Evaluation of the SSMIS Upper Air Soundings (UAS) channels for middle atmosphere assimilation

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Abstract

A major impediment for achieving ground to space NWP capability, is the lack of near-real-time middle atmospheric state measurements for assimilation. The only operationally available source of extensive meteorological observations in the mesosphere is provided by the Upper Air Sounding (UAS) channels of the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager/Sounder (SSMIS) instruments. To date, this data has been underutilized because: 1) typical global NWP models do not span the required vertical range (surface to 100 km), and hence do not include mesosphere; and 2) the fast radiative transfer (RT) models used in data assimilation systems lacked explicit treatment of the Zeeman effect on the oxygen molecule's interaction with the geomagnetic field in the microwave 60 GHz range at altitudes above 40 km. Version 2 of the Community Radiative Transfer Model (CRTM) has implemented the Zeeman-splitting spectroscopy calculations required for the UAS channels. In this poster we evaluate the utility of assimilating the newly developed SSMIS Unified Pre-Processor for the UAS (UPP-UAS) channels by comparing the radiances with the CRTM calculations using coincident SABER temperatures profiles. We also show an example UAS assimilation analysis using the Navy Global Environmental Model (NAVGEM).

SSMIS-UAS and CRTM

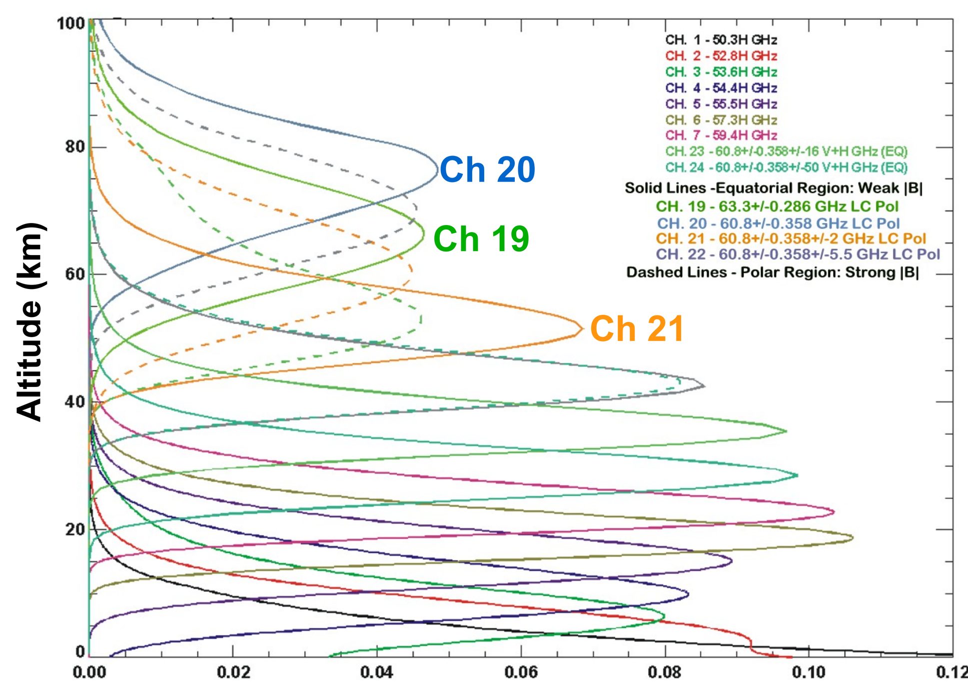


Figure 1. SSMIS-UAS weighting functions for a weak geomagnetic field typical of equatorial region (solid lines) and for a strong field typical of polar regions (dashed lines). The weighting function change (altitude shift) corresponds to Tb changes of ~10K for channel 19. Therefore assimilation of channels 19-21 is not useful without the RT calculations incorporating Zeeman splitting

SSMIS instrument includes Upper Air Sounding (UAS) channels in the 60 GHz oxygen absorption band which are sensitive to the upper stratosphere and mesosphere. The UAS channels are designated as channels 19-24. (see Fig 1). SSMIS is an operational sensor and the UAS data is the only real-time data routinely available in the mesosphere. There are currently 3 SSMIS instruments operating on the 3 Defense Meteorological Satellite Program satellites, F16, F17, and F18. These are polar orbiting, sun-sync (fixed local time sampling) with ascending equator crossing times of 1820, 1737, and 2012 respectively. An example of the spatial sampling of all 3 instruments for a single 6-hour assimilation window is shown in Fig 2.

