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CLOUD TOP PRESSURE FROM A SUBSET OF AIRS CHANNELS

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1. INTRODUCTION

The retrieval of cloud altitude from remotely sensed data dates back several decades. The techniques used have evolved from single channel to multispectral approaches as more spectral channels have become available and as the instrumentation has improved. The accuracy of the latest methods applied to operational satellite data provides cloud top pressure (CTP) assignment within 50 hPa under most conditions in the middle to upper troposphere (Menzel et al. 1983; Frey et al. 1999).

The method investigated in this study, the CO_2 slicing method, has been applied to a number of satellites and is used operationally with the Geostationary Operational Environmental Satellite (GOES) Imager and Sounder data (Smith and Platt 1978; Menzel et al. 1983; Liou 2002). It uses a multispectral approach to solve for CTP and effective cloud fraction (ECF) via a solution of the radiative transfer equation. This technique has traditionally been applied to atmospheric sounders, including the High-Resolution Infrared Radiometric Sounder (HIRS) and the Geostationary Operational Environmental Satellite (GOES) Sounder (Menzel et al. 1983; Menzel et al. 1989). More recently, the technique has been applied to a high-resolution imager to provide a finer spatial assessment of cloud top pressure with NASA's Earth Observing System Moderate Resolution Imaging Spectrometer (EOS MODIS, Frey et al. 1999). The technique has not, in the traditional approach presented by this paper, been applied to an instrument with more than four channels in the 13μm - 15μm carbon dioxide absorption spectral region. However, Smith and Frey (1990) and Holz (2004) have presented modified approaches for hyperspectral data.

The Atmospheric Infrared Sounder (AIRS, Aumann et al. 2003; Pagano et al. 2003) onboard the EOS Aqua platform provides 2378 channels in the infrared spectrum ranging from 3.75 to 15.3 μm. One of the first of its kind, it will act as a stepping stone for instruments such as the Cross-Track Infrared Sounder (CrIS, Smith 2005), which will replace the HIRS onboard the next generation of NOAA Polar Orbiting Satellites (NPOESS, Cunningham 2005) and the Hyperspectral Environmental Suite (HES, Menzel 2005) onboard the GOES-R platform (Davis 2005). Since hyperspectral measurements will be made from a variety of operational satellites in the future, the purpose of this research is to use AIRS data to investigate the utility of multiple combinations of channels in the CO_2 slicing technique for cloud height assignment. It is anticipated that the use of some of the additional 300 channels in the 12.2μm – 14.4μm region from AIRS, compared to the four channels on the GOES Sounder, and improved radiometric accuracy provided by the AIRS instrument will lead to more accurate height assignment of clouds.

This study will focus on the retrieval of CTP and ECF from the AIRS instrument. Retrievals will be performed using subsets of channels in the 13-15 μm region and will be compared to the four-channel retrievals of other instruments. The use of subsets provides increased sensitivity to clouds throughout the atmosphere, while minimizing redundancy. Both simulated and observed retrievals are performed to understand and quantify the inherent differences among retrievals from different instruments in idealized and realistic situations.

2. METHODOLOGY

2.1 CO_2 Slicing Technique

The CO_2 slicing technique (Smith and Platt 1978; Menzel et al. 1983; Liou 2002) is used in this work to retrieve cloud top pressure from the GOES and AIRS instruments. The technique, which is derived directly from the radiative transfer equation, is based on the equation:

$$I_\upsilon^{obs} - I_\upsilon^{clr} = \eta\varepsilon \int_{p_s}^{p_c} \widetilde{T}(p,0) \frac{\partial B_\upsilon[T(p)]}{\partial p} dp \qquad (1)$$

where, at wavenumber υ, I_υ^{obs} is the observed radiance and I_υ^{clr} is the clear radiance, p_s is the surface pressure, $\tilde{T}(p,0)$ is the transmittance from pressure *p* to TOA, and $T(p)$ is the temperature at pressure *p*. The equation is a function of two unknowns, the CTP (p_c) and the ECF ($\eta\varepsilon$).

The physical fractional cloud coverage, η, will not change among channels, and the cloud emissivity, ε, varies with wavenumber. However, it can be assumed that over the focal spectral range of 12.2 to 14.4 μm, the emissivity of a given cloud, ε, is similar (Ebert and Curry 1992). Therefore, by utilizing two channels within this spectral region, an expression can be written as a function of one unknown, p_c,

$$\frac{I_{\upsilon 1}^{obs}-I_{\upsilon 1}^{clr}}{I_{\upsilon 2}^{obs}-I_{\upsilon 2}^{clr}}=\frac{\int_{p_s}^{p_c}\tilde{T}(p,0)\frac{\partial B_{\upsilon 1}[T(p)]}{\partial p}dp}{\int_{p_s}^{p_c}\tilde{T}(p,0)\frac{\partial B_{\upsilon 2}[T(p)]}{\partial p}dp} \qquad (2)$$

where υ_1 and υ_2 represent two spectral bands within the noted spectral range. Since the unknown is a limit of integration, CTP must be solved numerically. Once the CTP is solved, the ECF can then be solved using a reference window channel.

2.2 Application of Technique

The application of the CO_2 slicing approach to AIRS data allows additional channel flexibility because of the increased number of channels in the region of interest. Since there are over 300 channels within the range of 12.2 μm to 14.4 μm, the use of all will introduce a level of redundancy. While Smith and Frey (1990) have shown improvement in cloud height assignment with hyperspectral aircraft data, they considered a somewhat different implementation that used each channel in the focal spectral region paired with a reference channel instead of each other. In this research a subset of AIRS channels was used with each other in the CO_2 approach. Several subsets of AIRS channels are discussed below.

The first subset of AIRS channels, hereby referred to as the Garand Subset (Garand and Beaulne 2004), is based upon five factors. The first is that it must be within the 12.2 to 14.4 μm range, so that the emissivity values can be assumed as being the same among all channels. The second factor requires that the channels are accurately simulated with appropriate radiative transfer code. The third is that ozone and water vapor sensitivity is minimized. The fourth is that the weighting function for each channel shows an isolated maximum at the level of contribution, as opposed to an elongated stratospheric contribution. Finally, channels with weighting functions peaking above 250 hPa are neglected.

