overpass swaths across North America each day, one valid in the 0700-0900 UTC timeframe and the other in the 1900-2100 UTC timeframe. The AIRS profiles can be obtained over land and water. This is helpful because the rawinsonde network only has data from 0000 UTC and 1200 UTC at specific land-based locations. Thus, AIRS has a higher spatial resolution than the rawinsonde network (including regions where traditional upper air observations are absent) and fills a temporal gap in the upper air data set. AIRS profiles have been shown to have a positive impact on simulations of convection and precipitation over and near the Gulf of Mexico (Chou *et al.* 2010), and this work is an extension of that project. The aim of this project is to determine the utility of the AIRS retrieved profiles for situational awareness in the pre-convective and convective environment.

This paper will demonstrate an approach to assimilate AIRS profile data into a regional configuration of the WRF model using its three-dimensional variational (3DVAR) assimilation component to be used as a proxy for the individual profiles.

Section 2 describes the AIRS instrument and how the quality indicators are used to select the highest quality data for producing the analysis product. Section 3 describes how case studies were selected and evaluated. Section 4 focuses on two case studies from 17 June and 28 June 2010 that highlight the impact of AIRS retrieved profiles. Finally, Section 5 provides a summary of the paper and discussion of future work.

2. Background

a. AIRS Overview

Both AIRS and the Advanced Microwave Sounding Unit (AMSU) are aboard the Earth Observing System (EOS) polar orbiting Aqua satellite and have an early afternoon equatorial crossing time. AIRS and AMSU construct an integrated temperature and humidity sounding network for numerical weather prediction and climate studies. AIRS is the first hypersepctral infrared radiometer designed to support the operational requirements for medium-range weather forecasting of the National Oceanic and Atmospheric Administration's National Center for Environmental Prediction (NOAA's NCEP) and other numerical weather forecasting centers (Aumann *et al.* 2003).

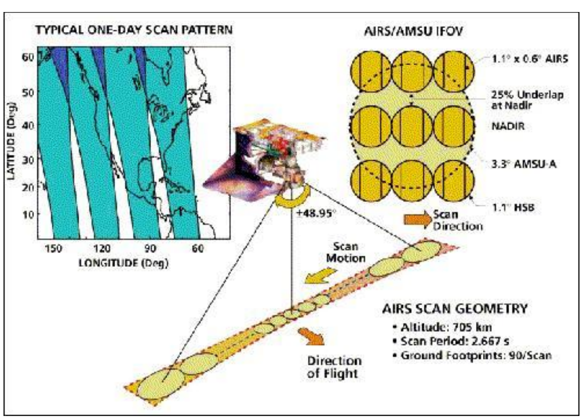

Fig. 1. Overview of AIRS instrument showing a typical one-day scan pattern, the scan geometry, and a graphical representation of the AIRS retrieved profile from one microwave AMSU footprint and nine infrared AIRS footprints.

AIRS is a hyperspectral grating spectrometer which measures the thermal infrared spectrum with 2,378 spectral channels covering the 3.75-4.59 μm, 6.20-8.22 μm, and 8.8-15.4 μm spectral regions with resolving power ranging from 1080 to 1590 (Tobin et al. 2006). AIRS has 15-km horizontal resolution footprints at nadir, relative to the AMSU with a 45-km footprint at nadir. To produce an AIRS retrieved profile, nine coincident AIRS footprints are blended with one AMSU footprint in a 3x3 coupling as illustrated in Fig. 1 (Aumann *et al.* 2003). Because AMSU is a microwave sounder, it can see through clouds and coupling the infrared footprints from AIRS with a footprint from AMSU allows AIRS to observe in clear and partly cloudy scenes. However, it is also has a negative impact because the resolution of AIRS profiles is reduced. AIRS can provide near-radiosonde-quality atmospheric temperature and moisture profiles with the ability to resolve some small scale vertical features (Aumann *et al.* 2003).

