291. IMPACT OF AIRS THERMODYNAMIC PROFILES ON PRECIPITATION FORECASTS FOR ATMOSPHERIC RIVER CASES AFFECTING THE WESTERN UNITED STATES

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1 BACKGROUND

1.1 Overview

This project is a collaborative activity between the NASA Short-term Prediction Research and Transition (SPoRT) Center and the NOAA Hydrometeorology Testbed (HMT) to evaluate a SPoRT Advanced Infrared Sounding Radiometer (AIRS: Aumann et al. 2003) enhanced moisture analysis product. We test the impact of assimilating AIRS temperature and humidity profiles above clouds and in partly cloudy regions, using the three-dimensional variational Gridpoint Statistical Interpolation (GSI) data assimilation (DA) system (Developmental Testbed Center 2012) to produce a new analysis. Forecasts of the Weather Research and Forecasting (WRF) model initialized from the new analysis are compared to control forecasts without the additional AIRS data. We focus on some cases where atmospheric rivers caused heavy precipitation on the US West Coast. We verify the forecasts by comparison with dropsondes and the Cooperative Institute for Research in the Atmosphere (CIRA) Blended Total Precipitable Water product.

1.2 AIRS

Figure 1. The Aqua satellite (from http://airs.jpl.nasa.gov).

AIRS is a radiometer aboard NASA's polar-orbiting *Aqua* satellite (Figure 1). It measures infrared radiation in 2378 frequency bands ranging from 3.7 to 15.4 microns. AIRS has a cross-track scanning geometry, observing 90 fields of view per scan, with a resolution of 13.5 km at nadir and a swath width of about 1600 km. The observed top-of-atmosphere radiation is dependent on atmospheric temperature and the concentration of water vapor and other constituents of the atmosphere. Through an inversion process, profiles of temperature and water vapor are retrieved from AIRS radiometric observations (Aumann et al. 2003). Since clouds are opaque to infrared radiation, profiles cannot be retrieved inside or below clouds, but useful retrievals can be obtained above clouds (as well as information on cloud top properties). Coupled with a microwave radiometer (AMSU), AIRS is also able to retrieve profiles in partly cloudy regions.

1.3 Atmospheric Rivers

The objective of assimilation of AIRS profiles over the Pacific is to attempt to generate a near-real-time enhanced 3D moisture analysis product that could be used by West Coast Weather Forecast Offices (WFOs) and the Hydrometeorlogical Prediction Center (HPC) for diagnosing the location, extent, and magnitude of atmospheric rivers. Atmospheric rivers are thin tongues of enhanced low-level water vapor and precipitation that propagate from the Intertropical Convergence Zone (ITCZ) northward and impact the West Coast of North America (Ralph et al. 2011). They are responsible for the transport of large amounts of water vapor and can have a large impact on precipitation. In particular, they often lead to intense multi-day rain events on the western coast of North America during the winter season due to orographic lifting, sometimes resulting in flooding and landslides.

1.4 Hypothesis

The Global Forecast System (Yang et al. 2006), an analysis and prediction system based on WRF and run operationally by the National Center for Environmental Prediction (NCEP) Environmental Modeling Center (EMC), routinely assimilates AIRS radiances. However, these radiances are used only in cloud-free areas. Because atmospheric rivers are typically associated with cloudy regions, the cloud-free AIRS radiances that are assimilated in the GFS may not fully capture these features. In contrast, assimilation of AIRS profiles, which allow for the use of data above clouds and in partly cloudy regions, may provide an enhanced view of atmospheric river features. Although data within and below clouds are excluded, we expect that using the available profile data in cloudy regions can augment the currently utilized observations and improve WRF model analyses and forecasts.

The final SPoRT product blends a GFS analysis with AIRS observations using the GSI DA system to produce a 3D analysis of integrated water vapor. This analysis can be used as either a situational awareness tool or for initialization of local EMS runs by West Coast Weather Forecast Offices.

