Bias Correction for Assimilation of Retrieved AIRS Profiles of Temperature and Humidity

Clay Blankenship[1*], Bradley Zavodsky[2], and William Blackwell[3]

[1]Universities Space Research Association, Huntsville, AL [2]NASA Marshall Space Flight Center, Huntsville, AL

[3]Massachusetts Institute of Technology, Cambridge, MA *clay.blankenship@nasa.gov

Abstract

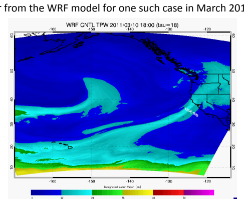
The Atmospheric Infrared Sounder (AIRS) is a hyperspectral radiometer aboard NASA's Aqua satellite designed to measure atmospheric profiles of temperature and humidity. AIRS retrievals are assimilated into the Weather Research and Forecasting (WRF) model over the North Pacific for an "atmospheric river" case. These events bring a large flux of water vapor to the west coast of North America and often lead to extreme precipitation in the coastal mountain ranges. An advantage of assimilating retrievals rather than radiances is that information in partly cloudy fields of view can be used.

Motivated by previous work which found inconsistencies in the range of humidities in the AIRS profiles and in the WRF model for a given layer, we developed a bias correction for the AIRS profiles. Corrections are significant in the upper troposphere and very small below 500 mb. Above about 200 mb, there is very little correlation between AIRS retrievals and the WRF model fields.

The bias-adjusted AIRS profiles are assimilated into WRF. Results are compared to a control run with no assimilation and a run with raw AIRS profiles. Validation is ongoing but it is hoped that the bias adjusted profiles will lead to better forecasts.

Atmospheric Rivers

Atmospheric rivers are transient, narrow regions in the atmosphere responsible for the transport of large amounts of water vapor. These phenomena can have a large impact on precipitation. In particular, they are often responsible for intense rain events on the west coast of North America during the winter season. (Ralph et al. 2011) This plot shows total precipitable water from the WRF model for one such case in March 2011.



The Atmospheric Infrared Sounder (AIRS)

The Atmospheric Infrared Sounder (AIRS: Aumann et al., 2003) is a radiometer aboard NASA's polar-orbiting *Aqua* satellite. 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. 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.

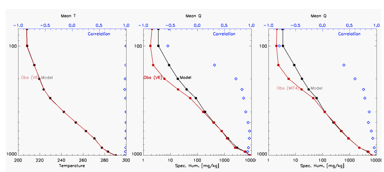
The *Aqua* satellite (from airs.jpl.nasa.gov).

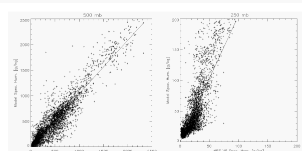
Background and Motivation

- Operational GSI assimilates AIRS radiances but excludes cloudy areas. AIRS profiles (JPL) are produced which have useful information above the cloud tops. This is an effort to best utilize those profiles to get more data in and around cloudy regions.
- Previous results (Blankenship et al. 2013) showed that assimilation of AIRS retrieved profiles of temperature and moisture can resolve the atmospheric river as a narrower feature, but there was an overall systematic drying trend in the analyses using AIRS.
- It was difficult to validate the impact of AIRS profile assimilation due to biases between the profiles and model humidity at upper levels.
- Also, validation against a CIRA Total Precipitable Water product was complicated by biases between the model and the TPW product.
- Operational NWP centers routinely use bias correction of satellite radiances do ensure that satellite observations do not, on average, change the model climatology of temperature and moisture. . Data assimilation algorithms are generally designed for use with unbiased observations (Dee 2005).

Bias Correction Methodology

- These plots show the mean profiles of temperature and moisture by layer for our WRF model run and for the AIRS profiles. Also plotted in blue (upper scale) are the correlations.
- We are also evaluating an AIRS profile product (Blackwell et al. 2011) based on a neural net retrieval. Their mean humidity profile is shown in the right panel below.
- Temperature bias is low at all layers
- Humidity bias is low at low levels.
- For upper levels (150 mb and higher), there is very low correlation between model and observations, suggesting poor retrieval skill or model skill, or both. We do not assimilate data at these levels.
- For intermediate levels (250 mb to 400 mb), there is a significant bias but high correlation between model and observations, suggesting that bias correction has a large potential benefit for those layers.