These selection criteria yielded 12 channels, which correspond to channels shown in Table 1 and the weighting functions in Figure 1. The weighting functions for this subset show that only two of the twelve channels peak above 500 hPa, with the highest peaking near 350 hPa. Also for this method, channel 528, which is near 12.2 μm, was used as the reference channel for ECF calculations. Estimated channel noise (NEdT) varies between 0.23-0.37 K for these channels. Though this subset was based on strong theoretical criteria, the appropriateness of this channel subset for the retrieval of CTP has not been assessed. Similarly, this channel subset was developed for the purpose of determining contaminated and uncontaminated radiances in a cloudy field of view (Garand and Beauline 2004).

The second subset is based on the selected channels used for data assimilation by various global modeling groups, such as the ECMWF, NCEP, UKMET, and Mètèo France. This community has selected 288 channels from the entire AIRS spectrum based on four criteria (Edward T. Olsen and Chris Barnet, personal communications). The first of these criteria is that channels are selected to correspond with wings of absorption lines, where absorption is weak. Therefore, with this criterion, these channels

Channel Number	Wavenumber (cm^{-1})	Wavelength (μm)	NEdT (K) @ 250K
205	708.133	14.12	0.260
222	713.029	14.02	0.244
233	716.233	13.96	0.237
253	722.135	13.85	0.240
263	725.123	13.79	0.269
273	728.137	13.73	0.306
300	735.690	13.59	0.236
306	737.546	13.56	0.345
311	739.100	13.53	0.335
356	753.380	13.27	0.351
363	755.650	13.23	0.374
476	801.463	12.48	0.398
528	820.834	12.18	0.300

Table 1 – List of bands and band characteristics for the Garand Subset. Channel properties available from AIRS Science Team website (http://airs.jpl.nasa.gov)

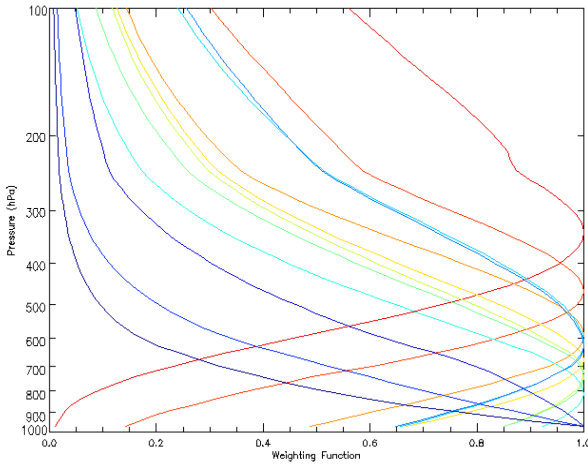

Figure 1 – Weighting functions for Garand Subset. Colors are used to differentiate between bands. Transmittance profiles are derived from a mid-latitude winter climatological profile.

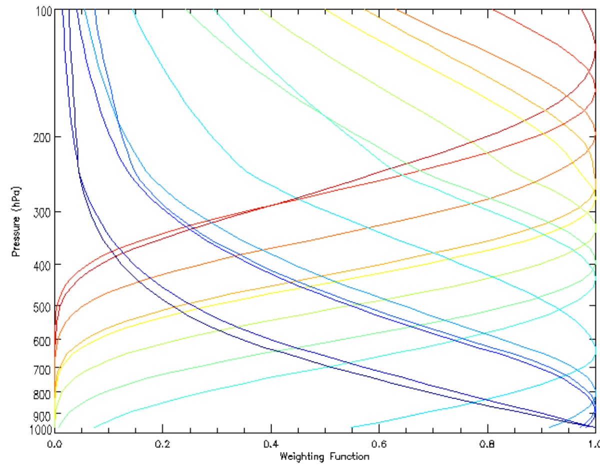

Figure 2 – Weighting functions for AIRS Science Team Subset. Colors are used to differentiate between bands. Transmittance profiles are derived from a mid-latitude winter climatological profile.

would have weighting functions which peak lower in the atmosphere. The second is that selected channels are chosen so that primary constituent absorption, be it ozone, water vapor, or carbon dioxide, has very little interference over a selected channel from secondary constituents. The third is that surface emissivity should exhibit very little variation over the selected channels.

The channels used by the AIRS Science Team for assimilation were down-selected for this

Channel Number	Wavenumber (cm^{-1})	Wavelength (μm)	NEdT (K) @ 250K
177	700.218	14.28	0.287
150	692.755	14.44	0.363
162	696.052	14.37	0.325
173	699.102	14.30	0.276
180	701.057	14.26	0.278
190	703.870	14.21	0.281
198	706.137	14.16	0.255
216	711.293	14.06	0.268
227	714.482	14.00	0.239
299	735.381	13.60	0.234
256	723.029	13.83	0.241
267	726.326	13.77	0.264
333	746.014	13.40	0.247
347	750.481	13.32	0.353
528	820.834	12.18	0.300

Table 2 – List of bands and band characteristics for the AIRS Science Team Subset. Channel properties available from AIRS Science Team Website

CTP retrieval study via a few additional selection criteria. First, only channels that are used for air temperature retrieval within the 12.2 μm to 14.4 μm range were considered. Therefore, channels for surface property, water vapor, and ozone retrievals were excluded. Second, channels whose weighting functions peak above 100 hPa were discarded, as clouds generally do not occur above this level. Similarly, stratospheric contribution, which is typically derived from a climatological profile, can be minimized. For channels with similar weighting functions, the channel that had the largest kurtosis value was selected for that pressure level. With these criteria, a subset of 14 channels, hereby known as the AIRS Science Team (AST) subset, were identified and are listed in Table 3.3, and includes the same reference channel, 528, as the Garand subset. The weighting functions for the AST subset shown in Figure 3.5 indicate that more upper-tropospheric coverage was gained with this set over the Garand subset, particularly between 400 hPa and 100 hPa. However, the number of channels covering the lowest portion of the troposphere was reduced in this subset. These differences and their affect on cloud height assignment were assessed through this study.

