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COMPARISONS OF CLOUD ANALYSES FROM INDEPENDENT INFRARED AND SOUNDER RETRIEVALS

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1. Cirrus Properties

Many sources of passive satellite data are potentially useful for detection and analysis of cirrus attributes. TIROS satellites are equipped with the Advanced Very High Resolution Radiometer (AVHRR), a five-channel passive radiometer with detectors that measure upwelling visible (0.63 μm), near-infrared (near-IR, 0.86 μm), middle wavelength IR (MWIR, 3.7 μm), and split longwave thermal IR (TIR, 10.7 and 11.8 μm) energy both day and night. The geostationary GOES Imager also has five bands, positioned at 0.63, 3.9, 6.7 water-vapor (WV), 10.8, and 12 μm. The NOAA polar-orbiting sounder instruments collectively known as TOVS (TIROS Operational Vertical Sounder) also collect data in the wings of the 15-μm CO_2 absorption band that are useful for detection of thin cirrus and specification of their height.

Cirrus is recognized as one of the most poorly quantified of all clouds. Cloud altitude is difficult to specify, because cirrus consist typically of ice particles distributed over a considerable vertical extent with complex optical properties and microphysics. In addition to the wide variability in properties common for other cloud types, cirrus clouds are unique in exhibiting a range of transmissivity values t that span the entire possible domain $0< t <1$. The transmissive nature of cirrus cloud turns out to be its most important (in a climate sense) and elusive (in a retrieval sense) attribute to specify. Transmissive cirrus clouds both emit and transmit thermal energy. Emissions occur at a rate dependent on cirrus emissivity and temperature, while transmissions depend most strongly on cirrus transmissivity and the temperature of the underlying warmer surface (either a lower cloud or the ground). If the semi-transparent nature of cirrus clouds is not properly modeled, its altitude is consistently underestimated when using passive infrared brightness temperature data.

2. Cirrus Analysis Algorithms

In this study, comparison is made of cloud attributes, both spatial and radiative, obtained for the same cloud scenes using radiance measurements from the independent imagers and sounders onboard geostationary GOES and polar-orbiting TIROS platforms. Emphasis is placed on cirrus radiative and spatial attributes, including frequency of occurrence, optical thickness, and cloud temperature. Imager retrievals analyze multispectral thermal infrared (TIR) radiances in the 3.9, 6.7, and 10.8-μm window channels using an updated TIR cirrus analysis algorithm (TIRCA), adapted from that of d'Entremont et al. (1990, 1993; 2001 this preprint volume). The sounder retrievals incorporate the CO_2 slicing technique (Wylie and Menzel, 1989) in the 13-15-μm carbon dioxide absorption bands. Cloud emissivity and temperature are common to both the imager and sounder retrievals, and will be compared directly.

Comparison was made of cirrus cloud attributes, spatial and radiative, obtained for both GOES and TIROS cirrus cloud scenes over Wisconsin, New England in September 1995, for a month-long analysis of polar-orbiting TIROS data over Florida in September 1996; and for a two-month period during the summer and fall of 2001 over the eastern US and western Atlantic.

Both the TIRCA and CO_2 slicing algorithms are designed to detect the presence of thin cirrus and to determine its radiative and spatial attributes. However, the capabilities of the two algorithms depart from each other in numerous respects. The most important differences between the two techniques are based on the differences in the spectral bands and the spatial resolutions of the sounder and imager sensors. Additionally, cloud altitude is retrieved independently of optical thickness by CO_2 slicing, whereas retrievals are coupled in the TIRCA algorithm. Thus the CO_2 slicing and TIRCA models mutually complement each other.

3. Comparisons with Radar

Nighttime AVHRR data for Channels 3, 4, and 5 were obtained over New England at ~2337 UTC on 16 September 1995, a time when surface-based radar observations of thin cirrus were available at Hanscom AFB as a part of an ongoing cirrus cloud field observation. The 35-GHz upward-pointing radar provides useful observations of cirrus cloud base and top against which satellite retrievals can be directly compared. Each satellite pixel has a resolution of approximately 1 km at nadir. Surface-based radar observations of the cirrus were collected for a period before, during, and after the NOAA satellite overpass time.

