The Development of Hyperspectral Infrared Water Vapor Radiance Assimilation Techniques in the NCEP Global Forecast System

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Abstract

Techniques to assimilate the Atmospheric InfraRed Sounder (AIRS) and the Infrared Atmospheric Sounding Interferometer (IASI) water vapor channels into the National Centers for Environmental Prediction's (NCEP) Global Forecast System have been examined. There are several problems which must be resolved in using these water vapor channels. In general, the non-linearity of the water vapor channels makes them difficult to assimilate. Channels which have significant dependencies on water vapor in the stratosphere are not yet used in most Numerical Weather Prediction systems and are currently not modeled well by the NCEP Global Forecast System.

We have conducted with some success, initial experiments focused on using water vapor channels which provide information in the troposphere and in the stratosphere. By adjusting the data thinning we assimilate those observations which result in less initial adjustment to the moisture field. The instability associated with the water vapor channels is therefore reduced however, over time, have a significant impact on the moisture field in the Troposphere and Stratosphere. Some preliminary results are shown.

1. Introduction

Humidity is poorly observed by conventional observing systems particularly in the tropics and southern hemisphere. The effective use of satellite measurements is essential in producing realistic moisture fields. The use of the water vapor channels on the TIROS Operational Vertical Sounder (TOVS) (Smith et al. 1979), the humidity sensors from the Advanced Microwave Sounding Units (AMSU-B) and more recently the Microwave Humidity Sensors (MHS) (NOAA 2005) have improved the humidity fields in Numerical Weather Prediction (NWP) analysis and forecast models. The use of the new hyperspectral infrared sounders such as AIRS (Aumann et al. 2003) and IASI (Chalon et al. 2001) with better spectral resolution in the water vapor region should improve the NWP analysis of water vapor even further.

In the past moisture products and, in particular, infrared water vapor radiances have been difficult to assimilate. Possible causes for making the radiance observations difficult to assimilate include the non-linearity of their Jacobians, their multivariance (solve for T an q) and their non-Gaussian distribution. A particular problem has been seen in the first few hours of the forecast is excessive amounts of precipitation in regions where various precipitable water products were assimilated. Other problems have been identified within the analysis such as an excessive increase in the penalty function associated with the analysis, poor convergence, and supersaturation in the moisture field. Various techniques have been tried to resolve some of the problems including improving the quality control, increasing the number of iterations used by the assimilation system, down-weighting the observations and in some cases removing the moisture product or turning off the satellite channel. The water vapor channels from IASI and AIRS are no exception. Figure 1 is an example of the water vapor channel instability noticed within the analysis system to calculate the bias. The bias calculated for the temperature channels is typically near zero after the first outer loop of the NCEP analysis. The bias for the water vapor channels continues to fluctuate throughout the assimilation cycle.

