Apperception of Clouds in AIRS Data

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1. Introduction

Our capacity to simulate the radiative characteristics of the Earth system has advanced greatly over the past decade. However, new space based measurements show that idealized simulations might not adequately represent the complexity of nature. For example, AIRS simulated multi-layer cloud clearing research provides an excellent groundwork for early AIRS operational cloud clearing and atmospheric profile retrieval. However, it doesn't reflect the complicated reality of clouds over land and coastal areas. Thus far, operational AIRS/AMSU cloud clearing is not only of low yield but also of unsatisfying quality. This is not an argument for avoiding this challenging task, rather a powerful argument for exploring other synergistic approaches, and for adapting these strategies toward improving both indirect and direct use of cloudy infrared sounding data.

Ample evidence is shown in this paper that the indirect use of cloudy sounding data by way of cloud clearing is sub-optimal for data assimilation. Improvements are needed in quality control, retrieval yield, and overall cloud clearing retrieval performance. For example, cloud clearing over land, especially over the desert surface, has led to much degraded retrieval quality and often a very low yield of quality controlled cloud cleared radiances. If these indirect cloud cleared radiances are instead to be directly assimilated into NWP models, great caution must be used. Our limited and preliminary cloud clearing results from AIRS/AMSU (with the use of MODIS data) and an AIRS/MODIS synergistic approach have, however, shown that higher spatial resolution multispectral imagery data can provide much needed quality control of the AIRS/AMSU cloud clearing retrieval. When AIRS and MODIS are used synergistically, a higher spatial resolution over difficult terrain (especially desert areas) can be achieved and with a much improved accuracy. Preliminary statistical analyses of cloud cleared radiances derived from (1) operational AIRS/AMSU, (2) operational AIRS/AMSU plus the use of MODIS data as quality control, and (3) AIRS/MODIS synergistic single channel and two field of views cloud clearing are presented. These results illustrate the strengths and weaknesses of the current AIRS/AMSU cloud clearing approach discussed above.

While major efforts and advances in sounding retrieval have been made with the AIRS/AMSU, and more recently with AIRS/MODIS cloud clearing retrieval, cloud clearing inadequacies remain and they are responsible for cloud artifacts in infrared measurements used to represent clear sky conditions within or near partly cloudy spatial domains. Cloud cleared radiances and their associated sounding profiles do not represent cloudy sky soundings nor should they be directly assimilated into numerical weather models without the necessary ancillary cloud information. Otherwise the model fields will be biased by clear sky conditions. Example ECMWF analysis and AIRS/AMSU cloud cleared retrieval profiles have demonstrated the above argument, specifically that AIRS/AMSU cloud cleared sounding profiles of both temperature and water vapor are distinctly different from the cloudy profiles exhibited in the ECMWF analyses. Global replacement of model profiles with cloud cleared radiances would bias the result toward cloud free conditions.

However, direct assimilation of cloudy sounding data may be feasible due to recent advances in fast and accurate forward radiative transfer models for the cloudy atmosphere. Although at an early stage of development, recent results indicate that successful cloud modeling will enable the direct assimilation of cloudy radiances in the near future.

2. Clouds in AIRS Data

Fig. 1 is a global composite of reflectance measurements made by the Moderate Resolution Imaging Spectroradiometer (MODIS) (King et al. 1992) instrument on board the Aqua satellite. As can be seen at the MODIS imaging measurement sampling size (1 km Field of View (FOV) at nadir), clouds cover most of the earth.

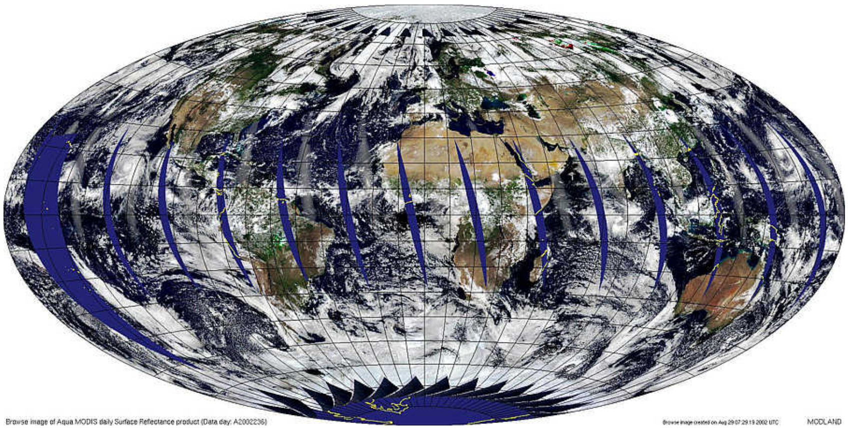

Fig. 1. Browse image of Aqua MODIS daily surface reflectance product showing cloud coverage.

For the Atmospheric Infrared Sounder (AIRS) (Aumann et al. 2003), which has nadir sampling FOV size greater than 14 km (depending upon scan angle), the impact of cloud cover is even greater. Some preliminary analyses have shown that only 5% of single AIRS FOVs are truly cloud free. The remaining 95% of AIRS data will require either cloud clearing, or an indirect approach to physically account for the effects of clouds, or a direct approach that explicitly accounts for the influence of clouds via careful radiative transfer modeling. In the indirect approach, radiance or profile retrievals corrected for the presence of clouds are assimilated into Numerical Weather Prediction (NWP) models. In the direct approach, the cloud affected radiances themselves are assimilated. Fig. 2 shows examples of AIRS spectra showing the contrast between the clear and cloudy observations. Under clear and humid conditions (left column spectra of fig. 2), spectral features due to gaseous absorption of water vapor, carbon dioxide and ozone are very prominent. Spectral features due to solar reflectance, surface emissivity and reflectivity are not so obvious but are also embedded in the clear sky signal. Where clouds exist, they act as strong absorbers and reflectors as can be seen in the cloudy AIRS spectra (right column of fig. 2). As can be seen, clouds mask the clear sky and surface property spectral signal even when the scene is not fully covered by clouds. The cloud radiation portion of the radiance to space is a highly non-linear function of cloud altitude (single or multi-layer), phase (ice, water or mixed), and habit (particle size and shape). The relative differences between left and right spectra in fig. 2 can be viewed as important cloud forcing information for weather and climate prediction or a nuisance when attempting to use the cloud contaminated radiance data to retrieve atmospheric thermodynamic profile information for NWP applications. If cloudy scene radiance data are to be assimilated into NWP models, a physical radiative transfer model that accurately accounts for gaseous absorption and cloud forcing is needed.

A global sampling of high spectral resolution AIRS spectra is shown in Fig. 3. Although the information content of infrared measurements appears to be perplexing, physical understanding, careful computer modeling, and appropriate assimilation strategies will provide the tools needed to assimilate these radiance data into NWP forecast models.

