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"Long Term Variations in the Global Cover of High Clouds"

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1. Introduction

The purpose of this project is to extend the Wylie and Menzel (1994 and 1999) cloud analysis back in time to include all data from the HIRS (High resolution Infrared Radiometer Sounder) instrument. The HIRS is a multi-spectral infrared sensor flown on the NOAA polar orbiting weather satellites. The primary purpose of the HIRS is to produce temperature soundings of the atmosphere. However it is also one of the best sensors for monitoring cloud cover. The Wisconsin analysis of HIRS data has been shown to be sensitive to the upper tropospheric cirrus clouds which are difficult to detect by other means (Jin et al., 1996). Cirrus clouds are especially important to studies of climate changes since they strongly affect radiative heating and cooling processes. Climatological information on these clouds is poor because they are often ignored in tradition weather reports and are difficult to detect in satellite data.

Wylie and Menzel currently have an 11.5 year record of HIRS data which was acquired from the daily operations of NOAA's Environmental Satellite, Data, and Information Service. The first discussions of annual and inter-annual changes in cloud cover using these data have been reported in Wylie and Menzel (1994 and 1999) using 8 years of data. However, HIRS instruments have been in operation since 1978 giving 22 years of data. NOAA's Pathfinder Project is making the archived HIRS data available. This grant is for the University of Wisconsin to work with the Pathfinder Project apply a global cloud analysis to the full HIRS record.

2. Current Status of the HIRS Data

Drs. John Bates and Darren Jackson of the NOAA/CIRES Environmental Technology Laboratory, Boulder, Colorado, have retrieved the HIRS data from NOAA's archive and are performing quality control studies. They looking for long term drifts in instrument channels and inter-comparing the 10 instruments that have been flown on the NOAA satellites. The data records of instruments have been overlapped in time as new satellites have been launched to replace aging satellites. Their studies will form a consistent record in time by statistically removing instrument drifts and biases.

The data quality, bias, and trend analysis of Drs. Bates and Jackson is nearly complete. Dr. Wylie of the University of Wisconsin has begun constructing the cloud analysis algorithm on a test sample of HIRS data. The cloud analysis applied to the NOAA Pathfinder data set will have some differences form the studies of Wylie and Menzel (1994 and 1999). These original studies restricted the amount of HIRS data used to only near-nadir fields of view (FOV). Wylie and Menzel initially had difficulty in obtaining data from NOAA/NESDIS at the start of their study in 1989. They reduced the volume of data that had to be transferred to Wisconsin by selecting only data near the nadir view sampling these data on every third scan line. This sampling made their monthly cloud cover summaries noisy. The initial impetus for the sampling was the band width of the electronic transmission system in place in 1989. However, they also eliminated the complication of calculating radiative transfer of slanted scan paths at different slanted angles through the atmosphere.

The cloud analysis in this project will use nearly all of the archived HIRS data including the slanted scan data. This will complicate the cloud analysis but provide better sampling for cloud statistics. Also the slant scans provide an opportunity to detect thinner clouds because they have a longer path through the cloud. The cloud heights retrieved from the slanted scans also tend to be higher than the nadir data. This is an artifact of the cloud retrieval algorithm which needs to be understood.

A study of the differences in cloud retrieval statistics between slanted path and nadir HIRS data was made in the first year. It is discussed in the Appendix of this report. This study is continuing with MODIS data. Another complication of using HIRS data at different slanted scan angles through the atmosphere is that the FOV of the sensor increases with scan angle. To understand what impact FOV changes have on our cloud statistics a higher resolution sensor is being used. The MODIS on the Terra satellite has similar infrared channels to the HIRS which are used for detecting clouds. The MODIS has a FOV size of 1 km at nadir. A range of FOV sizes can be tested by averaging the MODIS data to the 20 km nadir HIRS FOV and larger.

3. Schedule

The analysis of spatial resolution using MODIS data is expected to be completed in the summer of 2001. After this analysis the Appendix will be modified and submitted for publication to a journal.