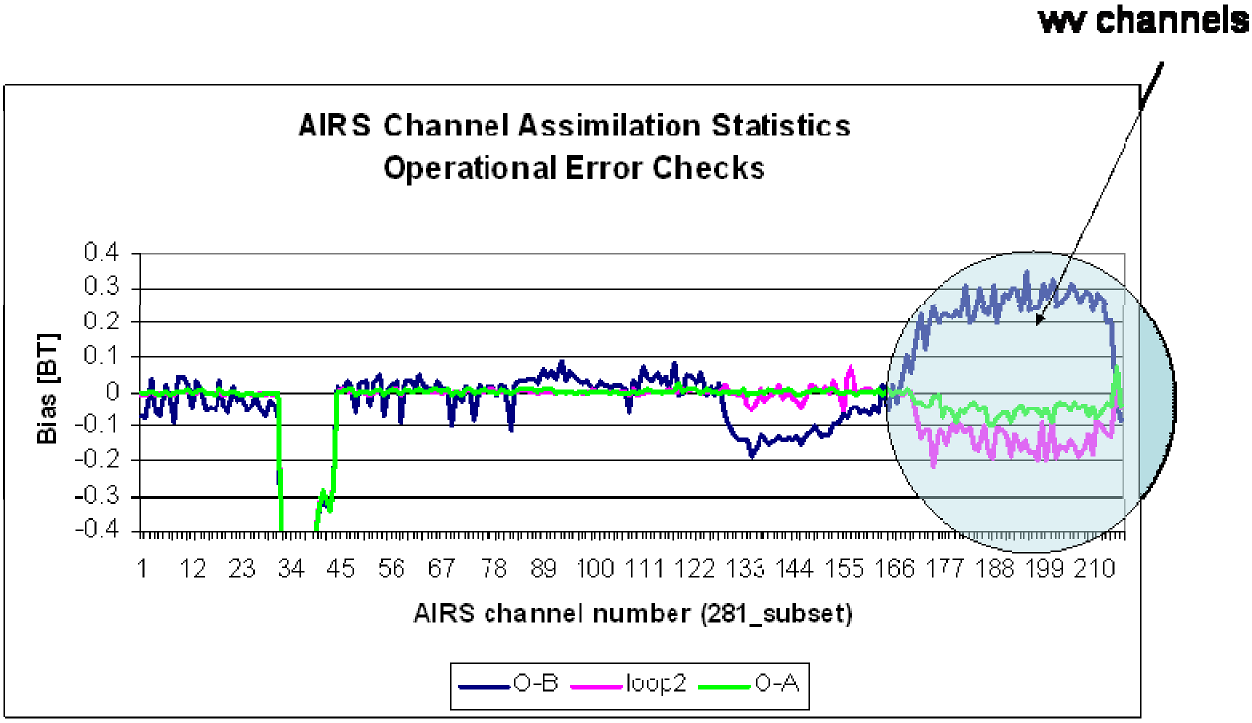

Figure 1: The average AIRS channel bias for a control assimilation cycle. The blue line is the observational fit to the model background (O-B), the magenta line is the observation fit before the second outer loop and the green line is the final observational fit to the analysis (O-A). Note: not all channels are being assimilated (e.g. channels 30-45).

2. Methodology

Typically the radiance gross error check is used to catch outliers that get past the quality control procedures. The standard deviation is calculated by deriving a distribution of the difference between the observed radiance and the radiance calculated by the model background. The gross error check within the NCEP global forecast system is typically set to about three times the standard deviation. For the water vapor channels this is ~4.5K.

In an attempt to minimize the inherent problems associated with the non-linearity of the Jacobians and the multivariance, we are using the gross error check as a threshold, rather than a check for outliers. By reducing the gross error check, in our case to ~0.9K, most of the problems in assimilating the water vapor channels are reduced. The stability of the bias has also improved and is now similar to the temperature channels as noted in figure 2. It may be noted we used a related method when assimilating AIRS data in the NCEP Spectral Statistical Interpolation (SSI) analysis (Le Marshall et al. 2006).