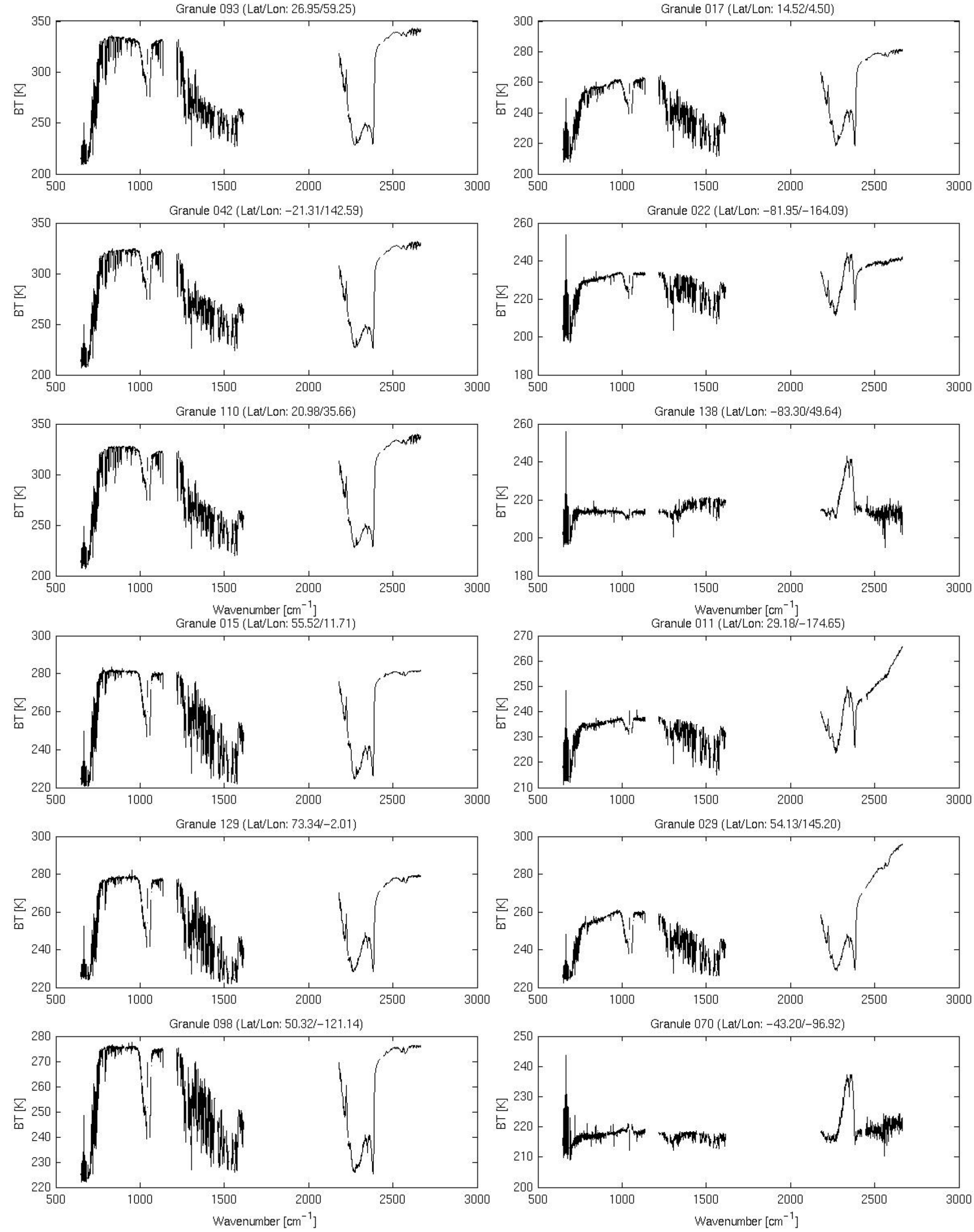

Fig. 2. Example AIRS clear (left column) and cloudy (right column) spectra showing the spectral differences due to cloud properties and their surrounding environments.

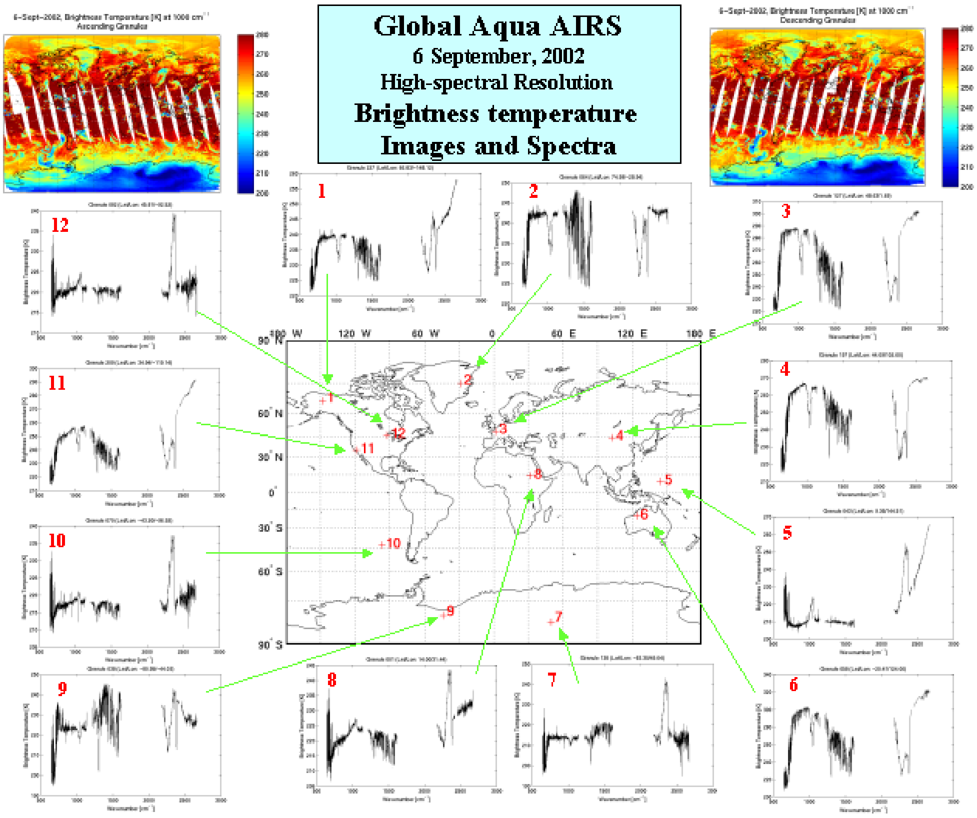

Fig. 3. Global AIRS spectra selected from 6 September 2002 to demonstrate the extraordinary wealth of measurements available to scientists for revealing subtle details of our earth-atmosphere system.

As an illustration, an observed cloudy spectrum (shown in black in fig. 4) is compared with different calculated spectra for various micro-physical properties, cloud particle sizes (effective diameters of 35, 45 and 60 microns) and cloud optical thicknesses (i.e., 1.20, 1.43 and 1.60). Assuming that the atmospheric conditions are known, one can calculate the cloudy scene spectra that match the measurements, within certain bounds of parameter uncertainty (Wei et al, 2004). This simple illustration demonstrates that our current understanding and theoretical modeling capability, which can be advanced to accurately retrieve the embedded cloud information, will enable future quantitative use of the cloudy scene radiance measurements for many applications, including NWP.