The spectroscopy, and hence radiative transfer (RT) modeling is more difficult than typical microwave measurements because of the interaction of oxygen molecule absorption spectrum with geomagnetic field (B). This interaction leads to Zeeman splitting of the absorption lines, which effectively shifts in peaks of the weighting functions in altitude depending on B. Data assimilation requires fast RT calculations of the anisotropic polarized radiative transfer to incorporate Zeeman splitting. Recently, the Zeeman splitting spectroscopy for the UAS channels has been added to the Community Radiative Transfer Model (CRTM, version 2) developed by NASA/NOAA Joint Center for Satellite Data Assimilation (Han et al.,2007).

We will focus only on channels 19-22 because they are the only channels with significant Zeeman sensitivity and are the primary mesospheric channels.

SABER and MLS

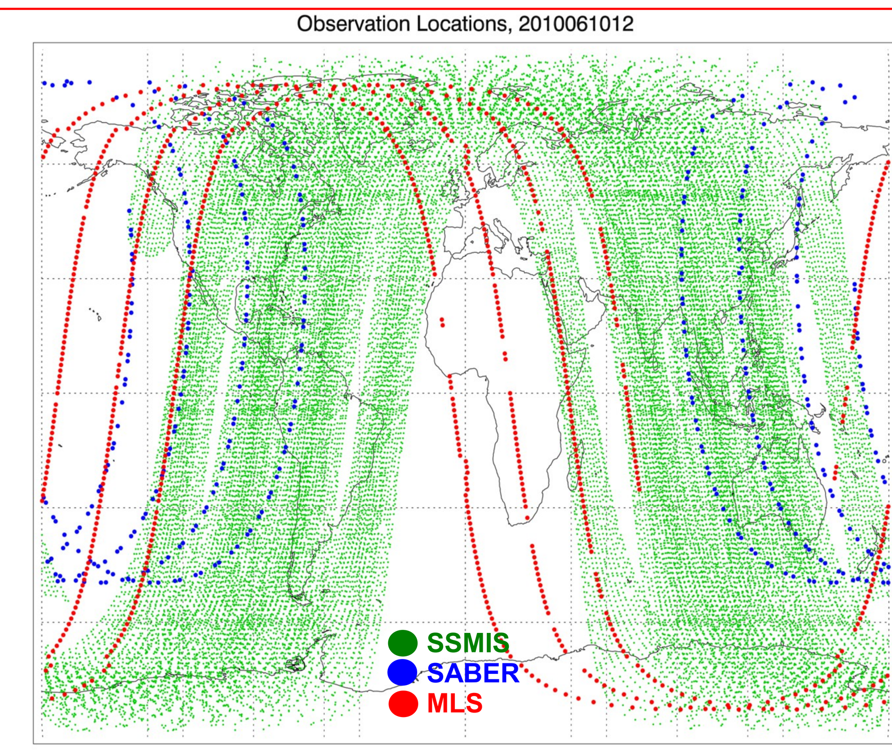
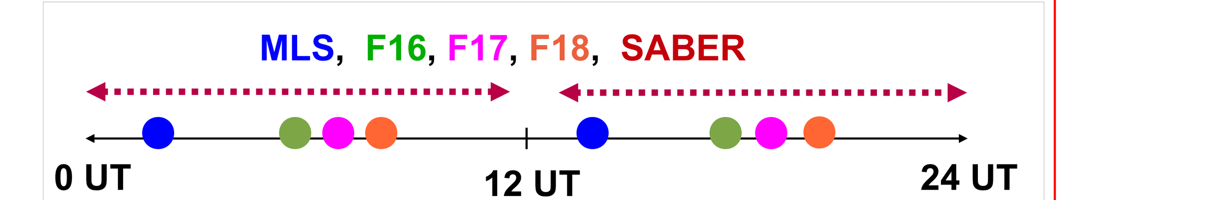


Figure 2. The location of SSMIS F16, F17, F18, SABER and MLS observations on 2010-06-10 during the 6 hours of 09-15 UT.

The most useful data set for comparison/validation of the UAS data are the temperature profile retrievals from the SABER instrument on the NASA TIMED satellite. SABER is a 10 channel broadband, limb-viewing, infrared radiometer which has been measuring stratosphere to thermosphere temperatures since Dec 2001. We use the version 1.07 SABER retrievals, which are described in Remsberg (2008). Because the local time of the SABER measurements varies, coincident measurements can be found with all of the SSMIS instruments.