A quality indicator (QI), P_{best}, is used to select the most favorable data from each profile for inclusion in the analysis product. Figure 4 shows the three-dimensional distribution of the AIRS profiles from the 2100 UTC 17 June 2010 analysis. In the figure, white regions indicate gaps in the data between successive AIRS orbital swaths and/or missing profiles due to a failure of the retrieval algorithm in dense overcast conditions. The black points represent the highest quality data, and each colored pixel represents the pressure level above which observations are assimilated. The pressure levels usually correspond to the level that AIRS scans down to, usually a thick layer of clouds. The red rectangle illustrates the bounds of the analysis domain. The AIRS retrieved profiles are assimilated as separate land and water soundings due to differences in sounding quality due to emissivity difficulties over land.

b. WRF-Var AIRS Profile Analysis

It is much easier for the human eye to recognize patterns in contoured maps rather than maps of point data. This is one motivation for meteorologists producing objective analyses. For convective forecasting, it is easier for forecasters to recognize patterns in the contoured plots of moisture and convective potential than trying to decipher point data taken from rawinsonde observations. Thus, one way to present individual point observations from the AIRS retrieved profiles is to create an objective analysis.

The concept of data assimilation to produce an analysis that can be summed up using the mnemonic relationship, A=B+C. An analysis, which represents the best guess as to the true state of the atmosphere (A), is produced by blending a background from a larger-scale model (B) with corrections from observations (C). For this task, a short-term WRF-ARW model forecast is used as the background field and AIRS retrieved profiles are the observations. The analysis is the resulting blended product that is being evaluated in this paper, and is produced using WRF-Var, which is the 3DVAR data assimilation system of the WRF. WRF-Var estimates the true state of the atmosphere by minimizing a cost function that statistically blends a previous forecast, observations, and their respective errors (Barker *et al.* 2004).

The background field for each analysis is a WRF forecast initialized at 0000 UTC or 1200 UTC (for A.M. and P.M. analyses respectively) using a “cold start” from a 40-km North American Model (NAM) analysis. The short-term forecast is run from the initialization time to the observation time of the AIRS profiles, respectively run at 0900 UTC and 2100 UTC. This short-term forecast is used as the background field for the WRF-Var analysis and is referred to hereafter as the control analysis (CNTL), representing current information that a forecaster might have at his/her disposal over data-void regions. This methodology follows the successful technique for assimilation of AIRS retrieved profiles presented in Chou *et al.* (2010).

3. Methodology

To evaluate the impact of AIRS retrieved profiles on convective situational awareness, the AIRS and CNTL analyses are compared to Rapid Update Cycle (RUC) analyses. The RUC is used here because it is a common, hourly analysis used by operational meteorologists for making short-term thunderstorm forecasts. In this way, the RUC is being used as a validation database. While it is not an ideal validation tool due to analysis/model error, the RUC analysis is a gridded analysis containing aircraft measurements from asynoptic hours. If the AIRS analysis provides a similar atmospheric structure to the RUC analysis and this structure differs from the CNTL, then the AIRS retrieved profiles are introducing impactful information that operational forecasters could use to aid them in convective situational awareness and forecasting.

Multiple meteorological parameters can be used to diagnose convective potential for thunderstorm development. Among these parameters are convective available potential energy (CAPE), convective inhibition (CIN), relative humidity (RH), winds, and precipitable water. Each of these metrics was evaluated for various case studies. However, using forecaster guidance from the Huntsville, AL NWS WFO, CAPE was determined to be one of the most vital parameters for diagnosing convection.

CAPE is an important metric because it is a quantitative measure of atmospheric instability, which is necessary information for forecasting thunderstorms. Plan view plots and vertical soundings of each analysis were compared to determine the potential impact from the AIRS retrieved profiles on thunderstorm situational awareness.

Case studies were selected by matching the location of AIRS overpasses for each day with the predicted thunderstorm activity over the southeast U.S. found using radar and Storm Prediction Center (SPC) convective outlooks. Cases were selected only if AIRS overpasses with high-quality data coverage occurred over the region of interest. The SPC storm reports were also used to verify that thunderstorms did occur in the target area on that case day. Radar images were also used to determine if the storms that occurred that day matched up with what the data showed and if the storms happened at the correct time.

What follows is a description of two cases from summer 2010 that highlight the use of AIRS for diagnosing convective potential.