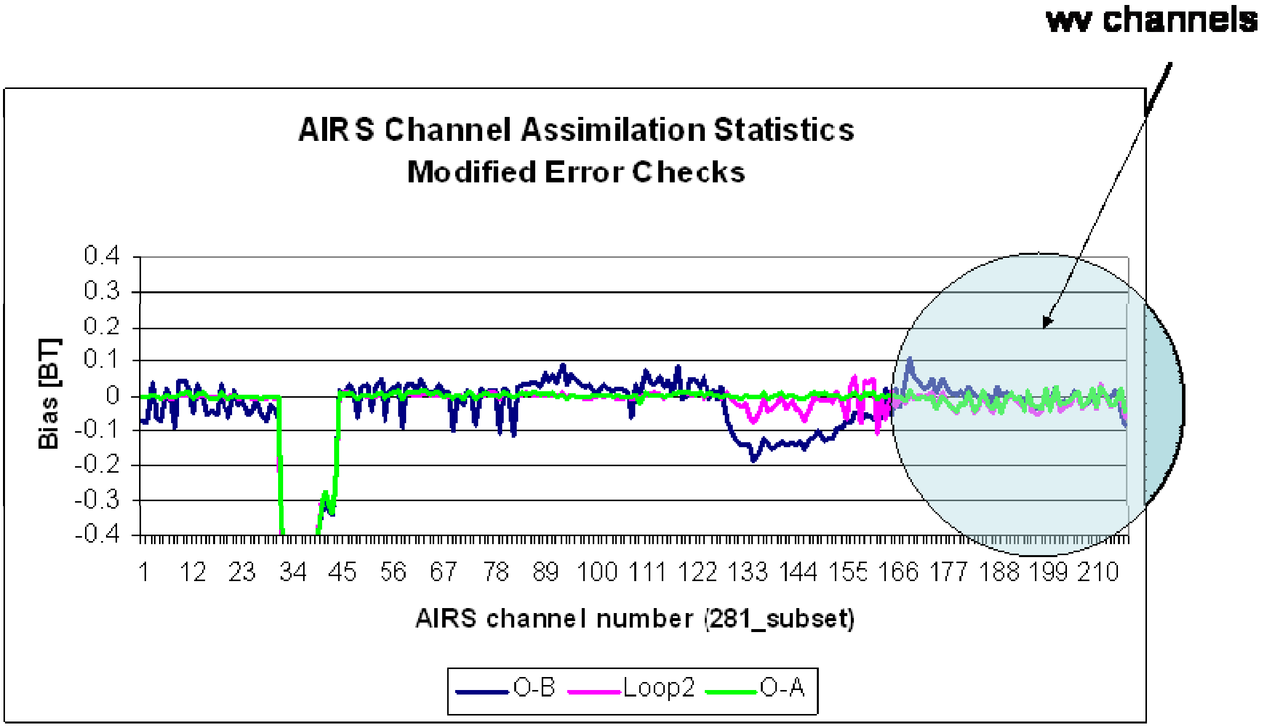

Figure 2: The average AIRS channel bias for an experiment assimilation cycle. The blue line is the observational fit to the model background (O-B), the magenta line is the observation fit before the second outer loop and the green line is the final observational fit to the analysis (O-A). Note: not all channels are being assimilated (e.g. channels 30-45).

3. Experiment Design

The February 2009 version of NCEP's Global Forecast System run at a horizontal resolution of T382 with 64 vertical layers was used for these experiments. The analysis system is NCEP's Gridpoint Statistical Interpolation (GSI) described in Derber et al. (1991), Wu et al. (2002) and Derber et al. (2003). The forecast system is NCEP's Global Spectral Model described in Kanamitsu (1989), Kalnay (1990), and Kanamitsu et al. (1991) with the recent changes found online at http://emc.ncep.noaa.gov/gmb/moorthi/gam.html and http://www.emc.ncep.noaa.gov/gmb/STATS/html/model_changes.html.

All of the observations used by NCEP operations were used in the Control and the Experimental runs. These include the various moisture observations from High Resolution Infrared Radiation Sounder (HIRS), AMSU-B, and the 281 channel subset of AIRS. 165 longwave channels from the 616 IASI subset were also used.

The IASI and AIRS water vapor channels used were divided into two groups depending on their sensitivity to moisture above the Troposphere. The channels which include strong water vapor absorption spectral lines and have a narrow spectral response are sensitive to moisture in the Stratosphere. IASI, with its narrow spectral bandwidth is better suited to infer Stratospheric moisture. Figure 3 is an example of an IASI channel Jacobian with sensitivity to moisture in the Stratosphere. The Tropospheric moisture experiment used 35 IASI and 27 AIRS water vapor channels sensitive to moisture in the Troposphere only. The Stratospheric moisture experiment used the same Tropospheric channels and used an additional 33 IASI and 11 AIRS water vapor channels which are sensitive to moisture in the Stratosphere.

