Improving Forecast Skill by Assimilation of AIRS Temperature Soundings

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1. INTRODUCTION

AIRS was launched on EOS Aqua on May 4, 2002, together with AMSU-A and HSB, to form a next generation polar orbiting infrared and microwave atmospheric sounding system. The primary products of AIRS/AMSU-A are twice daily global fields of atmospheric temperature-humidity profiles, ozone profiles, sea/land surface skin temperature, and cloud related parameters including OLR. Also included are the clear column radiances $\hat{R}_i$ used to derive these products which are representative of the radiances AIRS would have seen if there were no clouds in the field of view. All products also have error estimates. The sounding goals of AIRS are to produce 1 km tropospheric layer mean temperatures with an rms error of 1K, and layer precipitable water with an rms error of 20 percent, in cases with up to 90 percent effective cloud cover. The products are designed for data assimilation purposes for the improvement of numerical weather prediction, as well as for the study of climate and meteorological processes. With regard to data assimilation, one can use either the products themselves or the clear column radiances from which the products were derived.

The AIRS Version 5 retrieval algorithm (Susskind et al 2010), is now being used operationally at the Goddard DISC in the routine generation of geophysical parameters derived from AIRS/AMSU data. A major innovation in Version 5 is the ability to generate case-by-case level-by-level error estimates $\delta T(p)$ for retrieved quantities and the use of these error estimates for Quality Control. These error estimates are used to determine a case-by-case characteristic pressure p_{best}, down to which the profile is considered acceptable for data assimilation purposes. The characteristic pressure p_{best} is determined by comparing the case dependent error estimate $\delta T(p)$ to the threshold values $\Delta T(p)$. The AIRS Version 5 data set provides error estimates of $T(p)$ at all levels, and also profile dependent values of p_{best} based on use of a "Standard" profile dependent threshold $\Delta T(p)$. These "Standard" thresholds were designed as a compromise between optimal use for data assimilation purposes, which requires highest accuracy (tighter Quality Control), and climate purposes, which requires more spatial coverage (looser Quality Control). Subsequent research using Version 5 sounding and error estimates showed that tighter Quality Control performs better for data assimilation proposes, while looser Quality Control (better spatial coverage) performs better for climate purposes.

We conducted a number of data assimilation experiments using the NASA GEOS-5 Data Assimilation System as a step toward finding an optimum balance of spatial coverage and sounding accuracy with regard to improving forecast skill. The model was run at a horizontal resolution of 0.5° latitude x 0.67° longitude with 72 vertical levels. These experiments were run during four different seasons, each using a different year. The AIRS temperature profiles were presented to the GEOS-5 analysis as rawinsonde profiles, and the profile error estimates $\delta T(p)$ were used as the uncertainty for each measurement in the data assimilation process.

We compared forecasts analyses generated from the analyses done by assimilation of AIRS temperature profiles with three different sets of thresholds; Standard, Medium, and Tight. More details concerning these thresholds are given in Susskind et al, 2010. We compared the results of these forecasts to those generated from a "Control" analysis, in which all the data used operationally by NCEP in 2003 was assimilated, but no AIRS data was assimilated. Radiances from the Aqua AMSU-A instrument were assimilated operationally by NCEP and are included in the "Control". It should be noted that the Aqua orbit (1:30 ascending) is almost identical to that of NOAA 16 carrying HIRS3, AMSU-A and AMSU-B, so AIRS/AMSU temperature soundings are providing additional information to that contained in the AMSU-A/AMSU-B radiances on NOAA 16 in the same orbit, as well as those of the Aqua AMSU-A radiances. No AIRS data was assimilated operationally at that time. An additional set of data assimilation experiments was also performed in which all data used in the Control, as well as observed AIRS radiances, were assimilated as is now done operationally by NCEP and ECMWF. These experiments are referred to as Radiance Assimilation. Global correlation coefficients of forecasted 500 mb heights are shown in figure 1 for all of the experiments described above, with the exception of the assimilation of AIRS temperature profiles using Medium Quality Control, which lies between the results using Tight Quality Control and Standard Quality Control.