4. Case Study Analyses

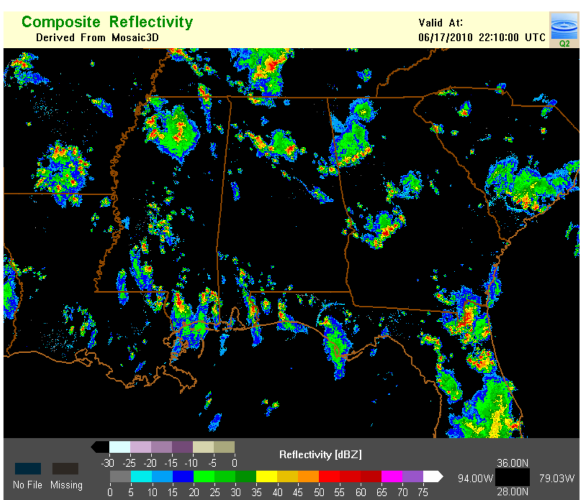

Fig. 2. Radar image from 2200 UTC on 17 June 2010, indicating widespread convection across the southeast U.S. Image from National Mosaic & Multi-Sensor QPE.

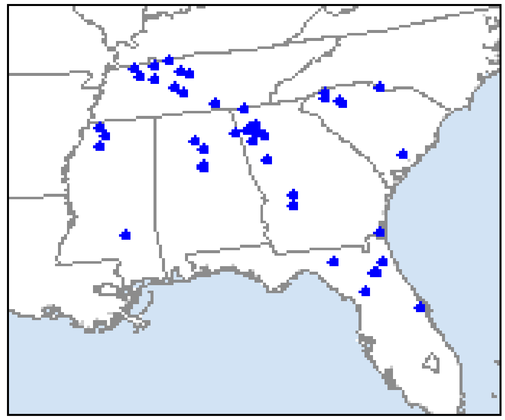

Fig. 3. Wind reports (blue triangles) from 17 June 2010. Image taken from Storm Prediction Center (SPC).

a. 17 June 2010: Southeast U.S. Convection

On 17 June 2010, thunderstorms started to initiate in the Gulf by 1100 UTC. They continued to propagate along the coast, starting just south of Mississippi and Alabama moving across the coast as far east as Florida. By 2200 UTC, widespread convection was occurring across the southeast United States and along the Gulf Coast (Fig. 2). Many of the storms across the southeast produced high winds resulting in a report from the SPC (Fig. 3). High quality AIRS data are located over the southeast U.S. and the Gulf of Mexico at 2100 UTC (Fig. 4), meaning much of the vertical structure of the atmosphere in these convective regions was sampled for this day.

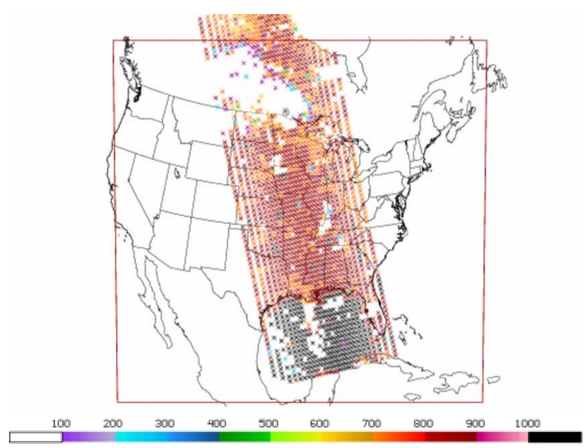

Fig. 4. Quality indicators (P_{best} ; hPa) for AIRS profiles assimilated at 2100 UTC on 17 June 2010.

