Progress Report on Reprocessing HIRS Cloud Measurements
Nov 2012 to Apr 2013
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1. Mitigating Sensor to Sensor Differences

Sensor to sensor calibration differences continue to be studied in collaboration with the STAR calibration team. The approach is to estimate radiance changes for a specific channel due to Spectral Response Function (SRF) modifications and related uncertainty. A linear model correlates the radiance change in a selected channel with the spectral radiances in selected HIRS channels. The hyper-spectral measurements from the Infrared Atmospheric Sounding Interferometer (IASI) on the MetOp satellite are used to simulate HIRS observations and to estimate the parameters in the linear models. The linear models are applied to the NOAA and MetOp HIRS data at Simultaneous Nadir Overpass (SNO) locations to estimate the inter-satellite radiance differences. The inter-satellite mean radiance biases are minimized with residual maximum uncertainty less than 1% after the impacts of SRF differences and uncertainties are taken out. With use of the MetOp HIRS as a reference, the optimized SRFs for every NOAA HIRS are found by minimizing the root-mean-square values of inter-satellite radiance difference. In the last six months the strategy for re-calibration was adjusted so that all HIRS sensors coincident with IASI are re-calibrated from direct comparisons and those prior to IASI from HIRS SNOs. In addition care has been taken avoid scan angles greater than 32 degrees from nadir in the re-calibrations. A paper by R. Chen, C. Cao, and W. P. Menzel titled "Inter-satellite Calibration of NOAA HIRS CO2 Channels for Climate Studies" has been submitted to JGR; it has been accepted for publication pending minor revision.

Table 1: Spectral shifts for bands sensitive to CO2 (4, 5, and 7) and H2O (12) suggested by direct comparison with IASI on NOAA 15 and thereafter and by HIRS sensor SNOs on NOAA 14 and earlier. Ch6 (13.6) shifts were not deemed necessary.

	Ch4(14.2)	Ch5(13.9)	Ch7(13.3)	Ch12(6.7)
hirs2n09	0.72	2.42	-0.67	1.1
hirs2n10	1.06	1.48	-1.12	3.0
hirs2n11	1.67	1.94	-0.04	4.2
hirs2n12	0.51	2.03	-2.25	4.1
hirs2n14	2.13	2.80	1.14	4.1
hirs3n15	-0.21	0.27	1.01	0.6
hirs3n16	0.22	0.62	0.47	0.8
hirs3n17	0.54	0.72	0.44	-0.3
hirs4n18	-0.71	-0.37	-0.49	3.3
hirs4n19	-0.00	-0.12	0.10	0.7
hirs4moa	-0.15	0.10	-0.15	2.2