Assimilation of Quality Controlled AIRS temperature profiles significantly improve 5-7 day forecast skill compared to that obtained without the benefit of AIRS data in all of the cases studied. In addition, assimilation of Quality Controlled AIRS temperature soundings performs better than assimilation of AIRS observed radiances. Based on the experiments shown, Tight Quality Control of AIRS temperature profile performs best on the average from the perspective of improving Global 7 day forecast skill.

One of the time periods studied contains Tropical Cyclone Nargis which devastated parts of Myanmar in May 2008. The Control analyses in the days prior to the landfall of Tropical Cyclone Nargis contained substantial misrepresentations, or even lack of representation, of the location a cyclone in the Bay of Bengal. Consequently, the storm track of this devastating storm was very poorly predicted ahead of time at NCEP (as occurred in reality). Reale et al (2009) showed that the prior analyses and subsequent forecasts of the Nargis

storm track were significantly better when AIRS Standard Quality Controlled temperature soundings were assimilated, and in fact an excellent prediction of when and where Nargis would hit land was produced from the AIRS Standard analysis 108 hours (4.5 days) ahead of forecast time. An intermediate ability to predict landfall of Nargis was produced using forecasts from the AIRS Radiance analysis. Reale et al did not examine the assimilation of Tight Quality Controlled AIRS temperature profiles in their study. Subsequent research has shown that as with 7 day Global forecast skill, assimilation of Tight Quality Controlled AIRS temperature soundings further improved the ability to forecast the characteristics of Tropical Storm Nargis.