The HIRS cloud detection system for the Pathfinder data set also will finalized at Wisconsin using a sample data set. It will be installed in the NOAA/CERES computes in the fall of 2001 in preparation for the processing of the full HIRS record. We expect the processing of the full HIRS data record to take place during the winter of 2001. The Pathfinder Project is using the HIRS record for studying water vapor changes in addition to cloud cover. Both will be analyzed at the same time. We, Drs. Bates and Jackson of NOAA/CERES and myself will be examining the cloud and water vapor statistics continuously as the HIRS record is analyzed. We will be prepared to make a second pass through the data in 2002 if major problems are found.

Appendix

Cloud Detection using HIRS High Scan Angle Data

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Abstract

Cloud analysis from the high scan angle HIRS data were compared to a similar analysis of near nadir data made at Wisconsin. This comparison was made to assess the ability of improving detection of thinner cirrus clouds with HIRS data. The high scan data reported more clouds than the nadir data increasing the cloud fraction by +0.06. High cloud reports (>6 km) increased by the same +0.06, middle level clouds (3-6 km) decrease by –0.04, and low level clouds increased by +0.10. The increase in high clouds appeared to be mostly from detection of thin cirrus clouds. However, the sensor FOV size also dramatically increased with scan angle which raised the reports of all clouds at all levels because holes and small spaces between clouds were more likely ignored. Modeling of the cloud detection algorithm showed that the sensitivity threshold for thin clouds dropped from a mean visible optical depth of 0.13 using nadir data to 0.06 at high scan angles. This sensitivity increase was primarily in the tropics and summer mid-latitudes. The winter hemisphere had a smaller change. The heights and densities of the clouds reported by the algorithm also increased.

1. Introduction

Global studies of the frequency and changes in cloud cover have been made with satellite data for understanding the earth's heat budget and developing models for predicting climate changes. Thin cirrus clouds have been given more attention because of they are difficult to simulate in weather forecast models yet have important affects on radiative propagation through the atmosphere. Three data sets collected from satellites have been extensively used for information on global cirrus coverage. They are; 1) the International Satellite Cloud Climatology Project (ISCCP, see Rossow and Schiffer, 1991 and 1999), the Stratospheric Aerosol and Gas Experiment (SAGE, see Woodbury and McCormick, 1983 and 1986; and Wang et al., 1996), and the Wisconsin analysis of HIRS data (Wylie et al., 1994; and Wylie and Menzel, 1999). The HIRS data have been shown to be more sensitive to thin cirrus than the ISCCP (Jin et al., 1996) and have been used to compliment the ISCCP cloud statistics.

The Wisconsin analysis has used only part of the HIRS data set restricting its analysis to data taken with fields of view (FOV) close to the nadir point of the satellite's path. This restriction was originally applied to reduce the volume of data processed and to simplify the radiative calculations eliminating data from slanted views of the clouds. However, the slanted views of the HIRS scan may make semi-transparent clouds easier to detect because they have a larger impact on upwelling radiation passing through the clouds then when viewed from the vertical.

This paper discusses the possibility of using the slanted views from the HIRS sensor. An experiment was made comparing two cloud analyses, the traditional near nadir HIRS data with data from the highest scan angles of the HIRS instrument. The differences in cloud statistics found in these two data sets are discussed. Radiative transfer modeling also is used to explain some of the differences and assess the ability to improve thin cirrus cloud detection using high scan angle HIRS data.

2. Method of Detecting Clouds

Wylie et al. (1994) and Wylie and Menzel (1999) extensively discussed their method of detecting clouds and retrieving cloud heights from HIRS data. The important feature of the HIRS data is the use of longwave infrared channels from 13-15 μm that have partial CO_2 absorption. These channels have different attenuations from CO_2 absorption and receive radiation from different levels in the atmosphere. The channel with the least attenuation sees upwelling terrestrial radiation from lower in the atmosphere than the channel with greater CO_2 absorption. The HIRS data is mainly used by NOAA for obtaining global temperature and moisture soundings which are used in NOAA's numerical models. Cloud retrievals are made at the University of Wisconsin from the same data. The Wisconsin cloud analysis is done for research purposes and is not disseminated as a forecast product. It is used for studying cloud frequencies along with annual and interannual changes in cloud cover.