3. RESULTS

3.1 Simulated Results

To test the CO_2 slicing technique on the AIRS channel subsets, a simulated application of the technique was performed. The purpose of doing this is to gain insight into the performance of the technique in an idealized situation. Since the actual application of the algorithm can be affected by both instrument noise and errors in the first-guess field, the simulated retrievals provided the ability to control those errors and investigate the trends and performance of the algorithm for the given channel subsets.

Simulated AIRS channel radiances were calculated using the Stand-alone AIRS Radiative Transfer Algorithm (SARTA, Strow et al. 2003). SARTA is the stand-alone version of the official radiative transfer algorithm of the AIRS Science team. Validated against numerous laboratory and field campaigns, the simulated channel radiances are accurate to 0.2 K for the channels in the 13-15 μm range (Strow et al. 2003). By prescribing a saturated, isothermal atmosphere below a specified cloud top, SARTA was used to generate radiances for an infinitesimally thin blackbody cloud (Zhang and Menzel 2002). For each input profile, a set of clear and cloudy radiances was obtained for specific cloud top pressures corresponding to each radiative transfer model level using a range of ECF values. Due to this simulation approach, specified CTP values are limited to the pressure levels in the RTA.

For comparison to GOES, a third channel subset was formed by applying a chi-squared goodness-of-fit test to determine which AIRS channels within the CO_2 absorption region have transmittance profiles most similar to the GOES Sounder channels. Due to the fact that the AIRS instrument has increased radiometric accuracy compared to the GOES instrument, the noise characteristics were then manually modified to better represent those of the GOES channels.

The first set of simulations was based upon a nearly saturated moist-adiabatic temperature profile, with an unstable boundary layer as shown in Figure 3. The sounding indicates that the tropopause is located at approximately 200 hPa, though the upper troposphere becomes significantly stable above 250 hPa. A series of simulated AIRS radiance observations were generated using this profile with infinitesimally thin clouds of varying effective cloud fractions assigned to each radiative transfer model level. These simulated AIRS radiances provided a variety of cloudy observations to study the sensitivity of the retrieval approach. CTP retrieval results for these simulated observations for the Garand, AST, and GOES channels are presented in Figure 4. It should be noted that the CTP error was calculated as the difference between the

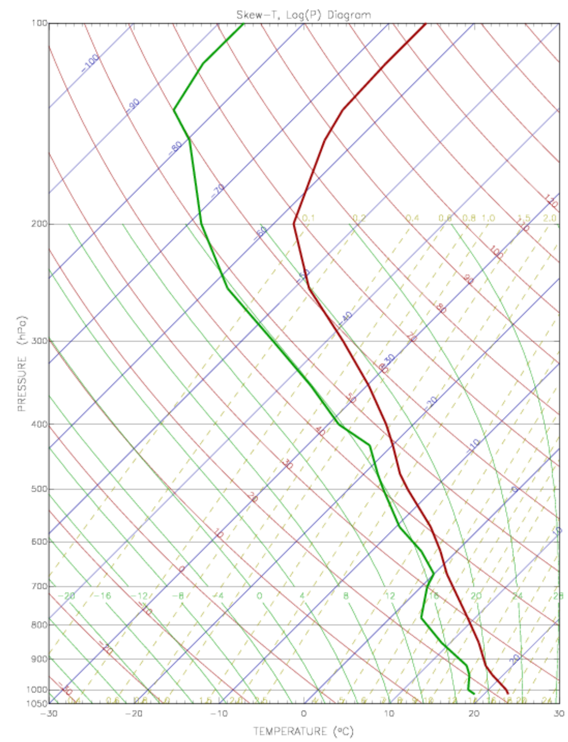

Figure 3 – Skew-T ln-p diagram showing temperature (red) and dew point temperature (green) for an atmosphere with a near-constant lapse rate.

retrieved and the specified, and that a negative value indicates a retrieved CTP of lower pressure, thus higher vertically, than the specified CTP. The nine panels correspond to the three channel subsets vertically and three specific ECF values of 0.05, 0.10, and 1.00 horizontally. The improvement of the AIRS CTP retrievals versus the GOES for ECF values of 0.05 is readily apparent. The GOES retrievals failed in this low ECF situation, while the AIRS provided numerous retrievals with varying bias. This was likely the result of the improved spectral and radiometric characteristics of the AIRS instrument. Since the retrievals are so close to the lower ECF limit, the retrievals fail if the calculated ECF values are less than 0.05. Therefore, there were failed retrievals in both the AST and Garand subsets as well. In looking at the 0.10 ECF value simulations, there was a consistent bias to retrieve clouds at a lower pressure than their actual specified CTP, and the retrievals appear to be much more consistent, and thus stable. All retrieved CTP values increase in accuracy as the actual CTP becomes smaller, indicating that the method is more accurate for high clouds. It is noted, however, that the GOES simulations again show an inability to retrieve values for low clouds with small ECFs, as