2 EXPERIMENT

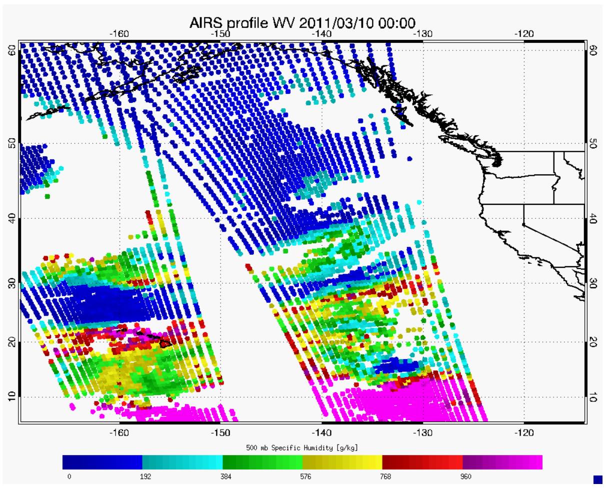


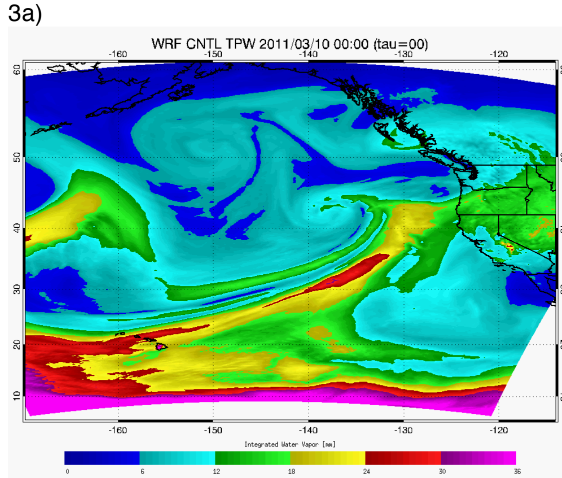
Figure 2. Specific humidity at 500 mb in the AIRS retrieved product. Each colored circle represents one satellite field of view. The white missing areas within the swaths had a cloud at or near 500 mb. The specific humidity is higher near the tropics and lower to the north as is typical. There is also a band of elevated humidity running east-west near the center of the figure, corresponding to an atmospheric river.

Figure 2 shows an example of the assimilated specific humidity retrievals at the 500 mb level. A feature of this product is the flag for lowest cloud-free level. In fields of view with partial cloud cover, we assimilate the AIRS retrieved profiles down to the lowest cloud-free level. This contrasts to the operational methodology for AIRS radiance assimilation, which eliminates all AIRS observations in fields of view where clouds are present.

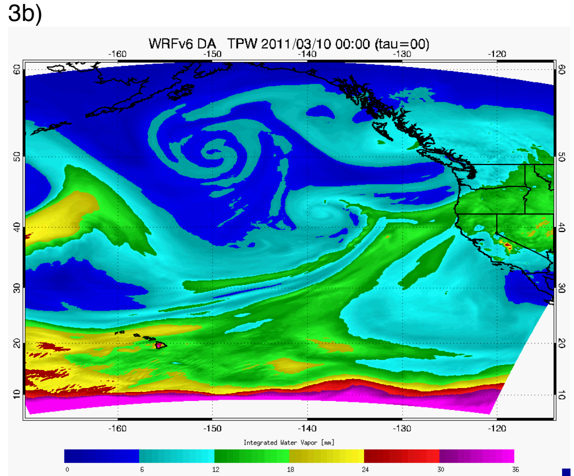
The experiment consists of two model simulations. The first (control) run is initialized with a GFS analysis (Figure 3a). The GFS does already include the affect of AIRS data through assimilation, but only at completely cloud-free locations. The second (DA) assimilates the AIRS profiles into the GFS background to give a new analysis (Figure 3b), which becomes the initial condition for the data assimilation run. Both model simulations have been configured to match the settings of the operational GFS environment.

Initial conditions for the two model runs are shown in Figure 3. Figure 3a shows the initial total Precipitable water (TPW) field for the control run, which is also the background field for the AIRS assimilation. Figure 3b shows the TPW analysis after AIRS assimilation, which is the initial condition for the DA run. Figure 3c shows the assimilation increment (panel b minus panel a) given by the color scale on the bottom, overlaid with ellipses corresponding to locations of assimilated AIRS observations, color coded by the lowest cloud-free pressure level (color scale to right of figure). Parts of three swaths are seen, with missing

3a)



3b)



3c)

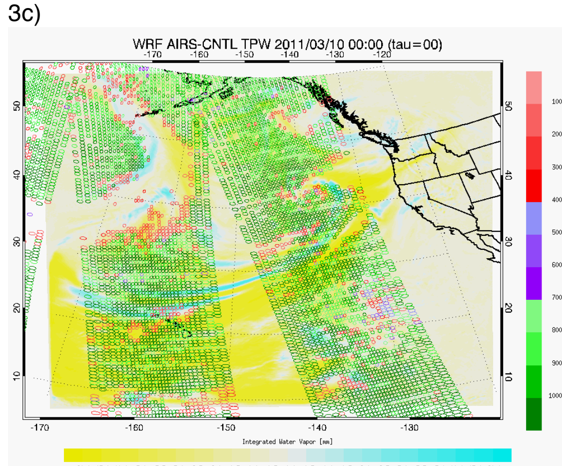


Figure 3. a) Background total precipitable water (TPW) field; b) Analysis TPW field; c) Analysis increment, with assimilated observations marked by ellipses (color coded by the lowest cloud-free retrieval level.