The NASA MLS instrument also provides temperature profile retrievals in the stratosphere and mesosphere (MLS reference). However, the MLS orbit is sun-synchronous with an equator crossing time that is not very close to any of the SSMIS instruments. Close time/space coincidences between MLS and SSMIS are only possible near the pole, where there is a convergence in local time and space for polar orbiting measurements.



Equatorial local time sampling. SABER times sweep across the indicated range over a ~60 day period.

Method of Comparison for SABER and UAS

First we find coincident measurements between SABER and the UAS soundings from the F16, F17, and F18 SSMIS instruments. The coincidence criteria is 1 degree (~111 km) separation and a time difference of +/- 3 hours. The number of coincidences is most sensitive to the time window because the SSMIS instruments have fixed local time sampling, while SABER local time slowly shifts.

We choose data from the 15th of each month from Apr 2010 to Mar 2011 in order to sample an entire year. Each day of data also provides global coverage for each SSMIS instrument. Even with only 1 day of month, the total number of coincident profiles, there are >30000 for each SSMIS sensor.

Because SABER profiles do not reach the surface, we use the NASA GEOS5 analysis for the T/P profile from the surface to 10 hPa. The GEOS5 analysis is interpolated to the time and location of the coincidence. We then add the SABER temperature profile from 10 hPa to 0.001 hPa to construct the complete atmospheric state.

Lastly, the CRTM model is run using the combined GEOS5 and SABER T/P profile, and using the Zeeman parameters (magnetic field vector and antenna pointing vector) taken from the coincident UAS data. The CRTM calculates the microwave brightness temperature (Tb) expected for each UAS channel given the SABER temperatures.