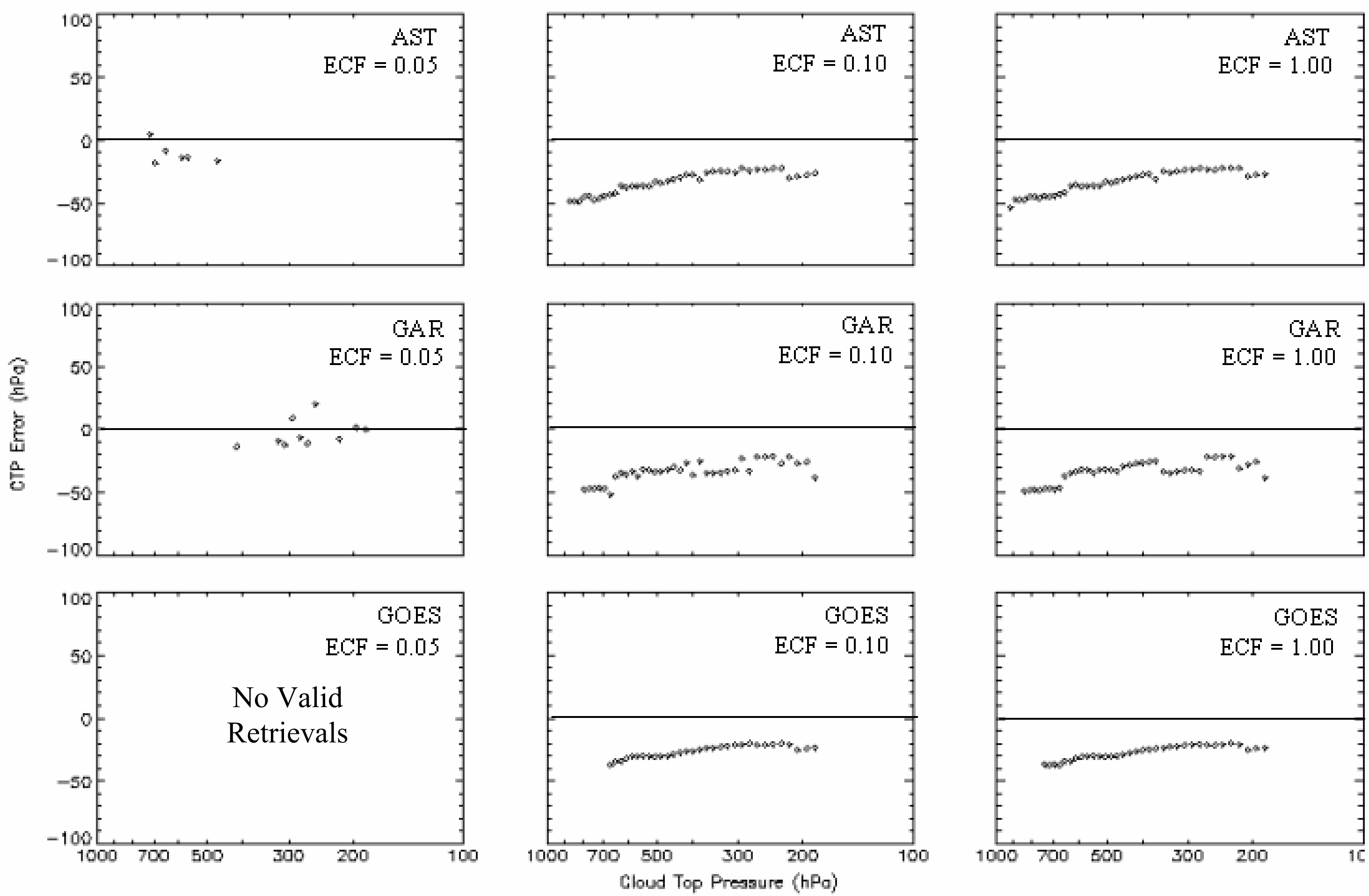

Figure 4 – Error in retrieved CTP versus actual CTP for clouds simulated in an atmosphere of a near-constant lapse rate, as seen in Figure 4.1, for the AST (top), Garand (middle), and simulated GOES (bottom) channel subsets for the ECF values of 0.05 (left), 0.10 (center), and 1.00 (right).

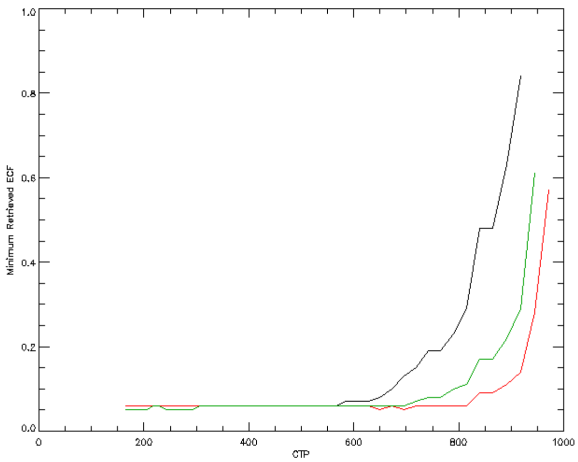

Figure 5 – A plot showing the minimum resolvable ECF for a CTP. The simulated GOES (black), Garand (Green), and AST (red) subsets are represented.

indicated by the lack of CTP retrievals below 700 hPa. The AST subset simulation retrieves more CTPs for low clouds than the Garand subset simulations. This indicated that the Garand subset may have too many or redundant channels in the lower troposphere.

When considering an ECF of 1.00, the same overall trends in bias are seen in the simulations as in the ECF=0.10 simulation. Each channel set appears to better resolve low clouds in this simulated opaque case, though the GOES performance is still limited relative to the two AIRS subsets. When considering the overall bias, there is a consistent trend towards lower retrieved pressure for all three subsets. This is largest for high CTP values (thus, low clouds vertically), where the error can exceed 50 hPa. The bias decreases to around 25 hPa for low CTP values (thus, high clouds vertically). However, when considering the fact that pressure decreases logarithmically with height, the error in vertical height depiction is closer to being constant. The bias is generally smaller for the GOES channels than the AIRS subsets, which show similar but not identical results. The Garand subset shows more variations in the error curves than the AST subset.

As noted, the GOES channel retrievals have a significantly higher rate of failure in the lowest levels of the troposphere. By considering the minimum retrieved ECF for each pressure level, it is seen that both AIRS subsets can resolve optically thin or broken clouds much more effectively than the simulated GOES retrievals as shown in Figure 5. The figure shows that the retrieval of CTP with GOES is limited by ECF for pressures greater than 600 hPa. For the Garand and AST subsets, this cut off is 700 and 800 hPa, respectively. At lower pressures, retrievals are not restricted by the ECF. This is significant because it indicates that the AIRS channel subsets can retrieve CTP more effectively at higher pressures and lower ECFs than GOES, which is likely the direct result of the improved radiometric accuracy of the AIRS instrument versus the GOES Sounder, as well as the improved spectral, and thus vertical, resolution. It is significant, as well, that the AST subset better resolves low clouds than the Garand Subset. This seems contrary to the expected outcome from inspecting the weighting functions of each subset (Figures 1 and 2), as the Garand subset has more channels in the lower troposphere than the AST subset. This, however, may indicate that the Garand subset has too many channels in the lower troposphere. Since the technique is based upon the ratio of two channels, if the two channels are too similar, they may become unstable and not converge.

