IMPROVEMENTS IN THE USAGE OF TOVS DATA AT THE NASA GODDARD DATA ASSIMILATION OFFICE

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1. INTRODUCTION

A major effort has been undertaken at the DAO to improve the assimilation of TOVS data. Over the past two years, an interactive retrieval system has been developed and implemented at the DAO. This system, known as DAOTOVS, is currently undergoing evaluation within the Goddard Earth Observing System Data Assimilation System (GEOS-DAS). DAOTOVS was designed to produce soundings over both land and ocean, and in cloudy as well as clear areas.

The initial experiments have shown positive impact in the GEOS-DAS in terms of 6 hour and 5 day forecasts. However, a full validation has not yet been completed. Here, we describe the progress to date on improvements in the usage of TOVS data.

2. THE DAOTOVS 1DVAR FRAMEWORK

DAOTOVS uses a variational cloud-clearing approach. Cloud-clearing is a procedure that removes cloud radiative effects through comparison of partly cloudy adjacent pixels. The approach combines aspects of the cloud-clearing techniques pioneered by Chahine (1974, 1977), Smith (1968), McMillin and Dean (1982), and Susskind *et al.* (1984), with variational approaches used by *e.g.,* Eyre *et al.* (1993). DAOTOVS simultaneously extracts cloud-clearing parameters and information about the atmospheric and surface state from microwave and infrared observations. The variational framework ensures that the state estimate is consistent with all available measurements. The DAOTOVS cloud-clearing implementation allows for complex cloud structures including multiple cloud layers with wavelength-dependent radiative properties.

3. PRELIMINARY RESULTS USING ATOVS 1B DATA

DAOTOVS retrievals have been validated using ozone data from the Total Ozone Mapping Spectrometer (TOMS), radiosondes, and the data assimilation background (Joiner and Rokke, 2000). DAOTOVS has been coupled to the GEOS-DAS forming an interactive system. This system is currently undergoing evaluation.

At the DAO, an emphasis has been placed on the middle atmosphere observations and impact studies. This has not been a focus for numerical weather prediction (NWP). However, it is important for the DAO as the use of its assimilated winds, to drive stratospheric chemistry and transport models, has increased. The preliminary results shown here will focus on the stratosphere.

In the follow series of figures, comparison will be made between two assimilation experiments: (1) Control (CTRL-NES): TOVS Retrievals from the National Environmental Satellite Data and Information Service (NESDIS) are assimilated (2) Experiment (EXP-DTOV): DAOTOVS interactive retrievals are assimilated. The experimental time periods are summer 1998 and 1999. Both experiments used identical assimilation systems (GEOS 2.7.2 run at 4°× 5° resolution in 1998 and 2°× 2.5° resolution in 1999). The GEOS-DAS has been described in detail in DAO-ATBD (1996,2000). The same observation and background error statistics are used in both experiments. The TOVS error statistics were optimized for the NESDIS retrievals (CTRL-NES). The errors contain a component with both horizontally- and vertically-correlated errors as well as a component with uncorrelated errors.

A bias correction is applied to the NESDIS retrievals. No bias correction is used with DAOTOVS retrievals. The only bias correction applied in DAOTOVS is to the radiances as described in the next section.

In EXP-DTOV, SSU data were not assimilated due to an inter-instrument bias between SSU and AMSU. Therefore, prior to July 3, 1998, when the level 1b AMSU data first became available, the upper-stratospheric information came from HIRS channel 1 which has an extremely broad weighting function. NOAA-15 data (including AMSU) were not assimilated in CTRL-NES because they were not available.

Observed minus 6 hour forecast (O-F) statistics can be misleading in the case of interactive retrievals. This is because interactive retrievals contain a significant component from the model first guess. This problem particularly important in the middle and upper stratosphere where there are no other observations. For example, if the interactive retrievals did not change the first guess, the O-F statistics would have zero bias and standard deviation (indicating a perfect forecast). Instead of using interactive retrievals as the observation for verification, we can use the operational NESDIS retrievals. The NESDIS retrievals do not incorporate a model as the first guess. However, it should be noted that these data are assimilated in CTRL-NES.

Figure 1 shows the geopotential heights presented to the assimilation system at 10 hPa. Note the significant differences between the NESDIS and DAOTOVS data. Similar patterns and magnitudes of the differences between NESDIS and DAOTOVS were observed up to the topmost analysis level. The incomplete coverage in the top panel is due to an equal-area thinning algorithm that is applied to the DAOTOVS data before they are ingested.

Figure 2 shows that more radiosonde heights are accepted by the on-line quality control at 30 hPa in EXP-DTOV. Similar results were obtained at other pressure levels and for winds as well as geopotential height. This may be due to more consistency between DAOTOVS and radiosonde data.