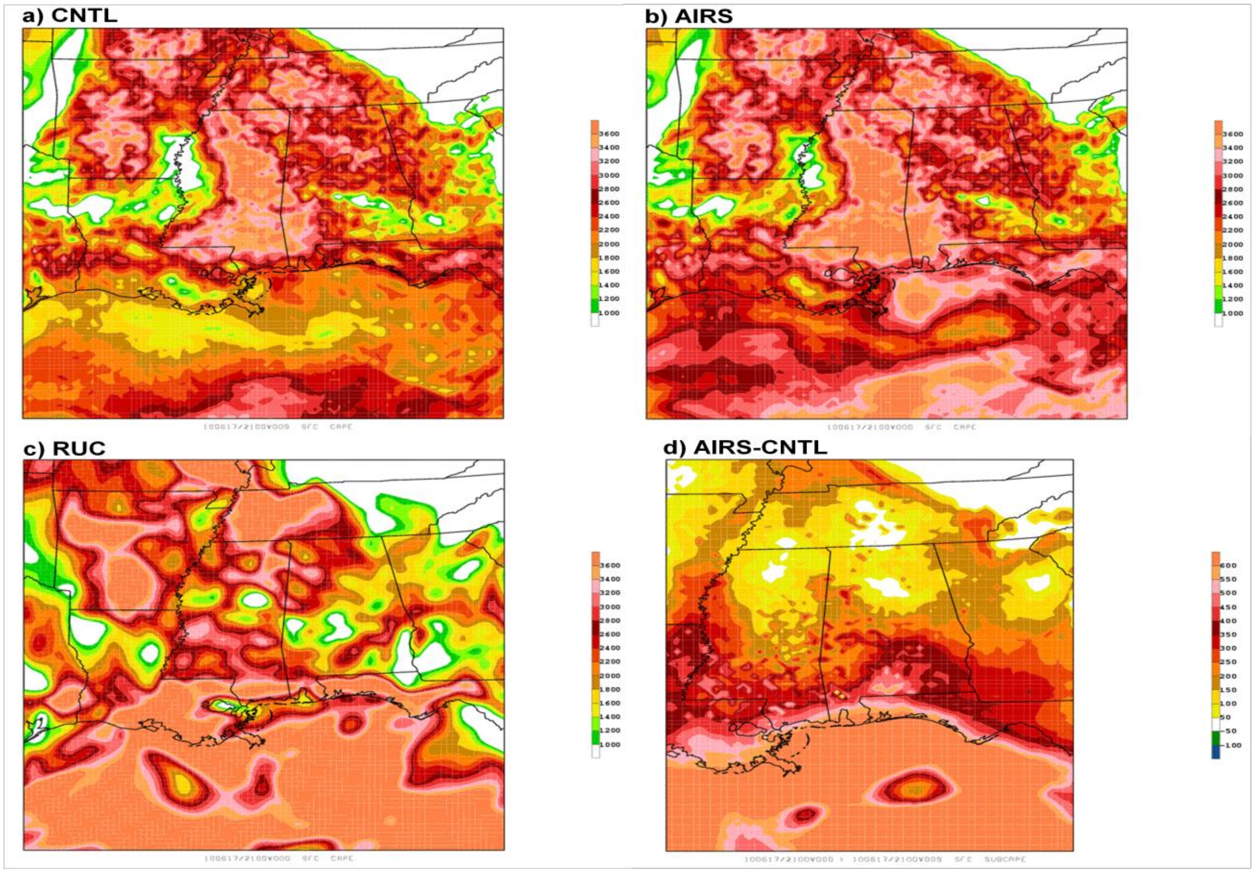

Fig. 5. Surface-based CAPE (J/kg) from a) the CNTL, b) AIRS, c) the RUC, and d) the difference; AIRS-CNTL at 2100 UTC on 17 June 2010 over the southeast U.S. and northern Gulf of Mexico.

Figure 5 shows a comparison between the CAPE in the CNTL, AIRS, and RUC analyses, along with the difference field between the AIRS and the CNTL. In this case, the AIRS run increases the convective potential over both land and water compared to the CNTL (Fig. 5d). Over land, the CNTL analysis shows lower values of CAPE compared to the RUC, but the AIRS analysis shows larger values of CAPE in central and southern Mississippi and

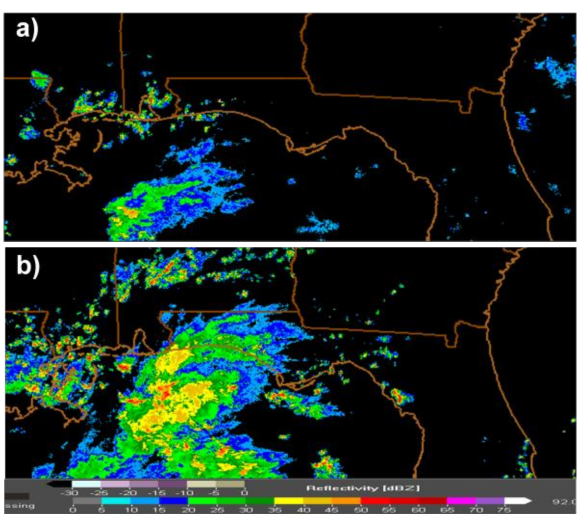

Fig. 6. Radar images from a) 0900 UTC and b) 1600 UTC on 28 June 2010 showing the origin and spread of thunderstorm activity. Image from National Mosaic & Multi-Sensor QPE.