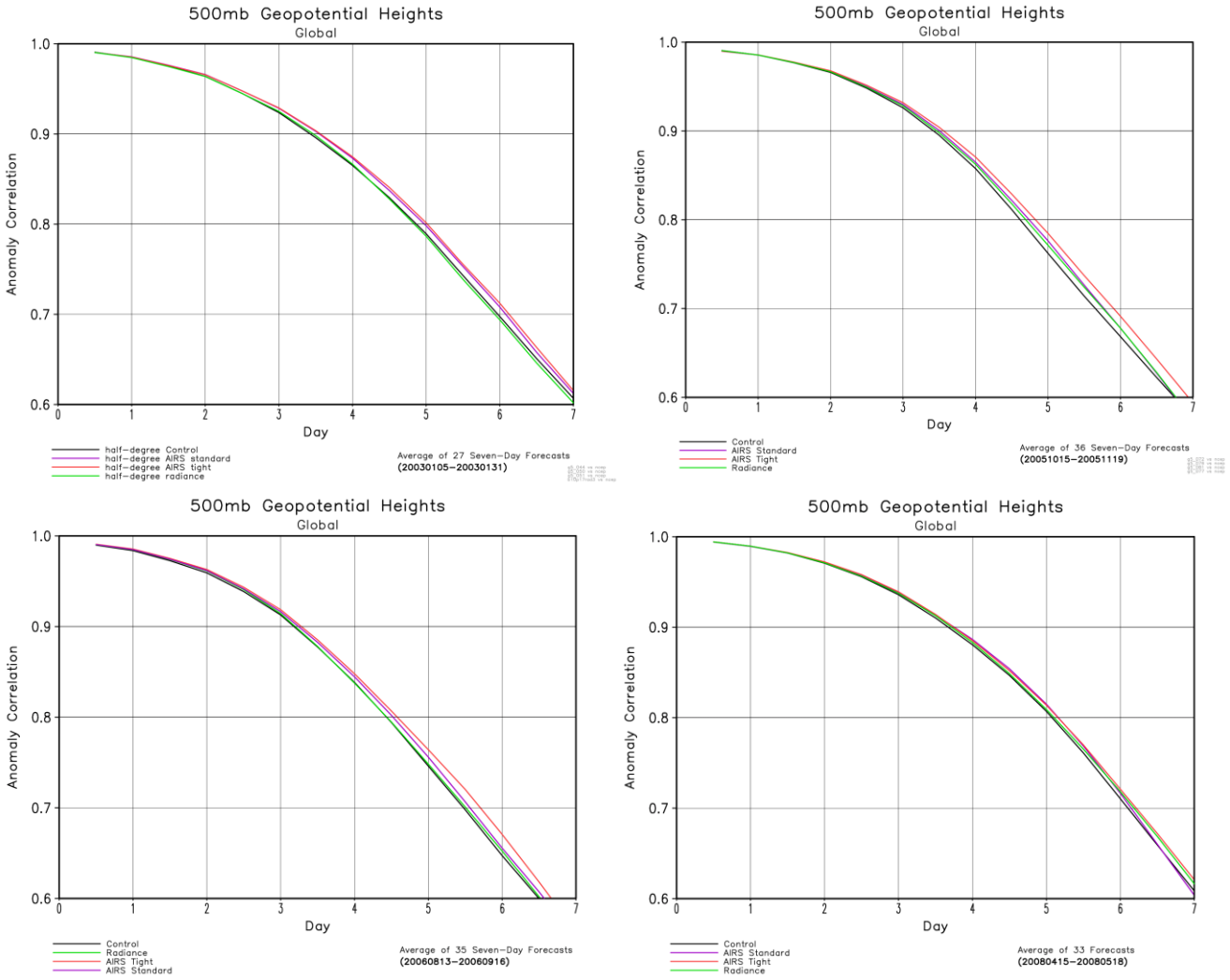

Figure 1

REFERENCES

Reale, O., W. K. Lau, J. Susskind, E. Brin, E. Liu, L. P. Riishojgaard, M. Fuentes, and R. Rosenberg, "AIRS impact on the analysis and forecast track of tropical cyclone Nargis in a global data assimilation and forecasting system", *Geophys. Res. Lett*, **36**, L06812, doi:10.1029/2008GL037122, 2009.

Susskind, J.; Blaisdell, J; Iredell, L.; and Keita, F. Improved Temperature Sounding and Quality Control Methodology Using AIRS/AMSU Data: The AIRS Science Team Version 5 Retrieval Algorithm, IEEE Transactions in Geophysics and Remote Sensing, TGRS-2009-00127-R2, in press, 2010.

IMPROVING FORECAST SKILL BY ASSIMILATION OF AIRS TEMPERATURE SOUNDINGS

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ABSTRACT

This paper uses AIRS temperature profiles derived by the AIRS Science Team Version-5 retrieval algorithm. The AIRS Science Team Version-5 retrieval algorithm is being used operationally at the Goddard DAAC in the processing (and reprocessing) of all AIRS data. The AIRS Science Team Version-5 retrieval algorithm contains two significant improvements over Version-4: 1) Improved physics allows for use of AIRS observations in the entire 4.3 μm CO_2 absorption band in the retrieval of temperature profile *T(p)* during both day and night. Tropospheric sounding 15 μm CO_2 observations are now used primarily in the generation of cloud cleared radiances $\hat{R}_i$. This approach allows for the generation of accurate values of $\hat{R}_i$ and *T(p)* under most cloud conditions. 2) Another very significant improvement in Version-5 is the ability to generate accurate case-by-case, level-by-level error estimates for the atmospheric temperature profile, as well as for channel-by-channel error estimates for $\hat{R}_i$. These error estimates are used for quality control of the retrieved products.

We have conducted forecast impact experiments assimilating AIRS temperature profiles with different levels of quality control using the NASA GEOS-5 data assimilation system. Assimilation of quality controlled *T(p)* resulted in significantly improved forecast skill compared to that obtained from analyses obtained when all data used operationally by NCEP, except for AIRS data, is assimilated. We also conducted an experiment assimilating AIRS radiances uncontaminated by clouds, as done operationally by ECMWF and NCEP. Forecasts resulting from assimilating AIRS radiances were of poorer quality than those obtained assimilating AIRS temperatures.