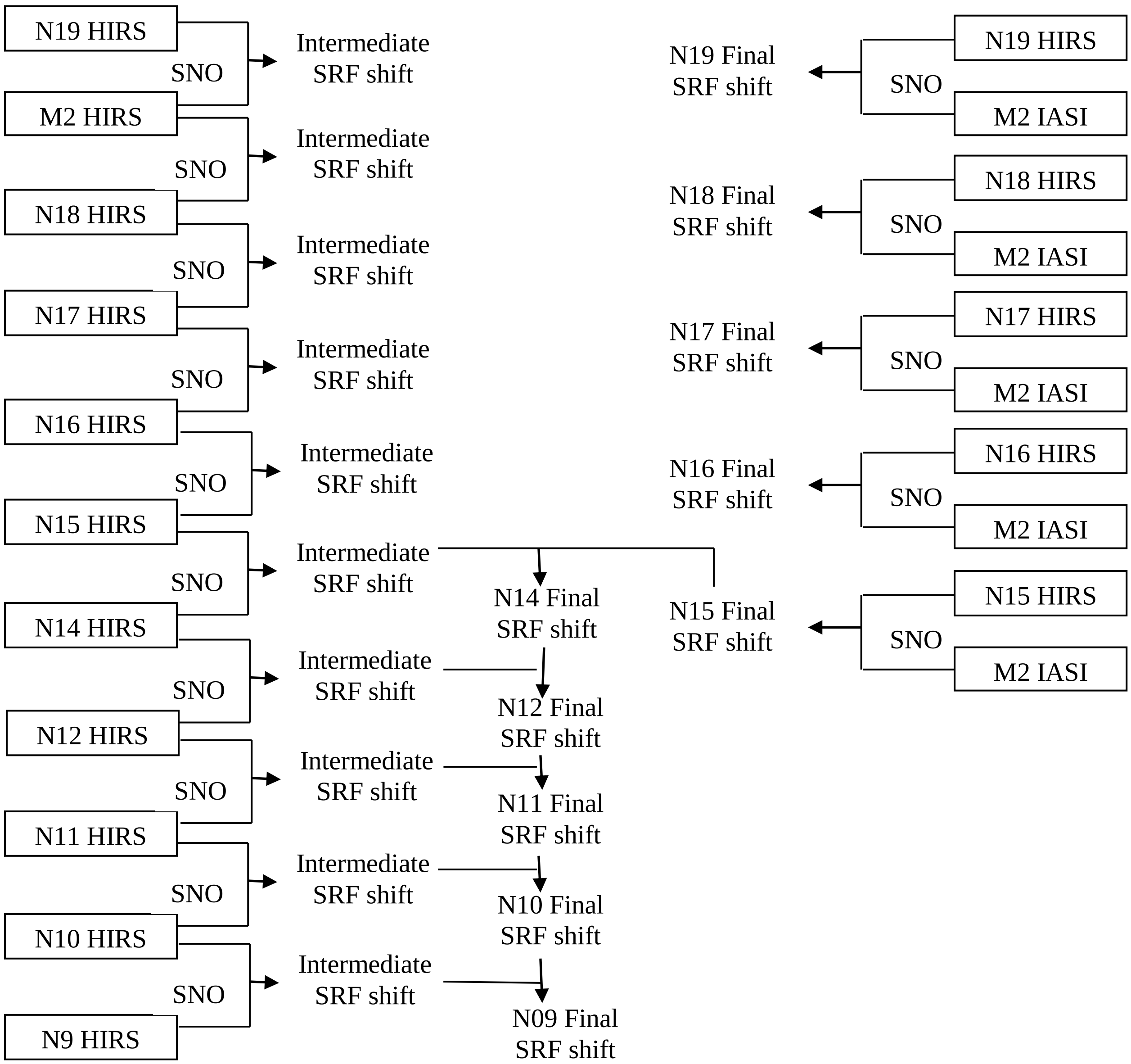

Figure 1: Schematic of the recalibration process using Metop IASI and SNOs

2. *Transfer NetDF4 L1B HIRS software to NCDC*

SSEC developed software for converting HIRS Level 1b and higher level data files to NetCDF-4. The flat file (i.e., Level 1b) to NetCDF4 converter has been tested with scientists to assure that the output files are well organized. Delivery of NetCDF4 L1B HIRS software was accomplished in December 2012. This included samples of source code, data, and documentation. This code produces NedCDF4 Level 1B files that contain counts and calibration coefficients, not radiances or brightness temperatures (BTs). Counts and calibration coefficients are in the data stream from the satellite; converting them to radiances (or BTs) has always been the job of the user (given the information in the NESDIS TM 107). The calculation of radiances from the raw counts plus calibration coefficients is straightforward. However, the calculation of BTs from the radiances remains a moving target because the spectral response functions (primarily for HIRS/2 sensors) are changing. The ultimate path to best calculate the BTs (ie Planck coefficients, etc.) will be part of our final report as a recommendation, after the final recalibration of HIRS Spectral Response Functions (see Item 1 in this report).

3. Reprocessing the HIRS Cloud Data Set

The HIRS data from NOAA-6 onwards have been re-processed using the original HIRS algorithm software with adjustments suggested by the MODIS experience and the spectral shifts suggested using Metop HIRS as a reference. Figure 2 shows the afternoon and morning high cloud trends over ocean before and after the spectral shifts. Sensor to sensor differences in the high cloud products are found to have been largely mitigated for the morning ascending orbits, but large discontinuities still are evident in the afternoon descending orbits. The causes are under investigation.

