P3.10 ASSIMILATION OF RETRIEVED WATER VAPOR PROFILES INTO THE NAVY OPERATIONAL GLOBAL ATMOSPHERIC PREDICTION SYSTEM (NOGAPS)

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1. INTRODUCTION

Water vapor profiles retrieved from AMSU-B (Advanced Microwave Sounding Unit-B) observations are assimilated using the NRL Atmospheric Variational Data Assimilation System (NAVDAS) with the Navy Operational Global Atmospheric Prediction System (NOGAPS) forecast model. This paper will explain the methods used to retrieve water vapor profiles, assimilate those profiles, and assess the impact of using these data on the analysis and forecast accuracy.

2. RETRIEVAL METHOD

The water vapor retrievals use observations at 150 GHz and 183.31±1, 3, and 7 GHz from the AMSU-B microwave radiometer on the NOAA-16 polar orbiter. The retrieval algorithm is a physical optimal estimation inversion of the observed brightness temperatures constrained by the NOGAPS background (6-hour forecast); this is equivalent to a one-dimensional variational assimilation (1DVAR) of radiances at each observation point. This algorithm is based on the one described in Blankenship et al. (2000) and incorporates the solution to the inverse problem given by Rodgers (2000).

The humidity profile retrieval algorithm uses background values of temperature profile, sea surface temperature, and surface wind speed from the NOGAPS forecast. These parameters are held fixed within the retrieval. The forecast also provides the first guess humidity profile. Clouds are turned off in this version of the retrieval.

The algorithm tries to minimize the cost function

$$J(x) = \left(\mathbf{y}-\mathbf{H}(\mathbf{x})\right)^T \mathbf{S}_{\boldsymbol{\varepsilon}}^{-1}\left(\mathbf{y}-\mathbf{H}(\mathbf{x})\right) + \left(\mathbf{x}-\mathbf{x_b}\right)^T \mathbf{S_a}^{-1}\left(\mathbf{x}-\mathbf{x_b}\right)$$

where **y** is the vector of observations (brightness temperatures), **H** is the forward model, $\mathbf{S}_{\boldsymbol{\varepsilon}}$ is the observed plus forward model error covariance matrix, **x** is the atmospheric state vector (humidity profile), $\mathbf{x_b}$ is the background state, and $\mathbf{S_a}$ is the background error covariance matrix. This is equivalent to maximizing the Bayesian probability of atmospheric state **x** given knowledge of $\mathbf{x_b}$, **y,** and their error characteristics. We solve for a new **x** which minimizes this function using a linearization of **H**(**x**) about the current **x**. This process is repeated until convergence is obtained. If the retrieval fails to converge within 12 iterations it is rejected, but most converge in 3 to 6 iterations

The retrieval algorithm returns the logarithm of specific humidity (ln Q) at the 26 NOGAPS pressure levels from 1013 to 122 hPa. (NOGAPS and NAVDAS have pressure levels up to 10 hPa, but the retrievals give little information in the stratosphere.) The retrieval error at each level is calculated from the specified background errors (NOGAPS forecast errors) and the observed plus forward (O+F) model brightness temperature errors (Rodgers, 2000). Figure 1 shows the NOGAPS forecast (retrieval background) and mean retrieval error profiles for ln Q, and Table 1 gives O+F brightness temperature errors. In the retrieval algorithm,

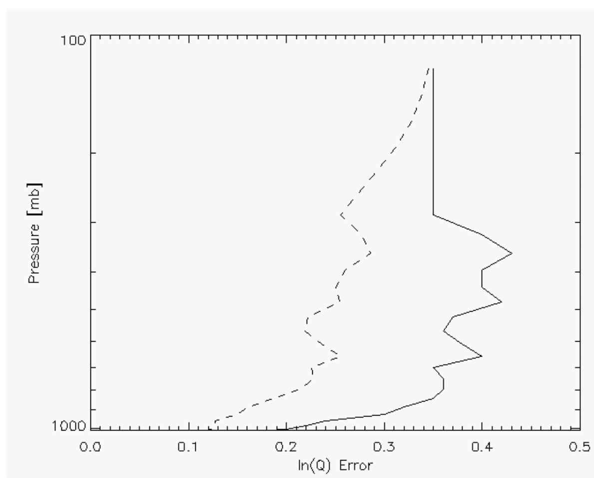

Figure 1. NOGAPS background error (solid) and retrieval error (dashed) for logarithm of specific humidity as a function of pressure.

