VALIDATION OF SATELLITE DERIVED CONUS CLOUD TOP PRESSURE USING CLOUD PHYSICS LIDAR DATA FROM THE ATREC FIELD CAMPAIGN

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1. INTRODUCTION

The primary objective of this study is to assess the accuracy of satellite derived estimates of cloud top pressure. These estimates are derived using single field of view hourly data from the Geostationary Operational Environmental Satellite (GOES-12) Imager and Sounder instruments. Cloud Physics Lidar (CPL) data taken during the Atlantic-THORPEX Regional Campaign (ATReC) are used as reference data set. Using airborne lidar data provides the advantage that the cloud top heights are measured rather than derived, as they are when ground based data are used. For comparison with the lidar data, satellite derived estimates of cloud top pressure are converted to cloud top height using aircraft dropsonde data where available, or ground-based radiosonde data.

Future space borne weather satellites will most likely contain hyperspectral instruments (GOES-R HES, GIFTS). In preparation for this next generation of instruments, some research has focused on what information may be attained using hyperspectral technology, and how current products may be improved using these data. This study includes an assessment of cloud top height using data from the University of Wisconsin Scanning High resolution Interferometer Sounder (SHIS), a hyperspectral sensor that also flew aboard the NASA ER-2 during AtREC. Since the SHIS and the CPL were co-located on the same aircraft, we expect their assessment of cloud top height will be in good agreement. However, differences in field of view, as well as differences in the actual quantities measured by the two instruments make this a useful and informative comparison, especially given the need to assess hyperspectral cloud products in preparation for future satellite missions.

2. METHODOLOGY

This study uses CPL data as a reference, or “truth” assessment of cloud top height, for comparison with GOES-12 Imager and Sounder derived cloud top height. Differences in measurement techniques between satellite and lidar prevent an exact one-to-one comparison between the cloud top heights derived from each instrument. The lidar is an active sensor, and measures backscattered energy by the cloud particles at the physical boundary of the cloud. The satellite is a passive sensor, and measures emitted energy from the radiative top of the cloud. The physical and the radiative cloud top are similar for clouds that are not optically thin. However, substantial discrepancies may exist for optically thin cirrus, and satellite retrievals of cloud height will be biased towards the middle of the cloud. The extent of this bias depends on the optical depth and emissivity of the cloud.

The ATReC experiment was conducted in proximity to Bangor, Maine during the Fall/Winter of 2003. This study uses data collected on 05 December 2003 and 28 November 2003. The NASA ER-2 carried a CPL, from which the reference cloud top height is derived, among other instrumentation. On 05 December, CPL data were collected for a 6.5 hour period starting at 1515 UTC (1015 local time, EST). The ER-2 flight track is shown in Figure 1. The University of North Dakota Citation flew below the ER-2 and released dropsondes from approximately 37000 ft (approximately 11,277 m), accumulating measurements of temperature, pressure, and dew point temperature.

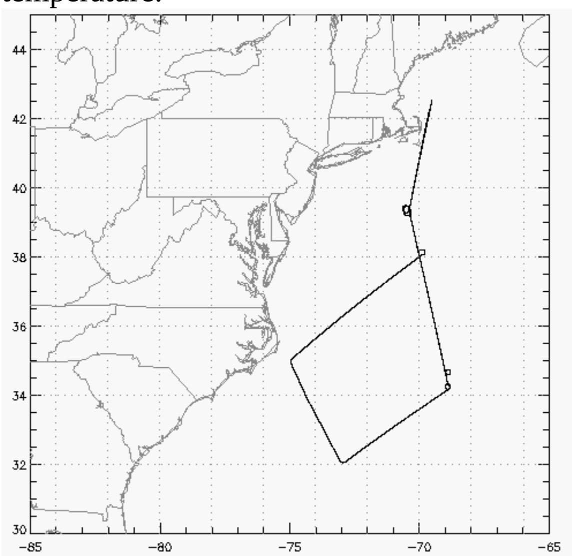

Figure 1. NASA ER-2 flight track for 05 December 2003.

On 28 November, data were collected over roughly a 4 hour period beginning at 1534 UTC (1034 local time, EST). The ER-2 flight track for this day is shown in Figure 2. The Citation did not fly on 28 November, so no dropsonde profiles were available. Therefore, a Pressure vs. Altitude relationship was derived using a radiosonde observation from the closest ground-based station (11 UTC observation from Manchester, NH).