The largest satellite data set on cloud frequencies and radiative properties of clouds is the International Satellite Cloud Climatology Project (ISCCP, Rossow and Schiffer, 1991 and 1999). It uses the 11μm infrared window channels and the 0.6μm visible channels on all weather satellites operated by 5 international organizations. The Wisconsin cloud analysis was compared to the ISCCP by Jin et al. (1996) who found that the major difference between the cloud data sets was the detection of thin cirrus by the Wisconsin HIRS analysis.

The Wisconsin Cloud Analysis was started in 1989 when data acquisition was difficult. To reduce the volume of data that had to be extracted from NOAA, a decision was made to use only data within 10° of nadir and sample that data on every third scan line and every third element on the scan line. This radically reduced the data volume that had to be taken from NOAA's system. Recent improvements in internet access and computing power have made all of the HIRS data available. However, to form a consistent record in time back to 1989, the Wisconsin cloud analysis still restricts the data it uses to near nadir fields of view (FOV).

To gain more information on optically thin clouds, the HIRS data from high scan angles were considered because they have longer paths through the clouds. An experiment in using high scan angle HIRS data was initiated in April 1999 as a second analysis added to the HIRS processing at Wisconsin. The normal Wisconsin analysis uses only HIRS data with in 10° of nadir. The second analyses used only HIRS data with scan paths from 42° to 59° from zenith through the atmosphere. The second analysis was continued for one year, April 1999 - March 2000, in parallel with the nadir analysis.

The Wisconsin cloud analysis detects clouds in the HIRS data by comparing the 11μm window channel blackbody radiance measurements to the surface temperature. The surface temperature analysis from the National Center for Environmental Prediction (NCEP) of NOAA is used over land while the sea surface temperature analysis from the National Environmental Satellite Data Information Service (NESDIS, also of NOAA) is used over water. A correction for attenuation by water vapor in the satellite measurement is made by comparing an additional HIRS channel at 8.3 or 12.2μm to the 11μm channel. NOAA satellites carry one but not both of these water vapor sensitive channels. To classify a HIRS FOV as containing cloud, the water vapor corrected 11μm blackbody temperature has to be 2.5 K colder than the surface temperature. All warmer FOVs are classified as cloud free and averaged for defining the clear radiances for the radiative transfer calculations.

The altitude of the cloud is calculated from the following form of the radiative transfer equation.

$$\frac{Rclr(Ch4) - Rcld(Ch4)}{Rclr(Ch5) - Rcld(Ch5)} = \frac{N\varepsilon(Ch4) \int_{psfc}^{pcld} \{\tau(Ch4, p) dB[Ch4, T(p)] / dp\} dp}{N\varepsilon(Ch5) \int_{psfc}^{pcld} \{\tau(Ch5, p) dB[Ch5, T(p)] / dp\} dp} \qquad (1)$$

Rcld is the radiance measured by the HIRS channel of the cloudy FOV. *Rclr* is an estimate of what the channel radiance would have been had the FOV been cloud free. The left side of (1) is the infrared signal that the cloud made on two HIRS channels, 4 and 5. The right side is and estimate of the cloud signal calculated from a temperature sounding. $\tau(Ch, p)$ is the transmittance from any level, p, to the top of the atmosphere in each channel calculated from the temperature and moisture sounding. $B[Ch,T(p)]$ is the emitted radiance for the channel at temperature level p from the Planck function. The derivation of (1) is given in Wylie et al. (1994). Equation (1) is simplified by assuming that the product of cloud emissivity and fractional coverage of the FOV, $N\varepsilon$, is the same in each HIRS channel since the channels are spectrally very close. $N\varepsilon$, therefore, can be eliminated from (1). This simplifies (1) to only one unknown parameter, *Pcld*, the pressure of the cloud level. The Wisconsin analysis reports *Pcld* for each HIRS FOV in which a cloud was detected.