Channel	150 GHz	183±1	183±3	183±7
Error	1.47 K	1.48 K	1.06 K	0.81 K

Table 1. Observation plus forward model error for AMSU-B channels.

background error covariances of ln Q have a 1 km scale length (r^2 of 0.5 at 1 km), and the O+F errors are treated as uncorrelated. The retrieval errors at each level are passed to NAVDAS. Currently, cross-correlations of the retrieved moisture field are set to zero, both within a profile (vertically) and between profiles (horizontally).

Figure 2 shows an example of the output from the retrieval. The structure of the environment of Typhoon Lingling is resolved, showing a tongue of

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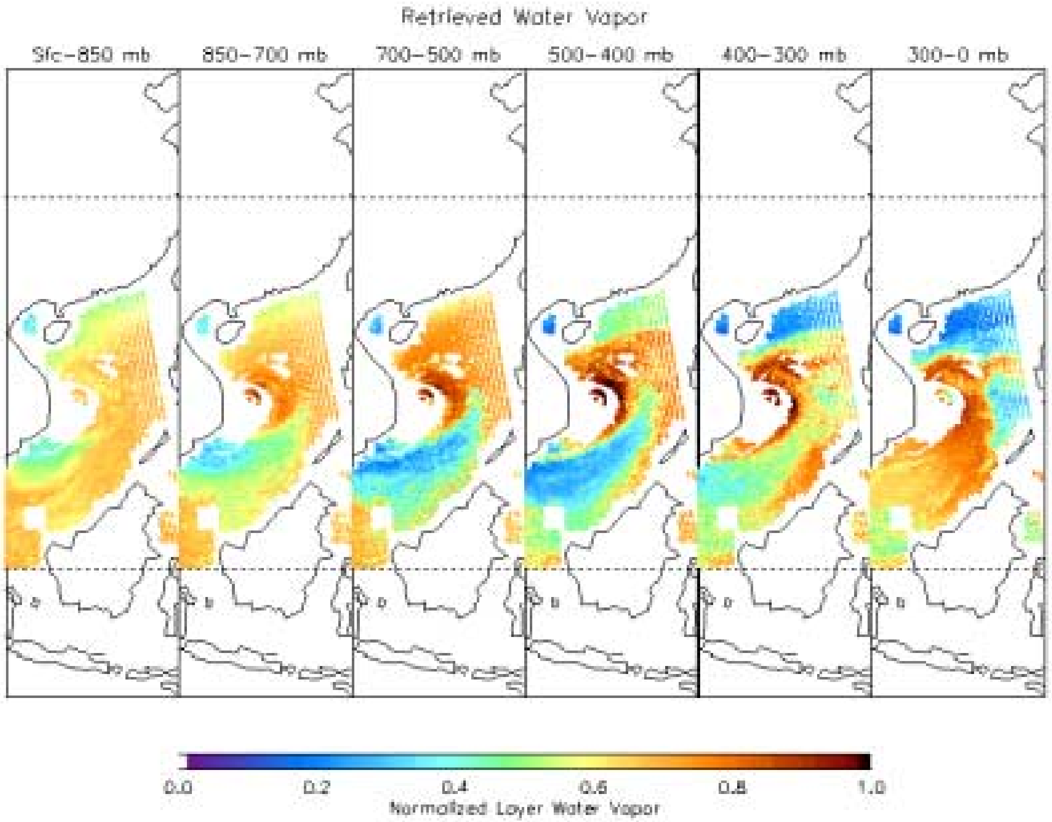

Figure 2. Retrieved layer-integrated water vapor for six layers, on 1 Nov 2001 at 0500 UTC. Each layer has its own color scale due to the large difference in water vapor density between levels.

entrained dry air, most pronounced at mid-levels, to the south of the storm, and the sharp boundary between dry and moist air to the north.

3. DATA ASSIMILATION METHOD

In order to keep the profiles somewhat independent of each other, the AMSU-B data are thinned to every fourth point of every fourth scan. Points over land, coast, and sea ice and points with over 0.2 mm of cloud liquid water (computed from 91 and 150 GHz measurements) are screened out. Retrievals which fail to converge (usually due to heavy cloud or precipitation in the scene), or which fail gross temperature departure checks are also rejected. After these checks, there are approximately 45,000 retrievals from the NOAA-16 AMSU-B per update cycle ready to be assimilated.

Retrievals are assimilated into the NOGAPS forecast model using the NAVDAS software (Daley and Barker, 2001). These data are assimilated simultaneously with many other data types including radiosondes, surface observations, satellite winds, and NESDIS temperature retrievals from HIRS (High Resolution Infrared Sounder) and AMSU-A. NAVDAS is run on a 6-hour cycle at 00, 06, 12, and 18 UTC. All observations within ±3 hours of the analysis times are used along with the 6-hour forecast from the last update to produce a new analysis, which is then used as the starting condition for the next NOGAPS forecast.