Extreme differences exist between the CPL and satellite fields of view. To simulate a spatial resolution more representative of a satellite field of view, the CPL data were averaged. The 10 points before and after each data point were averaged to get the value for each data point. This averaging method was chosen because with the speed the plane was flying (about 200 m/s) and the lidar pulse rate (1 shot per second), 20 shots covered roughly 4 km. This corresponds with the spatial resolution of the GOES Imager. Averaging more points for comparison with the GOES Sounder did not produce a significant improvement in the results. Thus, an average of 10 data points on either side of each CPL measurement was used for comparison with both satellite instruments.

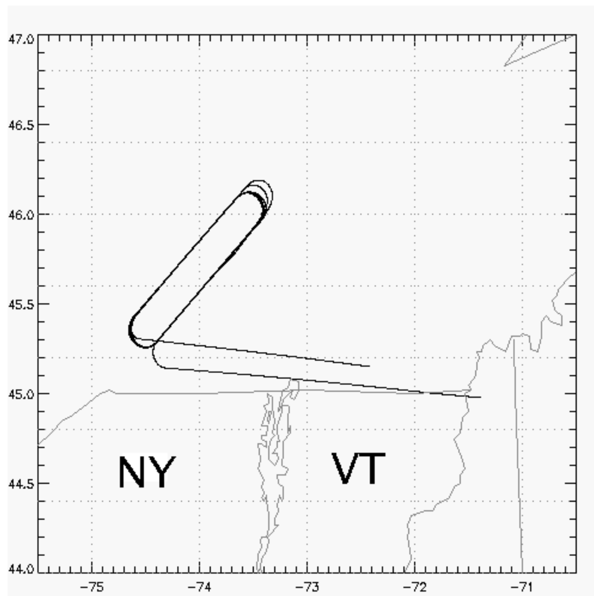

Figure 2. NASA ER-2 flight track from 28 November 2003.

3. SATELLITE VS. CPL COMPARISON

Figure 3 shows the GOES-12 Sounder (blue), GOES-12 Imager (red), and CPL (black) derived cloud top heights over the entire time range of CPL data available (1552 - 2112 UTC) on 05 December. This figure indicates that the trend in cloud top height for the CPL and both the Imager and Sounder are similar. However, the Sounder appears to consistently underestimate the cloud height with respect to the CPL, while the Imager (which offers improved spatial resolution over the Sounder; 4 km vs. 10 km) captures some of the smaller features that are missed by the Sounder. About 19.4% of the Sounder pixels and 28.1% of the Imager pixels were within

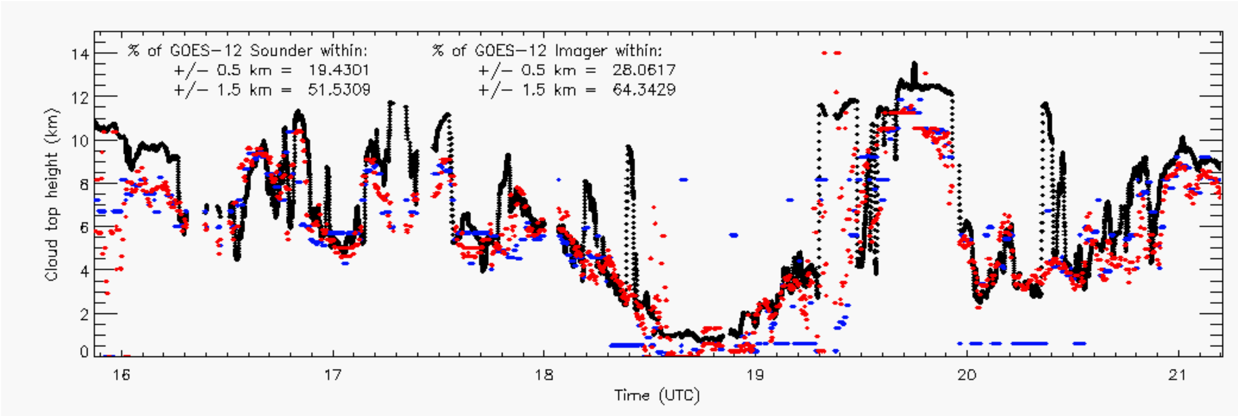

Figure 3. Cloud top height as derived from GOES-12 Imager (red), Sounder (blue) and CPL (black), for 05 December 2003.

+/- 0.5 km of the CPL measurement, while 51.5% of the Sounder pixels and 64.3% of the Imager pixels were within +/- 1.5 km of the CPL measurement. Figure 4 shows the distribution of differences and error statistics. The root mean square differences for the Sounder and the Imager were 2.78 km and 2.25 km, respectively.