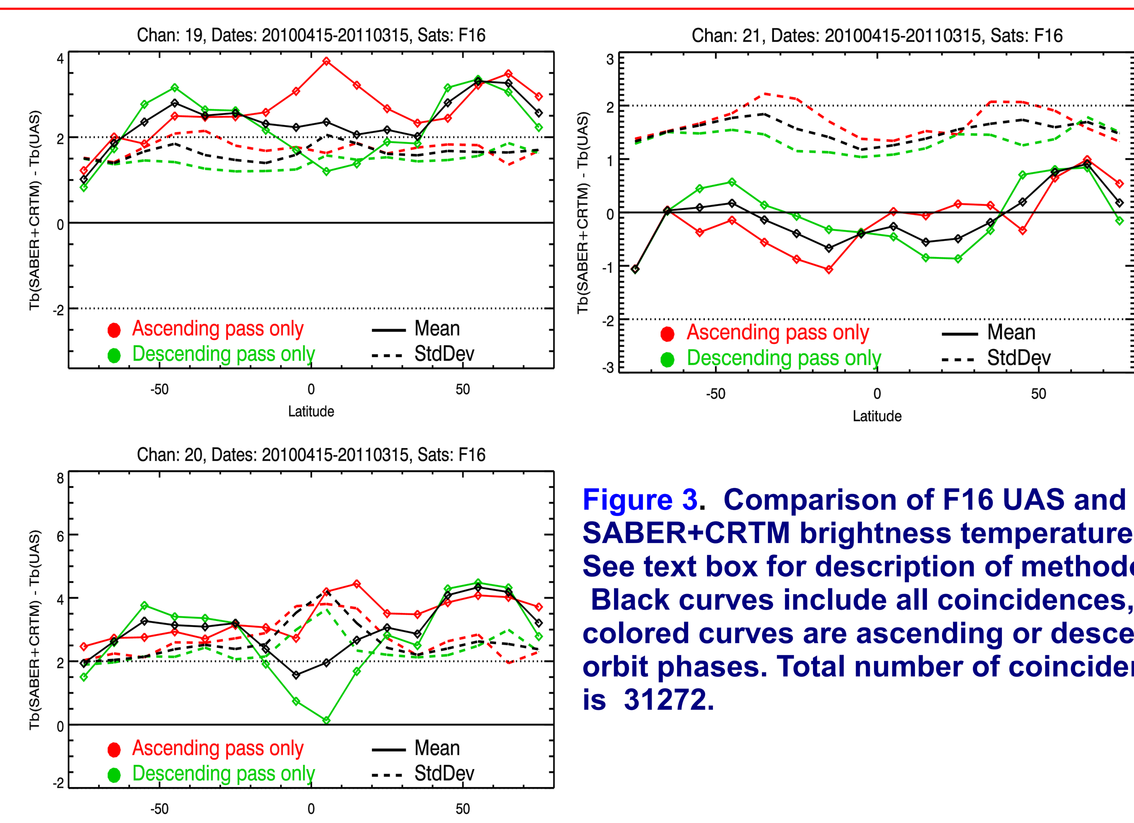


Figure 3. Comparison of F16 UAS and SABER+CRTM brightness temperatures. See text box for description of methodology. Black curves include all coincidences, colored curves are ascending or descending orbit phases. Total number of coincidences is 31272.

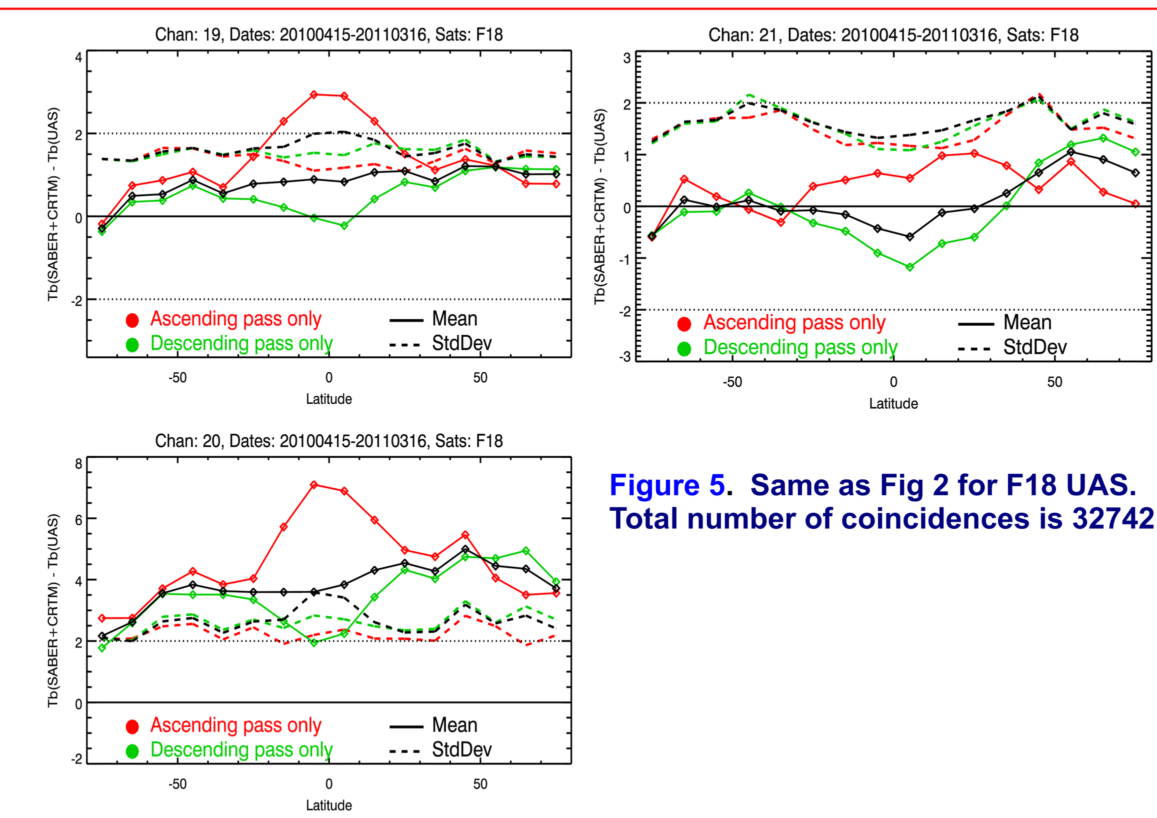


Figure 5. Same as Fig 2 for F18 UAS. Total number of coincidences is 32742.