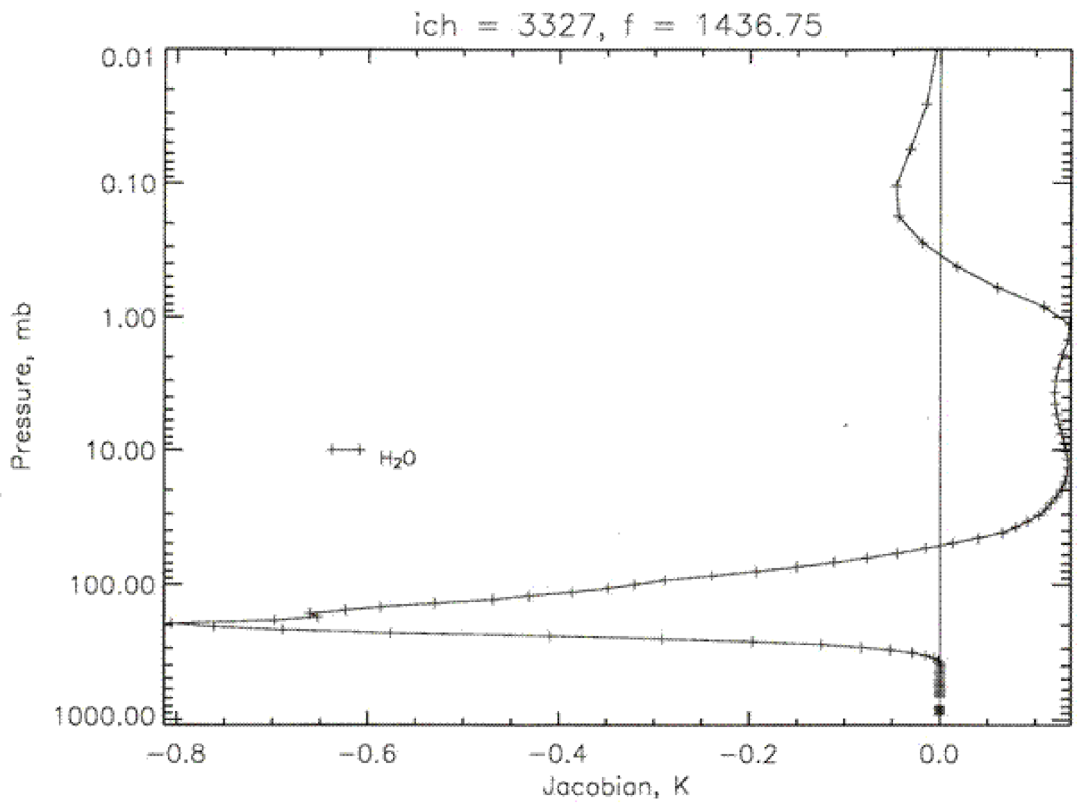

Figure 3: Water Vapor Jacobian for IASI channel 3327 which is sensitive to moisture in the Stratosphere. Courtesy Chris Barnet.

The gross error check for the water vapor channels were set (IASI) or reduced (AIRS) to 0.9K. The assimilation weights were also set (IASI) or reduced (AIRS) to generate RMS fits near (but above) the NEDR/NEDT. One month (during two seasons) was used to allow the bias corrections and the forecast model moisture field to adjust. The experiments were then run for one month (during 2 seasons). The first month in each season is not used in evaluating the results.

4. Results

Results of incorporating these assimilation techniques and using water vapor channels from the AIRS and IASI (experiment) have shown improvements in the moisture field when compared to simulations using the NCEP operational configuration (control). Some of these improvements are shown by the average differences in precipitable water field in the analysis and the improvements in the average 12 hour forecast of the Tropospheric moisture experiment. The impact in the precipitable water field is seen in Figure 4. Using the hyperspectral water vapor channels decreased moisture in the polar regions (reds) and increased moisture in the tropics (greens) (Figure 4(a)). The Forecast Impacts out to 12 hours (Figure 4(b)) were almost entirely positive or neutral. Differences in precipitation between the control and the experiment were generally small (not shown) and mostly in the tropics where the inter-tropical convergence zone was active.

Typically, adjustments to the moisture field are short lived due to various interactions with other precesses such as precipitation, clouds and radiation. Our initial results are no exception. The Forecast Impact (Zapotocny et al. 2005) suggest that improvements in relative humidity are evident in the 12 hour forecast (Fig. 5 (a)) but are reduced by 24 hours (Fig. 5 (b)).