This case consisted of high, mid-level, and low clouds. For the calculation of error statistics, high, mid-level and low clouds are considered to be those with heights greater than 10 km, between 4 and 10 km, lower than 4 km, respectively. Table 1. shows the error statistics for each of the three height regimes. The best agreement between satellite and CPL derived cloud top height was for mid-level clouds. The GOES-12 Imager also exhibited good agreement for low clouds (0-4 km), however, the GOES-12 Sounder exhibited

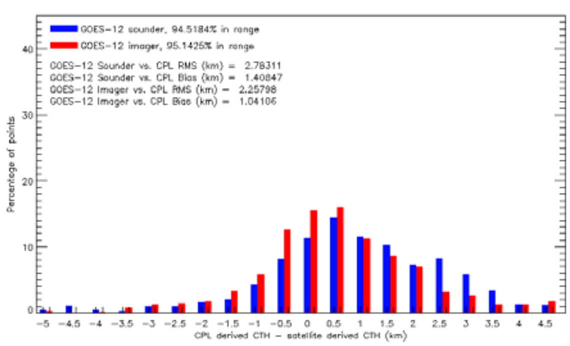

Figure 4: Distribution of differences between CPL CTH and GOES-12 derived CTH for 05 December 2003.

high percent errors and a non-uniform distribution of differences in this region. High clouds (above 10 km) proved to be the most difficult type for the satellites to assess, due to the sometimes optically thin nature of cirrus, and the frequent occurrence of cloud overlap.

	GOES-12 Imager	**GOES-12 Sounder**
RMS (high)	4.101	4.846
Bias (high)	3.137	3.791
RMS (mid)	1.802	2.056
Bias (mid)	0.814	0.899
RMS (low)	1.078	2.219
Bias (low)	0.086	0.926

Table 1: RMS/bias statistics for high (> 10 km), mid (> 4 km and < 10 km), and low (< 4 km) level clouds, for 05 December 2003.

Figure 5 shows the CPL derived cloud top height along with the GOES Imager and Sounder derived cloud top heights from 28 November, 2003. This figure confirms that qualitatively, both satellite instruments seem to consistently assess the general trend of cloud height over this time period. The Sounder agreed with the CPL to within +/- 0.5

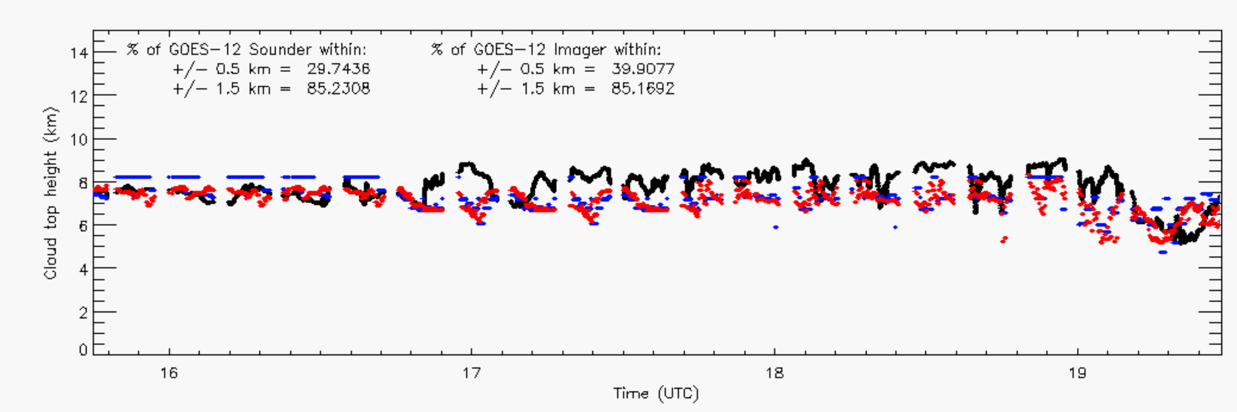

Figure 5. Cloud top height as derived from GOES-12 Imager (red), Sounder (blue) and CPL (black), for 28 November 2003.

km for about 29.7% of the data points, and to within +/- 1.5 km for about 85.2% of the data points. The Imager agreed with the CPL to within +/- 0.5 km for about 39.9% of the data points, and to within +/- 1.5 km for about 85.1% of the data points. This case consists entirely of mid-level clouds (between 4 and 10 km in height). Figure 6 shows the corresponding histogram of cloud top height differences over the same time period. Just under 63% of the GOES Imager and about 62% of the GOES Sounder data points are within 1 km of the CPL. There is a slight but consistent underestimation of the cloud top height by the GOES instruments which may most likely be attributed to the non-uniform nature of the clouds in this scene. Lower