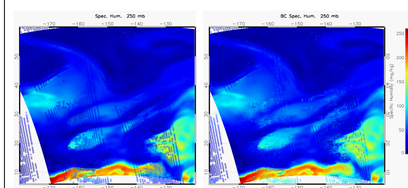




- For this first test, we simply derive a regression relationship for each level between model and observations for all collocated points in the current run.
- Apply this relationship to produce "corrected" observations.
- This ensures the DA step does not bias the model background up or down while preserving the spatial information in the AIRS retrievals.

Bias-Corrected Observations

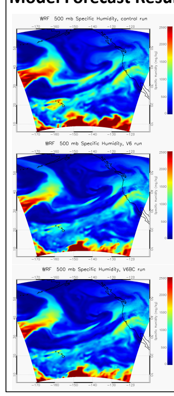
The following figures illustrate the effect of the correction on the assimilated observations. The background field is the same in both cases, showing the model specific humidity at 250 mb. The small crosses indicate the locations of the AIRS profiles and are colored according to their 250 mb humidity. The left panel has the raw observations and the right panel has the bias corrected observations, which agree more closely with the range of nearby values in the model field.



WRF Experiment Setup

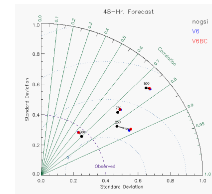
- Atmospheric River in March 2011
- WRF domain in eastern North Pacific and western North America at 12 km resolution
- WRF 48-hr forecast initialized on 10 March 2011
- Initial and boundary conditions come from GFS, which incorporates assimilation of various observation types including AIRS radiances (but not in cloudy areas)
- Data assimilation using Gridpoint Statistical Interpolation (GSI, Developmental Testbed Center 2011)
- Model runs:
  - No GSI (control)
  - AIRS V6 profile assimilation
  - Bias-corrected AIRS V6 profile assimilation

Model Forecast Results



These plots depict 48 hour forecasts of 500 mb specific humidity for the three runs. The runs with AIRS profiles assimilated have a narrower atmospheric river feature near the center of the domain. While there is little difference between the raw and bias-corrected AIRS runs, this consistency gives us confidence that the narrower, weaker atmospheric river is not simply a consequence of a dry bias in the AIRS profile retrievals.

Validation against ECMWF Re-Analyses (ERA)



This Taylor diagram shows standard deviation (normalized by layer mean humidity, distance from origin), correlation (on curved axis), and normalized rms error (dotted lines) for model specific humidity at four layers (250, 500, 750, and 900 mb), validated against ECMWF Re-Analyses (ERA). Differences between uncorrected and bias-corrected AIRS runs are marginal.

Selected statistics are given below, with bias and error standard deviation normalized by the layer mean value.

48-hr. Stats	Control	AIRS V6 DA	BC AIRS V6 DA
250 mb Bias	-0.14	-0.12	-0.12
250 mb Error Std. Dev.	0.43	**0.37**	**0.37**
250 mb Correlation (r^2)	0.68	**0.77**	**0.77**
500 mb Bias	0.10	0.12	0.12
500 mb Error Std. Dev.	0.59	0.58	0.58
500 mb Correlation (r^2)	0.56	0.59	0.58
750 mb Bias	**-0.11**	-0.21	-0.21
750 mb Error Std. Dev.	0.48	0.48	0.49
750 mb Correlation (r^2)	0.57	0.57	0.56
900 mb Bias	**-0.22**	-0.30	-0.29
900 mb Error Std. Dev.	**0.29**	0.32	0.32
900 mb Correlation (r^2)	**0.49**	0.40	0.41

Ongoing Work

- Test robustness of correction from day to day and season to season, investigate proper timescale to update correction.
- Do a cycling model run for a period of weeks to the impact of continued assimilation.
- Further validation, including against rainfall analyses on the west coast.
- Perhaps validation of forecast cloud cover vs. satellite observations.

References

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