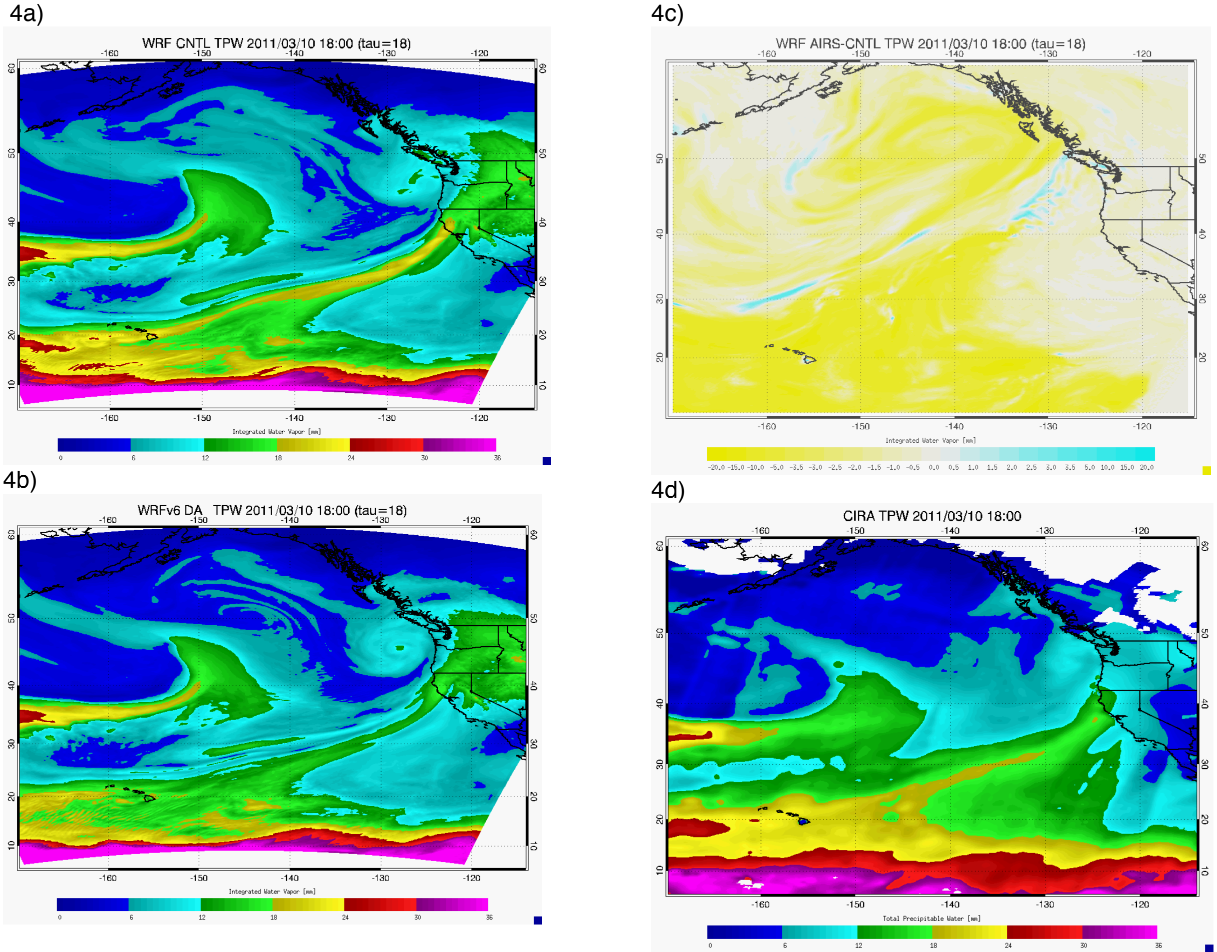


Figure 4.18 UTC TPW from a) Control Run; b) DA Run; c) Increment (DA minus Control); d) CIRA analysis

areas where data were rejected due to too much cloud or other quality control criteria. Green points have data down to the surface or low levels (700 mb or greater) while red points have data only down to the 400 mb level at best. We can expect profiles with more vertical levels used (green points) to have a larger impact. The impact of AIRS observations (measured by TPW increment) is near zero in most areas away from the observations. Both version 5 and 6 of AIRS profiles were assimilated but differences in analyses were found to be minimal, so we only present results from version 6 profiles.

