Improving Forecast Skill by Assimilation of AIRS Cloud Cleared Radiances R_i^{CC}

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Background

ECMWF, NCEP, and GMAO routinely assimilate radiosonde and other in-situ observations along with satellite IR and MW Sounder radiance observations. NCEP and GMAO use the NCEP GSI Data Assimilation System (DAS).

GSI DAS assimilates AIRS, CrIS, IASI channel radiances R_i on a channel-by-channel, case-by-case basis, only for those channels *i* thought to be unaffected by cloud cover. This test excludes R_i for most tropospheric sounding channels under partial cloud cover conditions.

AIRS Version-6 R_i^{CC} is a derived quantity representative of what AIRS channel *i* would have seen if the AIRS FOR were cloud free. All values of R_i^{CC} have case-by-case error estimates δR_i^{CC} associated with them.

Our experiments present to the GSI QC'd values of AIRS R_i^{CC} in place of AIRS R_i observations. GSI DAS assimilates only those values of R_i^{CC} it "thinks are cloud free". This potentially allows for better coverage of assimilated QC'd values of R_i^{CC} as compared to R_i .

QC and Data Selection Applied to R_i^{CC}

Having accurate values of R_i^{CC} is more important than having good spatial coverage, but both are important.

AIRS Version-6 assigns a QC flag to each value of R_i^{CC} based on thresholds of δR_i^{CC}, given in brightness temperature units $\delta \Theta_i^{CC}$.

R_i^{CC} has a QC flag of 0 if $\delta \Theta_i^{CC} \leq 1K$; QC=1 if $1K < \delta \Theta_i^{CC} < 2.5K$; and QC=2 if $\delta \Theta_i^{CC} > 2.5K$. In our experiments, we pass values of R_i^{CC} to the GSI only if QC=0.

The GSI operational system selects a single AIRS FOV within a 145 km x 145 km area, to assimilate observed radiance values R_i. GSI selects the FOV which: 1) has the highest channel radiance in an 11 µm window channel and 2) is closest to the center of the 145 km area. This FOV is thought to be the clearest within the box.

GSI applies the same procedure to select a single AIRS FOR to assimilate values of R_i^{CC} in the 145 km x 145 km area.

Objectives of the Experiments

The original objective of this research assessed the degree of improvement in seven day forecast skill achieved by assimilating values of AIRS R_i^{CC} in place of AIRS R_i , everything else being done the same.

As part of our research, we noticed that assimilation of CrIS/ATMS observations along with those of AIRS/AMSU caused a negative effect on the analyses and subsequent forecast skill. We believe that this finding is a consequence of CrIS/ATMS observations on NPP being taken in roughly the same place and time as AIRS observations, each one being assimilated in the same 145 km x 145 km area. We feel it is better to assimilate these otherwise similar observations taken from only one of the satellites, not both. Our results should not be interpreted to mean that assimilation of AIRS R_i is better than assimilation of CrIS R_i .

Forecast Impact Tests

All experiments use MERRA2 with the GMAO DAS. We ran forecasts with a resolution of 0.25° x 0.25°; analyses with 0.5° x 0.5°.

Data period covers September 1, 2014 – October 31, 2014.

Six data assimilation experiments were run:

1) "AIRS radiances" assimilates all data GMAO used operationally at that time, including R_i of AIRS/AMSU, CrIS/ATMS, and IASI/AMSU.
2) "AIRS R_i^{CC} "uses the same data but with AIRS R_i^{CC} in place of AIRS R_i.
3) "No AIRS"uses the same data but uses no AIRS data at all.
4) "AIRS radiance, no CrIS/ATMS" is like "AIRS radiance" but uses no CrIS/ATMS data.
5) "AIRS R_i^{CC} , no CrIS/ATMS" is like "AIRS R_i^{CC}", but uses no CrIS/ATMS.
6) "No AIRS, no CrIS/ATMS" uses neither AIRS data nor CrIS/ATMS data.

52 independent 7 day forecasts were run from each 0Z analysis starting September 10. Forecasts are verified against the concurrent NCEP analysis.