Index Terms—*Forecasting, infrared measurements, infrared spectroscopy, meteorology, remote sensing*

1. VERSION-5 TEMPERATURE PROFILE QC

AIRS Version-5 retrievals contain case-by-case level-by-level error estimates for all accepted profiles [1]. These error estimates are used to determine a case-by-case characteristic pressure p_{best}, down to which the profile is considered acceptable. All accepted profiles are assigned to have high quality down to at least 70 mb. The characteristic pressure p_{best} is defined as the highest pressure (somewhere between 70 mb and the surface pressure) at which the error estimate is not greater than a pressure dependent error estimate threshold. The Version-5 pressure dependent thresholds, called Standard Quality Control thresholds, were optimized bearing in mind what was considered to be the best trade-off between accuracy and spatial coverage for use in both data-assimilation and climate applications. Data assimilation, in general, requires high accuracy retrievals, while climate studies require good spatial coverage with less accurate, but unbiased, retrievals.

Figure 1a shows in black the rms error of Global Quality Controlled Version-5 temperature profiles on January 25, 2003 using the Standard Version-5 thresholds. Figure 1b shows the percent of cases accepted for Version-5 using the Standard Quality Control cutoffs. The red curves in Figures 1a and 1b represent Quality Controlled Version-5 temperature profile retrievals using a tighter set of Quality Control thresholds, called Tight Quality Control. Tightening thresholds leads to significantly more accurate Quality Controlled retrievals, but with a lower percentage of accepted retrievals as a function of pressure, resulting in poorer spatial coverage.

Figure 2 shows the spatial distributions of Quality Controlled Version-5 temperatures at 700 mb for ascending (1:30 PM local time) orbits on January 25, 2003, using both Standard Quality Control and Tight Quality Control. Areas with surface pressure less than 700 mb, such as over East-Antarctica, show up as data gaps in this figure as do orbit gaps. There is also a

