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Integrating High Spatial Resolution Imager Observations to improve Cloud-cleared Radiances from Hyperspectral Infrared Sounders

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Abstract: Today, most Numerical Weather Prediction (NWP) centers are assimilating cloud-free radiances. Radiances from the Atmospheric Infrared Sounder have been directly assimilated in NWP models with modest positive impacts. However, since only 5% percentage of AIRS fields of view (fovs) are cloud-free, only very small amounts of the data in the lower troposphere are assimilated. (Note that channels in the mid-upper stratosphere are always assimilated since they are never contaminated by clouds.) The highest vertical resolving power of AIRS is in the lower troposphere. To further improve forecast skill, there is a need to increase the number of channels in the lower troposphere. This can be accomplished by assimilating cloud-cleared radiances, which has a yield of about 50%. Since cloud-cleared radiance may have residual cloud contamination and forecast accuracy is very sensitive to the accuracy of the input observations, a technique has been developed to use the 1 km infrared channels on the Moderate Resolution Imaging Spectroradiometer (MODIS) to quality control the cloud-cleared radiances derived from an array of 3 x 3 high spectral infrared sounder AIRS 14 km fovs. This is accomplished by finding MODIS clear radiances values within the AIRS field of view. The MODIS clear radiances are compared to cloud-cleared AIRS radiances that have been convolved to the MODIS spectral resolution. Our studies have found that the cloud-cleared radiances error statistics are very similar to cloud-free (clear) when MODIS data are used to remove potential outliers in the population of AIRS cloud-cleared radiances. At NOAA/NESDIS we provide AIRS products to the operational NWP community. Our processing system is currently being modified to provide the same service for the Infrared Atmospheric Sounding Interferometer (IASI) and the Cross-track Infrared Sounder (CrIS).

Key-words Atmospheric remote sensing, Atmospheric profiles, Hyperspectral soundings

1 Introduction

The Atmospheric InfraRed Sounder (AIRS)[1,2] is the first of a new generation of high spectral resolution infrared sounder with 2378 channels measuring outgoing radiance between 650 cm-1 and 2675 cm-1. The improved vertical resolving power of the AIRS has greatly improved the accuracy of temperature (1 K/1 Km layers) and moisture soundings (15% / 2 Km layers). The AIRS is accompanied by the Advanced Microwave Sounding Unit-A (AMSU-A) and Humidity Sounder for Brazil (HSB). Unfortunately the HSB malfunctioned 10 months after the May 2002 launch. AIRS temperature and moisture soundings (retrievals) have vertical resolutions of 1 – 2 km, instead of 3 – 5 km from current National Oceanic and Atmospheric Administration (NOAA) operational sounders - such as the High resolution InfraRed Sounder (HIRS)3, AMSU-A and AMSU-B. The three NOAA instruments are often referred to as the Advanced TIROS Operational Vertical Sounder (ATOVS) [4]. The HSB is essentially the same as the NOAA AMSU-B instrument without the 89 GHz channel. Because forecast skill is dependent on the quality of the information that is assimilated into the forecast model, AIRS/AMSU products are expected to significantly improve weather forecasts [5]. Over the past decade there have been many improvements in the assimilation of satellite data into forecast models. Major NWP centers have replaced atmospheric temperature and moisture soundings (i.e. retrievals) in forecast models with calibrated clear radiances [6-9]. Five months after the launch of AIRS/AMSU, NOAA/NESDIS [10] started to distribute spatially and spectrally thinned radiances to Numerical

Weather Prediction (NWP) centers. The distributed data is thinned because of current communication and NWP computational limitations. The nominal distributed dataset contains 324 out of 2378 channel radiances from the center of every 3 x 3 array of AIRS 14 km fields of view (fovs). Each 3x3 array is associated with an AMSU 42 km fov. Currently the impact of AIRS on forecasting has been positive. ECMWF was the first to report a positive impact, however it was small (McNally, private communication) and much smaller than the impact of the first AMSU. A much larger impact was recently achieved by NCEP [11], and this was accomplished when the clearest instead of the center field was used. Currently the state-of-the-art of NWP radiance assimilation is to use clear-only radiances, because of incomplete physics and prediction of clouds. At a 14 km spatial resolution, the percentage of fovs which are completely clear for all channels is only about 5%. In other words, the percentage of assimilated AIRS channel radiances will range from 100% of the spectrally and spatially thinned data for channels peaking in the upper stratosphere, above the clouds, to no more than 5% of the thinned data for channels peaking in the lower atmosphere (because of cloud contamination). However, because the very high vertical resolving power of AIRS is concentrated in the lower atmosphere, the lower peaking and likely cloud contaminated AIRS channel radiances are the most important. Therefore one can expect additional larger positive impacts of AIRS radiances if we can treat or remove cloud contamination. The AIRS science team approach to infrared cloud contamination is to use multiple contaminated fovs to remove the clouds. This technique is called cloud-clearing [12-15]. Cloud-cleared radiances are generated from the AIRS processing system and the yield of successfully cloud-cleared radiances is about 50%, a factor of ten greater than the yield of clear-only cases. Our earlier studies have demonstrated that the root mean square (rms) errors of cloud-cleared radiances in the infrared window regions are about 0.3 K larger than perfectly clear observations. Retrieval accuracy from cloud-cleared radiances are much improved over AMSU only observations, and only slightly degraded when compared to absolutely clear data. However, cloud-cleared radiance errors can be reduced to clear-only levels when MODIS is used to quality control (QC) the AIRS cloud-clear radiances