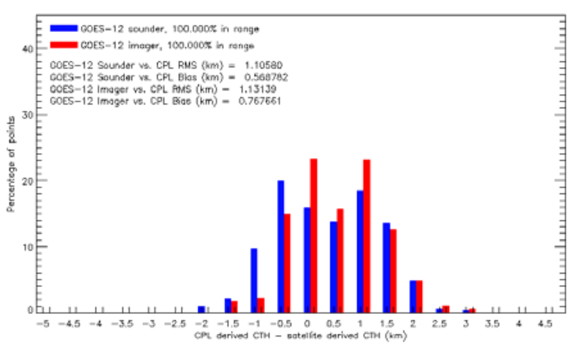

Figure 6. Histogram of differences between CPL derived cloud top height and GOES-12 Imager and Sounder derived cloud top height for 28 November 2003.

clouds or clear sky pixels may be present within the satellite field of view that do not fall within the CPL field of view, thus lowering the satellite's estimate of the cloud top height.

4. BROADBAND VS. HYPERSPECTRAL COMPARISON

Figure 7 shows the cloud top heights from 05 December, between 16 and 19 UTC. Red pixels are derived from the GOES-12 Imager, and black pixels are derived from the CPL. Heights shown in orange were derived from the SHIS using a modified CO_2 slicing approach. This plot shows qualitatively that the SHIS exhibits better agreement with the CPL in regions where either high or low clouds are present. Figure 8 shows the corresponding histogram of differences. As would be expected based on temporal and spatial co-location issues, the cloud top heights derived from the SHIS show the lowest RMS and bias vs. the CPL. The root mean square differences for the Sounder, Imager, and SHIS were 2.05 km, 1.77 km, and 1.52 km, respectively. While further studies are certainly necessary to assess the accuracy of these methods, this preliminary result indicates promise for the future use of hyperspectral technology in the assessment of clouds.

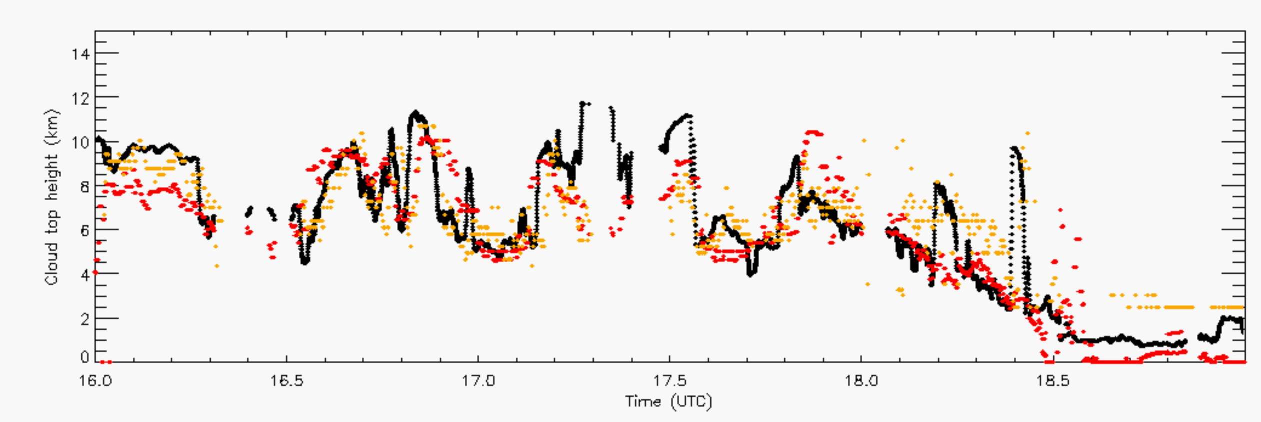

Figure 7. Cloud top height as derived from GOES-12 Imager (red), CPL (black), and SHIS (orange) for a selected time period on 05 December 2003.

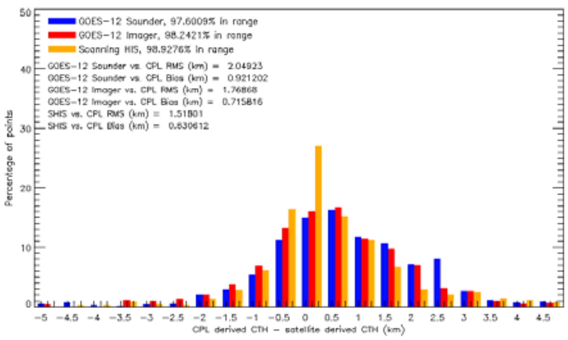

Figure 8. Histogram of differences between CPL derived cloud top height and GOES-12 Imager, GOES-12 Sounder, and SHIS derived cloud top height for 05 December 2003.

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5. SELECTED REFERENCES

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