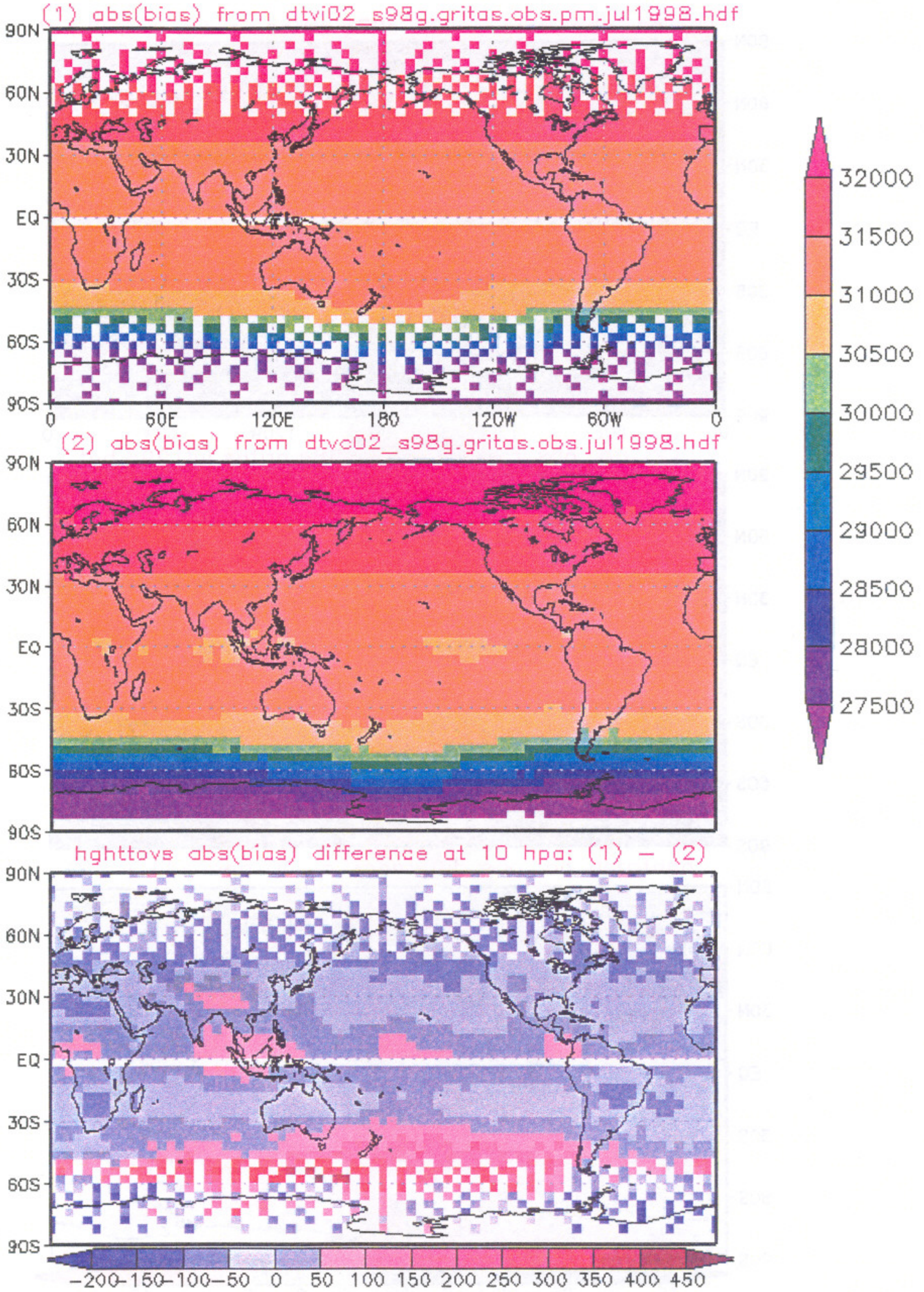

Figure 1: Top panel: DAOTOVS geopotential heights (in meters) at 10 hPa (monthly mean for July 1998); Middle panel: NESDIS TOVS geopotential heights at 10 hPa; Bottom panel: Difference between top and middle panels