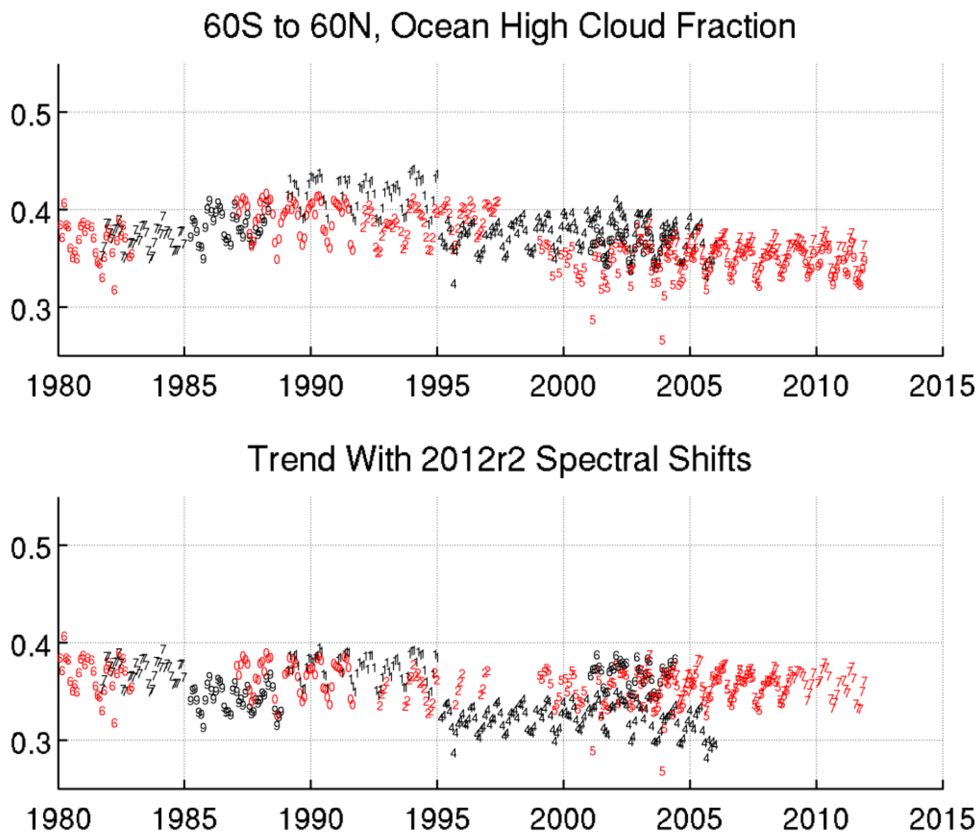

Figure 2: Afternoon and morning high (CTP<440 hPa) cloud over ocean trends from 1980 through 2011 given in fraction of total HIRS observations before (top) and after (bottom) the latest spectral shifts. The number indicates the NOAA satellite (e.g. 0 for NOAA-10, 1 for NOAA-11, and so on) and the color indicates the orbit (red for descending morning and black for ascending afternoon).

The HIRS cloud algorithm incorporation of the AVHRR cloud mask and software adjustment continues. In the past six months the UW team has
1) incorporated updated spectral response functions for HIRS bands 4, 5, and 7 for use in the HIRS forward model radiance calculations,
2) adjusted codes and files where necessary to use gfortran compiler as required,
3) began conversion of input/output routines to use netcdf as required - previous versions used hdf for HIRS radiance inputs and binary files for outputs,
4) began organizing the various codes for June 2013 delivery. This includes creation of separate directories for clear-sky processing, cloud top pressure generation, and a shared directory for codes common to both processes,
5) processed HIRS data from 2009 to test consistency of results over an extended time period - monthly high, middle, and low cloud frequencies were created using both NOAA-17 and METOP-A input data - the results showed very consistent results between the two sensors through all seasons,
6) processed NOAA-18 HIRS input data for January, April, July, and October 2008 and compared high cloud top height results to those of MODIS and CALIOP - monthly HIRS minus CALIOP cloud top height biases for single-layer clouds with optical depths > 0.25 and higher than 8 km were -1.41 km, -1.44 km, -1.35 km, and -1.30 km, respectively. These are similar to Collection 6 MODIS cloud height biases, e.g., -1.71 for the month of August 2006. These and other comparisons to MODIS data were presented as a poster at the 2012 Fall Meeting of the American Geophysical Union in San Francisco (3-7 December, 2012). Figure 3 compares CALIOP single layer high clouds with HIRS.