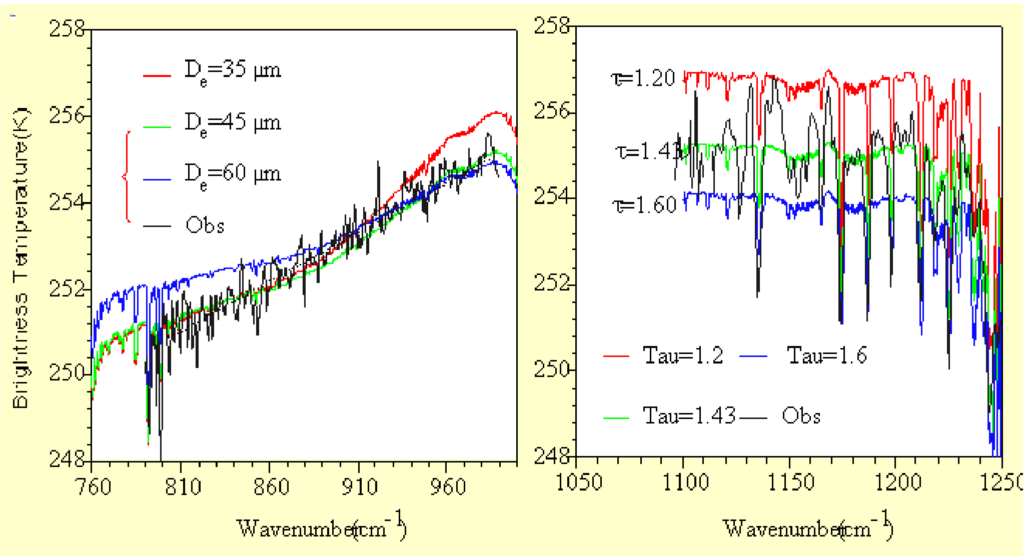

Fig. 4. Simultaneous retrieval of the effective size (D_e) and optical thickness (Tau) of ice clouds from HIS spectra. (Left) brightness temperature versus particle size assuming Tau=1.43, and (right) brightness temperature versus optical thickness assuming D_e is 45 microns (Huang et al., 2004)

3. Cloud Clearing Issues

Cloud clearing is an indirect approach to allow data assimilation or retrieval to use cloud contaminated measurements to represent clear sky atmospheric conditions either within or alongside partly cloudy areas. A single day of global ECMWF analyses and AIRS cloud cleared retrievals, provided by the AIRS science team, were used to demonstrate the information content. Figs. 5 and 6 are global coverage of the data used in the following analysis.

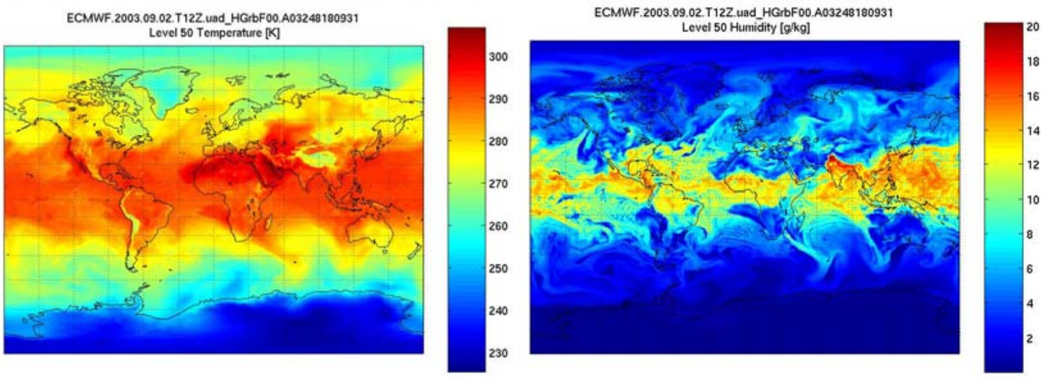

Fig. 5. ECMWF analyses of temperature (left) and water vapor (right) near the surface on 2 September 2003.

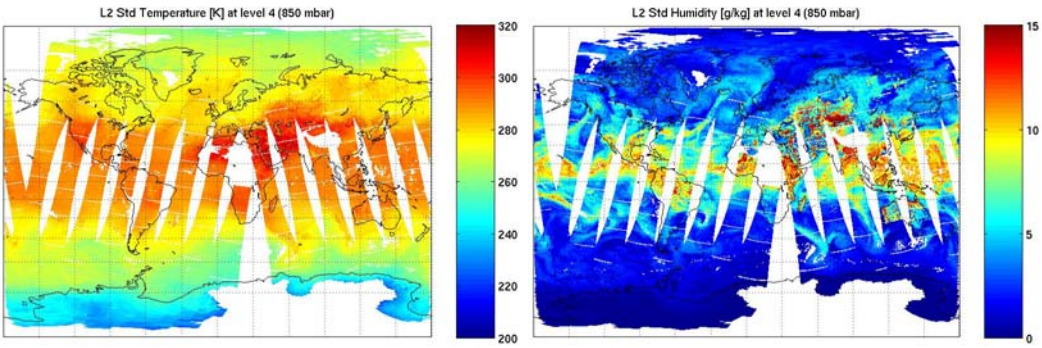

Fig. 6. AIRS cloud cleared radiance retrieved temperature (left) and water vapor (right) for the 850 mb level on 2 September 2003.

One day of ECMWF global analysis data (129960 profiles, half of the total available profiles) (fig. 7) and all available AIRS science team retrieval profiles taken during the same day (fig. 8) form a useful dataset for comparison. Comparing figures 7 and 8 shows that the global temperature structure is distinctly different under regions covered by clouds of differing phase. Unlike the analysis provided by ECMWF, the same day's AIRS cloud cleared radiance temperature retrieval structure has no distinction between clear and cloud cleared. This is precisely what cloud clearing is designed to achieve, that is, to produce retrievals of temperature profiles for the clear portion of the partly cloudy sky. However there is a consequence of representing the whole globe without clouds. Providing NWP models with only clear sky atmospheric profiles will severely bias the model fields since these conditions differ significantly from the ever-present partly cloudy sky condition.

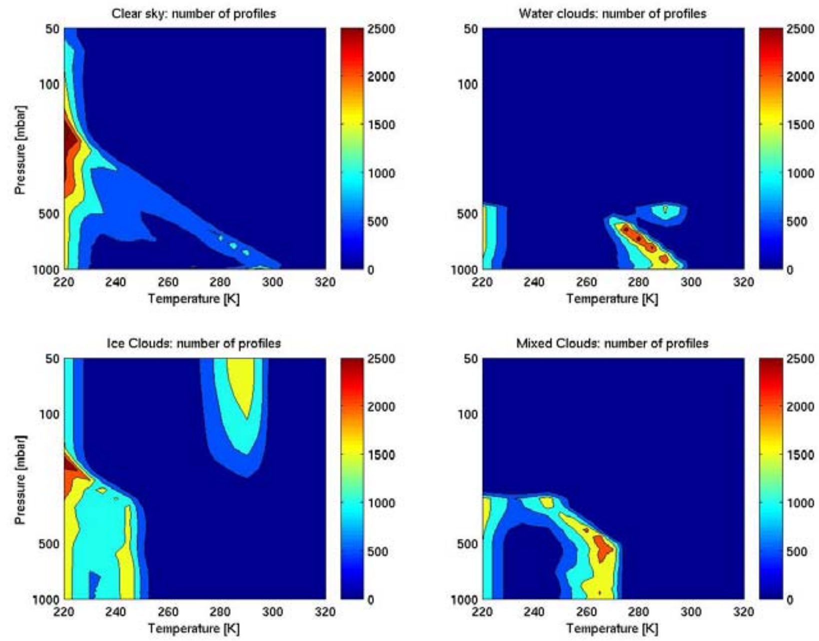

Fig. 7. Color contour histograms of ECMWF global temperature classified into (a) clear (upper left), (b) water cloud (upper right), (c) ice cloud (lower left) and (d) mixed phase (lower right) cloud according cloud information flag recorded in the analysis data file.