Satellite moisture profiling information is incorporated via the assimilation of retrievals rather than radiances because NAVDAS does not recompute Jacobians while solving the 3DVAR equations. Special coding is required within NAVDAS to handle a nonlinear operator. This approach lets the 1DVAR retrieval handle the nonlinearities inherent in a water vapor profile retrieval so all observations input to the 3DVAR system (NAVDAS) are linearly related to model quantities.

Two separate forecast runs were performed, a control run and a run assimilating the AMSU-B water vapor profile retrievals. They were run from 4 May 2002 at 0 UTC to 22 May 2002 at 0 UTC.

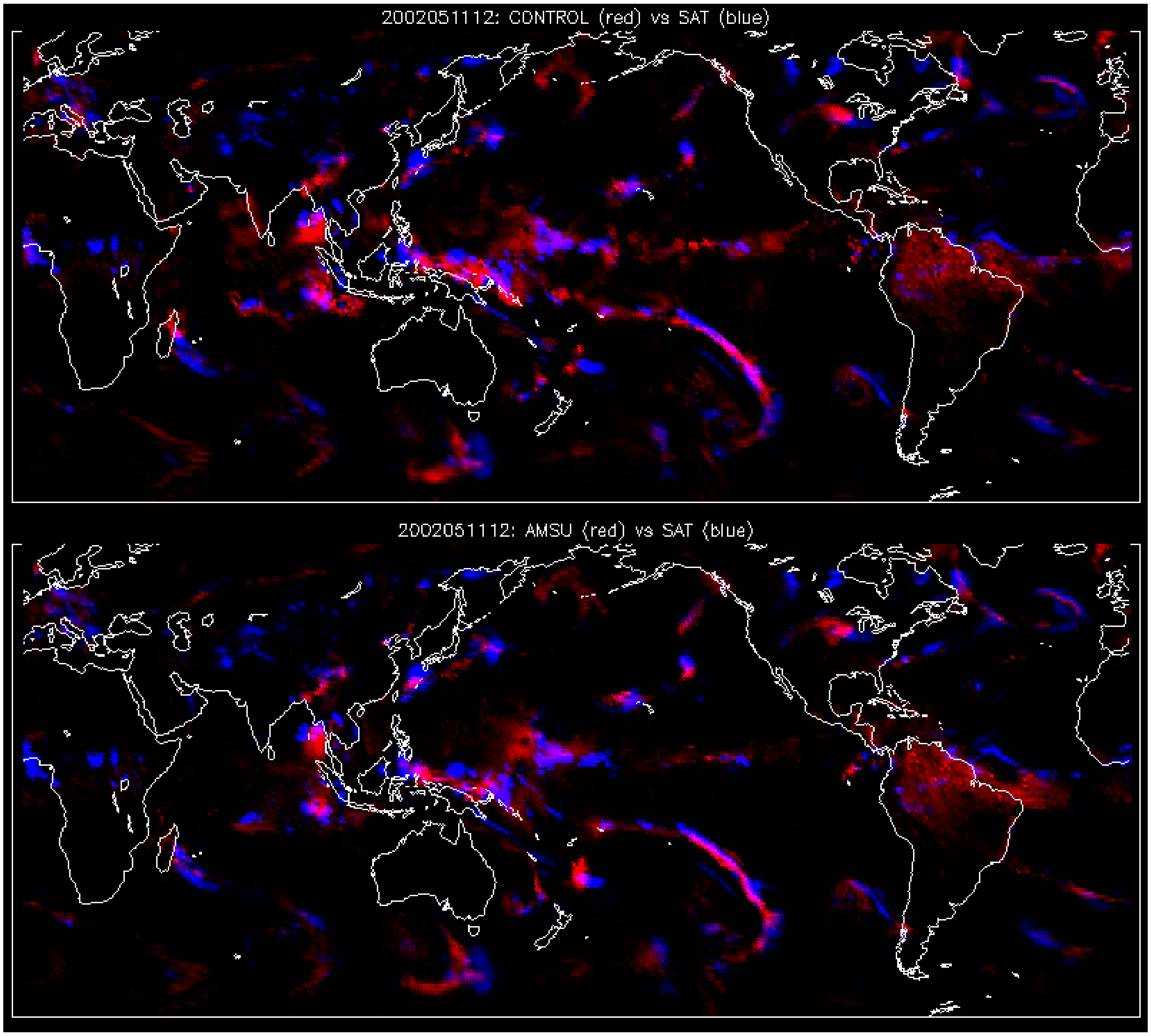

Figure 3. Top: 6-hour control-run rain forecast (red) and satellite rain observations (blue) for 12-18Z on 11 May 2002. Bottom: as above, but forecast is from run with assimilated water vapor profiles.