The HIRS data also can be used to estimate the optical density of the cloud. Using the 11 μm window channel the infrared emissivity can be estimated.

$$N\varepsilon = \frac{Rclr - Rcld}{Rclr - B(Tc)} \qquad (2)$$

Rclr and *Rcld* are for the 11 μm window channel. $B(Tc)$ is the Planck function estimate of upwelling radiance at 11 μm had the cloud top been opaque to infrared radiation (i.e. ε=1.0).

The emissivity-cloud fraction product, $N\varepsilon$, can be used to estimate the optical depth of the cloud by assuming no scattering in the upwelling infrared radiation and that the visible optical depth, OD_{vis}, is twice the 11 μm optical depth.

$$OD_{vis} = -2\ ln(1.0 - N\varepsilon) \qquad (3)$$

Wylie and Menzel (1999) discussed the dependence of the Wisconsin cloud analysis on the source of the clear radiance value, *Rclr*. It can be calculated from the temperature sounding using the transmittance and Planck functions. This is easy to do but it has to assume that the sounding data are accurate without biases and that the satellite calibration from which *Rclr* is calculated, also is without bias. In the real would, biases in the temperature sounding products are substantial. Additional bias errors in satellite data also are possible. Both bias errors can combine to create fictitious clouds in (1) or mask out thin cirrus. To minimize the affects of bias errors in the satellite calibration and sounding analyses, the Wisconsin method uses satellite measurements of *Rclr* interpolated to the cloudy FOVs as previously mentioned. The left side of equation (1), *Rclr-Rcld,* is a difference of two satellite measurements in the same channel. The right side of (1) contains only radiative calculations from temperature sounding data without any satellite data. This separation minimizes the effects of bias errors in the satellite radiance and sounding data.

Wylie and Menzel (1999) found that HIRS data from different scan angles could not be mixed without affecting the results of the analysis. The cloud mask finds most of the clear FOVs near the nadir scan angle because atmospheric attenuation at high scan angles slightly lowers the radiation measured by the satellite, even in clear air. This affect is often call "limb brightening" in the literature. The HIRS does not scan to the limb of the earth, but never the less, it is affected by the same attenuation problem.

To eliminate the problem of using HIRS data from a range of scan angles discussed in Wylie and Menzel (1999), the HIRS data were divided into two groups, the near nadir data traditionally used and a second group containing slanted paths of 42° to 59° through the atmosphere. All other HIRS data with slanted paths between 10° and 42° were ignored. The *Rclr* measurements were made separately from each group. With this method, the *Rclr* data came from the same range of scan angles as *Rcld* in (1) for each group eliminating problems discussed in Wylie and Menzel (1999). It should be noted that the right side of equation (1) does account for the HIRS scan angle in the transmittance function, $\tau(Ch, p)$ calculation.

3. Results

Each HIRS analysis reported the frequencies of clouds detected. The difference between the high scan angle cloud analysis and the traditional nadir analysis is shown in Figure 1. The cloud frequencies plotted in Figure 1 have considered the fact that only one cloud level, *Pcld*, can be calculated for each HIRS FOV using (1). Thus the lower levels are sampled less that the higher levels because of obscuration from high clouds. This produces slightly different statistics than other satellite studies which do not account for the fact that they sample the lower troposphere less frequently than the upper troposphere.

The HIRS data were separated into three latitudinal zones; 1) the northern mid-latitudes from 30°-60° north, 2) the tropics from 20° south to 20° north, and 3) the southern mid-latitudes from 30°-60° south. Oceanic and land areas are combined in Figure 1.

The high scan angle cloud analysis has three differences from the traditional nadir analysis; 1) it found 0.10 more low clouds from 1-3 km, 2) -0.04 less middle level clouds from 3-6 km, and 3) 0.06 more high clouds above 6 km (Table 1). The decrease in middle level clouds and increase in high clouds was expected because the slanted path through the cloud would make some thin clouds appear to have a larger $N\varepsilon$ than the nadir data as previously discussed. Some optically thin clouds were assigned lower altitudes in the nadir data because equation (1) could not be solved. The measurement, *Rclr-Rcld*, must be > 1.0 mW/m^2/steradian/wave-number for each channel. If this condition is not met, a height is still assigned by equating the blackbody temperature of the 11μm radiance to the temperature sounding. The 11μm window channel temperature is warmer than the cloud top altitude because of infrared transmission through the cloud.