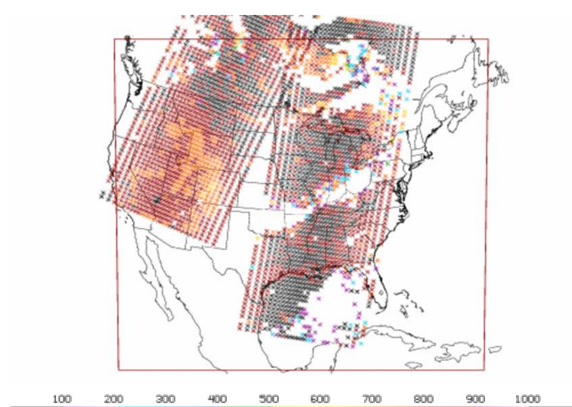

Fig. 7. Same as Fig. 1 but for 0900 UTC on 28 June 2010

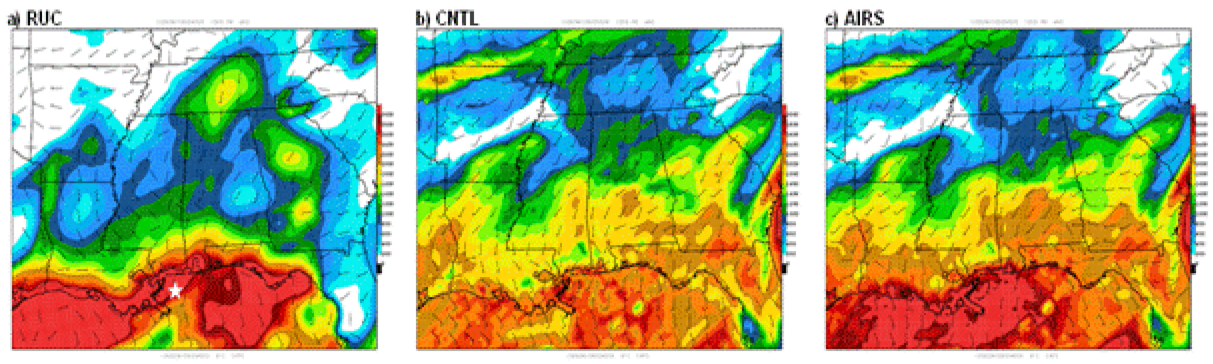

Fig. 8. Surface-based CAPE (J/kg) from a) the RUC analysis, b) the CNTL analysis, and c) the AIRS analysis at 0900 UTC on 28 June 2010. The white star marks the location of the sounding shown in Fig. 9. Wind (kts) is shown for 1000 hPa level.

Alabama, where less widespread convection occurred throughout the day. In this case, AIRS adds more CAPE than the CNTL over land, which might be an overestimation (Fig. 5b). Over the Gulf of Mexico, the AIRS analysis also shows larger values of CAPE than the CNTL; however, in this region, the increase in CAPE is also seen in the RUC. The higher CAPE values from AIRS are consistent with the observed convection that occurred over the Gulf Coast (Fig. 2), which shows that AIRS likely gave an accurate depiction of the over water instability.

b. 28 June 2010: Gulf Coast Convection

On 28 June 2010, thunderstorms started to initiate in the Gulf of Mexico just before 0900 UTC (Fig. 6a). The storm system expanded across the northern Gulf of Mexico and eventually propagated northward across the coasts of Louisiana, Mississippi, Alabama and the Florida panhandle by 1600 UTC (Fig. 6b). While there is a large patch of clouds over the eastern Gulf, several high-quality AIRS retrieved profiles are located over the Gulf Coast and just off the Florida panhandle in the area of convective initiation at 0900 UTC (Fig. 7).