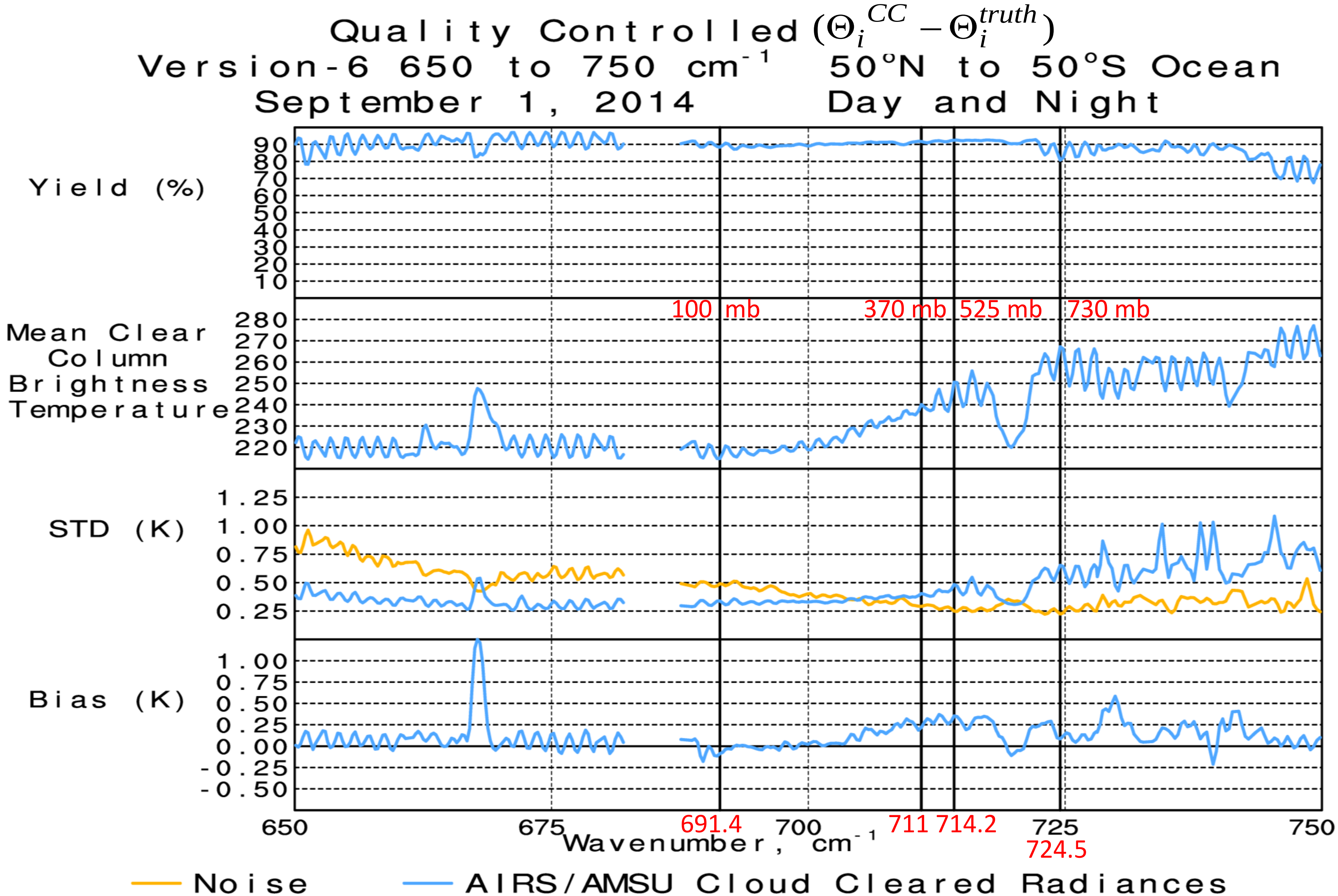
Sample Statistics Relating to QC'd Values of R_i^{CC}

The next figure shows statistics relating to the percent yield and accuracy, compared to radiances computed from ECMWF "Truth", of values of AIRS R_i^{CC} with QC=0 for channels between 650 cm^{-1} and 750 cm^{-1}. Results are shown for all retrievals over ocean 50°N-50°S on September 1, 2014, the first day of our experiments.

Percent yield is close to 100% for channels sounding the stratosphere, and falls to about 70% as mean brightness temperatures increase, indicating that the channels sound closer to the surface.

Errors in R_i^{CC} can be less than single spot channel noise if the retrieval thinks that R_i is not affected by clouds in the FOR. In this case, R_i^{CC} is given by the average value of $R_{i,j}$ the 9 AIRS FOV's in the AIRS FOR, and the effective channel noise is 1/3 of the noise for a single FOV.