3 RESULTS

3.1 Comparison with CIRA TPW

For both model runs, validation was performed based on 18 h forecasts. We compare forecast total precipitable water (Figures 4a and 4b, with differences in 4c) to the CIRA Blended TPW analysis (Figure 4d; Kidder and Jones 2007). The most obvious change is a general reduction in TPW. Systematic biases exist between the WRF, CIRA, and AIRS retrieved water vapor concentrations. It is difficult to validate without first doing a bias correction because the biases are larger than the increments. Table 1 shows statistics from this experiment, validated against the CIRA TPW. The CIRA TPW has been scaled by a constant factor of 0.687 to match the means of the observations and analyses at the initial time (0 UTC) within the domain. Based on this metric, assimilation of AIRS increases the magnitude of the TPW bias, going from -.27 mm to -1.83 mm. This suggests that the AIRS humidity retrievals are biased low relative to the WRF fields. The standard deviation is reduced in the assimilation run, which is an encouraging result. The next step will be to bias correct the AIRS retrievals before assimilation in order to make the biases of the two forecasts similar in magnitude.

Model Run	**Bias**	**Stdev**	**RMS**
Control	-.27	3.09	3.09
AIRS DA	-1.83	2.57	3.15

Table 1. Statistics for 18h forecast total precipitable water (in mm) validated against the scaled CIRA TPW.

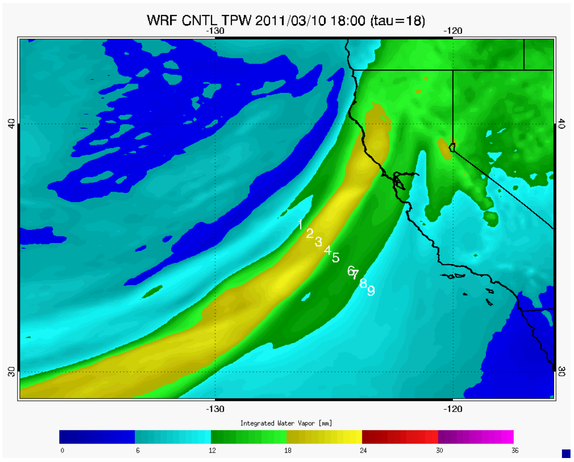


Figure 5. Detail of Figure 4a showing the locations of dropsondes deployed at approximately 18 UTC on 10 Mar 2011.

3.2 Validation against Dropsondes

The forecasts are also validated against dropsonde profiles from the Winter Storms and Pacific Atmospheric Rivers (WISPAR) field campaign (Ralph et al., 2011). The numbers 1 to 9 on Figure 5 indicate the positions of dropsondes used in this validation. These were deployed in a transect across the atmospheric river a few hundred km off the California coastline. The initial times for the dropsondes all occurred between 1826 and 1917 UTC, making them all within 80 minutes of the analysis time. Figure 6 shows the humidity profiles from five of the drops (odd numbers 1 to 9) in dashed lines with the two collocated forecast profiles in solid black (control run) and orange (assimilation run) lines. There is little impact below 800 mb or above 500 mb, but the assimilation run matches the validation data more closely at intermediate levels in most cases. This is verified by Figure 7, which shows the mean for the dropsondes, control run, and forecast run among all 9 dropsondes, with the standard deviation and rms error for the two forecasts compared to the dropsondes. The biases relative to the dropsondes are reduced between approximately 500 to 700 mb and the error standard deviations are reduced between 400 to 700 mb.). We expect smaller impact near the surface where more data is removed by clouds and higher in the atmosphere where the radiative signal is smaller, so this is consistent with expectations.

4 FUTURE WORK

Several additional refinements and validations are planned. We will test the use of a bias correction (scaling) for the AIRS profiles. Additional work is currently underway to evaluate the impact of these analyses on short-term precipitation forecasts by validating against NLDAS-2 precipitation analyses (Xia et al. 2012). We plan to examine some additional cases from the winter of 2012-2013 and also do a layer-by-layer comparison against a CIRA layer precipitable water product. Finally, we will also test the assimilation of a neural network retrieval of AIRS profiles (Blackwell et al., 2011).

5 ACKNOWLEDGEMENT

We thank John Forsythe of CIRA for supplying the blended TPW analyses.