The emissivity and effective altitude estimates obtained for the Hanscom cirrus sample are plotted in Figure 1. Pixel-by-pixel retrievals were selected $\pm$30 minutes upwind and downwind of the radar site within the cirrus clouds. The TIRCA cloud altitudes for these pixels are consistent with TPQ-11 ground-based radar measurements of cirrus cloud base and top. The TPQ-11 radar measured cirrus base and tops in the 5.5 - 10 km range for the time period several hours before and after the 2337 UTC satellite overpass. The retrieved cirrus effective altitudes are not in dispute with the radar observations of cloud base and top, lending confidence that the transmissive characteristics of the thinner cirrus are being properly accounted for in the model.

With this data set it is not possible to verify the cirrus emissivity estimates except to say that if the effective cirrus altitudes retrievals are reasonable, then the emissivities are also likely to be reasonable since these two parameters are coupled in the TIRCA physical retrieval model.

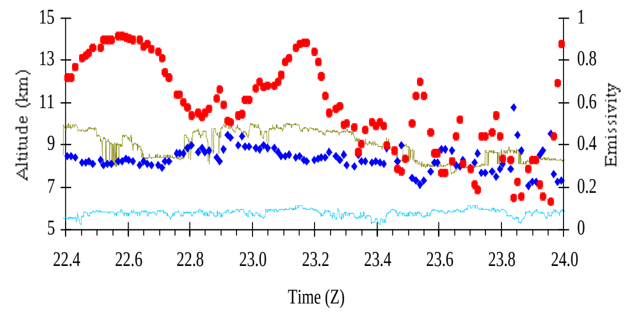

Figure 1. Enhanced cirrus cloud-top (diamonds) and emissivity (circles) retrievals over Hanscom AFB compared to TPQ-11-derived cloud top and base (solid lines)

4. CO_2-Slicing and TIRCA Analysis Inter-Comparisons

In recent years CO_2 slicing has been extensively applied to both TIROS and GOES data to obtain cirrus emissivity and altitude statistics on a global scale (Wylie, Menzel, and Woolf, 1991; Menzel, Wylie, and Strabala, 1992). Satellite data cloud climatologies produced thus far using the CO_2 slicing method have been extensive, focusing on determining the geographical, seasonal, and diurnal changes of cloud cover (Wylie and Menzel, 1989).

Because of this legacy, a comparison study was performed over Florida during September 1996 between CO_2 slicing and the imager-based TIRCA cloud retrievals. NOAA AVHRR and TOVS data were collected from September 1996 over Florida and the southeast U.S (Figure 2). Basic cloud-detection processing was performed using the SERCAA Phase 1 and 2 algorithms described by Gustafson et al. (1994). Further processing then was performed using the TIRCA cirrus altitude and emissivity retrieval algorithms. CO_2 Slicing was applied to the TOVS High-Resolution Infrared Sounder (HIRS) data and the SERCAA

AIRC model analyzed data from the AVHRR sensor. The final CO_2 Slicing and AIRC products are pixel-level representations of cloud altitude, pressure, and emissivity. Comparisons were made of cirrus cloud altitudes obtained for the same cloud scenes using measurements from the two independent sensors onboard the same NOAA TIROS polar orbiting satellites.

Figure 2. Data collection and analysis area for September 1996

AVHRR HRPT and coincident HIRS CO_2 sounder radiance data valid 4-23 September 1996 over the southeastern United States, the Gulf of Mexico, and the southwestern North Atlantic were analyzed for cirrus effective altitude. Figure 3 contains a frequency distribution of retrieved cirrus effective altitudes for the two independent analysis models. There is strong agreement between the altitude climatologies in the 7-to-13-km range. The largest differences between the two retrievals are in the 5-to-7 and greater-than-13-km range bins. The TIRCA analyses show more clouds at lower altitudes, and CO_2 slicing shows more clouds at higher altitudes. Stratified summary statistics show the same pattern both day and night, showing that algorithm diurnal biases of any sort are not responsible for the overall lack of agreement in the very low and very high cirrus. Reasons for this disagreement are under study.