We mark the locations of 4 channels, 691.4 cm^{-1}, 711.0 cm^{-1}, 714.2 cm^{-1}, and 724.5 cm^{-1}, indicated on the figure, as well as the peak pressures these channels nominally sound.



% yields of all channels are better than 70%. Biases of $(\Theta_i^{CC} - \Theta_i^{truth})$ are very small and its STD is for the most part less than twice the channel noise. Some spikes are a result of errors in the truth field.

Analysis Increments

Channel radiances R_i or R_i^{CC} in a time period will affect the analysis if:

1) A value of R_i or R_i^{CC} is presented to the analysis in a 145 x 145 km grid.

   More values of R_i are presented to the analysis than values of R_i^{CC}:
   - There are nine times as many locations of R_i than of R_i^{CC}, and some fall in additional grid areas
   - Values of R_i^{CC} in some grid areas are rejected by AIRS R_i^{CC}, QC

2) A value of R_i or R_i^{CC} is accepted by the analysis. This occurs if the analysis thinks R_i or R_i^{CC} is unaffected by cloud cover. More values of R_i are rejected by the analysis than R_i^{CC} for a given channel for this reason. This difference in acceptance rate increases as channels see deeper into the troposphere.

If R_i or R_i^{CC} is accepted by the analysis in a grid area, it will result in an Analysis Increment ($\Theta_i - \Theta_i^A$) where Θ_i (or Θ_i^{CC}) is the channel brightness temperature(K) and Θ_i^A is the computed cloud-free brightness temperature using the 6 hour forecast.

September 1 0Z Analysis Increment statistics for four channels

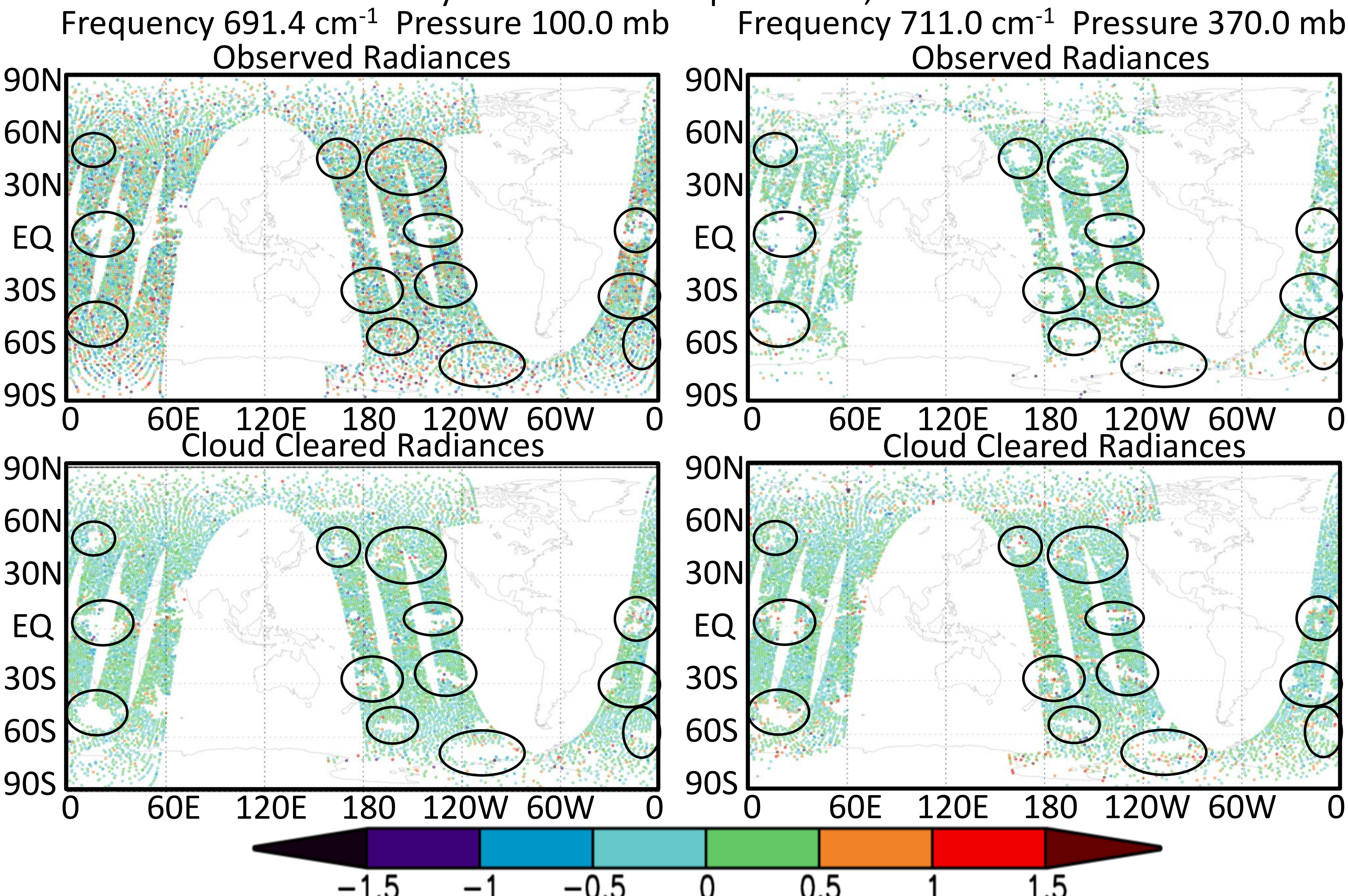
Observed radiances has 10841 possible grid areas – channel independent