3.2 Intercomparison Results

It is the purpose of this section to apply the methodologies previously discussed to a series of case studies that represent a variety of cloud formations in the real atmosphere. Background fields, such as the clear-sky radiance and the transmittance profiles, were determined from temperature and moisture profiles obtained from the MM5 model. The simulations in the previous section show the sensitivity of retrieving CTP and ECF for simulated environmental conditions. These factors will provide an explanation for some of the differences in CTP and ECF values from real situations. The technique, as described in Section 2, was applied to AIRS and GOES observed radiances.

Though more subtle differences will be addressed in the poster, there are two regions of focus for this section. First, the general stratiform feature over the Great Lakes was considered (Figure 6, Point A) in the CTP fields shown in Figure 7. The CTP retrievals from AIRS and GOES (Figure 7a-c) in this region seem to be in good agreement. For example, both seemed to depict a depression of cloud top pressure of 75 hPa over the northeastern quadrant of Wisconsin compared to the western half of the state. In this region, however, it does appear that the GOES retrieved CTPs are 50 hPa greater, in its cloud top pressures relative to the AIRS retrievals. Both the GOES and the AIRS retrievals in this region seemed to be consistent with the MODIS CTP

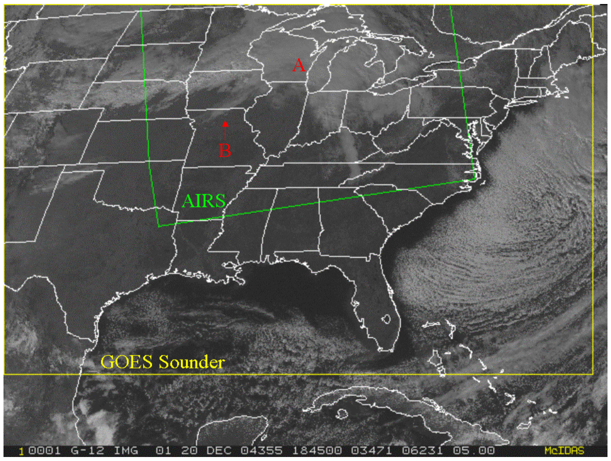

Figure 6 – Visible image from the GOES Imager from 1845 UTC on 20 Dec 2004. The yellow box indicates the coverage of the GOES Sounder, and the green box indicates the coverage of the AIRS granule. Points A-D represent the features mentioned in the text.

retrievals (Figure 7d), though differences exist due to the significantly different spatial resolution of GOES and AIRS relative to MODIS.

It should be noted that the MODIS CTP algorithm assigns pressures to pixels where the MODIS cloud mask indicates a cloud or region as labeled "uncertain clear". This often results in a cloud conservative mask and subsequent CTP product as seen in Figure 7d with a much larger region covered by low clouds and corresponding CTPs

The cirrus deck extending from Iowa through Missouri into northeastern Kansas (Figure 6, Point B), shows a failure of GOES along cloud edges. In viewing the CTP retrievals for GOES, there was a very significant lowering of CTP along the cloud edges. This artifact, though present in two AIRS retrievals, was more prevalent around most of the cloud in the GOES retrieved CTP values. The AIRS retrievals have the center of the deck as being lower in pressure, by 50 hPa, than the GOES retrievals. Similarly, the deck appears thin

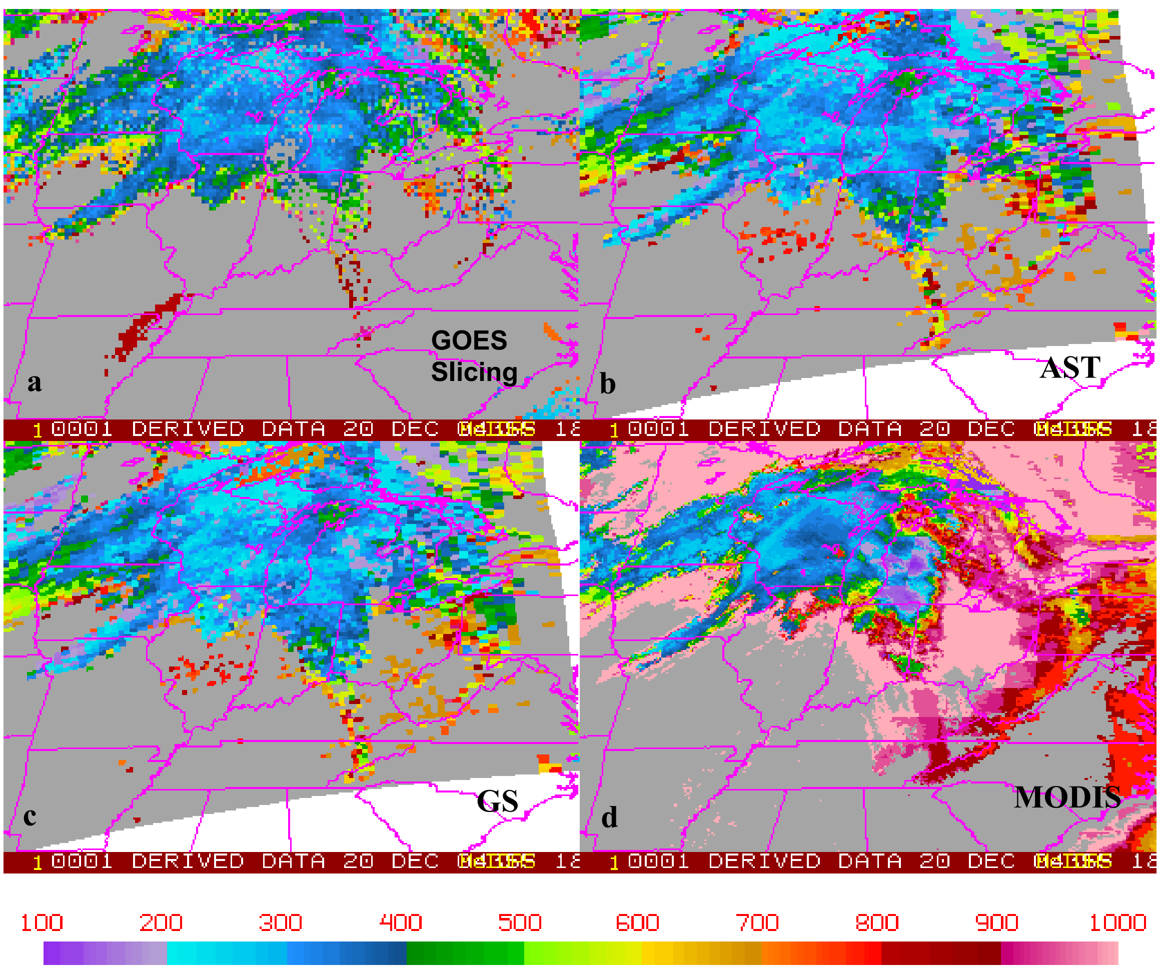

Figure 7 – Cloud top pressure retrieval from GOES (a, top-left), AIRS Science team (b, top-right), Garand Subset (c, bottom-left), and MODIS (d, bottom-right) for 1846 UTC (GOES) and 1853 UTC (AIRS and MODIS), respectively, on 20 Dec 2004.