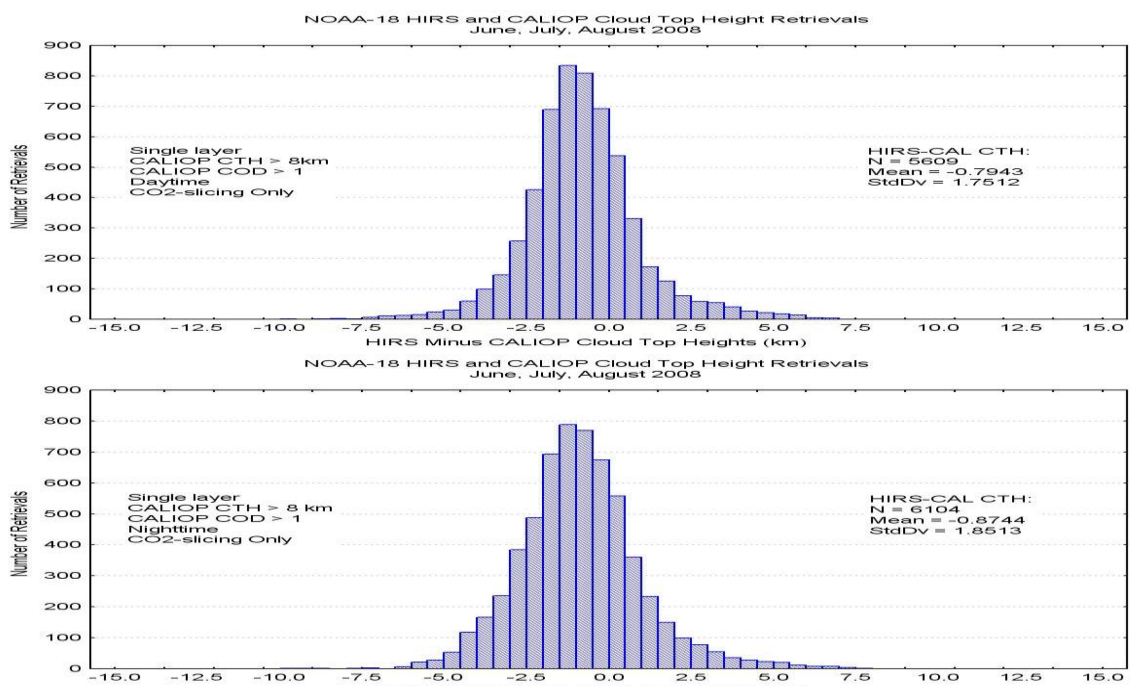

Figure 3: HIRS-CALIOP CTH distributions for June, July, August, 2008 for daytime (top) and nighttime (bottom) when CALIOP sees a cloud higher than 8 km and thicker than COD of 1. HIRS is lower on average by 0.8 to 0.9 km.

Figure 4 shows a comparison of the Clear Sky Radiance Bias for January 2009 with and without the PATMOS cloud mask for HIRS band 5 at 13.9 µm. In previous HIRS processing, cloud presence was assumed in all fields of view and cloud properties were processed based on model calculated clear versus observed cloudy radiances; if the difference was within instrument noise for all spectral channels, clear sky was inferred. Difficulties arose when model calculated clear radiances were suspect (as they often are in the early morning when land surface temperatures are not tracked very well in the model). This is evident in Figure 4 over North and South America. This is avoided in the new HIRS processing that calculates cloud top properties only where the PATMOS cloud mask indicates the presence of clouds.