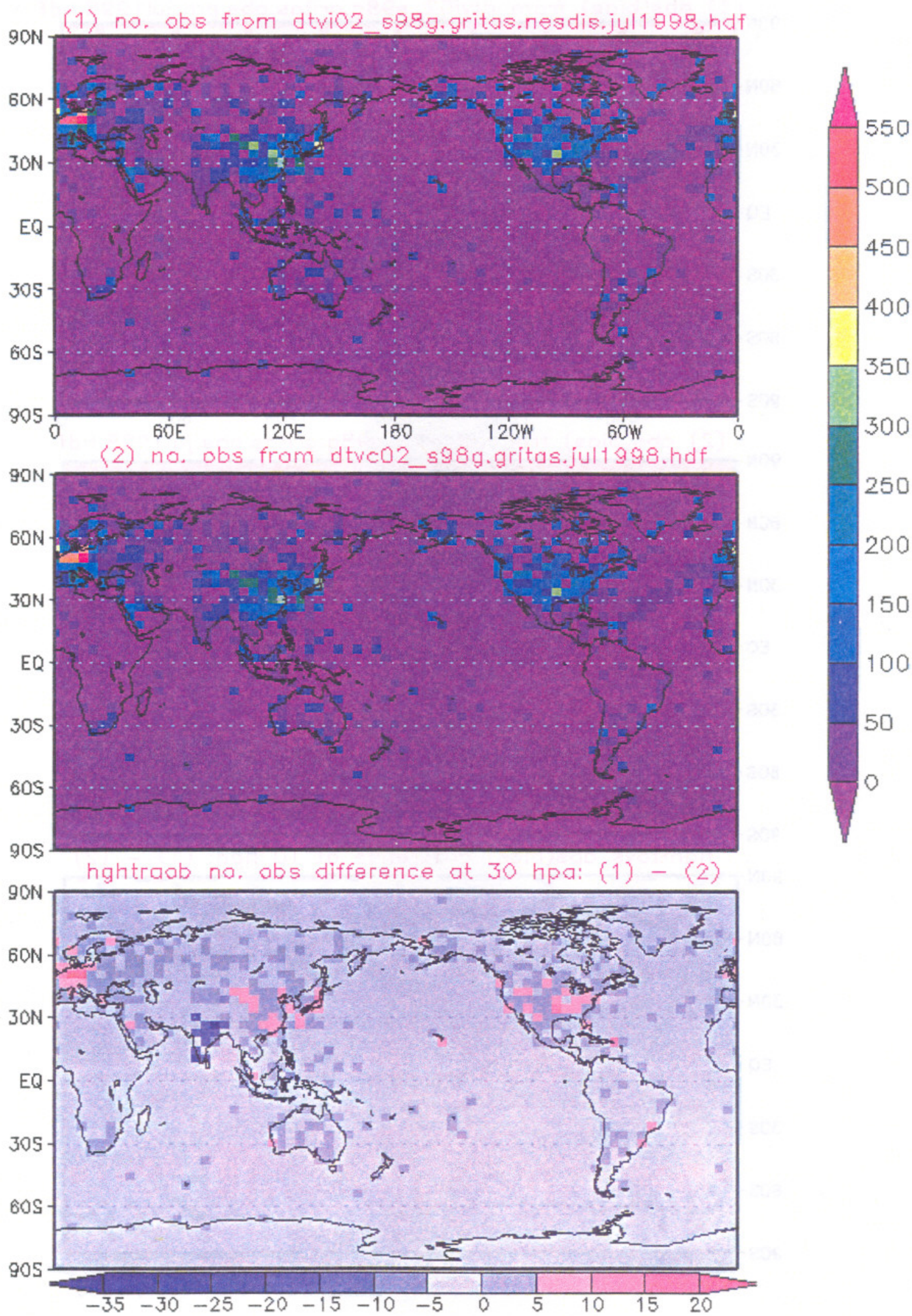

Figure 2: Similar to Figure 1 but showing the number of accepted radiosonde geopotential height observations at 30 hPa for EXP-DTOV (top) and CTRL-NES (middle).

Figures 3-4 show the bias and standard deviations of the 6 hour observed minus forecast (O-F) departures with respect to the NESDIS TOVS retrievals at 2 hPa. Even though the NESDIS TOVS data are assimilated in CTRL-NES, the forecasts from EXP-DTOV agree better with the NESDIS TOVS retrievals than in CTRL-NES.

Similar improvements in EXP-DTOV as compared with CTRL-NES were also seen in June 1998 before the introduction of AMSU data. This indicates that some of the improvements in EXP-DTOV are due to the interactive retrievals, and some are due to the introduction of AMSU data. However, the O-F departures for CTRL-NES were significantly smaller in June so that the degree of improvement was not as dramatic. Improvements in EXP-DTOV over CTRL-NES using this metric are seen at all altitudes down to the surface. However, the improvements diminish towards the surface.

The current statistics package does not allow for similar O-F comparisons with radiosondes. This is because a different sample of radiosonde data are accepted data in each experiment. Given that more radiosonde data were accepted in EXP-DTOV, the radiosonde statistics still showed slight improvements in EXP-DTOV over CTRL-NES.

Five day forecasts have also been generated. The anomaly correlation and RMS statistics show a positive result on average. However, the degree of improvement depends upon which analysis is used as verification. There are currently not enough forecasts available to generate reliable statistics. More forecasts are currently being run.

The two assimilations have also been compared with other climate data sets such as satellite-derived outgoing longwave radiation (OLR), clouds, and precipitation. The results show no significant degradation in climate diagnostics such as clouds with EXP-DTOV even though the DAS was tuned in assimilation mode using the NESDIS retrievals.

4. SYSTEMATIC ERROR CORRECTION FOR RADIANCES

There has been a focus at the DAO on systematic errors and correction methods. Treatment of systematic errors is crucial for the successful use of satellite data in a DAS, because these errors can be as large or larger than random errors. The usual assumption in data assimilation is that observational errors are unbiased. If biases are not effectively removed prior to assimilation, the impact of satellite data will be lessened and can even be detrimental. Treatment of systematic errors is important for short-term forecast skill as well as the creation of climate data sets.