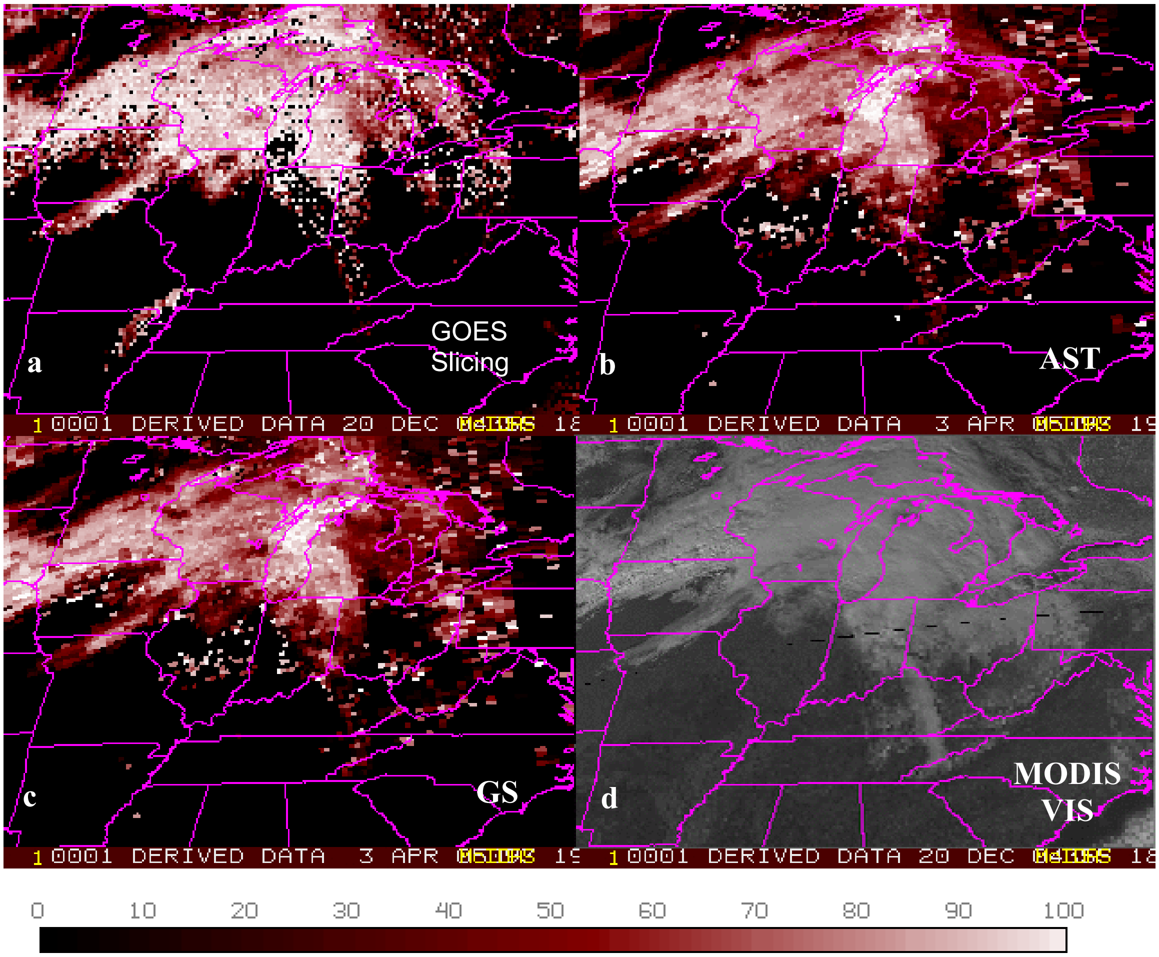

Figure 8 – Effective cloud fraction retrieval from GOES (a, top-left), AIRS Science team (b, top-right), and the Garand Subset (c, bottom-left). Also shown is the MODIS visible imagery (d, bottom-right) for 1846 UTC (GOES) and 1853 UTC (AIRS and MODIS) on 20 Dec 2004.

as it extends into western Missouri and northeastern Kansas. The AIRS values keep the CTP consistent with the rest of the deck, but the GOES values begin to drop the CTP significantly. This is consistent with the assumption that the radiometric accuracy of AIRS improved the accuracy of the technique, as the cloud optical depth was probably small. The MODIS product shows similar features over the deck. There are edge effects in the MODIS retrievals, but there are also signs of the trends stated above. Direct visual comparison, however, was somewhat difficult in this region as the difference in spatial resolution between the MODIS and the AIRS and GOES Sounder instruments is significant, and this is a small-scale feature.

When considering the ECF calculations for this stratiform region over the Great Lakes, as shown in Figure 8, the two AIRS subsets corresponded well. Both depict a clearing in western Wisconsin, though the retrieved ECF values are lower than the GOES in this clearing. Over the entire deck, however, both tended to be consistent with each other.

When viewing the ECF of the thin cirrus region, both the GOES and AIRS retrievals are fairly consistent, though the GOES ECF values do depict more variation in the optically thin clouds. Similarly, the AIRS ECF values decreased in regions where the cloud emissivity drops. The GOES ECF values corresponding to the cloud edges do not display a trend of dropping, which was inaccurate in that the cloud edges will have a cloud fraction that is not unity, therefore, the ECF would be less than unity. This corresponds to the cloud edge CTP values being lesser than the deck of the cloud. Thus, the approach applied values to the GOES data that produces less accurate CTPs in regions of low ECF. This probably corresponds to the decreased spectral and radiometric accuracy of the GOES Sounder relative to AIRS.