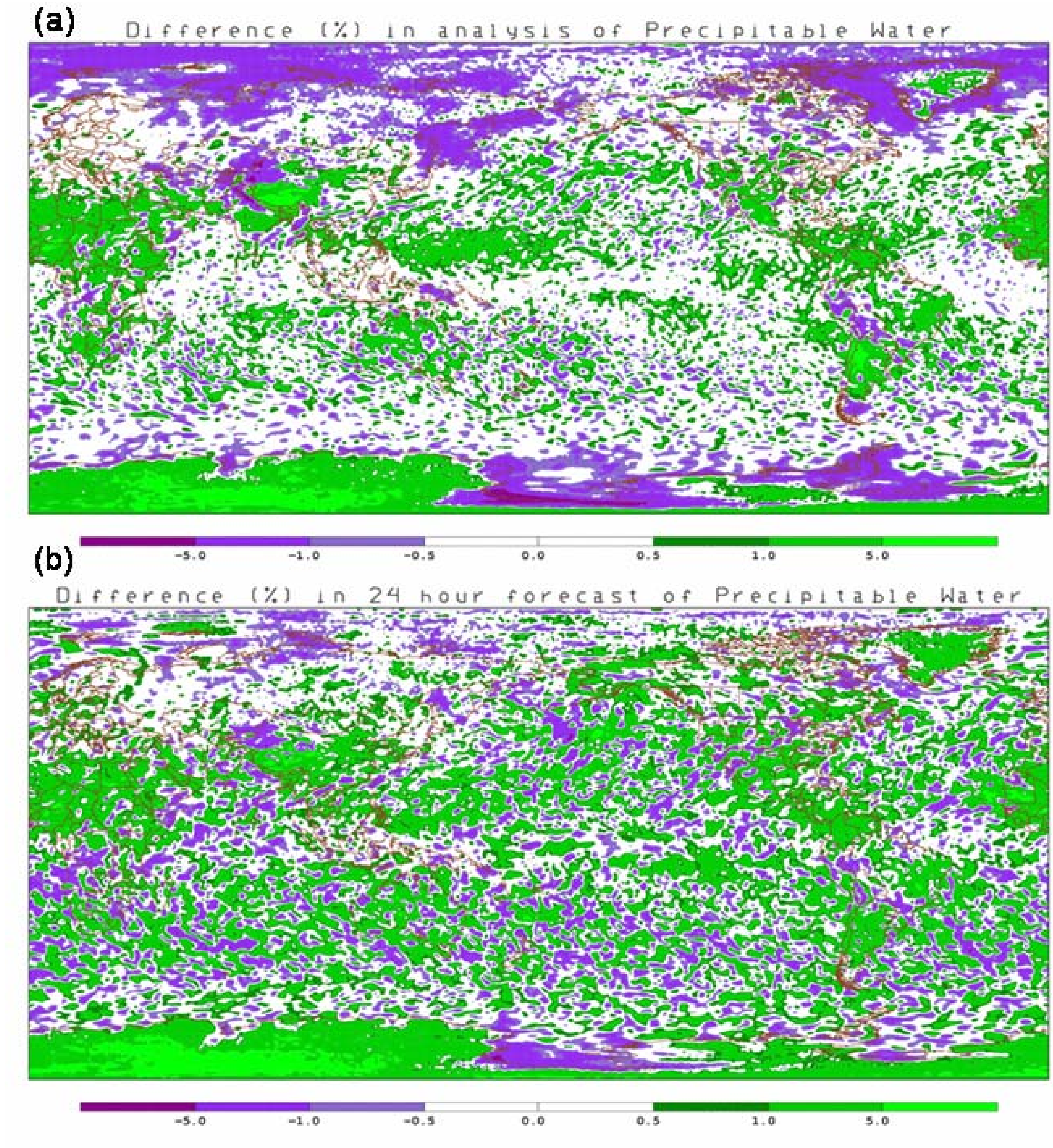

Figure 4: Geographic distribution of monthly average changes in precipitable water between the control and the experiment for (a) the analysis and (b) the 24 hour forecast. Color bar units are percent [%].