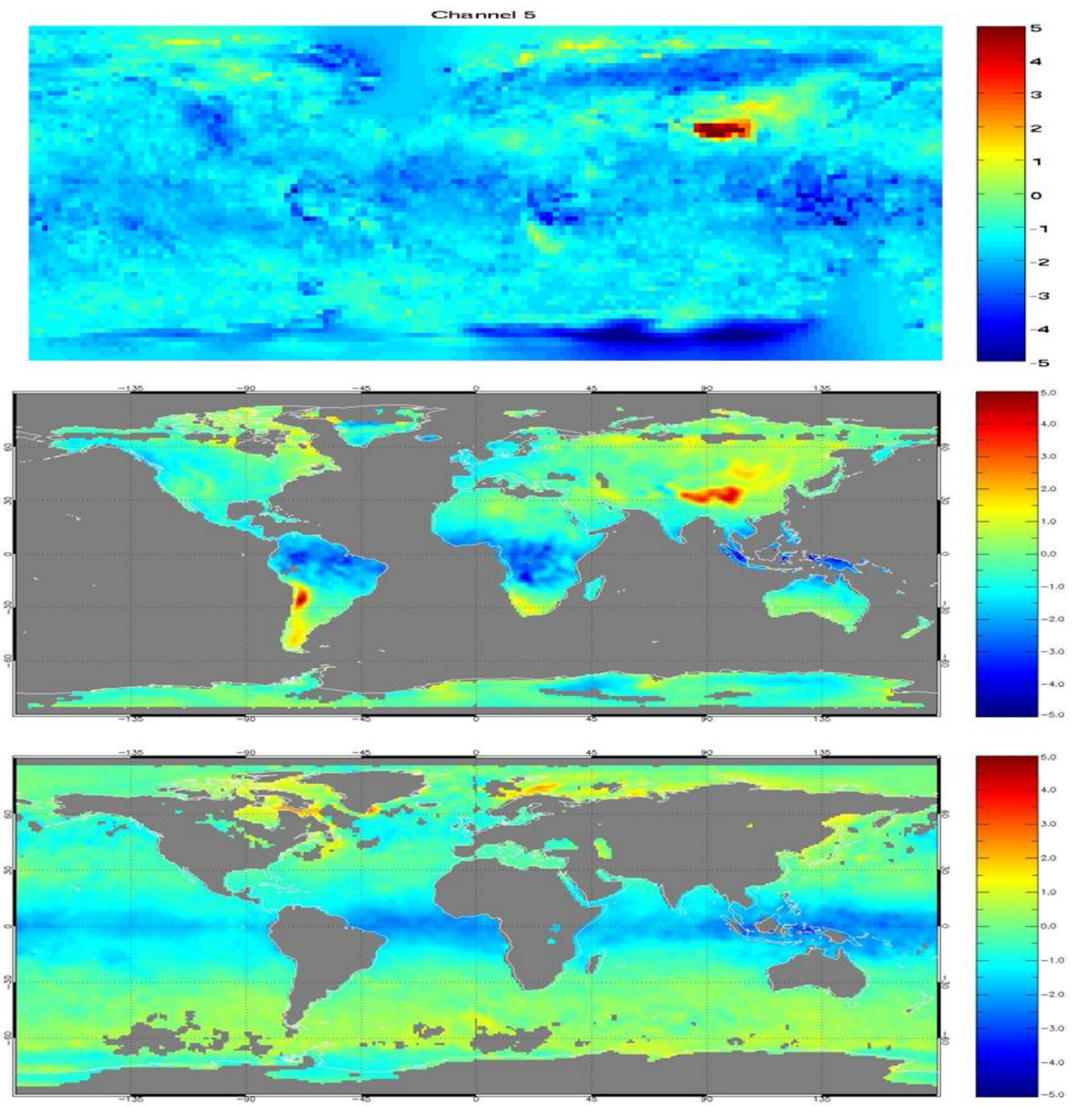

Figure 4: NOAA-17 HIRS Clear Sky Radiance Bias (observed minus calculated) for January 2009 without the AVHRR cloud mask (top) and with the AVHRR cloud mask over land (middle) and ocean (bottom) for the descending pass in the early morning. Biases are larger (more negative) when cloudy skies are misinterpreted to be clear.