Cloud cleared radiances has 10461 possible grid areas – channel independent

	691.4 cm^{-1} ≈ 100 mb	711.0 cm^{-1} ≈ 370 mb	714.2 cm^{-1} ≈ 525 mb	724.5 cm^{-1} ≈ 730 mb
Accepted radiances				
Observed	**10079**	5961	3887	2902
Cloud cleared	8897	**8894**	**8162**	**4146**
% Accepted				
Observed	**92.97**	54.99	35.86	26.77
Cloud cleared	85.05	**85.02**	**78.02**	**39.63**
Mean Increment (K)				
Observed	-0.0019	-0.0077	-0.0058	-0.0090
Cloud cleared	-0.0004	0.0037	-0.0004	-0.0092
STD Increment (K)				
Observed	0.5484	0.3326	0.3161	0.3127
Cloud cleared	**0.2820**	0.3041	0.3439	0.3354

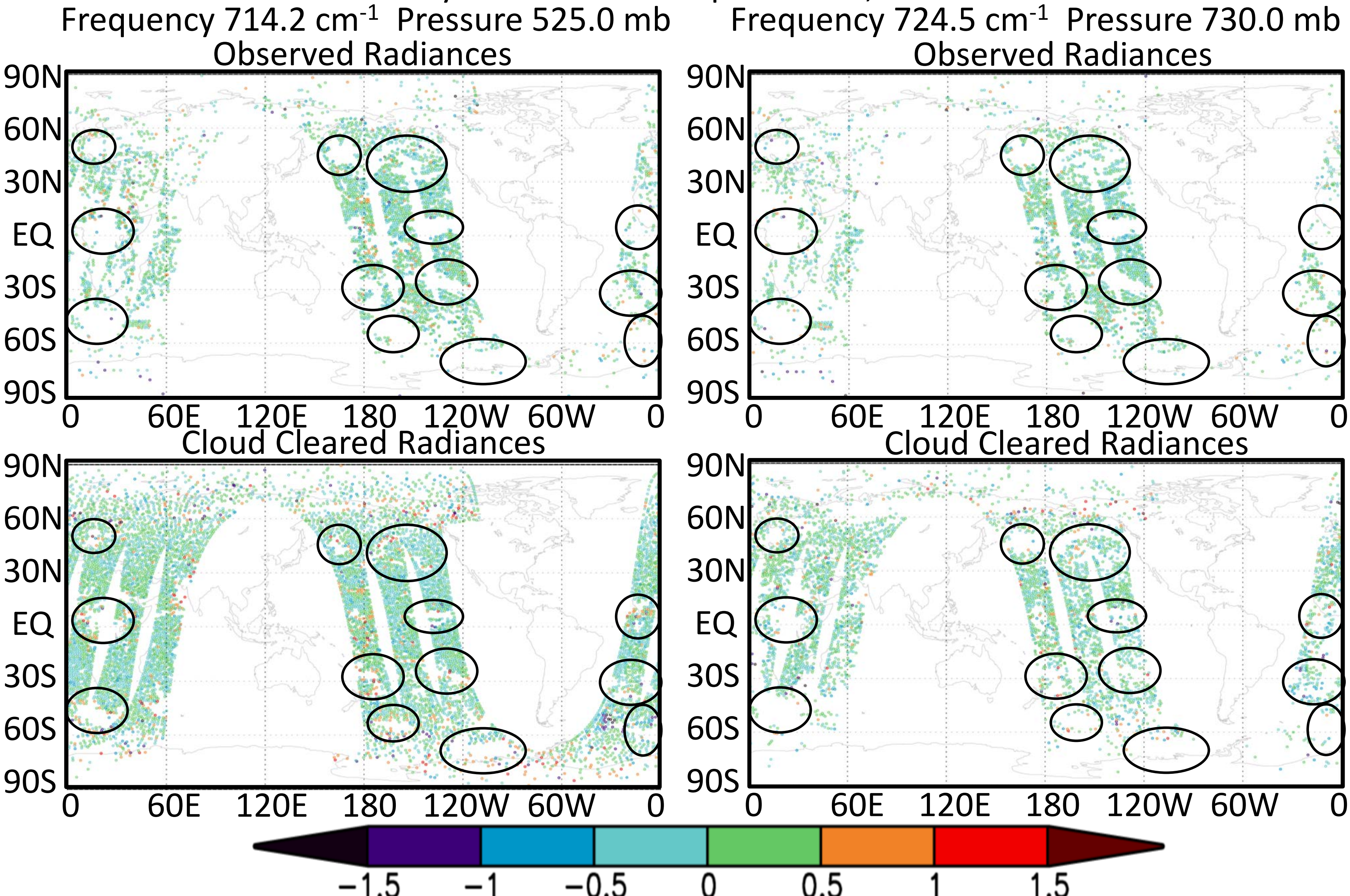
Bold numbers indicate a much better statistic