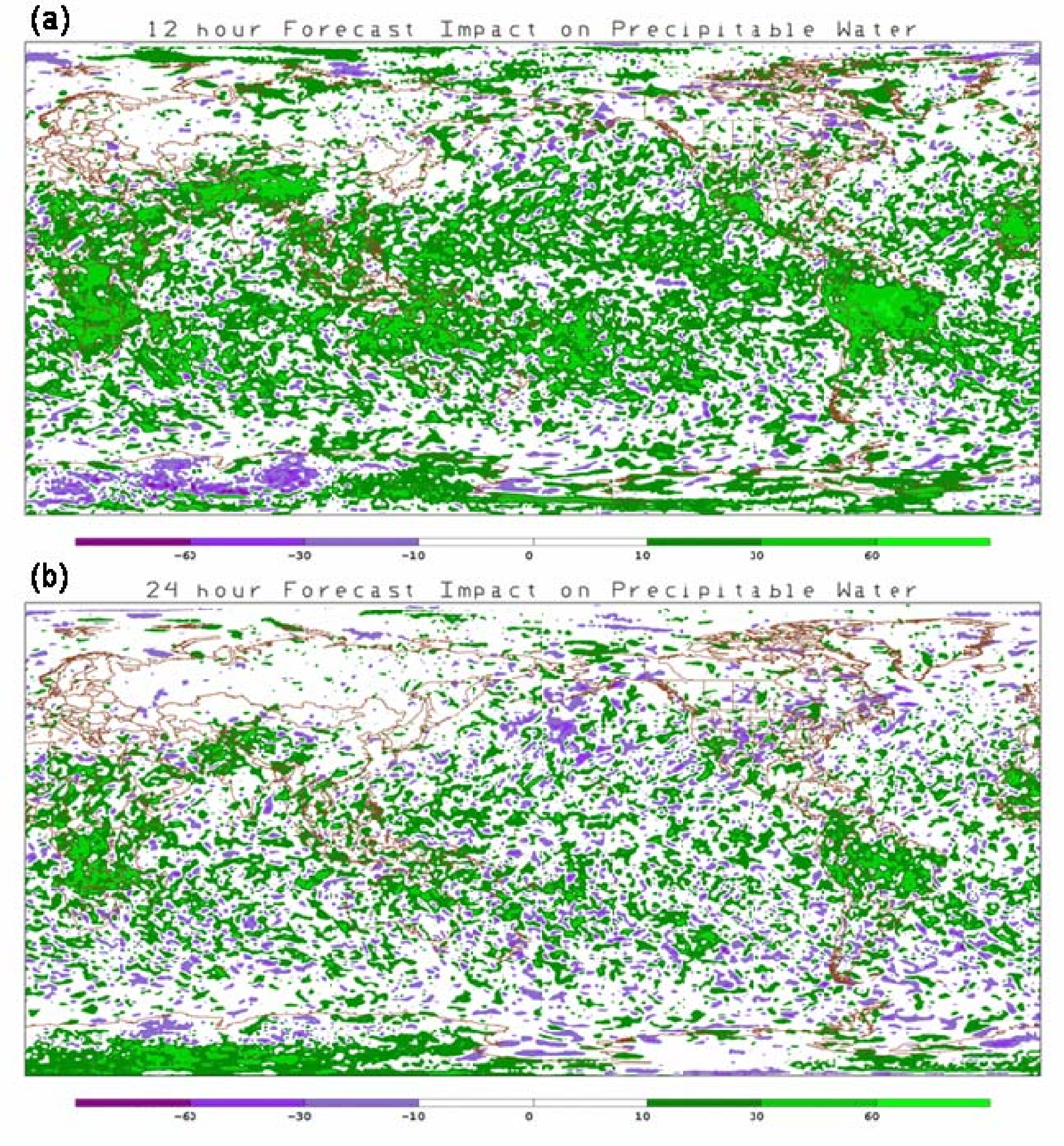

Figure 5: Geographic distribution of Forecast Impact on precipitable water for (a) 12 hour and (b) 24 hour forecasts. Color bar units are percent [%]

Some of the AIRS and IASI water vapor channels are sensitive to moisture in the stratosphere. When these specific water vapor channels are used to adjust the moisture in the Stratospheric moisture experiment, general circulation features appear in the stratospheric moisture field. Figure 6 (a) and (b) depict a large anti-cyclonic circulation in the north Pacific in two layers of the moisture field above the tropopause.