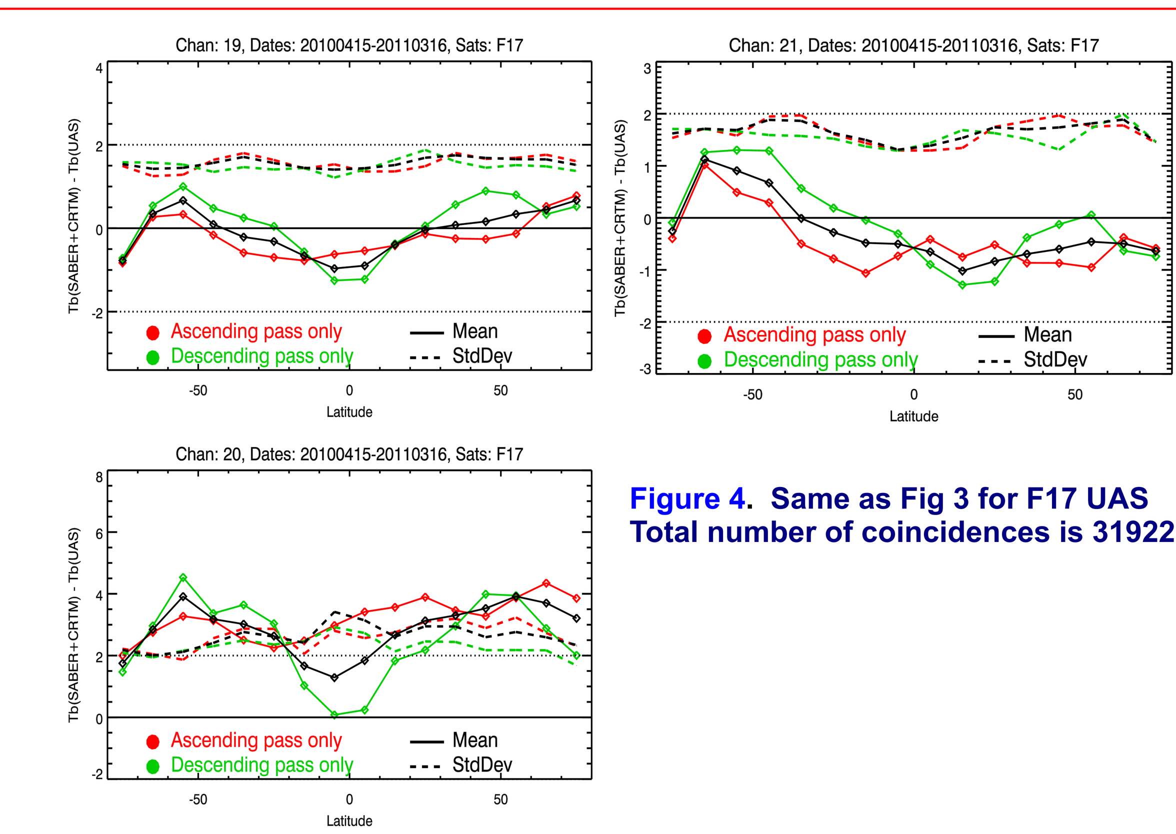


Figure 4. Same as Fig 3 for F17 UAS Total number of coincidences is 31922.

Note: Microwave radiance is expressed as a "Brightness Temperature" (Tb) based on back-body emission. A 1K change in Tb generally corresponds to a 1K change in the mean atmospheric temperature integrated over the weighting functions (see Fig 1).

Understanding the Error Sources

(1) An assessment of SABER temperature errors was performed by Remsberg et al. (2008). The estimated precision was ~1 K at 32 hPa, and monotonically increasing to ~4 K at 0.01 hPa. Estimated biases were; SABER too low by ~1K near the stratopause, and to low by ~2K in the middle mesosphere. The saber retrievals in the thermosphere depend on composition data from the WACCM model, which could lead to systematic errors (most important for UAS channel 20 comparisons).

(2) The accuracy of the CRTM calculation was evaluated in Han et al (2007) by comparison with more accurate line-by-line spectroscopic calculations. The RMS differences for channels 19, 20, and 21 were 0.34 K, 0.64 K, and 0.33 K respectively.

(3) The random Tb error for the UAS measurements used here is estimated as ~1.2 K for channels 19 and 20, and ~0.95 K for channel 21.

Conclusions about SABER-UAS comparisons

Good News:

* Given that it is difficult for a GCM to model the mesosphere to an accuracy of few degrees, the SABER-UAS differences are small enough that we can expect a positive impact from UAS assimilation.