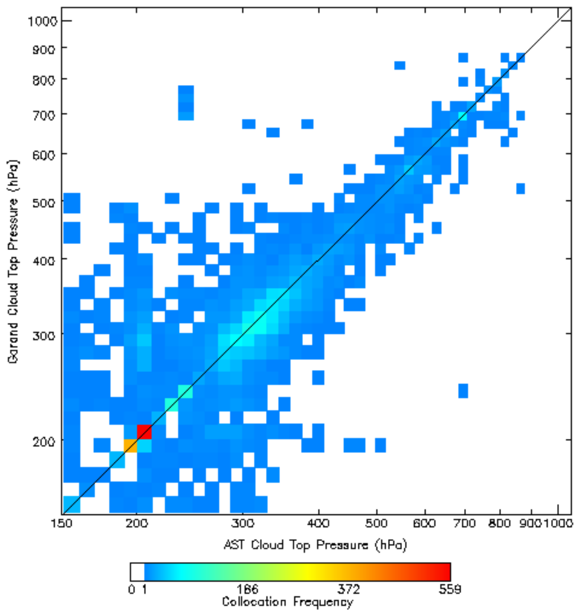

Figure 9 – Plot showing the frequency of event occurrence for collocated points for the AST channel subset and the Garand channel subset for 20 Dec 2004.

The CTP and ECF values for the two AIRS subsets showed many similarities. Figure 9 presents a scatterplot of retrieved CTP from the Garand and AST channel subsets for the 20 December 2004 case study. Since CTP values were retrieved at the pressure levels of the RTA, the colors in the scatterplot provide the frequency of occurrence for collocated Garand and AST retrievals. A significant linearity exists between the subsets, which indicates good agreement between the two. In fact, 58.7% of all observations lie within two bins or pressure levels of each other, and the points for each dataset have a correlation coefficient of 0.749, which is strong for binned data. However, the AST subset produces slightly lower pressures (higher clouds), on the average of 7.4 hPa, as indicated by the scatter in the upper-left hand portion of the chart.

Since the CTP values show strong correlation, it is readily expected that the ECF values, which are derived from the calculated CTP values, will also show a strong correlation. Figure 10 presents a scatterplot of the retrieved ECF values for the two subsets. A strong linear trend is present between the two techniques, with a correlation coefficient of 0.84. The scatter present, though minor, is directly related to the scatter seen in CTP retrievals (Figure 9) as the ECF is a function of CTP.

3.3 Comparison to Ground Truth

The use of a “ground truth” is a useful aid for the previous intercomparison. Vertical profiles of backscatter from a vertically pointed laser, or lidar, are used to measure cloud top heights. The micropulse lidar (MPL, Spinhirne 1993) in operation at the Southern Great Plains (SGP) Department of Energy’s Atmospheric Radiation Measurement (DOE ARM) site in Lamont, OK provided the source of validation data. The micropulse lidar data was used as ground truth to help validate these trends in CTP. Figure 11 shows the CTP and ECF retrievals for the AST AIRS subset and GOES on 3 April 2005. It can be seen that the GOES retrievals depict CTP with higher pressure and ECF values than the AST retrievals. Figure 12 shows a time series of corrected backscatter from the MPL from 1800 to 2100 UTC on 3 April 2005. The shading on the plot is relative to the backscatter intensity from the clouds. As seen in the figure, patches of cirrus of varying thickness pass over the region during this three-hour period. The CTP inferred from the plot all appear to be between 200-210 hPa, and the clouds vary in thickness from a few hPa to over 100 hPa.

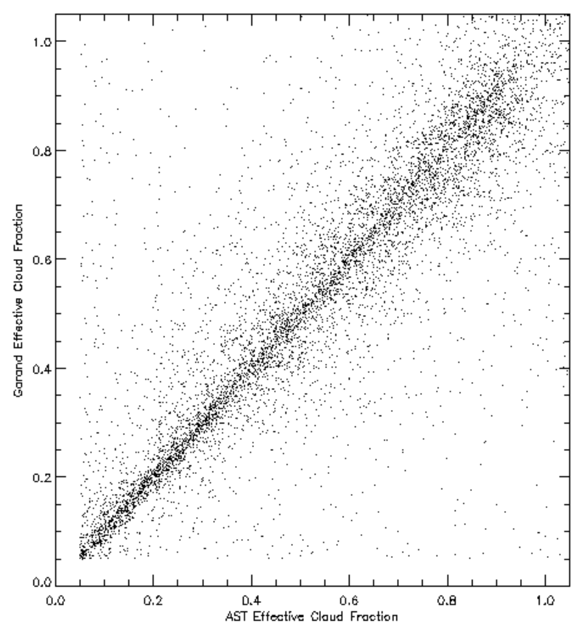

Figure 10 – Scatterplot comparing the AIRS Science Team channel subset retrieved ECF values versus the Garand subset ECF values for 20 Dec 2004.

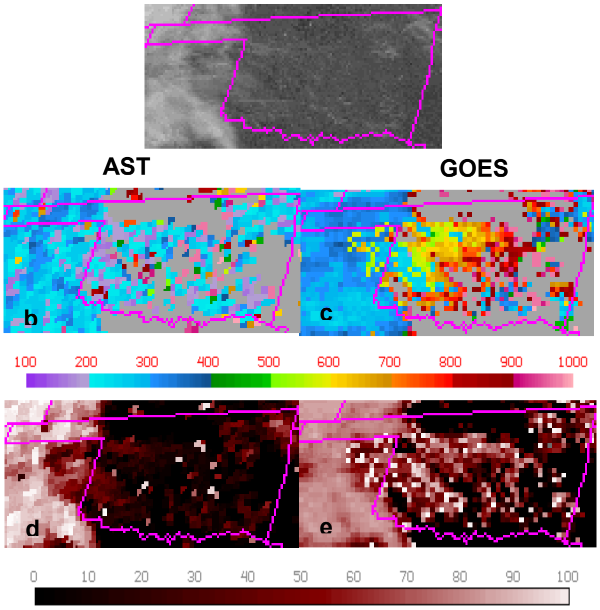

Figure 11 – Visible image from GOES (a), CTP retrievals from the AST subset and GOES (b and c, respectively), and ECF retrievals from AST subset and GOES (d and e, respectively) for 2005 3 Apr 2005.