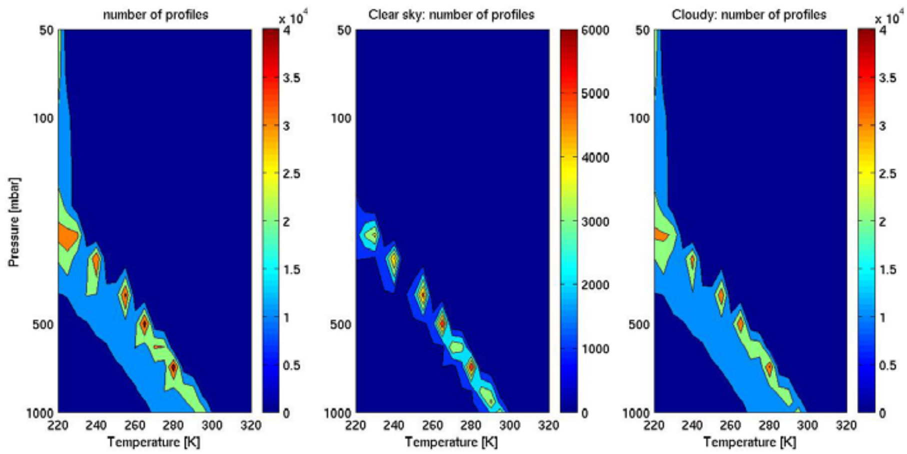

Fig. 8. Color contour histogram of AIRS science team standard temperature retrieval classified into (a) all (clear and cloud cleared combined, left panel), (b) clear (middle panel), and (c) cloud cleared (right panel) in the retrieval data file.

Figs. 9 and 10 show for water vapor features similar to that shown for temperature in figs. 7 and 8, respectively. The same conclusion can be reached, that is, AIRS clear and cloud cleared water vapor retrieval profiles are similar to the clear conditions shown in the ECMWF analysis. The clear water vapor profiles are vastly different from those associated with water, ice and mixed phase cloud conditions. NWP model assimilation of cloud cleared water vapor radiances will tend to produce a clear sky bias in the global humidity conditions.

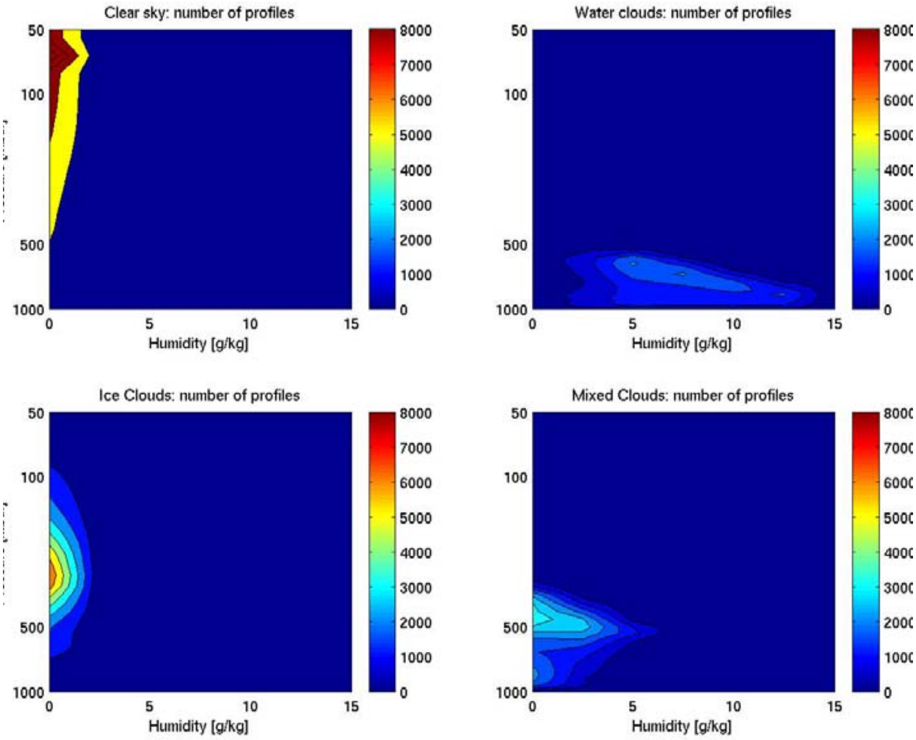

Fig. 9. As for fig. 7 except for water vapor profile.

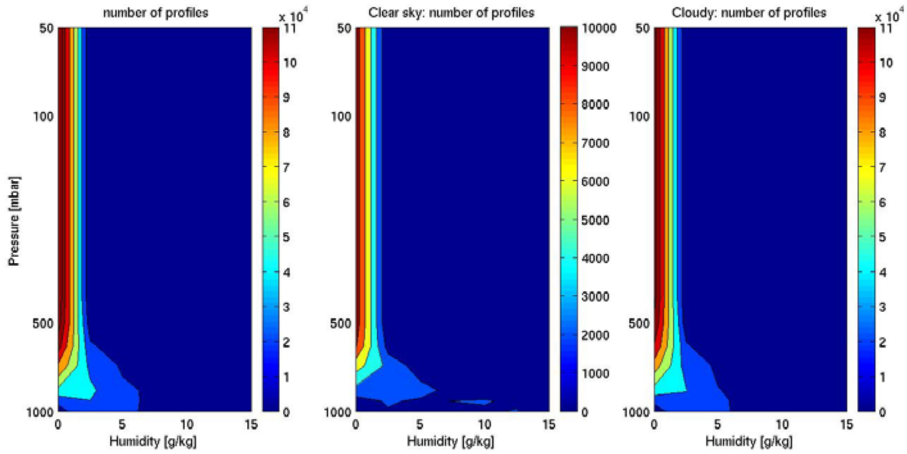

Fig. 10. As for fig. 8, except for water vapor profile.

Cloud-clearing Technique: Fig. 11 shows a grid of AIRS FOVs including a surrounding target area where a reference AIRS clear spectrum is identified using the MODIS cloud mask. A single AIRS FOV spectrum is defined as being clear if more than 95% of the MODIS pixels within the AIRS FOV are declared by the MODIS cloud mask as "confident clear". Such an AIRS spectrum is selected as "reference clear" and is used in evaluating the cloud cleared radiances derived from the 9 FOVs' "golf ball" within the interior of the grid shown in Fig. 11. If multiple "reference clear" AIRS FOVs are found, the warmest of these is selected as the final "reference clear".