The large increase in detection of low clouds from 1-3 km occurred because of two factors; 1) the HIRS FOV increased in size, and 2) atmospheric attenuation increases with slant angle making the blackbody radiance temperature colder than the nadir views. From the nadir scan angle of 0° to a 42° from zenith, the HIRS FOV dimensions increased by a factor of 1.5 and the area increased by a factor of 2.2, more than double the area of the nadir FOV. At the farthest reach of the HIRS scan, a 59° angle from zenith, the FOV dimensions increase by a factor of 2.5 and the area increased by 5.6 over nadir. The cloud height algorithm can not measure *N*, the fractional coverage of the cloud in the FOV, so the effect of the FOV size increase can not be determined separately from the other factors.

4. Simulation of Scan Angle Affects

The increase in atmospheric attenuation with scan angle was estimated by calculating the upwelling radiation using the atmospheric transmittance calculation, $\tau(11, \alpha, p)$ and the Planck function, $B[11, T(p)]$.

$$R(11,\alpha) = \int_{Psfc}^{0} B(11,T(p))d\tau(11,\alpha,P)dp \qquad (4)$$

$R(11,\alpha)$ is the upwelling radiation for the 11μm window channel. From α=0° to α=42°, $R(11,\alpha)$ decreased by 1.0 K in all three latitude belts. For α=59°, the end of the scan, the decrease in $R(11,\alpha)$ rose to 2.2 K. The observed change between the HIRS nadir and high scan data sets was a 1.0 K decrease similar to the simulation of the 40° scan angle with (1).

The first test in the Wisconsin cloud retrieval algorithm is the comparison of the HIRS 11μm window channel blackbody radiance temperature to the surface temperature which was previously discussed in Section 2. The decrease in measured 11 μm blackbody radiance from atmospheric attenuation would push some of the marginally cold clouds across the threshold to being > 2.5 K colder than the surface temperature resulting in more cloud reports.

A simulation of the minimum density, $N\varepsilon$, of a cloud that could be detected also was made. Some very thin clouds are missed because their infrared signature (*Rclr-Rcld*) is < 2.5 K in the 11 μm channel. The other channels with CO_2 absorption have smaller infrared signatures so the 1.0 mW/m^2/steradian/wave-number requirement of *Rclr-Rcld* discussed in Section 3 required solving (1), rejects fewer data than the initial 2.5 K test in the 11μm window channel. To simulate the minimal detectable cloud, the 11μm test is used.

To simulate a very thin cloud, equation (4) was used for the clear radiance term ($Rclr=R(11,\alpha)$). The cloudy FOV radiance can be simulated by expanding (4) with components for one transmissive cloud at one level.

$$R(Ch,\alpha) = \int_{Pc}^{0} B(Ch,T(p))d\tau(Ch,\alpha,P)dp + N\varepsilon B(Ch,T(Pc)) + \qquad (5)$$

$$(1-N\varepsilon)(1/\cos(\alpha)\{ \int_{Psfc}^{Pc} B(Ch,T(p)d\tau(Ch,\alpha,P)dp + B(Ch,T(sfc))\}$$

The first term is the radiation emitted above the cloud similar to (4). The 2nd term is the emission from the cloud top. The 3rd term is the radiation emitted from the air below the cloud and the 4th term is the radiation emitted from the earth's surface. The radiation passing through the cloud is attenuated by the transmission of the cloud ($1-N\varepsilon$) in the 3rd and 4th terms. Since we can view this cloud from a variety of angles, the cloud transmission is decreased by $1/\cos(\alpha)$.

Equations (4) and (5) were used to calculate *Rclr-Rcld* for a range of $N\varepsilon$ by successive iterations. The value of $N\varepsilon$ where $(Rclr-Rcld) \leq 2.5$ K was selected as the minimum density cloud that the Wisconsin analysis could detect. Only one level for the cloud, *Pc*=300 Hpa, was used in the simulation. The test was applied to the soundings from the NCEP analysis for five days in

January 2001. The soundings were taken from each analysis at intervals of 5° of latitude and 5° of longitude from 65° south to 65° north latitude. The average value of $N\varepsilon$ in latitudinal belts is shown in Figure 2.