For comparison to the MPL cloud data, the corresponding CTP values for the AIRS subsets and the GOES retrievals were averaged over a three by three array of pixels centered on Lamont, OK, so that the satellite CTP values represented about a 50 km region. These values were compared to the MPL CTP values corresponding for 1945 UTC as shown in Figure 12 as a “dash”. The retrieved CTP values for the AST and Garand subset-based AIRS retrievals were 207 and 260 hPa, respectively for a cloud of 10 to 20 hPa thickness. The GOES retrieved CTP over the averaged sample is 854 hPa. The AIRS values for both the AST and Garand subsets showed a great improvement over the retrieved GOES values. The improvement of the AIRS versus the GOES illustrates the limitation of the four GOES CO_2 channels for optically thin clouds. In the GOES retrievals, since three of the four channels peak below this cloud formation, the difference between the observed and the clear in the lower channels is minimal, allowing channel uncertainties to affect the retrieval accuracy. However, the AIRS instrument channel subsets have more of a vertical resolution aloft.

The trends seen in the concurrent data is further emphasized by the pixels upstream, or later in time relative to the MPL, and downstream, or earlier in time (dots in Figure 12). An estimate of the cloud motion was obtained from a sequence

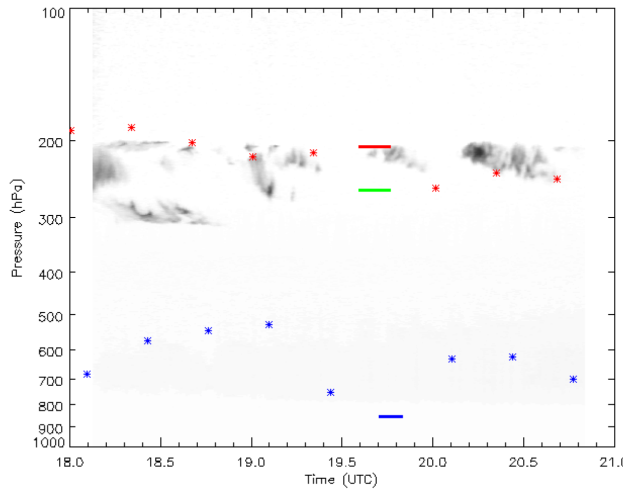

Figure 12 – Time series plot of backscatter (shaded, relative units) from the Micropulse Lidar in Lamont, OK in pressure coordinates for 1800-2100 UTC on 3 Apr 2005. Horizontal lines represent a 3x3 averaging of CTP for the GOES (blue), AST AIRS (red), and Garand AIRS (green) over the site. The stars represent CTP values from up- and down-stream of the lidar collocation with their approximate time of lidar overpass for the AST AIRS (red) and GOES (blue) values.

of GOES imagery and was used to collocate AIRS pixels upstream and downstream from the MPL site. For these locations, the GOES values were consistently below the cloud tops, with the difference ranging from 300 to 600 hPa. Furthermore, the AIRS is generally more consistent, with the CTP values all within 50 hPa of the cloud top. The time-sequenced Garand retrievals are not shown, but show similar trends to the AST measurements. AIRS shows the ability of to distinguish these cloud features more precisely than the GOES Sounder.

4. CONCLUSION

The utility of retrieving CTP and ECF from the AIRS instrument via the CO_2 slicing technique was demonstrated in this study. The method was applied in both simulated and actual cases to demonstrate the improvement, both qualitatively and quantitatively, of retrievals from the AIRS instrument as compared to its multispectral predecessors.

The simulation study showed similar retrieval biases between the two AIRS channel subsets and the four GOES channels. The biases for clouds with small CTP were less than that of a high CTP, and the increase in bias was fairly linear. The magnitude of the CTP biases for both the AIRS and GOES typically varied between 20 and 50 hPa. The AIRS instrument produced more successful CTP retrievals for clouds with low ECF values than GOES, particularly for low clouds.

In considering the relationship between the AST and Garand subsets, the overall performance of the retrieval algorithm is similar between the subsets, as shown by the corresponding high correlations in the retrievals and the consistent biases in the simulations study. In the simulations, the AST subset was shown as being slightly more able to accurately retrieve low-level clouds with low ECFs than the Garand subset. This was opposite to what could be expected from investigating the weighting functions of each band, as the Garand subset has more bands in the lowest portion of the troposphere. This is likely the result of these low-level channels being too similar, thus causing the retrieval process to become unstable.

The investigations with observed data showed a significant improvement in the quality of the AIRS retrievals over GOES. In opaque cloud situations, the GOES retrievals produced higher CTP values than the AIRS channel subsets. On the edges of clouds, or in other regions of low ECF, AIRS generally maintained the spatial continuity of CTP better than GOES. In these regions, the GOES retrievals produce CTP and ECF values which are unrealistic. The retrieval technique with the AIRS channel subsets produced significantly more retrievals of CTP and ECF than GOES for regions of low clouds and low ECF. This provided a substantial improvement in CTP coverage in low and middle level cloud regions with the AIRS channels.

The CTP retrievals from both AIRS and GOES were compared to a limited amount of MPL data at the Oklahoma ARM/CART site. The AIRS CTP values showed good agreement to the MPL data in a broken and transmissive cloud region, with the AST subset retrievals providing better CTP estimates than the Garand subset. The GOES retrievals did not agree well with the MPL data, placing the cloud top at far too large of a CTP.

The improvement of CTP/ECF retrievals with the CO_2 technique applied to AIRS over the GOES retrievals has been demonstrated in a number of cases. The improvements are significant and likely result from the increased radiometric accuracy and spectral resolution of the instrument. The increase in spectral resolution provides many additional channels in the CO_2 absorption band that provides better vertical resolution of both CTP and allows for better estimates of ECF. Since future operational platforms, both in geosynchronous and sun-synchronous orbit, will have hyperspectral sounders, this study shows that the traditional approach is still readily applicable and can provide more data to improve the quality of CTP and ECF retrievals.

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