2 AIRS Cloud Clearing

Cloud-clearing [16] begins with an AMSU physical retrieval of atmospheric temperature, moisture (liquid and vapor), microwave spectral emissivity, and skin temperature. The AMSU retrieval is used to compute an estimate of the AIRS radiances for the clear component of the scene. Cloud clearing assumes that the only difference between a set of AIRS fovs is the amount of clouds, therefore, the clear radiance estimate can be used to retrieve a set of extrapolation parameters from a set of AIRS cloudy fovs. Scenes that fail the cloud clearing assumptions, have a poor clear state estimate, or are too cloudy are rejected. The extrapolation parameters for accepted scenes are then used to compute the cloud cleared radiances for any channel that is sensitive to clouds. Channels that are not sensitive to clouds are averaged over the 9 fovs.

The traditional use of a microwave instrument as a clear estimate for infrared cloud clearing suffers from the fact that the current microwave instruments have low information content in the lower troposphere due to the small number of channels and error in the antenna pattern side-lobe corrections. In addition, the microwave surface properties are inherently different than those at infrared wavelengths. The addition of MODIS information content can be used to create a more accurate AIRS cloud cleared radiance product. MODIS, which is also on AQUA, has 1 km spatial resolution broad-band infrared channels which can be superimposed within the AIRS fov. A weighted average of the clear MODIS data, determined by the MODIS “confident” clear mask within an AIRS fov, is used within the AIRS cloud clearing algorithm in two ways. First, the MODIS clear data is used to improve the knowledge of the infrared surface to allow cloud clearing to discriminate clouds near the surface. This is accomplished by using MODIS to specify an infrared emissivity first guess based on MODIS surface type classification and, in addition, using MODIS thermal window channels to constrain the retrieval of the surface emissivity and temperature from AIRS. Secondly, the MODIS clear thermal imager sounder channels contain additional information about the clear infrared radiance in the lower troposphere (specifically MODIS channels 27, 28, 33-36) and these can improve the clear estimate of AIRS channels used for cloud clearing. The improved knowledge of the infrared surface and the increase information content in the lower troposphere will allow for an improved cloud cleared radiance product from AIRS. This, in turn, improves all of AIRS geophysical products.

The direct use of MODIS clear observations as described above is currently under development. The results reported here are based on using MODIS to quality control AIRS. This is currently accomplished by averaging the clear-sky 1 km MODIS fovs within the AIRS 3 x 3 arrays. Then the AIRS radiances are convolved using the MODIS spectral response functions. Currently we use only MODIS channel 33. We require that the clear-sky MODIS channel 33 and the convolved cloud-cleared AIRS to MODIS channel 33 agree within 0.5 K. To determine if this test has reduced errors in the cloud cleared radiances (brightness temperatures), simulated clear radiances are computed from the ECMWF analysis. Fig. 1 shows the bias and rms of differences between a) cloud-cleared radiances and clear radiance simulated from the ECMWF analysis (46% of all cases), b) absolutely clear cases and ECMWF clear radiances (4% of the 46%), and c) MODIS QC AIRS cloud-cleared radiances minus ECMWF clear radiances (50% of the 46%). The results demonstrate that when MODIS is used for QC, the rms errors are virtually identical to the clear-only cases. Even though the population is reduced by half, the QC AIRS cloud-cleared radiance population is greater than clear-only by more than a factor of 20.

3 Summary

We have demonstrated very good retrieval performance from AIRS in clear, partial cloudiness, and cloud-cleared fov's. The impact in NWP will likely remain small, unless AIRS cloud contaminated or cloud-cleared radiances are assimilated. The challenge for the NWP satellite data assimilation community is to assimilate AIRS data in the presence of clouds, otherwise the full impact of high spectral resolution infrared observations will not be realized. Another option, of course, is to assimilate AIRS retrievals, which are also derived in near real-time. These retrievals have been optimized for the instrument characteristics of the AIRS and AMSU instruments on Aqua and properly account for the spectrally correlated properties of cloud cleared radiances.

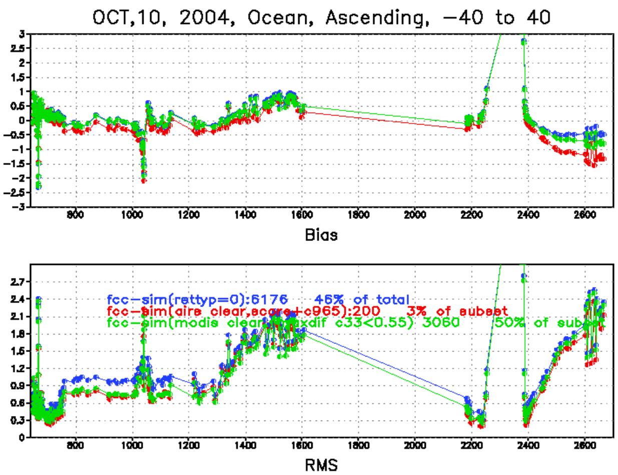

Fig. 1. Bias and rms of differences between a) cloud-cleared radiances and clear radiance simulated from the ECMWF analysis (blue), b) absolutely clear cases and ECMWF clear radiances (red), and c) MODIS QC AIRS cloud-cleared radiances minus ECMWF clear radiances (green)

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