To objectively validate the AIRS science team cloud cleared radiance performance, the following procedure is implemented:

1. Find at least one neighboring AIRS single FOV (S-FOV) within or surrounding the AIRS golf ball that is clear (according to MODIS cloud mask for which that within this FOV at least 99% is clear). In other words, from 25 candidates (fig. 11 below) find one clear AIRS FOV as the " clear ground truth" to estimate cloud clearing (CC) error.

2. Compute the bias (mean of differences), the Root Mean Square Error (RMSE), and Root Mean Square Difference (RMSD) spectra from all AIRS/AMSU golf ball CC radiances that have a corresponding clear S-FOV (as defined as above) radiance spectra.

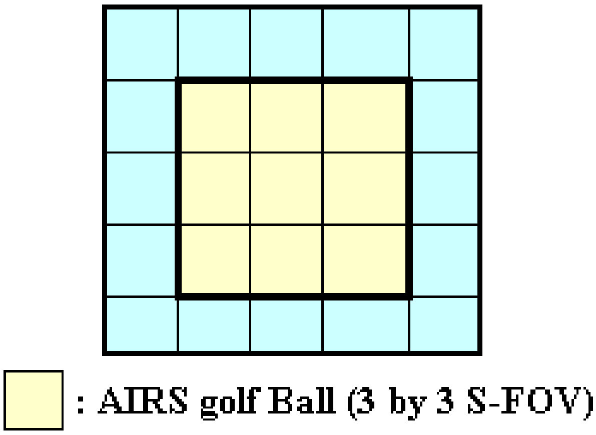

Fig. 11. AIRS golf ball (3 by 3 of AIRS single FOVs) and its surrounding FOVs used as a target area for finding the reference clear spectrum.

Fig. 12 shows 24 day and 24 night AIRS granules for 6 September 2002 on which day version 3.5.0 cloud cleared radiance granules were available for obtaining the error statistics.

Figs. 13 and 14 are the bias and RMSE of AIRS science team cloud cleared radiances derived from the selected granules shown in fig. 12 using the concept of "reference clear" as defined in fig. 11 and described above. Over ocean, shown in fig. 13, both day and night time, bias and RMSE of cloud cleared radiance errors are relatively small, although higher than the detector noise level, as required for high vertical resolution retrievals. In this case, the RMSE assessed here is a factor of two higher than the AIRS science team theoretical estimated levels (red curves). Thus, over ocean the AIRS/AMSU cloud clearing produces reasonable performance, but unfortunately the errors are still significantly larger than the noise level required to extract the highest vertical resolution information retrievable from the AIRS clear sky sounding radiances.

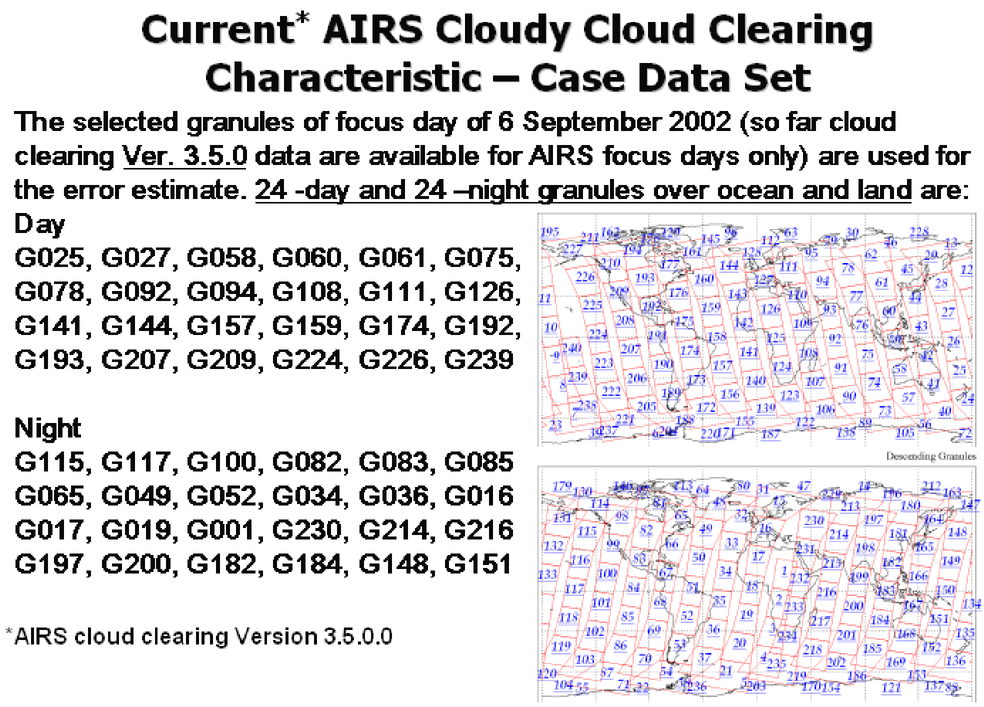

Fig. 12. Selected AIRS granules used in the calculation of cloud clearing radiance error.

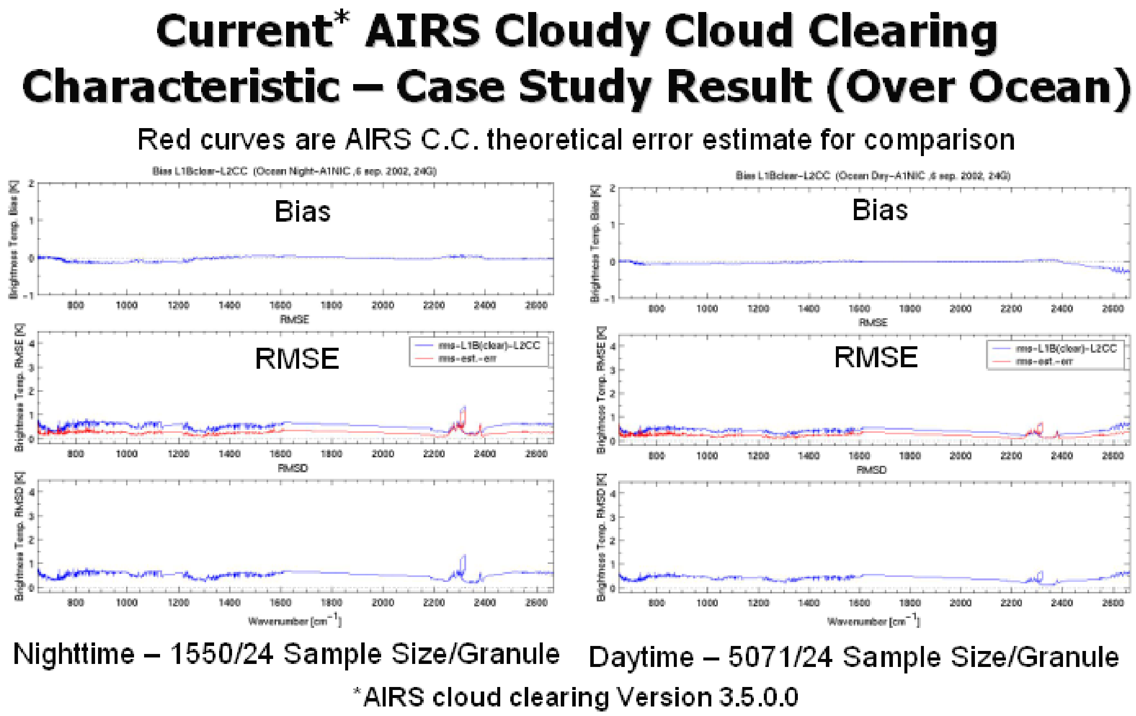

Fig. 13. Brightness temperature bias (upper panel) and RMSE (middle panel) of AIRS Version 3.5.0 cloud cleared radiances over ocean for nighttime (left) and daytime (right).

