P2.3 LIMB BIASES IN CO_2 CLOUD HEIGHT ALGORITHMS WITH RESPECT TO HIGH ALTITUDE CIRRUS

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1. INTRODUCTION

Upper-level cirrus cloud climatologies have been composed from satellite-derived data sets using data collected from zenith angles of less than 10º (e.g. Wylie et al., 1994, and Wylie and Menzel, 1999). The cloud height data, obtained from Carbon Dioxide (CO_2) Slicing algorithms applied to National Oceanic and Atmospheric Administration (NOAA) polar orbiting High-resolution Infrared Radiation Sounder (HIRS) data, are used in the composition of the climatologies.

It is believed that data from the limbs can produce bogus clouds and cloud top heights although there does not seem to be a rule as to where reliable data begins and ends with respect to nadir (center of image). Several effects can contribute to bogus clouds and heights (Glahn, 1966). 1. Limb darkening refers to the change in the radiation received by the radiometer at the far limbs of its scan. Limb darkening appears as bright edges on images made from HIRS and AVHRR data. The limbs appear brighter (colder) because less radiation is received at the instrument than nadir. 2. The path through the atmosphere that radiation takes depends on the scan angle of the instrument. The shortest path is at nadir and the longest paths are at the limbs. On the limbs, a greater optical depth of the atmosphere is sampled. 3. Ambiguities in cloud heights can be found in isothermal regions. This would cause problems with the highest cirrus clouds since they are located near the tropopause. 4. Inaccurate temperature profiles could cause inaccurate cloud top height determination. 5. Instrument calibration errors.

Theoretically, limb darkening and the other effects have a large impact on properties derived from HIRS and AVHRR data (i.e., CO_2 derived cloud top heights). CO_2 Slicing algorithms derive clear pixels and cloud top heights from the HIRS infrared bands with partial CO_2 absorption (13 to 15µm), from the "window channel" (11µm) and from the water vapor channel (8.3µm). The clearest channel, 11µm, sees little atmosphere and mostly the surface. The CO_2 channels and water vapor channel, on the other hand, see only atmosphere. When the HIRS scans at an angle into the atmosphere, each CO_2 channel finds its mass of CO_2 higher in altitude than when it is looking from nadir. Since the algorithms find the mass higher, it is perceived as colder. Water vapor channels behave in the same way. Because of this limb darkening effect, it is thought that some of the very high cirrus detected at the limbs may be bogus.

In order to fully evaluate whether or not high clouds are present in the limbs, a long-term study between satellite derived cloud tops and in situ measurement by aircraft would be needed. Such studies as McFarquhar et al. (2000) and Booker and Stickel (1982) show that high thin cirrus is present at very high altitudes in the tropics. Since there is clear evidence of cirrus at high levels, this study will examine the differences between calculated cloud top heights at nadir and high scan angle measurements.

2. DATA AND METHODS

During February 2001, a unique data set was collected between Kwajalein, Republic of the Marshall Islands (8º44'N 167º44'E) and Wake Island, US Territory (19º17'N 166º39'E). NOAA-14 HIRS multispectral data were archived from both islands providing a look at oceanic data from 15ºS to 40ºN. This dataset is used to investigate any limb biases that may be present in the CO_2 cloud detection and height routine and the radiometer viewing pattern. Cloud heights are converted from pressure to height coordinates using the hydrostatic equation.

Using a Lagrangian framework, data is divided into three groups: left, center and right. Each scan-line of data has 56 bins of data. The left two bins, two center bins and right two bins are archived and used to make comparisons. Cloud height versus latitude are plotted for clouds above 12 km for nadir (Figure 1), left limb (Figure 2), and right limb (Figure 3). The plotted data appears in "bands" south of 20ºN. This is due to the fact that the heights are originally calculated to the nearest 50 hPa and then converted hydrostatically to

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height coordinates. The authors believe that because the atmospheric temperature profile in the tropics is relatively constant from day to day, the data appear in these horizontal planes after the conversion to height coordinates.