Analysis Increments September 1, 2014 0Z



Spatial gaps in assimilated observed radiances are smaller at 691.4 cm^{-1} than those of cloud cleared radiances but the analysis increments are noisy when no gap exists. Gaps grow at 711.0 cm^{-1} for observed radiances, but not for cloud cleared radiances.

Analysis Increments September 1, 2014 OZ



The spatial gaps rapidly increase in size for observed radiances as channels sound deeper into the troposphere. Gaps grow more slowly for cloud cleared radiances, which also has much better coverage in the poles for these channels.

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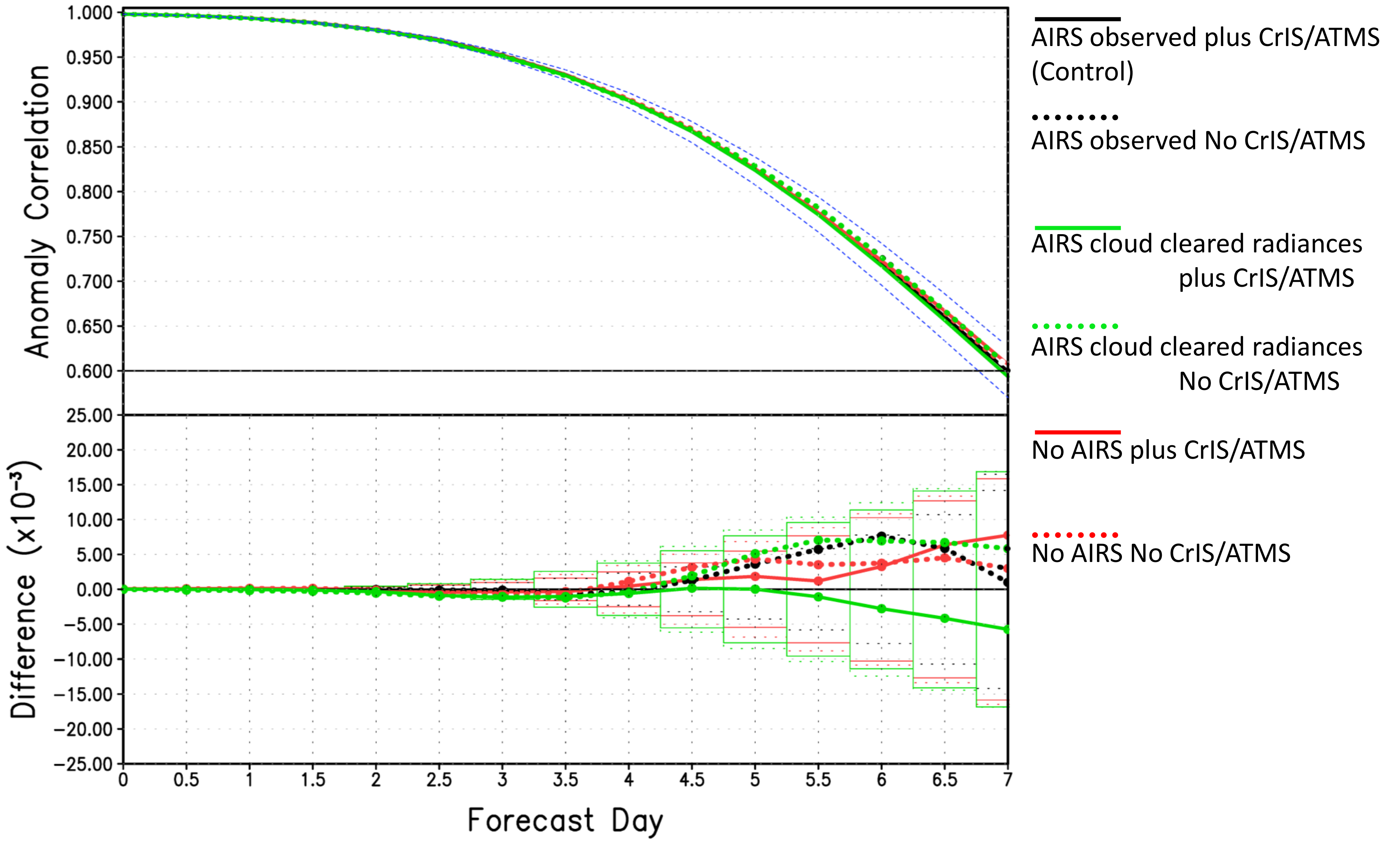
Comparative 7 Day Forecast Skill of All Experiments