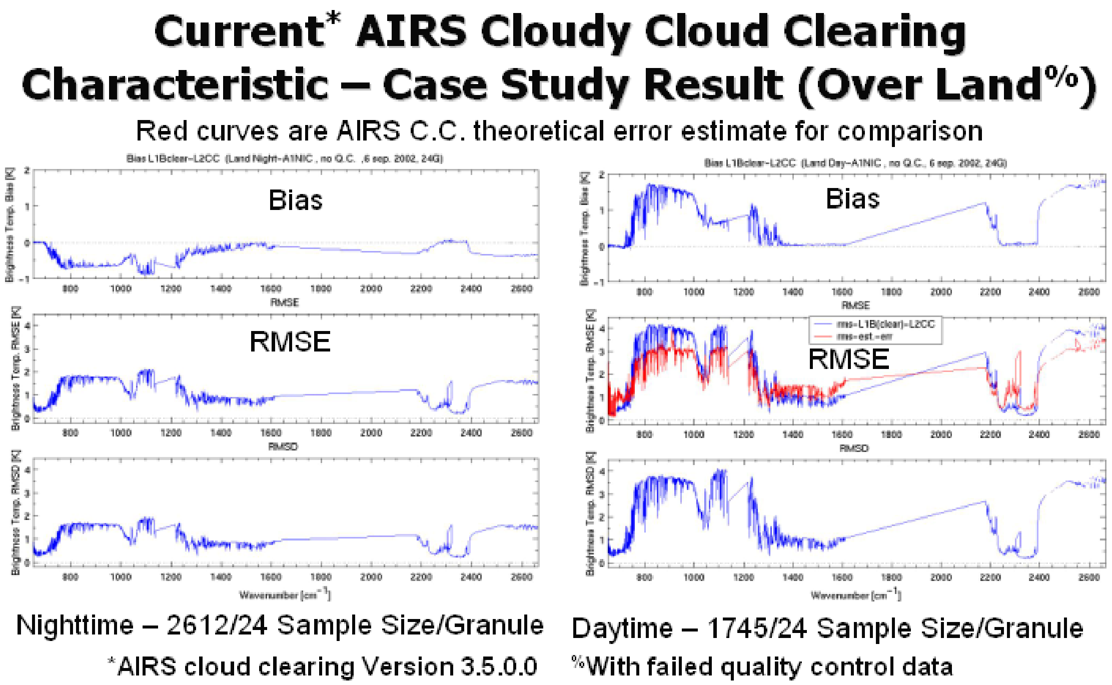

Fig. 14. As for fig. 13 except errors are representing cloud cleared radiances over land only.

Over land areas the AIRS/AMSU science team cloud clearing error situation is much worse. Much higher errors, both in bias and RMSE, occur compared to the algorithm's over ocean counterpart. As a matter of fact, most of the cloud cleared radiances have very low yield (low number of cloud cleared retrievals pass its stringent quality control) and, as a result, all retrievals with or without passing quality control are used in the assessment of the cloud clearing error. The official AIRS science team's land estimated error (red curve in fig. 14) is also significantly higher than its ocean counterpart, consistent with the error estimated by the procedure used here. Looking further into the cloud clearing performance over land, one can find that the daytime results have significant degradation possibly due to the solar reflection of bright clouds and land surfaces and also due to the fact that there is a significant differential between surface skin and air temperatures which is not captured by the microwave data used as the clear sky information used for the cloud clearing procedure. In short, current AIRS/AMSU science team cloud clearing retrieval performs much better over ocean than over land areas, the poorest performance being for daytime viewing conditions. A major overhaul of the algorithm is now underway, but the case made here is that the use of AMSU data alone for the clear sky information used for AIRS cloud clearing is insufficient over land, particularly for daytime viewing conditions. On the other hand, co-located high spatial resolution MODIS infrared data may potentially complement AIRS/AMSU cloud clearing to achieve reliable performance over land and ocean regions alike.

MODIS/AIRS synergistic (Smith et al., 2003) and AIRS/AMSU (Susskind et al, and Aumann et al, 2003) cloud cleared retrieval for one single granule over ocean and desert surface shown in fig. 15 are analyzed.

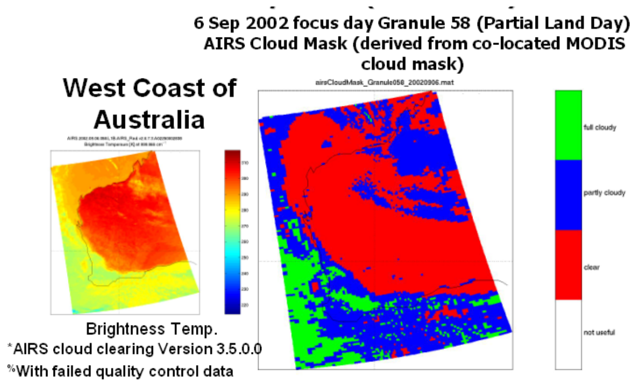

Fig. 15. AIRS window brightness granule (left) and AIRS single field of view cloud mask (right) image of 6 September 2002.

Bias and RMSE of cloud clearing error using AIRS/MODIS and AIRS/AMSU science team cloud cleared radiances are shown in fig. 16. For this case study AIRS/AMSU cloud clearing exhibits large bias and relatively large RMSE. Although AIRS/MODIS approach has slightly smaller RMSE than AIRS/AMSU it does have much smaller bias (near zero except for short wave region). The near zero bias of AIRS/MODIS cloud clearing approach is appealing for the NWP data assimilation application. The fact that there is a large cloud cleared (CC) radiance RMSE exhibited in the window regions of the spectra indicates that much of the magnitude of the CC radiance RMSE is due to surface skin temperature and emissivity spatial differences which exist between the cloudy scenes (Huang et al, 2004) and the neighboring clear sky validation scenes. Such differences would be expected to exist over the Australian continent.