3. DISCUSSION

Besides showing the amount and altitude of clouds detected at nadir and in the limbs, Figures 1, 2 and 3 have clear signatures of meteorological features. During February 2001, the subtropical high was anchored near 20ºN. Mid-latitude systems were affecting areas to the north of Wake Island (north of 25ºN).

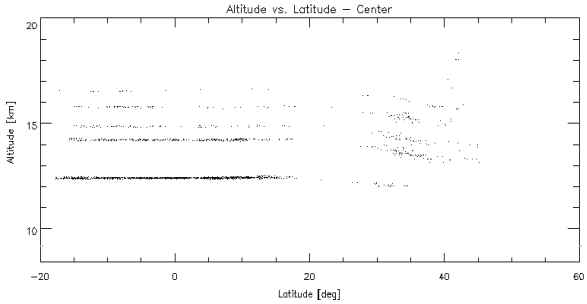

FIGURE 1: Detected clouds above 12 km plotted by altitude and latitude from the two nadir scan bins.

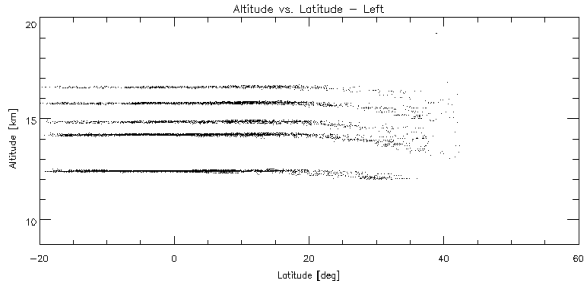

FIGURE 2: Detected clouds above 12 km plotted by altitude and latitude from the left limb scan bins.

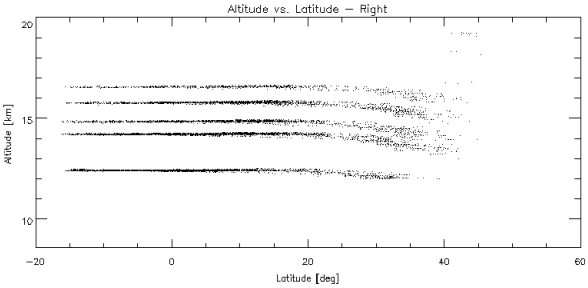

FIGURE 3: Detected clouds above 12 km plotted by altitude and latitude from the right limb scan bins.

The subtropical high is clearly visible in the nadir data (Figure 1) with only a scant few clouds detected above 12 km in the region of the subtropical high. The limb data (Figures 2 and 3) also show fewer incidents of cirrus detection around 20ºN, but is not as pronounced as in the nadir data. The difference in detected high clouds could be due to the ability to better detect sub-visible cirrus in the limbs as the satellite samples a greater optical depth of the thin cirrus.

The transition from the tropics to the mid-latitudes is also apparent. Both nadir and limb data show a downward slope of the cirrus clouds from ~20ºN toward the poles. This is associated with a decrease in altitude of the tropopause from the equator to the poles.

Upon closer inspection of the data, it appears that left and right limbs and nadir calculations all produce high clouds. There does not appear to be a significant difference in quantity and altitude of clouds detected between the right and left limbs. Nadir computations produce few very high clouds (above 13 km) as compared to the left and right limbs. Between 15º and 25ºN, nadir computations produced very few cirrus clouds (above 12 km) but produced many more clouds below 12 km than the right and left limbs. Left and right limb computations also produce fewer high clouds in this region as compared to the areas south of 15ºN. The number of cirrus clouds detected above 12 km decreases north of 25ºN in both the right and left limbs and at nadir.

This paper illustrates the need for future study of high cloud detection and verification. High clouds are detected at nadir and in both of the limbs, but with far more counts in the limbs. It is not clear whether the limb data is over detecting, or if the nadir calculations are undercounting clouds. The difference could likely be a combination of both. These results indicate that global cloud climatologies composed from CO_2 Slicing analysis could be seriously underestimating global cirrus coverage.

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4. REFERENCES

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