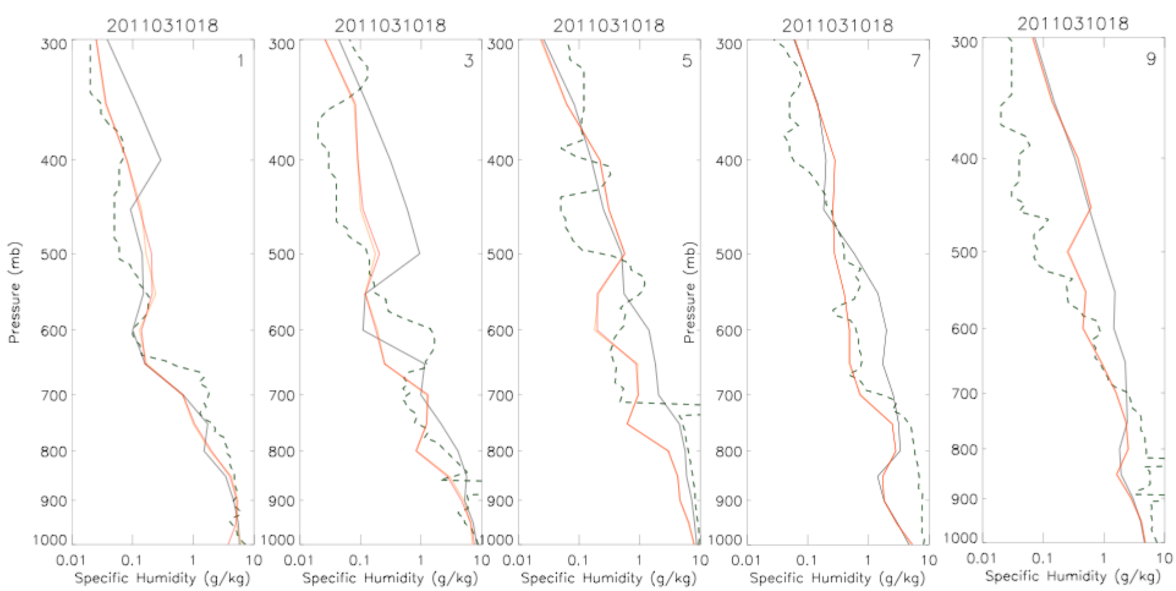


Figure 6. Control (black) and Assimilation Run (orange) profiles of forecast (18h) specific humidity at dropsonde locations, along with dropsonde-measured profiles (green, dashed). Numbers in the upper right corner of these plots correspond to positions indicated in white (numbers 1-9) on the 18h forecast maps in Figure 4a/b/d.

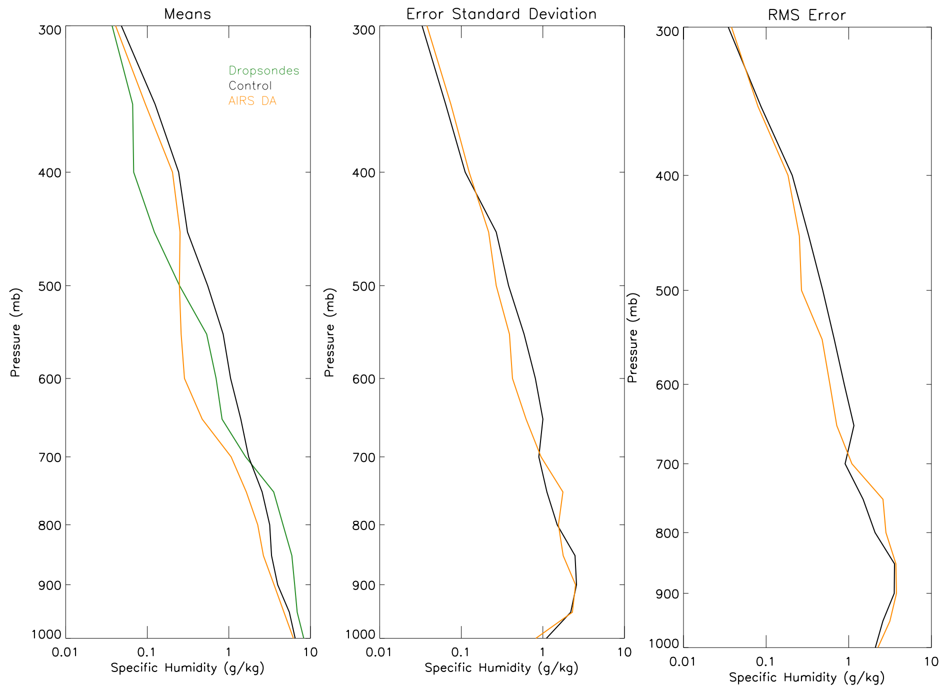


Figure 7. Mean profiles of control, assimilation run, and dropsonde specific humidity, at the dropsonde locations. Profiles of error standard deviation and RMS error of both WRF runs.

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