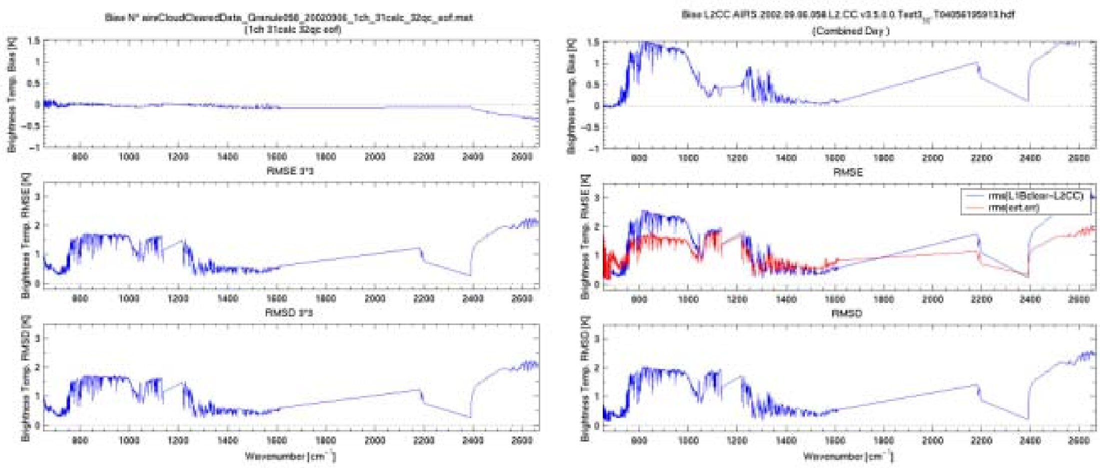

Fig 16. Comparisons of AIRS/MODIS (left panel) and AIRS/AMSU (right panel) cloud clearing error in terms of bias (upper panel) and RMSE (middle panel) derived from granule 58 of 6 September 2004. Note that red curve in the middle right middle panel is AIRS science team own estimated error.

In order to better illustrate the accuracy differences of the cloud cleared radiances derived from AIRS/AMSU and AIRS/MODIS, the cloud cleared AIRS radiances obtained from both approaches are convolved spectrally to simulate MODIS infrared band images of 20, 29, 31, and 33. The MODIS band spectral response functions used for the convolution are shown in Fig. 17.

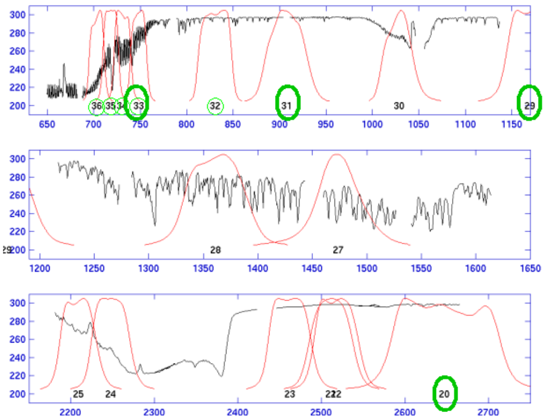

Fig. 17. MODIS spectral response functions with labeled band number used in the study.

In fig. 18, the MODIS band images simulated from the convolved AIRS cloud cleared radiances are compared with the actual MODIS clear single pixel images. The retrieved AIRS cloud cleared radiances convoluted with the MODIS spectral response functions should resemble the MODIS clear sky images observed during the same orbit time. Indeed the AIRS/MODIS cloud cleared brightness temperature image of all MODIS bands are shown to be very similar to that observed with MODIS. As can be seen, of the MODIS/AIRS cloud clearing approach captures all the small and large spatial and spectral patterns that have been observed by MODIS. The lower resolution and highly unstable MODIS band images derived over land using the AIRS/AMSU cloud cleared radiances provide evidence that this is an unsatisfactory approach for deriving cloud cleared radiance over land areas of the globe.

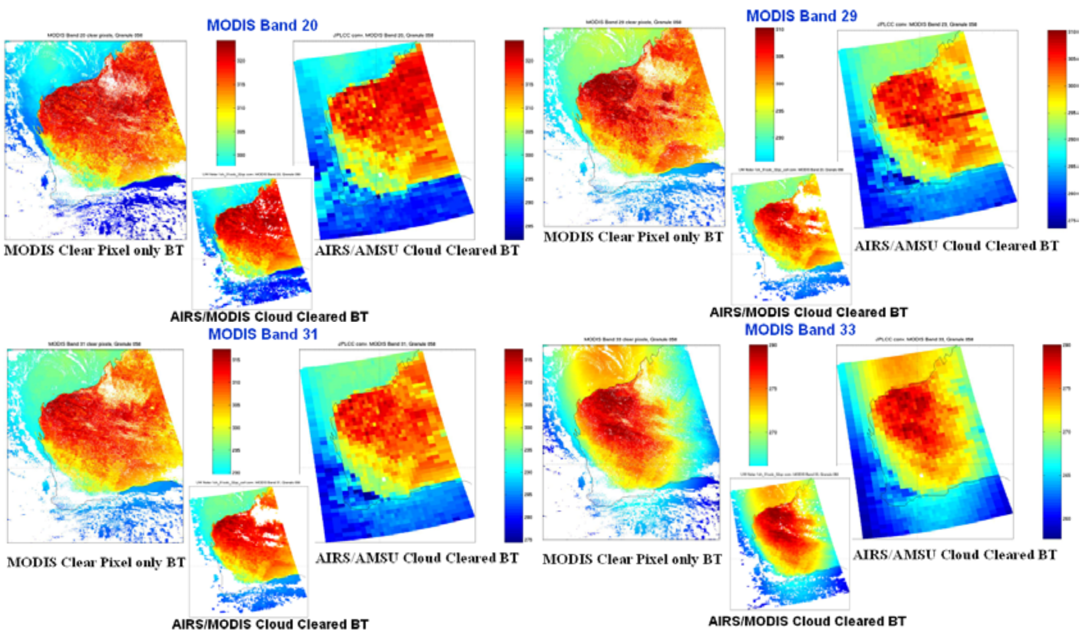

Fig. 18. Plots of brightness temperature of MODIS and AIRS/MODIS and AIRS/AMSU cloud cleared MODIS simulated images used to validate cloud clearing performance. Images of band 20 (upper left), band 29 (upper right), band 31 (lower left), and band 33 (lower right) are shown respectively. For each panel MODIS clear pixel (left), AIRS/MODIS cloud cleared MODIS simulated (middle), and AIRS/AMSU cloud cleared MODIS simulated (right) brightness temperature for the different MODIS bands are displayed.

4. Ultraspectral Infrared Cloud Forward Modeling

Building a comprehensive cloud property database that accounts for the single-scattering effects of ice and water clouds is essential for the modeling of cloudy infrared measurements (Huang et al 2003). The current database considers 7 shapes of ice crystals in the form of aggregates, solid hexagonal columns, droxtals, hollow columns, plates, bullet rosettes and spheroids. It also considers 38 size bins of particle ranging from 2 to 3100 microns in terms of particle maximum dimension. The database calculates 49 key wavelengths from 3.08 to 100 microns to cover all potential aircraft and space-borne multispectral, hyperspectral, and ultraspectral measurement specifications. The single scattering properties are used to parameterize cloud absorption and reflectance effects so that forward radiative transfer computations in the presence of cloud can proceed swiftly. The parameterized cloud albedo and transmissivity functions for ice clouds are derived as functions of optical thickness (ranging from 0.04 to 50), effective sizes (ranging from 10 to 157 microns), effective shape (from the list of the above 7 crystal habits), zenith angle (from 0 to 80 degrees), and of wavenumber (from 500 to 2500 1/cm). For water clouds, the optical thickness range is from 0.06 to 150 and the effective size from 2 to 20 microns. These albedo and transmissivity databases are then used in the calculation of cloud component radiance to account for the scattering and absorption of clouds.