We judge the comparative forecast skill of each experiment by the 52 day ensemble area mean values of 500 mb height anomaly coefficients of 0 to 7 day forecasts as compared to NCEP truth. An anomaly coefficient of 1 represents a perfect forecast and an anomaly coefficient of 0.6 represents a useful forecast.

The top of the next two charts shows 52 day area mean anomaly correlation statistics for each of the six experiments run. In all figures, dashed curves do not assimilate CrIS/ATMS observations and solid curves do assimilate CrIS/ATMS. The first chart shows statistics for Global Mean forecast anomaly correlation coefficients and the second chart shows Northern Hemisphere Mean forecast anomaly correlation coefficients.

The bottom of each chart shows the differences of the individual anomaly correlation coefficients from that of the operational GMAO analysis procedure: AIRS observed + CrIS/ATMS. Positive differences indicate improved skill as compared to the baseline.

Forecast 500 mb Height/Anomaly Correlation Coefficients
September 10 to October 31, 2014 Global



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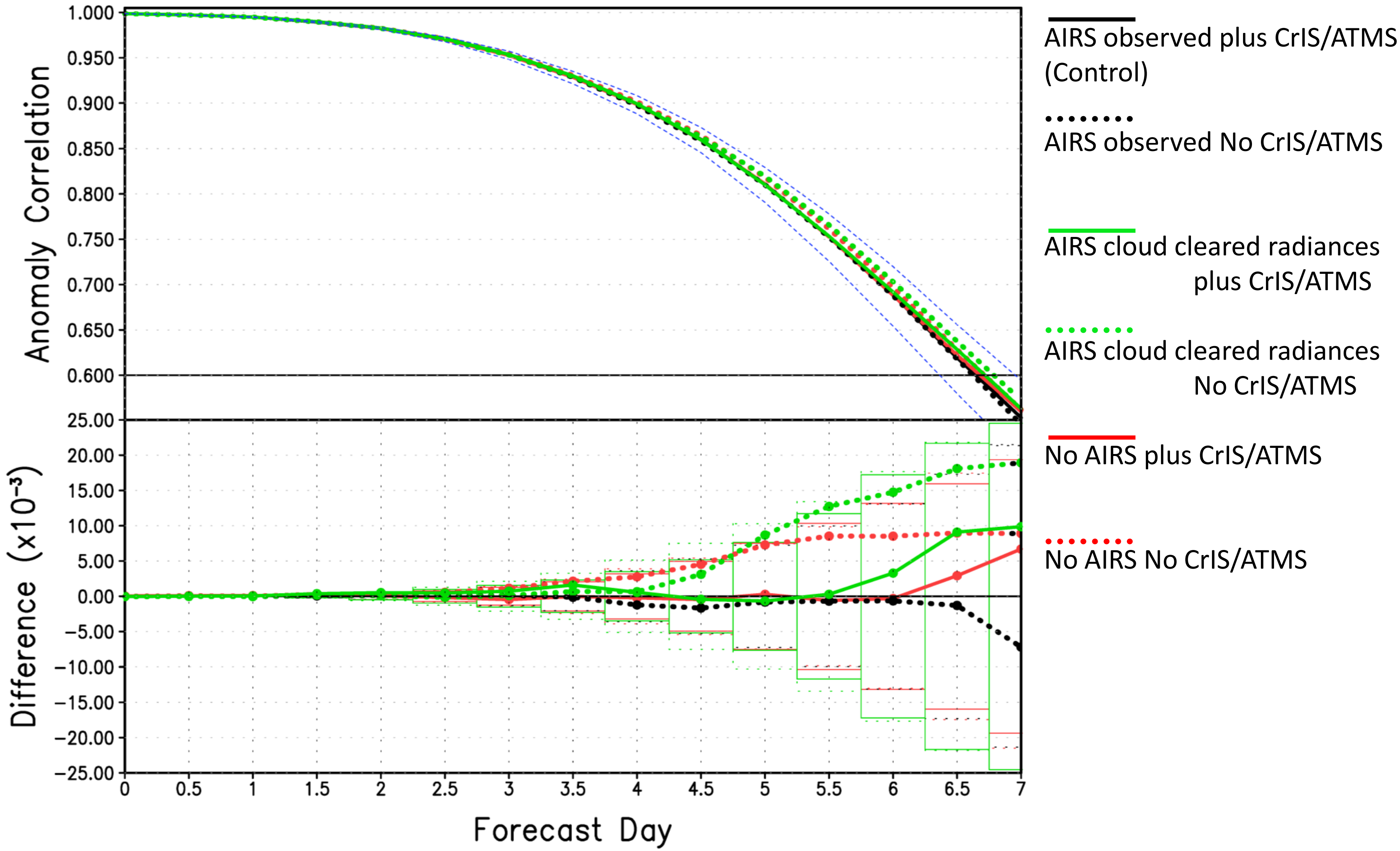
Forecast 500 mb Height/Anomaly Correlation Coefficients
September 10 to October 31, 2014 Northern Hemisphere Extra-tropics



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Summary of Results

All forecasts shown have skill at 6.5 days but most have little or no skill at 7 days.

Global Mean forecast skill from both AIRS analyses not assimilating CrIS/ATMS observations (dashed curves) are superior to those assimilating CrIS/ATMS observations.

Globally, 6 day forecast skill assimilating either observed or cloud cleared AIRS radiances, without CrIS/ATMS, is superior to those assimilating no AIRS observations.

5-7 day Northern Hemisphere Extra-tropical Mean forecast skill is greatest using AIRS cloud cleared radiances without CrIS/ATMS and poorest using AIRS observations, with or without addition of CrIS/ATMS.

In general, the GMAO baseline assimilation procedure, using observed AIRS radiances along with CrIS/ATMS, performs poorest.