* The standard deviations of the Tb comparisons are ~1.5 - 2 K. They are a little larger than the random UAS errors, which is reasonable considering the additional errors associated with SABER, the CRTM, and imperfect coincidences.

* Radiance bias correction schemes in modern assimilation systems can correct for biases that depend on instruments, that depend on the ascending/descending nodes, and which have large-scale latitudinal structure. The biases in Figs 4-5 are generally less than 4K with a significant portion being a constant, global-mean offset. We can expect that a bias correction scheme will remove most of this bias.

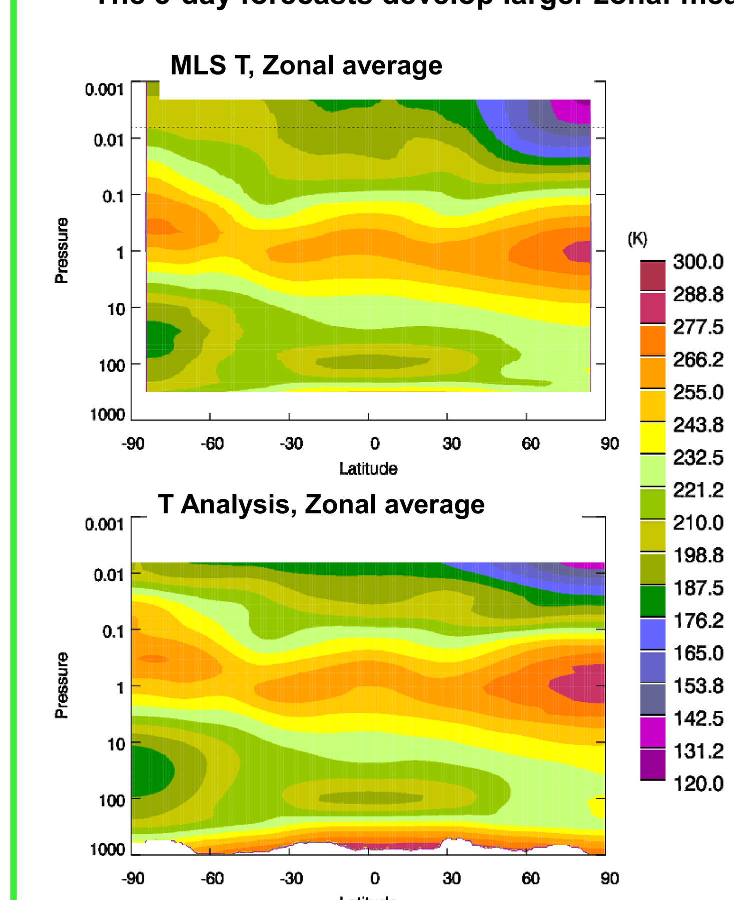
Bad News:

* Because each SSMIS instrument measures at a unique local time, and the coincidences with SABER are not a random sample of ascending/descending nodes or season, it will require much more work to understand the individual error contributions from SABER, CRTM, and SSMIS to the observed differences.

* Coincidences between SSMIS and MLS in the polar regions (not shown) show biases which are different, but similar in magnitude to the SABER comparisons. MLS has it own large vertical weighting function in the mesosphere, has a unique local time, and the relative biases between SABER and MLS are not well determined because of temperature tides. Therefore MLS comparisons are also difficult to interpret.

Example analysis using SSMIS-UAS

- A test UAS analysis is performed using the Navy Global Environmental Model (NAVGEM) system, a 4D-Var algorithm described in Xu et al., 2005 and Rosmond and Xu, 2006.
- Model resolution is T239 (0.75 degree resolution) with 60 vertical levels and a top at 0.005 hPa. The top levels above 0.01 hPa are highly diffused "sponge" layers. This semi-lagrangian model and has not been fully tuned/developed for the mesosphere. (It differs from NRL's NOGAPS-ALPHA which has been used for 3DVAR mesospheric analysis, described in other presentations, and featured in journal publications.)
- MLS (not assimilated) is used for comparison in Figs 6-7. The standard suite of conventional observations and IR/microwave radiances are assimilated.
- The comparisons below show that the UAS analysis reproduces the mean temperatures that agree reasonably well with MLS, although there is a large cold bias at the top (P < .01) where the "sponge" layer exists. The analysis also shows some unusual vertical layering in the mesosphere, that is probably due to the large vertical spacing between the UAS channels 19, 20, and 21 (see Fig 1), which introduces layered perturbations. Additional work is needed to remove these features. .
- The 5-day forecasts develop larger zonal-mean temperature biases compared to the analysis. This illustrates how the UAS assimilation is correcting model bias.