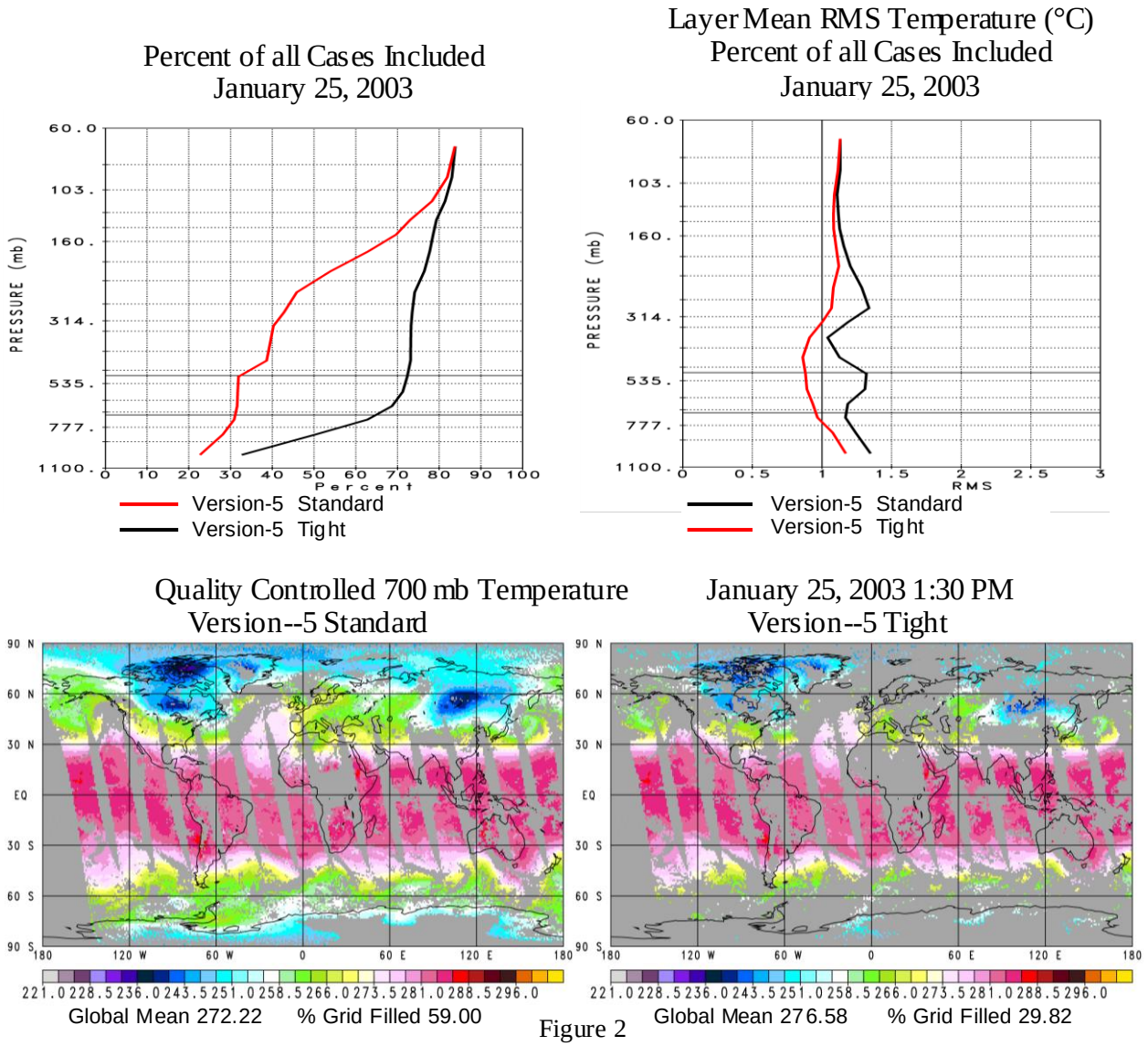

Figure 2

missing granule over the Sahara during this time period. Other data gaps are due primarily to areas containing extensive cloud cover. Version-5 temperature soundings using Tight Quality Control result in significantly poorer 700 mb spatial coverage at high latitudes than those using Standard Quality Control. Both Standard and Tight Quality Control give extensive spatial coverage of 700 mb temperatures over ocean, 50°N-50°S, even though this region contains many partially cloudy areas.

2. FORECAST IMPACT EXPERIMENTS

We conducted a number of data assimilation experiments as a step toward finding an optimum balance of spatial coverage and sounding accuracy with regard to improving forecast skill. The data assimilation and forecast system used is the GEOS-5 DAS, which represents a combination of the NASA GEOS-5 forecast model with the NCEP operational Grid Point Statistical Interpolation (GSI) global analysis scheme. All analyses and forecasts were run at a 0.5° x 0.625° spatial resolution.

We conducted a number of experiments utilizing AIRS data in each of four different seasons, each in a different year. The four periods studied were January 1 – January 30, 2003; October 15 – December 19, 2005; August 10 – September 16, 2006; and April 15 – May 18, 2008. Seven day forecasts were run every day in each experiment, beginning 5 days after the start of each experiment. The forecasts were verified every 12 hours against the ECMWF analysis, which was taken as "truth".

Four different sets of data assimilation experiments

were run during each time period: Control; AIRS Standard; AIRS Tight; and Radiance. In the "Control" analysis, all the data used operationally by NCEP was assimilated, but no AIRS data was assimilated. Radiances from the Aqua AMSU-A instrument were also assimilated operationally by NCEP and are included in the "Control". It should be noted that the Aqua orbit (1:30 ascending) is almost identical to that of NOAA-16 carrying HIRS3, AMSU-A and AMSU-B, so AIRS/AMSU temperature soundings, if used, provide additional information to that contained in the AMSU-A/AMSU-B radiances on NOAA-16 in the same orbit, as well as those of the Aqua AMSU-A radiances. No AIRS data of any kind was assimilated operationally at that time.

In AIRS Standard and AIRS Tight Assimilations, all information used in the Control was assimilated as well as Quality Controlled AIRS Version-5 temperature profiles. The AIRS Version-5 temperature profiles were presented to the GSI analysis as rawinsonde profiles, assimilated down to appropriate pressure level p_{best}. The case-by-case level-by-level error estimates of the temperature profiles were used as the uncertainty of each temperature measurement.