Assimilation of AIRS Retrieved Products

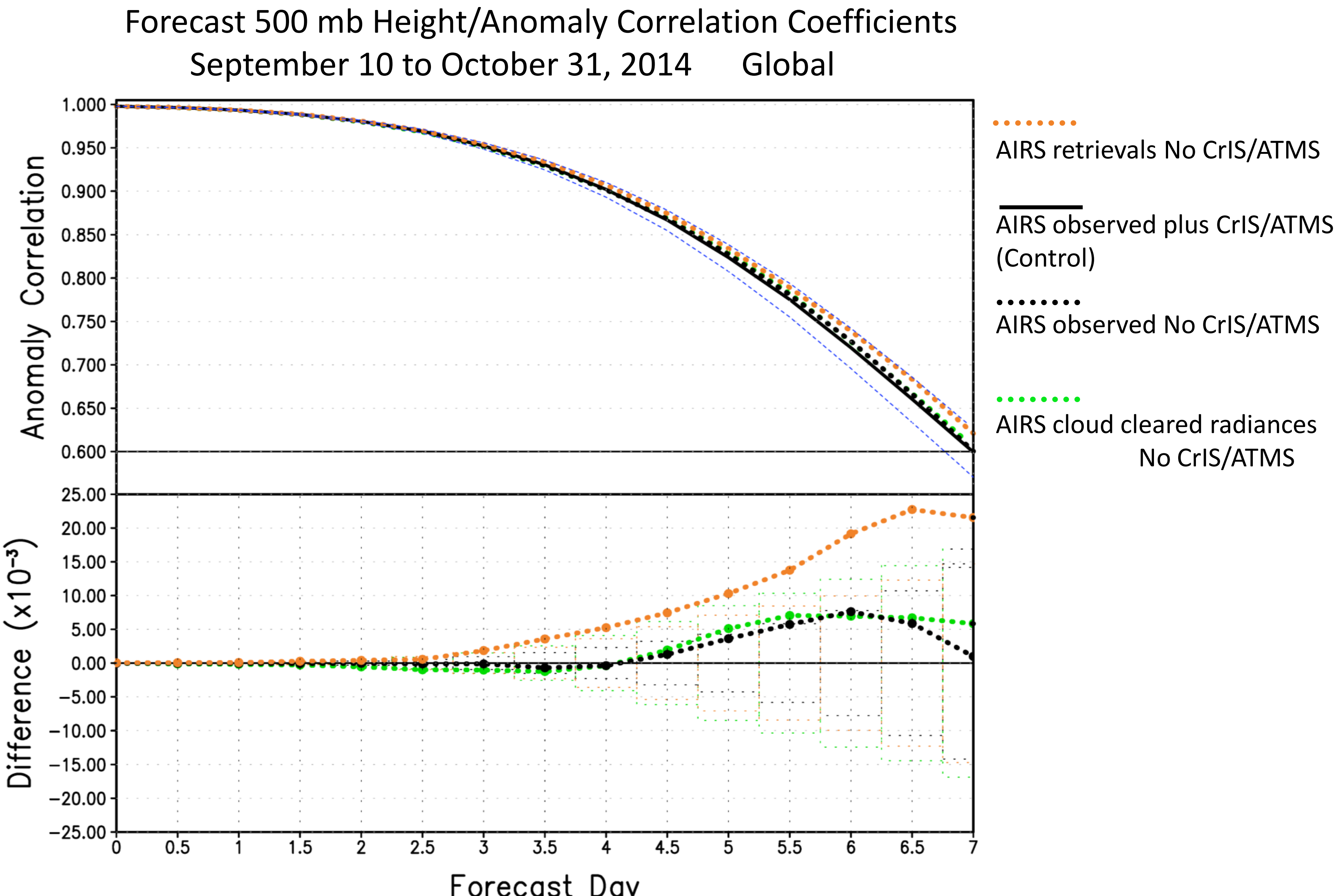
All of our previous research involved assimilation of QC’d AIRS temperature profiles *T(p)*. We assimilated a single retrieved temperature profile within a 1x2 array of AIRS FOR's.

In the course of our current research we learned:

- GMAO assimilates a single set of radiances in a given 145 km x 145 km area
- The biggest positive contribution of AIRS radiances to improving forecast skill comes from channels in the water vapor band
- Assimilation of CrIS/ATMS observations along with AIRS does not perform well

We recently conducted a data assimilation experiment over the same time period shown before in which we assimilated QC’d values of AIRS *T(p)* exactly as we have done before, but without CrIS/ATMS observations.

Results of this experiment, shown in the next figure, are very encouraging. The performance of Assimilation of *T(p)* is better than that of any other experiment.



Global Mean 500 mb height anomaly correlation coefficients assimilating *T(p)* are better than those of all other experiments at all time scales.

Future Experiments Assimilating AIRS Retrievals

We will conduct further experiments in which, one at a time, we will examine the benefit of:

- Assimilation of only a single AIRS retrieval in a 145 km x 145 km area as done with radiances
- Loosening the Data Assimilation QC thresholds – we think Version-6 DA thresholds are too tight and reject too many retrievals in polar regions
- We will also try assimilation of QC'd values of AIRS water vapor profile. We are concerned about the effect of known biases in Version-6 water vapor profile. We really need Version -7.

Results of these experiments should be even better than what we are now getting. Stay tuned!