5 Recoding the HIRS TPW Algorithm

Conversion of MODIS algorithm software to retrieve HIRS moisture layers (high. middle, and low level) and total column moisture continues. The TPW and TO3 algorithm is based on synthetic regression coefficients derived using a fast radiative transfer model on a global set of atmospheric temperature, moisture, and ozone profiles. The radiative transfer calculations of the HIRS spectral band radiances have been performed with and without spectral shifts for the training profiles using the JCSDA Community Radiative Transfer Model. Recent progress includes the following. (1) The UW HIRS TPW regression algorithm has been adapted to compile with gfortran. (2) Four global days (15 Jan, 15 Apr, 15 Jul, and 15 Oct 2009) have been selected to evaluate the HIRS TPW product in four seasons. The UW HIRS TPW algorithm has been run for these four days with and without the suggested SRF shifts. The PATMOS-X cloud mask has been used to define the clear pixels. The IASI dual regression (DR) retrieval (Smith et al. 2012) has been modified and set to run for these 4 days as well to provide a comparison. We are comparing these data with NOAA17/HIRS3 TPWs. (3) The UW space-time gridding (STG) algorithm (Smith et al., 2013) has been prepared to perform this evaluation. The STG algorithm projects data from their unique instrument domain to a uniform space-time domain: the instrument observations (or retrievals) are first snapped into nearest neighbor clusters then the clusters are averaged into single grid cell values. The result is a uniform equal-angle latitude-longitude grid. The space-time algorithm is used here to create daily averages on $1° \times 1°$ grids of TPW retrievals. Figure 5 shows the global TPW images for HIRS and IASI on MetOp-A for daytime 15 January 2009. Similar gradient features are evident in both; IASI DR retrievals are drier over the oceans and coverage is more limited due to low cloud masking issues. Comparisons with additional TPW estimates are planned.

Smith, W. L., E. Weisz, S. Kirev, D. K. Zhou, Z. Li, and E. E. Borbas, 2012: Dual-Regression Retrieval Algorithm for Real-Time Processing of Satellite Ultraspectral Radiances. J. Appl. Meteor. Clim., **51**, Issue 8, 1455-1476.

Smith, N, W.P Menzel**,** E. Weisz, A. Heidinger and B.A. Baum, 2013. A uniform spacetime gridding algorithm comparison of satellite data products: Characterization and sensitivity studies. J. Appl. Meteor. Clim., **52**: 255–268, doi: 10.1175/JAMC-D-12-031.1.

6. Investigating HIRS Stratospheric Cloud Trends

The paper by U. Kolat, W. P. Menzel, E. Olson, and R. Frey titled "Very High Cloud Detection in More than Two Decades of HIRS Data" is being published by JGR. An online version will be available shortly. It describes Upper Tropospheric / Lower Stratospheric (UT/LS) cloud detection trends using HIRS measurements sensitive to CO_2 (BT14 > BT13.3) from NOAA-10 onwards; the UT/LS cloud detection maxima in the western Pacific region of the ITCZ shows a decreasing trend from 1987 to 1996, followed by an increasing trend from 1996 to 2001, and thereafter a decreasing trend resumes. The overall trend seems to be saying that deep convection in the tropics has been in a slight decrease for the past twenty years.