A systematic error correction algorithm has been developed as part of DAOTOVS. This scheme corrects for spectroscopic errors, errors in the instrument response function, and other biases in the forward radiance calculation for TOVS. Such algorithms are often referred to as "tuning" of the radiances. This parameterization has been applied to the HIRS2 9.6μm channel (channel 9), which is affected by ozone, using collocated ozone profiles from the Solar Backscatter UltraViolet (SBUV) radiometer (Joiner *et al.*, 1997).

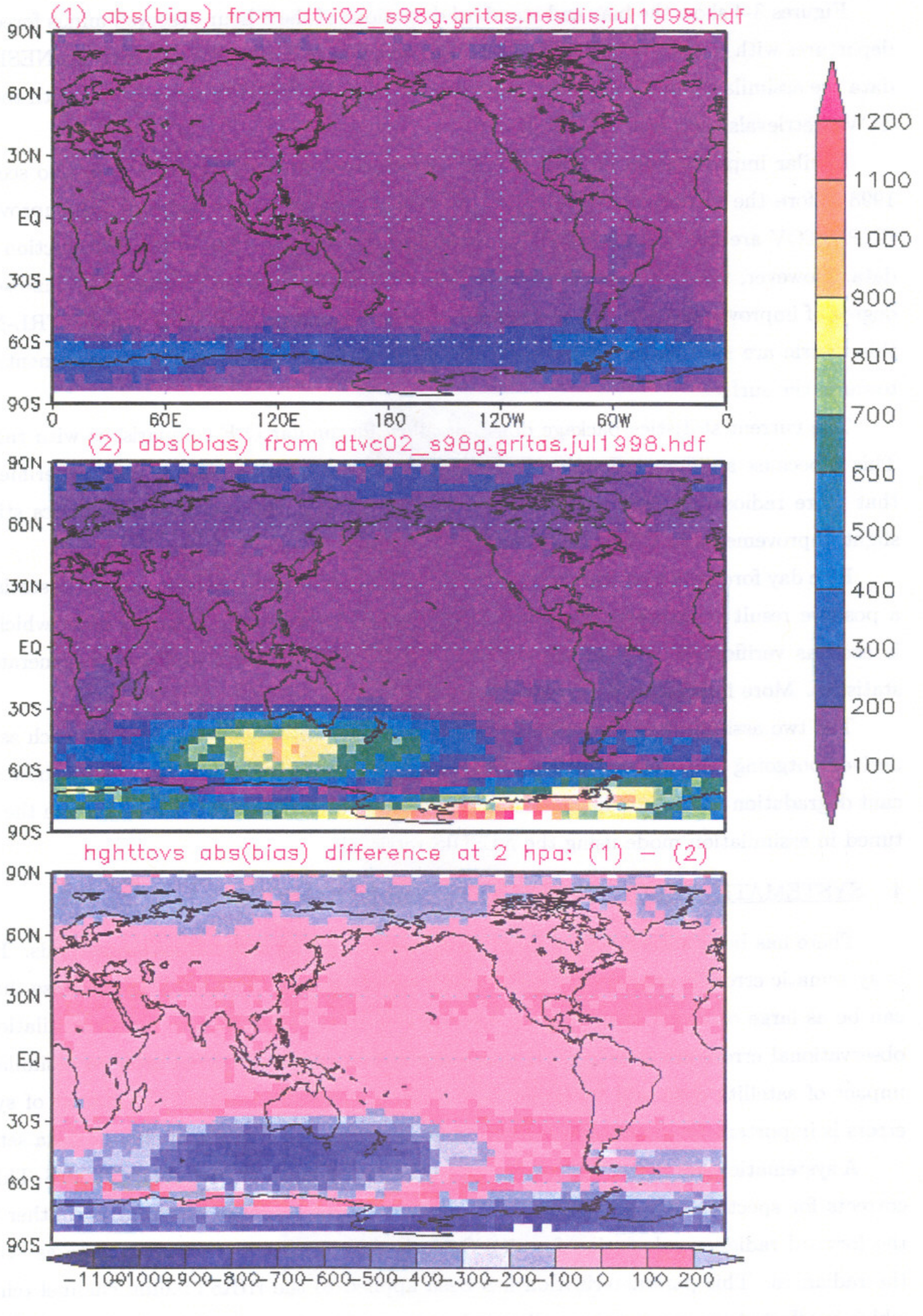

Figure 3: Similar to Figure 2 but showing the geopotential height (m) monthly mean 6 hour observed minus forecast (O-F) bias using NESDIS TOVS retrievals at 2 hPa.