5. Emissivity and Cloud Fraction

The TIRCA and CO_2 cirrus analysis models are useful for verifying independently derived cirrus characteristics within the same cloud scene. The CO_2 technique retrieves effective emissivity $N\varepsilon$, the product of cloud fraction "N" and emissivity "ε," and is capable of detecting thin cirrus at levels where the carbon-dioxide weighting functions peak. For each relatively coarse HIRS field of view a cirrus cloud fraction estimate "N" can be made from the AVHRR imager data using a multispectral cloud mask. The sounder emissivity ε can then be decoupled from the effective emissivity $N\varepsilon$ by dividing by "N." This in turn allows for direct comparison between the imager and sounder emissivity retrievals for those AVHRR cloudy pixels that lie within the HIRS sounder pixel.

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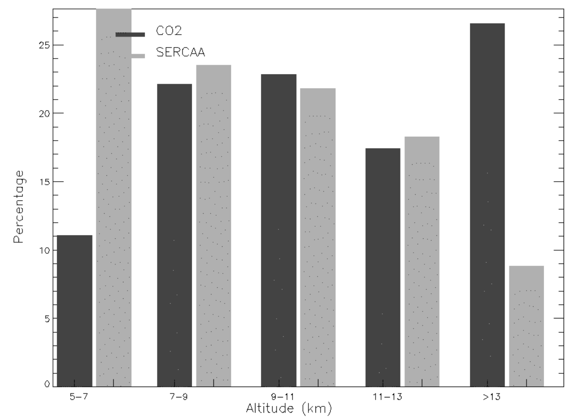

Figure 3. Frequency distribution of effective cirrus altitude for SERCAA and CO_2 Slicing

Figure 4 contains a scatter plot of the CO_2 effective emissivity $N\varepsilon_{CO2}$ vs. TIRCA cloud fraction N for a TIROS overpass above Wisconsin on 28 Oct 86. Points above the line $N\varepsilon = N$ are spurious because ε is constrained to be ≤ 1, and thus $N\varepsilon \leq N$. Visual inspection of the AVHRR image data show that the large majority of $N\varepsilon$ values above the $N\varepsilon = N$ line are from CO_2 opaque cloud reports ($N\varepsilon = 1$) in areas where TIRCA found little or no cirrus and where the CO_2 radiances detect no *transmissive* cloud (i.e., the cirrus fraction is zero but the cloud fraction N is one). Note from the scatter of $N\varepsilon$ vs. N that it is not proper to consider CO_2 Slicing $N\varepsilon$ analyses as representative of either cloud fraction or emissivity, but rather as a coupled product.

Nε	0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1	29	5	1	1		3				
.9										
.8										
.7										1
.6		1				1		1		1
.5				1						1
.4							1	1	1	
.3				1		1	1	3		3
.2		1		1	2	2	2	2		1
.1		1	2	1	2	1	1			
0	62	4	1	2	2	2	1	1		

Cirrus Fraction N

Figure 4. Scatter plot of CO_2–Slicing HIRS effective emissivity Nε (y axis) vs. AVHRR cloud fraction N. 62 HIRS FOVs were labeled "clear" by CO_2 Slicing and TIRCA

6. Eastern-US Climatology

As of this writing a new climatology comparison is underway over the eastern US and western North Atlantic. Analyses will be compared using techniques similar to those discussed in Section 4, and results will be presented at the poster conference. Particular emphasis will be placed on high-cirrus/low-cirrus differences, although it is suspected that with enhancements to both the CO_2 Slicing and TIRCA algorithms since the time of the Florida study, discrepancies may be small for cirrus at all levels.

7. Summary

SERCAA cloud analysis algorithms (Gustafson et al., 1994), complete with a multispectral infrared cirrus analysis technique (called here "TIRCA," see this preprint volume), were successfully applied to a large data set and compared to both CO_2 Slicing analyses and ground-based radar observations. The effective altitudes obtained by the CO_2 slicing and SERCAA models compare well for the cirrus and liquid water-droplet clouds observed during 4-23 September 1996 over Florida. The altitude summary statistics retrieved by the CO_2 slicing and SERCAA models are not in dispute with each other, after accounting for a high-cirrus bias evident in the CO_2 reports. The agreement between the two independent analyses of the same cirrus image scenes over a 20-day period provides an independent metric against which the performance and accuracy of CO_2 Slicing cirrus climatologies can be judged.

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