Compared to the RUC, the CNTL analysis has much lower values of surface-based CAPE (Figs. 8a and 8b). The AIRS analysis has significantly higher values of surface based CAPE over the northern Gulf of Mexico when compared to the CNTL analysis (Figs. 8b and 8c). When AIRS is compared to the RUC, the images are very similar with high values (3,000+ J/kg) of CAPE located over much of the Gulf. Winds at 1000 hPa are plotted on top of the surface based CAPE fields in Fig. 8 indicating that southerly winds are advecting the unstable air from the Gulf northward, which is consistent with the radar images.

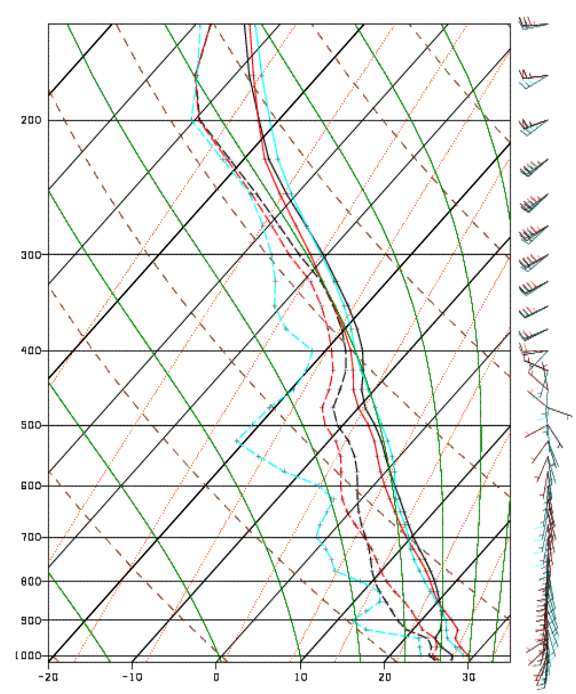

Fig. 9. Sounding at 0900 UTC on 28 June 2010 located in the Gulf of Mexico just southeast of Louisiana (29.5°N, 88.5°W) and marked by a white star on Fig. 8a.

Figure 9 shows a representative vertical sounding from 0900 UTC off the southeast Louisiana coast (29.5^{o}N, 88.5^{o}W; denoted by the white star in Fig. 8a). The solid lines depict the temperature values and the dashed lines are dew point values. In the figure, red lines represent the AIRS analysis sounding, blue lines represent the RUC analysis sounding, and black lines represent the CNTL analysis sounding. The CNTL sounding is cooler than the RUC near the surface and slightly warmer than the RUC in the mid-troposphere resulting in a more stable profile. The structure of the CNTL sounding provides an explanation as to why CAPE values in the CNTL analysis are smaller than the RUC in this region. Meanwhile, the AIRS analysis sounding warms the CNTL analysis in the lower levels and cools the upper levels resulting in a more unstable sounding that more closely resembles the RUC. The AIRS sounding more accurately represents the vertical structure of the atmosphere than the CNTL, which indicates that the stability parameter changes in the AIRS analysis are a result of the vertical sounding closely representing reality rather than some arbitrary artifact of the sounding itself.

5. Conclusions and Future Work

A methodology for transitioning AIRS thermodynamic profiles to operational meteorologists using a WRF-Var analysis has been developed and applied to multiple case studies from the Summer of 2010. A short-term WRF forecast is used as the background for the analysis, and quality indicators are used to select only the highest quality data, which are assimilated as separate land and water soundings. Each case study was examined for multiple convection variables, with the structure of the vertical profile and its stability found to be where the AIRS profiles had most utility. Most impact from the AIRS retrieved profiles occurred over the data-void Gulf of Mexico with fields of convective potential closer to the RUC than the CNTL. Because the AIRS analysis is considerably different than the CNTL, the AIRS product impact would add information to operational convection situational awareness. Mixed results were found when AIRS data were used over land in some of the case studies, so it is premature to determine whether AIRS would be an effective tool for convective situational awareness in these regions. Additional analyses of problematic convective forecasts over the southeast are needed to determine the operational impact of AIRS. Pending the outcome of these further analyses, SPoRT plans to transition the AIRS product to targeted WFO partners that have identified this forecast challenge as important to their region.

Acknowledgments

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