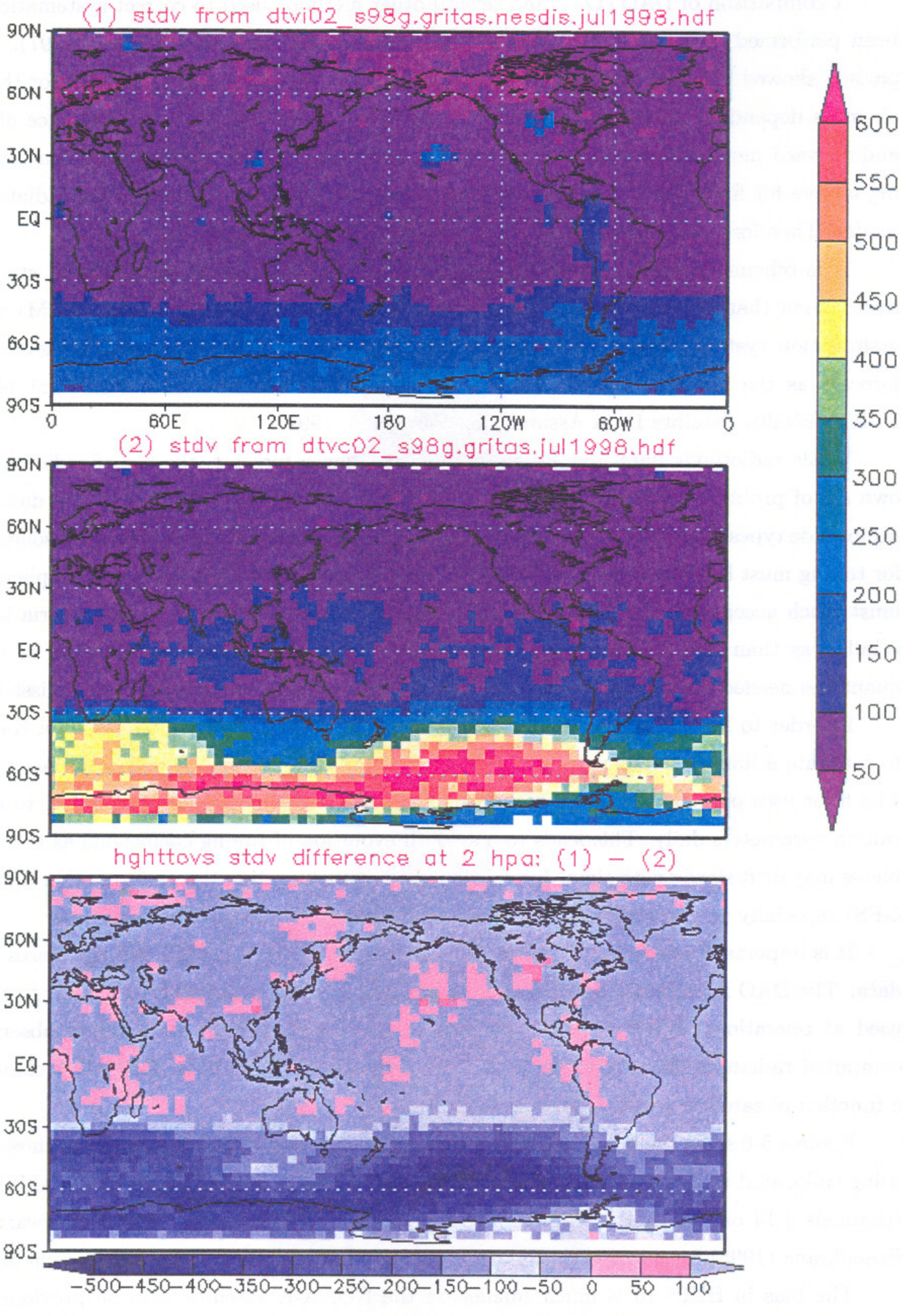

Figure 4: Similar to Figure 3 but showing the standard deviation.

A comparison of DAOTOVS and several other methods used to correct systematic errors has been performed with similuated data and collocated radiosonde data (Joiner, 1997). This comparison showed that the DAOTOVS parameterization was better able to account for the complex, air-mass dependent biases that are seen in the differences between TOVS radiance observations and forward model calculations. This is because the DAOTOVS parameterization includes scaling factors for fixed gas and water vapor transmittances that are applied to the radiative transfer model. Therefore, the tuning parameters are more physically based.

This scheme is unique in that it uses collocated radiosondes as the unbiased state estimate rather than that of a short-term forecast from the general circulation model (GCM) used in the assimilation system. Some NWP centers have experienced difficulties using a short-term GCM forecast as the unbiased truth. This is because GCM's can also have significant biases (*e.g.,* D. A. McNally, Satellite Data Assimilation Workshop, 1999).

While radiosonde data may be more unbiased than a forecast, the use of radiosondes has its own set of problems. Stringent quality control must be applied to the radiosonde data and some radiosonde types may need to be excluded as a result of significant biases. The radiosonde matchups for tuning must be done in clear conditions, and radiosondes used for tuning stratospheric channels must reach acceptable altitudes. The number of collocations matching these criteria is relatively small (less than 100 per day). In addition, the radiosondes do not measure all of the surface quantities needed for a radiance calculation (*e.g.,* surface skin temperature and emissivity).

In order to be able to use the radiosonde data for tuning, we have developed a Kalman filter to estimate a limited number of tuning coefficients for each channel as well as surface parameters. The filter uses previous estimates of the tuning parameters, as well as their errors, to update the tuning parameters daily. This leads to a smooth evolution of tuning coefficients as the instrument biases may drift slowly with time. In addition, we are investigating the usage of other data (perhaps GPS) especially in the upper-stratosphere where radiosonde data are not available.