NCEP and ECMWF now assimilate AIRS observations operationally. The current operational practice is to directly assimilate observed AIRS radiances rather than AIRS temperature soundings. The operational methodologies used by both NCEP and ECMWF do not have the capability to derive and assimilate cloud cleared AIRS radiances. Instead, the analysis procedures used at both Centers select and assimilate only these AIRS observations which are "thought to be unaffected by clouds." These uncontaminated radiance observations are influenced primarily from temperatures in the stratosphere and also above clouds in areas where clouds are present. Our results from AIRS indicate that roughly 95% of AIRS pixels are cloud contaminated. Therefore, information from most tropospheric sounding AIRS observations is not included in the operational AIRS radiance assimilation process. In the Radiance Assimilation experiment, we assimilated AIRS radiances according to the NCEP operational procedure. In these AIRS Radiance Assimilation experiments, all other data assimilated in the Control was also included, but no AIRS temperature profile data was assimilated.

Figure 3 shows the average over all the experiments, of the 12 hour to seven day forecast 500 mb Geopotential Height anomaly correlation coefficients verified against the ECMWF analysis for the Northern Hemisphere extra-tropics. An anomaly correlation of 1.0 represents a perfect forecast and an anomaly correlation of 0.6 represents the limit of what is considered to be a useful forecast. An improvement in forecast skill of one experiment compared to another is indicated by the increase in hours (shift to the right) for that forecast to have the equivalent skill compared to another. In the Northern Hemisphere Extra-tropics, assimilating Quality Controlled AIRS soundings resulted in an improvement in average seven day forecast skill of roughly five hours compared to the Control for the Tight AIRS assimilation, and 4 hours for the AIRS Standard Assimilation.

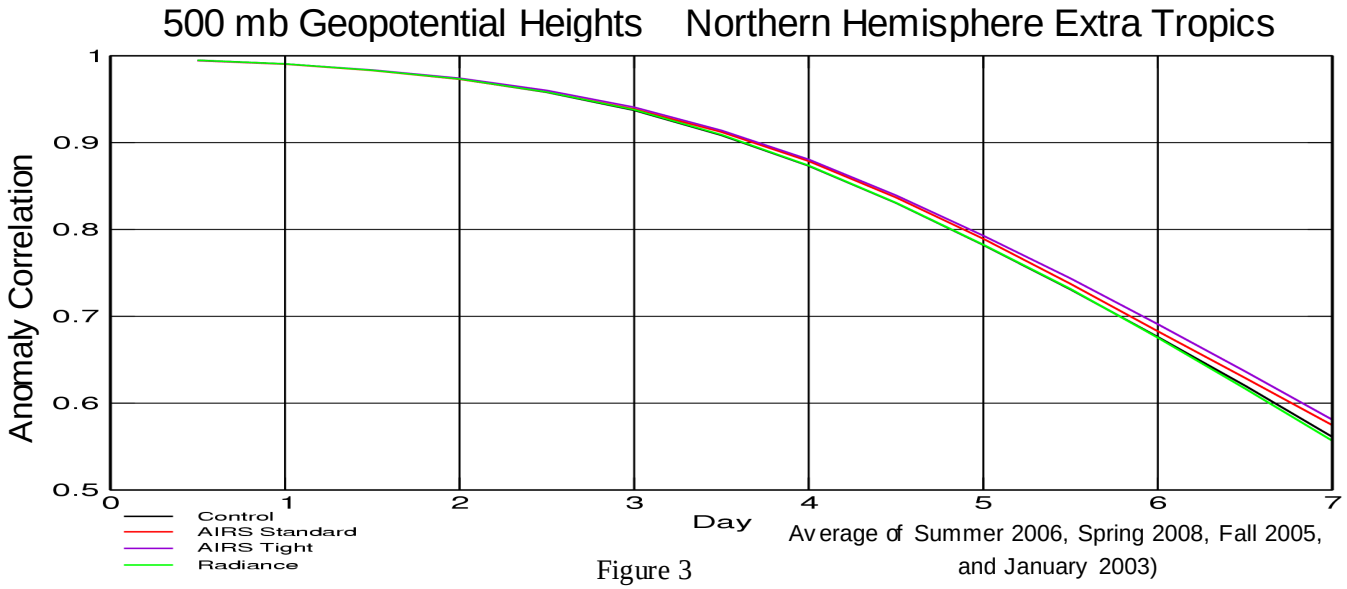

Figure 3

Assimilation of AIRS radiances unaffected by clouds resulted in a substantially reduced forecast impact in the Northern Hemisphere Extra-Tropics, compared to the Control. At least a part of this loss in forecast impact of Radiance Assimilation in the Northem Hemisphere Extra-Tropics results from the significant loss of spatial coverage of the AIRS tropospheric sounding channels used in the data assimilation process due to cloud contamination.