5. Summary and Conclusions

Based on the current infrared sounding instrument field of view (FOV) size >14 km, depending upon scan angle, the probability of cloud free single FOV measurements are less than 5 to 10 % at best. To improve the use of ultraspectral sounding data in numerical weather prediction model and generation of environmental and atmospheric products one must find ways to efficiently treat the effects of clouds. Unfortunately clouds greatly complicate the processing of ultraspectral infrared sounding data and, at present, a complete physical treatment of clouds is prohibitive. The computation of few thousands of cloudy radiances within each FOV is very time consuming when both absorption and scattering of clouds, and how these couple to clear air emission/absorption and earth surface reflection, need to be accounted for simultaneously.

Using AIRS cloudy data we have shown that spectral signatures of clouds are compounded by, not only the atmospheric variations (vertical inversion, horizontal temperature and water vapor gradient, solar reflection, etc), but also cloud in-homogeneity (multiple cloud layers and mixed phase sub-pixel elements), surface effects (spectral variation of surface emissivity and reflectivity) and local thermodynamic disequilibrium. Interpolation of clear and cloudy AIRS data becomes a complicated issue and the use of clear or cloud contaminated infrared data becomes the focal point of data preprocessing if this information source is to be assimilated or used to derive products in a timely fashion.

The cloud clearing approach generates spectral radiances as if they represented a clear portion of the measured partly cloudy area. The cloud clearing performance of the current AIRS science team algorithm using AIRS and AMSU is analyzed alone and with a synergistic AIRS and MODIS approach. Over ocean, the AIRS/AMSU cloud clearing performs in a reasonable manner in that the bias and root mean square error of cloud clear radiances compare favorably with nearby "cloud free" AIRS radiance spectra used here as the measure of the "clear truth". The AIRS science team theoretical estimated cloud clearing error is in reasonable agreement (i.e., within a factor of two) with this performance measure. However, current AIRS cloud clearing retrieval over land suffers from the surface effects (infrared emissivity and solar reflection). Case studies over land (especially over desert) are analyzed to demonstrate the advantages and drawbacks of both AIRS/AMSU and AIRS/MODIS synergistic approaches. This preliminary analysis has shown that the potential large bias and root mean square error of cloud clearing is indeed occurring over land areas using the AIRS/AMSU approach. The AIRS/MODIS approach, however, seems to be able to produce cloud cleared radiances much more reliably with smaller bias and random error. This was expected in that MODIS, unlike

AMSU, sees the surface radiance in much the same manner that AIRS sees the surface (i.e., the proportion of clear scene and the surface emissivity characteristics are the same for MODIS and AIRS).

It is crucial to note that the above preliminary comparison and results are conducted using a large percentage of failed quality control AIRS/AMSU cloud cleared retrievals of Field of Regards (an FOR is an area covered by a 3 by 3 array of single FOVs, also referred to as “golf balls”) for evaluation of both AIRS/AMSU and AIRS/MODIS (at 1 by 2 FOV resolution) cloud clearing retrieval performance. Although a fair comparison, one must keep in mind that it is not using the latest AIRS/AMSU science team cloud clearing retrieval that has still not been validated and is currently undergoing major algorithm overhaul.

While major efforts and advances have been made in the AIRS/AMSU and, more recently, the AIRS/MODIS cloud clearing retrieval, cloud clearing by definition accounts for the cloud effects with a clear sky replacement strategy. Cloud cleared radiances and their associated sounding profiles, in practice, cannot represent cloudy sky sounding nor should be directly assimilated into a numerical weather model without the necessary ancillary cloud information. The example single day of ECMWF analysis and AIRS/AMSU cloud cleared retrieval profiles have demonstrated the argument that AIRS/AMSU cloud cleared sounding profile, both temperature and water vapor, are distinctly different from the cloudy profiles exhibited by the ECMWF analysis. Replacing the whole globe of cloudy profiles with cloud cleared profiles, without the benefit of ancillary cloud property data, is essentially providing the NWP model with initial states not consistent with the truth.

The needs for improving the yield of AIRS data used in numerical weather prediction models and for producing global sounding retrieval are urgent. Complicated and novel approaches to the assimilation of cloudy infrared radiances should be examined. At present University of Wisconsin-Madison is partnering with Texas A&M University to develop a physically based fast parameterized cloudy infrared ultraspectral forward model that is both fast and sufficiently accurate to allow future direct assimilation and retrieval of cloudy data without other preprocessing such as cloud clearing. Preliminary cloud microphysical parameterization approach (Yang et al., 2001 and 2004) can be summarized as:

- Cloud single scattering properties are computed by rigorous composite models, such as the finite-difference time-domain (FDTD) technique, the T-matrix method and an improved geometric optics method (IGOM) for nonspherical ice crystals, and the Lorenz-Mie solution for “equivalent” ice spheres.
- Seven ice crystal habits (aggregate, hexagonal column, hexagonal plate, bullet rosette, hexagonal hollow column, spheroid, and droxtal) are considered.
- A database of the single-scattering properties of ice crystals at the infrared spectrum, from 3 to 100 μm, and a particle size spectrum from 2 μm to 10000 μm in terms of the particle maximum dimension are generated.
- Parameterized cloud transmissivity and reflectivity are derived to account for the multiple scattering effects due to clouds.
- Fast infrared gaseous absorption forward model is modified to include cloud transmissivity and reflectivity to form fast parameterized cloudy model.
- “True” cloudy forward model calculations are performed by LBLRTM follow by the DISORT multiple scattering to accurately account for both gases and clouds effects in deriving the top of atmosphere radiances to characterize the accuracy of the fast parameterized cloudy forward model.
- Fast cloudy forward model performance is estimated by the comparison of the differences between the cloud radiances of this fast model and the “true” model.

- Improved cloud parameterization will be necessary if testing against the "true" model shows difference above NWP threshold requirements.

An application of these cloud radiative transfer models to AIRS retrievals has already been conducted by Smith et al 2004.

In summary, in order to assimilate cloudy radiances into numerical weather prediction models, besides using clear channels selected within each FOV, two candidate approaches are: (1) an indirect method whereby clear sky equivalent radiances are derived, and (2) a direct method in which the actual cloud radiances are assimilated. For the indirect method of assimilating cloud cleared radiances, great care must be taken, since it has been demonstrated that the direct assimilation of clear radiances that are located in the cloudy regions have the potential for clear sky bias which will negatively impact NWP analyses and forecasts. In these assimilation regions, the associated cloud parameters, such as cloud height and optical properties, and associated cloudy sky thermodynamic characteristics, must accompany cloud-cleared radiances. The new and challenging task becomes the inclusion of cloud properties and associated atmospheric thermodynamic characteristics using assimilation in the current model.

In the direct cloudy radiance assimilation method, a parameterized cloudy forward model that is both fast and accurate is needed. Thus far, only limited work has been carried out and a significant research and development effort is still needed in order to implement a method for the direct assimilation of cloud contaminated radiance observations. The limitation of the accuracy of the fast cloudy sky radiative transfer model and its practical application into the radiance assimilation process require considerable study and attention.

6. References

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