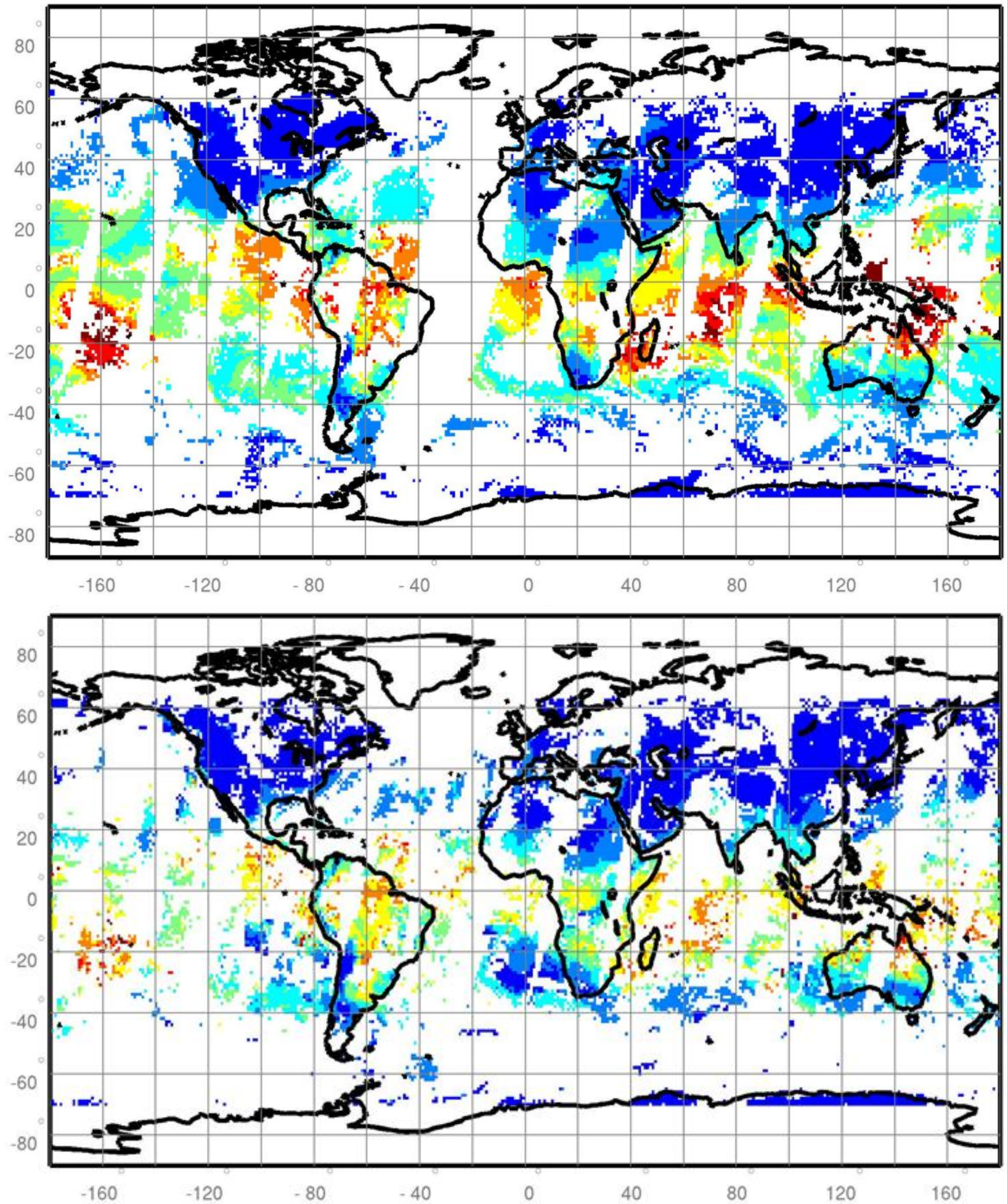

Figure 5: TPW from MetOp-A HIRS4 (top) and IASI (bottom) for daytime on 15 January 2009.

7. Remaining Work

7.1 Continue validation of cloud results against CALIPSO where possible. Compare TPW results globally against MODIS, AIRS, IASI, and GDAS for all seasons (2Q13).

7.2 Transfer cloud algorithm (CO_2 slicing plus PATMOS-X cloud mask) with output in NetCDF4 format to NCDC (2Q13).

7.3 Transfer TPW algorithm (with surface emissivity enhancement) to NCDC (3Q13)

And pending the availability of modest additional resources:

7.4 Switch to CRTM (from PFAAST) in cloud algorithm (4Q13).
7.5 Transfer STG L3 gridding software to NCDC to facilitate intercomparisons (4Q13).