It is important to carefully monitor the accuracy of forward models and the biases in satellite data. The DAO is currently developing a monitoring system for DAOTOVS similar to those being used at operational NWP centers. For example, we will monitor statistics of observed minus computed radiances using both the model and collocated radiosondes. This will include biases as a function of satellite zenith angle and latitude.

Figures 5-6 show the bias and standard deviations of observed radiances minus those computed using collocated radiosonde data. Note the relatively small biases (< 0.5 K) in the AMSU channels (channels 3-14 on the right side of the figures). DAOTOVS currently uses the forward model of Rosenkranz (1995) for microwave channels and Susskind *et al.* (1983) for infrared channels.

The bias in HIRS 15 is much smaller on the NOAA-K satellite than on previous satellites. Similar bias reduction has been observed at other NWP centers with different radiative transfer models. These results point to improvements in instrument calibration of the NOAA 15 instruments

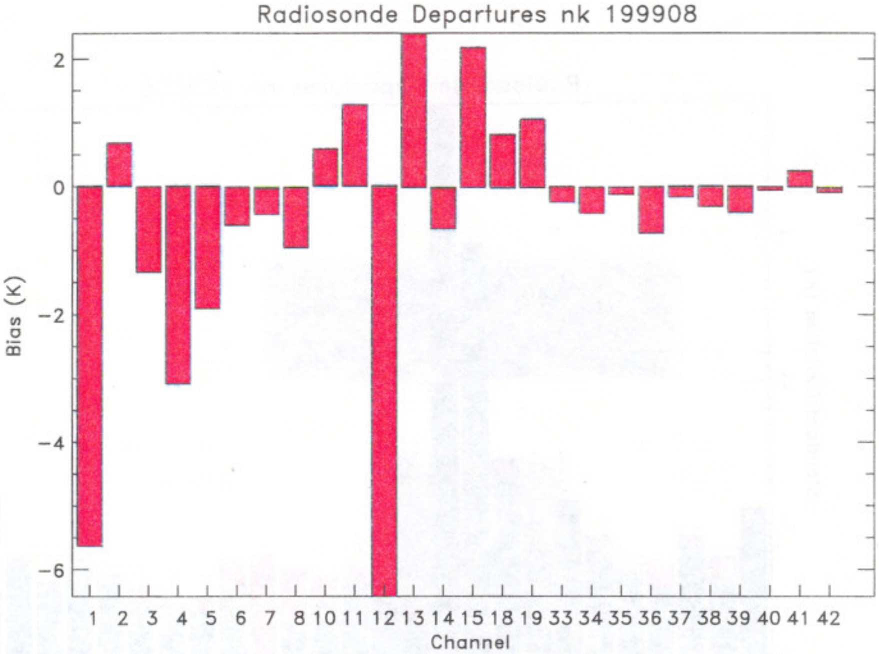

Figure 5: Bias in observed brightness temperatures minus those computed from radiosondes for NOAA 15 (nk) in August 1999. HIRS left, AMSU right, red: before tuning; green: after tuning.

as compared with earlier satellites.

Figures 9 and 10 show brightness temperature biases (observation minus computed from radiosondes) for MSU 2 and AMSU 4, respectively, averaged over one month before and after correction. The mean bias over all angles has been subtracted from the untuned data to more clear show the scan angle dependence. The scan angle dependence of the bias is very different for NOAA 14 and NOAA 15. The biases are much reduced with the DAOTOVS correction scheme. Figure 11 similarly shows an example of how the latitude-dependence of the bias is also reduced on average.

5. ONGOING DEVELOPMENT AND EVALUATION

Improvements have been made in cloud-detection and field-of-view determination since Joiner and Rokke (2000). These improvements are currently being examined within the GEOS-DAS. The impact of cloud- and land-affected data will be evaluated within the GEOS-DAS. If these data are not producing a significantly positive impact, they can easily be removed from the DAS.

The quality of medium-range forecasts will continue to be examined as part of the impact assessment. Other diagnostics, such as using winds to drive constituent transport models, will also be used as validation.

The current experiments have only assimilated temperature data. The next step is to assimilate both temperature and humidity data. The evaluation of these experiments will involve careful comparison with independent data sets.