In the Southern Hemisphere Extra-Tropics (not shown), seven day forecasts from the Radiance Assimilation again produced essentially no improvement compared to the Control. Forecasts from the AIRS Tight Assimilation resulted in about a 2 hour improvement in average forecast skill compared to the Control, and forecasts from the Standard Assimilation resulted in a 2 hour degradation of forecast skill compared to the Control, and a 4 hour degradation compared to those from the Tight Assimilation. This demonstrates the importance of using appropriate Quality Control when assimilating the AIRS temperature profiles.

It is a very encouraging result that assimilation of Quality Controlled AIRS temperature soundings has resulted in a significant improvement globally in the skill of seven day forecasts compared to that obtained using the operational procedure of assimilating AIRS radiances rather than temperatures. Even more significant is the finding that assimilation of AIRS temperature soundings results in a significant improvement in the depiction of severe tropical weather systems and the subsequent ability to predict storm tracks for these events. We have studied in detail eight intense tropical cyclone events which took place during the time of the four data assimilation experiments conducted and have found that in each case, the AIRS Tight Analysis improved the depiction of the tropical cyclones in the GEOS-5 – DAS with regard to their intensity, confinement and position. The cause of the improvements was the ability to detect tight, strong upper-tropospheric positive thermal anomalies over areas of organized convection. In all cases, a much better prediction of the location and time of landfall of these tropical cyclones was obtained using forecasts from the AIRS Tight Assimilation compared to what was obtained using either the Control or Radiance Assimilation analyses. For example, Reale et al. showed the ability to accurately predict landfall five days ahead of time for Tropical Cyclone Nargis, which devastated parts of Myanmar with considerable loss of life in May 2008 [2]. This storm track was not predicted accurately from either the Control or Radiance Assimilation analyses. Zhou et al. have also shown that assimilation of Quality Controlled AIRS temperatures led to significantly improved analyses and forecasts of accumulated precipitation for three tropical cyclones compared to what was obtained using the Control or Radiance Assimilations [3].

Our experiments indicate that the potential to improve operational forecasting skill exists by the assimilation of Quality Controlled AIRS temperature profiles rather than AIRS radiances as currently done operationally. In order to test if this is indeed the case, we are currently porting the NCEP Operational Data Assimilation System (DAS) to GSFC. We plan to conduct the same experiments on the Operational DAS to see if assimilation of Quality Controlled AIRS temperatures will improve forecast skill in a pseudo-operational environment. Even if this proves to be the case, we will also have to demonstrate that this approach can be accomplished in a timely enough fashion for operational use. This is not expected to be an issue however as the temperature retrievals are performed very rapidly and it is computationally faster to assimilate temperatures than it is to assimilate radiances.

3. REFERENCES

[1] J. Susskind, J. Blaisdell, L. Iredell, and F. Keita, "Improved Temperature Sounding and Quality Control Methodology Using AIRS/AMSU Data: The AIRS Science Team Version-5 Retrieval Algorithm," *IEEE Trans. in Geophysics and Remote Sensing*, TGRS-2009-00127-R2, in press, 2010.

[2] O. Reale, W. K. Lau, J. Susskind, E. Brin, E. Liu, L. P. Riishojgaard, M. Fuentes, and R. Rosenberg, "AIRS Impact on the Analysis and Forecast Track of Tropical Cyclone Nargis in a Global Data Assimilation and Forecasting System", *Geophys. Res. Let.*, vol. 36, L06812, doi:10.1029/2008GL037122, 2009.

[3] Y. P. Zhou, K.-M. Lau, O. Reale, and R. Rosenberg, "AIRS Impact on Precipitation Analysis and Forecast of Tropical Cyclones in a Global Data Assimilation and Forecast System," *Geophys. Res. Let.*,vol. 37, L02806, doi:10.1029/2009GL041494, 2010.