4. VALIDATION

These results are from the first run of NAVDAS with AMSU-B water vapor profile retrievals and are therefore preliminary. One method of validation is comparison with independent rain observations. 6-hr. rain forecasts from a control run and a run with AMSU-B humidity profiles assimilated were compared with the output of a combined microwave/infrared satellite rain product. This product uses a geostationary infrared rain rate algorithm which is updated continuously from polar orbiting microwave sensors (Grose et al., 2001). Figure 3 shows the two forecasts each superimposed on the satellite rain algorithm. Statistics for days 5-14 are given in Table 2. The correlations and rms errors are almost identical. However, we can see regions of improvement in the retrieval-aided forecast. In particular, the water vapor profiles improve the rain forecast in the tropical Eastern Pacific. Where the control run forecasts a continuous band of precipitation along the Equator, the modified run correctly confines rain here to a few regions.

Run	RMS Error	Correlation
Control	.386	.280
AMSU-B	.390	.270

Table 2. RMS error and correlation coefficient for days 5-14 of the control and AMSU-B runs of NAVDAS.

Figure 4 shows anomaly correlations for 500 mb heights for the Northern and Southern Hemispheres, for the two runs. The assimilated AMSU-B retrievals have a positive impact in both cases (except beyond 108 hours in the SH). Other anomaly correlations and rms error comparisons show a mixture of positive and negative impacts.

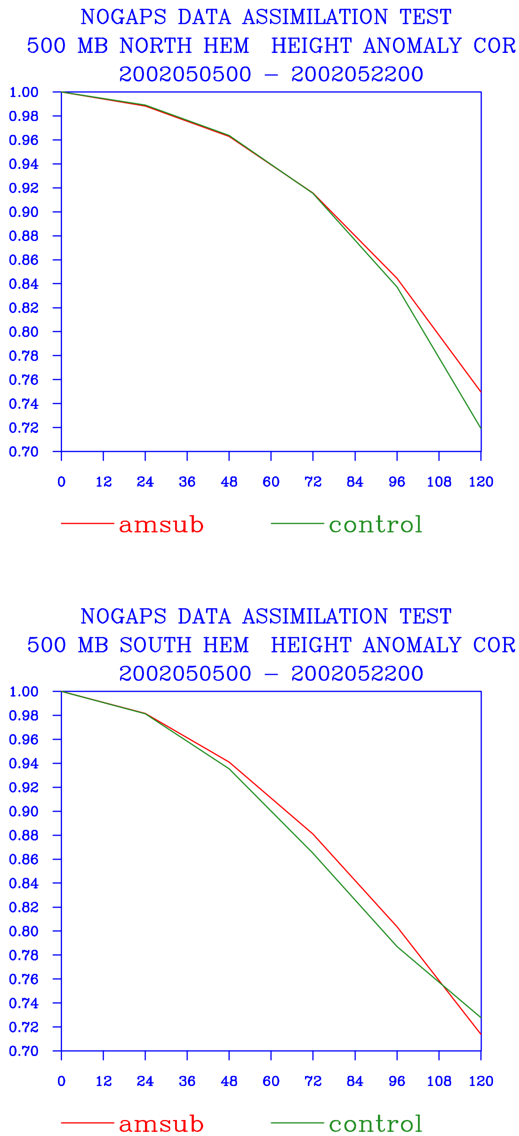

Figure 4. 500 mb height anomaly correlations for Northern (top) and Southern (bottom) Hemispheres.

5. FUTURE WORK

This is a preliminary run; longer datasets will give more statistical certainty in validation. Other planned validation techniques include comparison against radiosondes and the output of other models. Additionally, forward modeled brightness temperatures will be compared with observations from the HIRS water vapor channel. This will provide an independent physical verification of the accuracy of the upper-tropospheric water vapor.

Possible modifications to the retrieval include use over land (only using upper-tropospheric channels and defaulting to the model humidity for lower levels) and switching on the cloud retrieval. Further work can also be done at the retrieval-NAVDAS interface, including accurate specification of vertical and horizontal covariances in the retrieval error, determination of the best humidity variable (e.g. relative humidity, specific humidity, or their logarithms) to use, and use of cloud information from the humidity retrieval. Ultimately, we hope to show that the assimilation of retrieved moisture profiles from AMSU-B produces more realistic water vapor fields and quantify the impact on forecast skill.

6. ACKNOWLEDGEMENTS

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