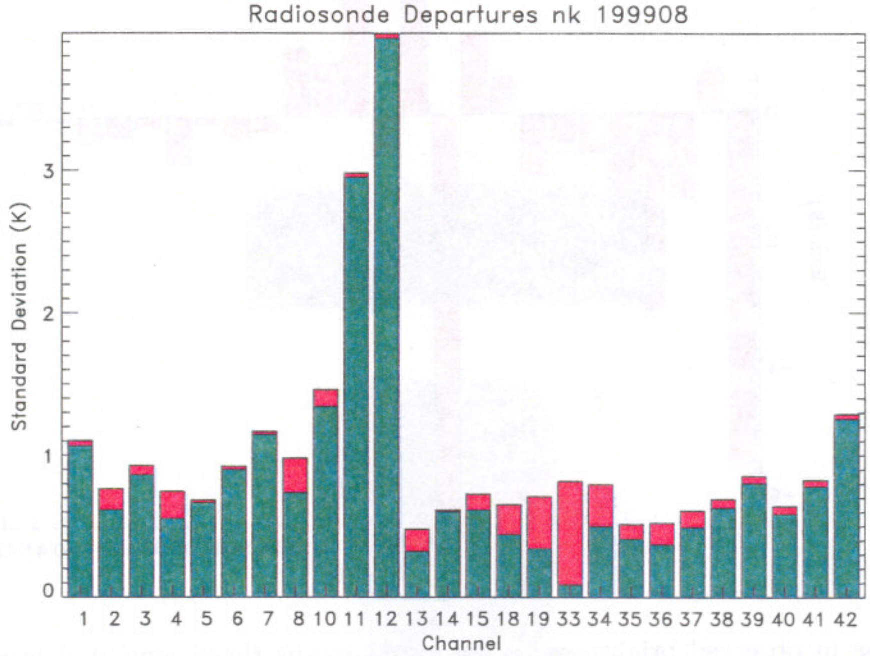

Figure 6: Similar to figure 5 but showing standard deviations.

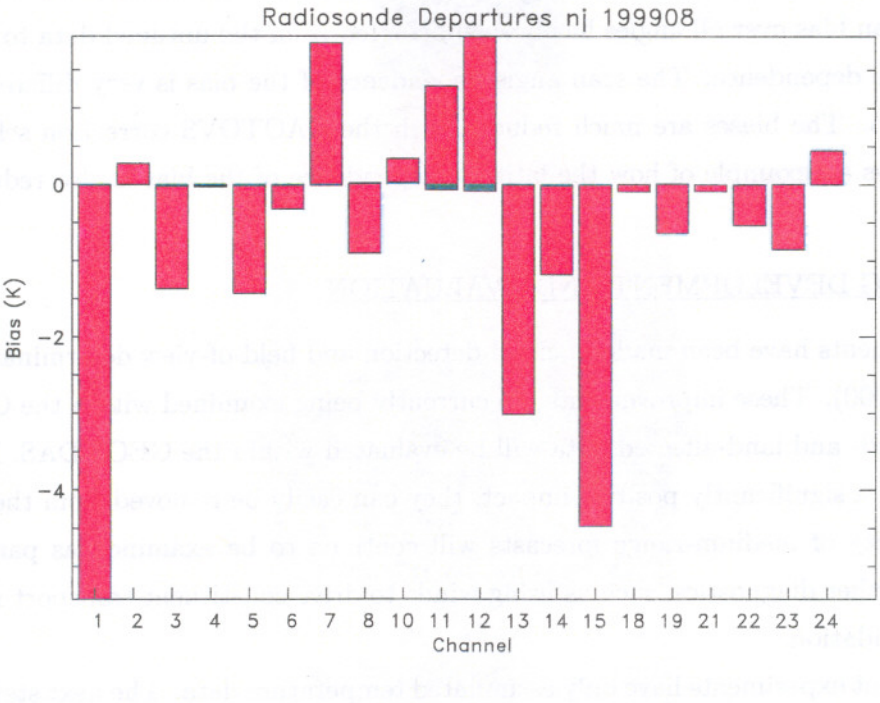

Figure 7: Similar to figure 5 but for NOAA 14.

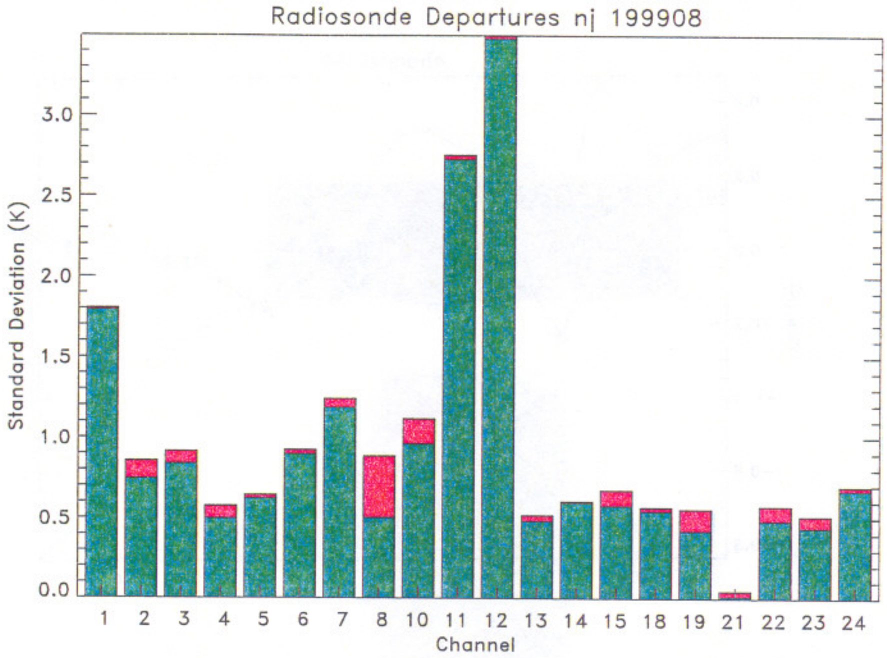

Figure 8: Similar to figure 6 but for NOAA 14.