Average of 23 analysis/forecasts during July 6-28, 2010. Forecasts are initialized from analysis. MLS average includes all data from July 5-29.

Figure 6. A 30-day NAVGEM analysis using UAS data, compared with MLS temperatures.

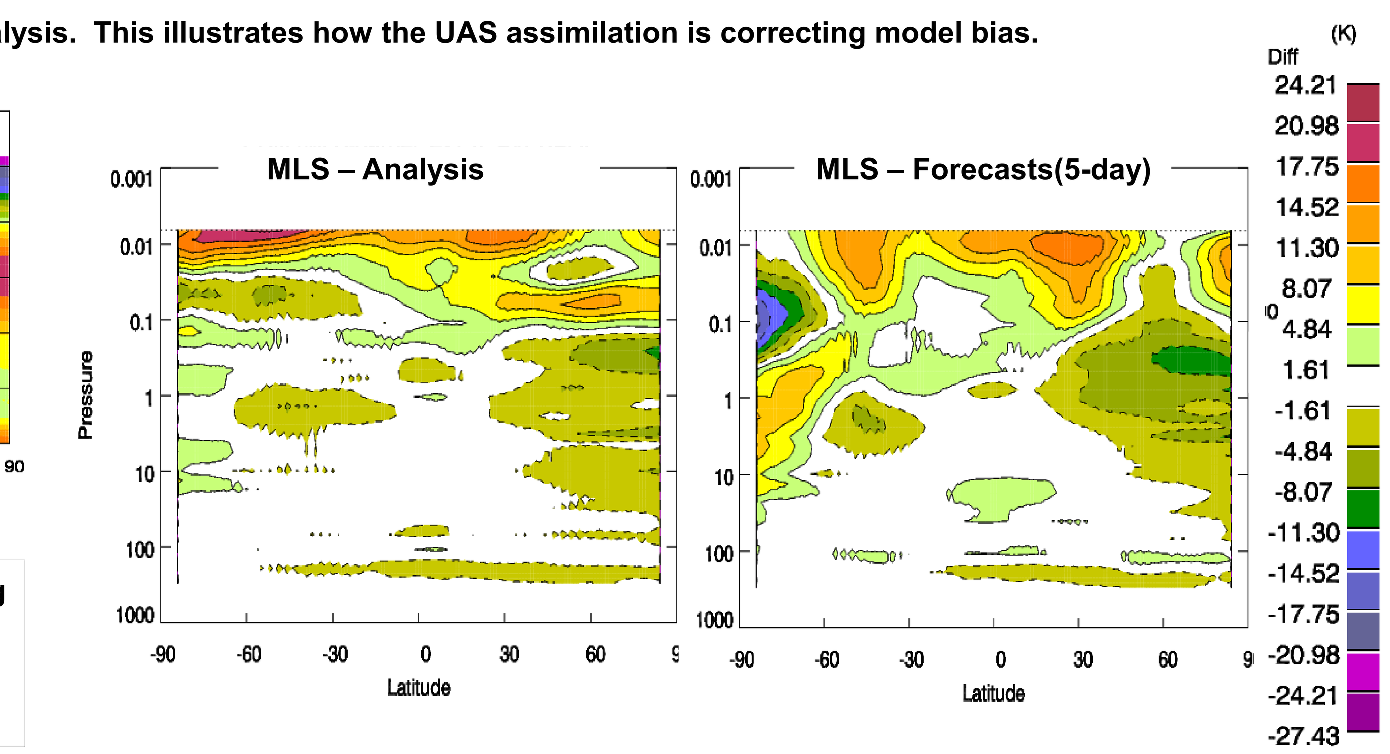


Figure 7. Difference plots for Fig 6. The analysis (left panel) exhibits some layering in the mesosphere which may be related to the large vertical spacing between the UAS channels. Because of the MLS fixed local time sampling and possible biases, agreement to within ~5K is probably sufficient. The larger biases that develop in the 5-day forecast (right panel) show that the assimilation is reducing model bias. Because the forecasts differences do not exhibit the vertical layering in the mesosphere like the analysis, it is further evidence that the UAS assimilation needs further tuning.

References

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