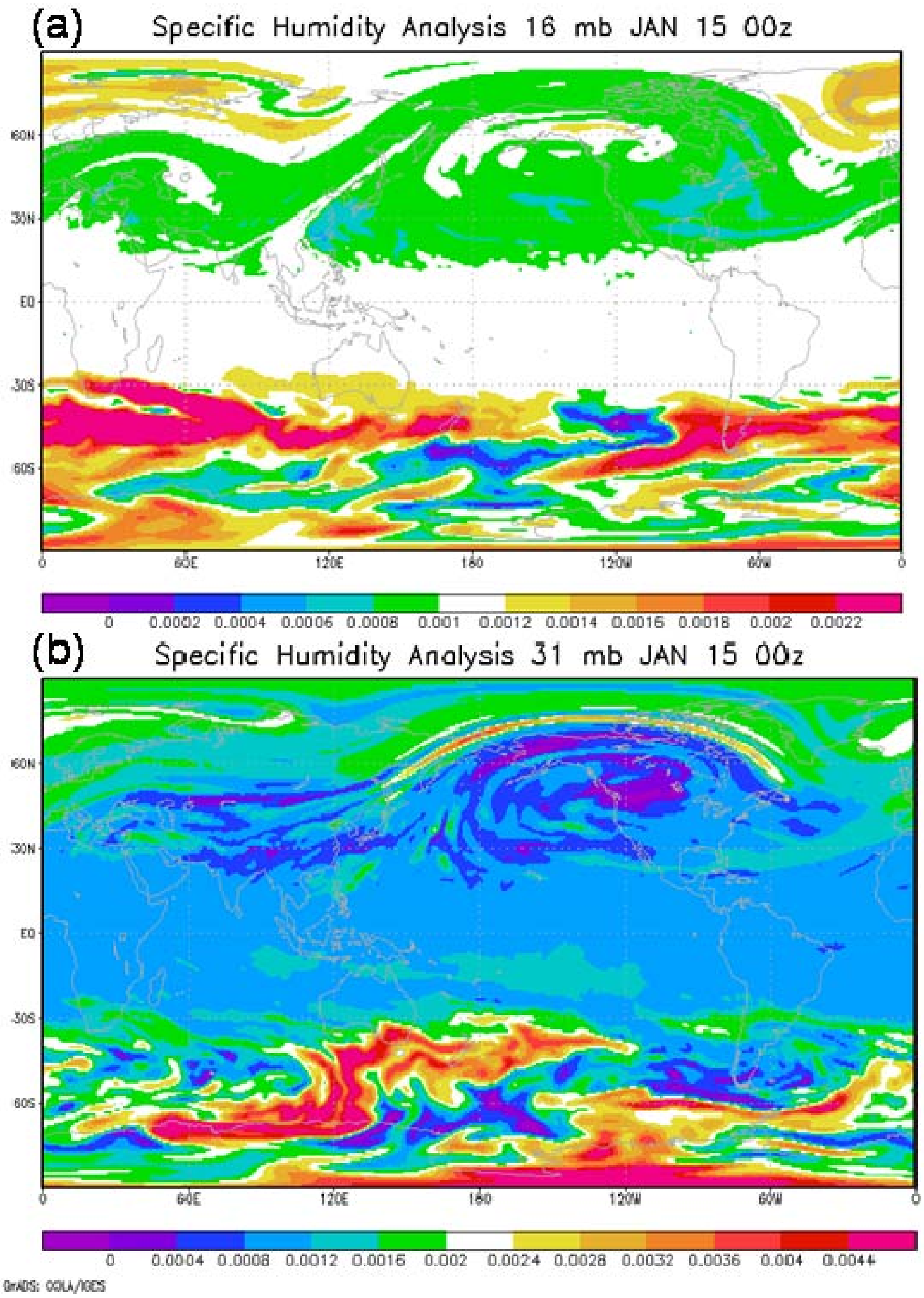

Figure 6: The specific humidity analysis at (a) 16 mb and (b) 31 mb when using some of the AIRS and IASI water vapor channels sensitive to moisture in the stratosphere. Color bar units are g/kg.

Other issues are being investigated in relation to this study. The background error variances and the error structure function for the pseudo-relative humidity in the stratosphere will need to be updated, given the new information from IASI and AIRS. Some areas of cold temperature biases and lower heights in the stratosphere have also been associated with the assimilation of the hyperspectral water vapor channels. Work is underway within the analysis to resolve this.

5. Conclusion

A method to assimilate water vapor channel radiances to improve the moisture in the Troposphere and Stratosphere has been developed for the NCEP GSI analysis. This method reduces the detrimental effects of the non-linearity of the jacobians and the multivariance inherent with water vapor radiances. Preliminary improvements in the precipitable water field along with improving the structure seen in the Stratosphere moisture are shown. These early experiments demonstrate the potential gain available from the successful use of these moisture channels in NWP.

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