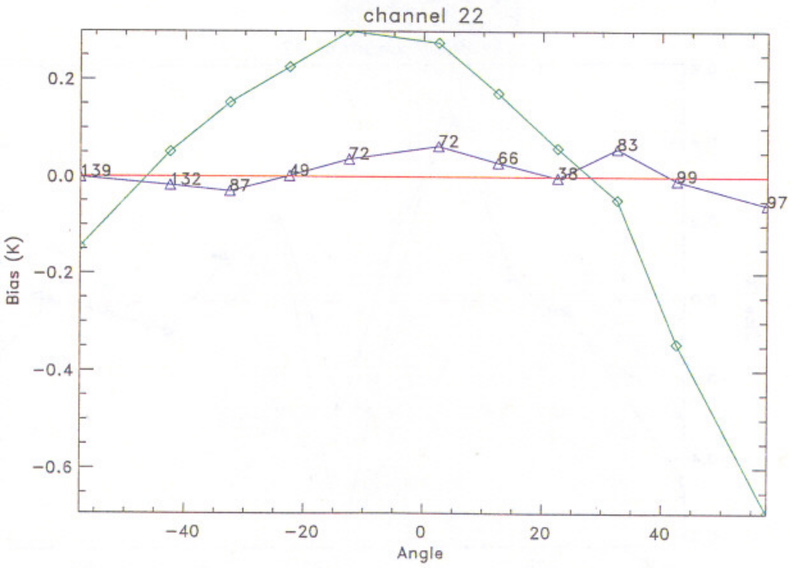

Figure 9: Radiosonde brightness temperatures bias and standard deviation for MSU channel 2 in August 1999. Triangles: after correction; diamonds: before correction. The number of collocated radiosondes in each bin is indicated next to the tuned values.

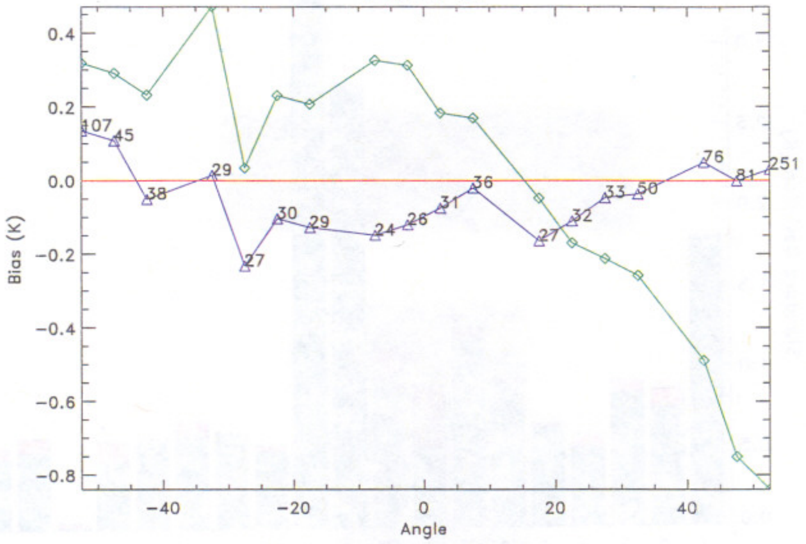

Figure 10: Similar to Figure 9 but for AMSU channel 4.

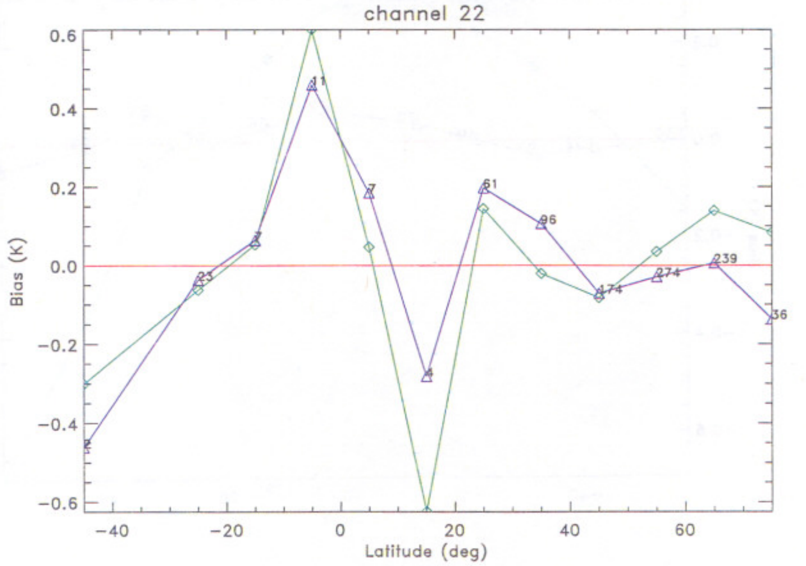

Figure 11: Similar to Figure 9 but as a function of latitude.

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