The minimum detectable $N\varepsilon$ has little change from 40° south to 20° north latitude. These are the warm tropical and sub-tropical latitudes. The simulation period also is in the Austral summer. The minimal $N\varepsilon$ increases mostly in the winter hemisphere high latitudes. This latitudinal change probably comes from the smaller differences between the cloud level temperature (*Tc*) and the surface temperature in the winter hemisphere.

The affect of HIRS scan angle is shown in Figure 3 by latitudinally averaging the minimal detectable NE. From scan angles α=0.0 to 60°, the minimum $N\varepsilon$ drops from 0.064 to 0.026, < one half of its nadir value. This is a very large change in sensitivity. Using (3) the change in visible optical depth of the minimum detectable cloud also shows a decrease from 0.133 to 0.052.

The heights of the cloud, *Pcld*, retrieved from (1) are also affected by the HIRS scan angle. To quantify this effect equation (1) was solved using simulated radiances for *Rclr* and *Rcld* calculated from (4) and (5) similar to the minimum detectable cloud test. Simulations were made from two soundings at 5° and 40° north latitude assuming *Pc*=300 hPa and varying cloud densities from $N\varepsilon$=0.25, 0.50, and 0.75. For each simulated cloud a cloud level, *Pcld*, was calculated from (1), an effective emissivity, $N\varepsilon$, from (2), and a visible optical depth from (3).

The retrieved cloud heights, *Pcld* (Figure 4), became higher with scan angle (*Pcld* decreased). The height change was greater at 40° north latitude than in the tropics, 5° north. Cloud density did not affect the height change. Identical *Pcld* results were found for each cloud density within one sounding. The only differences were between soundings at different latitudes; the tropical sounding had smaller changes than the 40° north latitude sounding.

The $N\varepsilon$ retrieved from (2) also changed with scan angle (Figure 5). For this variable, the differences between mid-latitude and tropical soundings were minimal. For the dense clouds, ($N\varepsilon$=0.75) the upward trend of $N\varepsilon$ with scan angle reversed between α=50° and the previous α=40°. This change in trend occurred because the retrieved cloud level, *Pcld*, was above the tropopause and *B(Tc)* increased for $\alpha \geq$ 50°. The retrieved visible optical depths from (3) also similar increases with scan angle (Figure 6) since they are calculated from $N\varepsilon$.

The increase in $N\varepsilon$ with scan angle generally follows a cosine function of scan angle (Figure 5). The only exceptions are at scan angles α~60° where the cloud heights retrieved (*Pcld*) moved into the tropopause.

5. Summary and Conclusions

The high scan angle HIRS data increased the globally averaged cloud fractions from 0.70 to 0.76, an increase of +0.06. This increase came from three causes: 1) the increase in path length of radiation passing through the thin clouds, 2) the increase in the FOV size of the sensor, and 3) an increase atmospheric attenuation of upwelling radiation. The atmospheric attenuation was measured and predicted to be ~ 1 K and the smallest problem. The increase in high scan FOV areas of 2.2-5.6 over the nadir was the principal cause for increase in low cloud reports. High level cirrus cloud reports increased from frequencies of 0.32 to 0.38, a +0.06 change. Most of this change was an increase in reports of thin cirrus by +0.04 believed to come from the increased optical depth from the slant viewing geometry of the clouds. However, the large increase in FOV size of the HIRS high scan angle data also is embedded in these statistics.

The density of the minimally detectable cloud decreases from an effective emissivity ($N\varepsilon$) of 0.064 at nadir viewing angles to <0.044 for scan angle >40° by radiative modeling. This converts to minimum detectable visible optical depths of clouds decreasing from 0.133 at nadir to <0.09 for α>40°.

The sensitivity also decreased in the winter hemisphere (also from radiative modeling). The minimum detectable $N\varepsilon$ increased from 0.06 in the tropics to 0.08 at 60° north latitude (α=0°) – an increase of one-third. The higher scan angle simulation found a similar increase.

Radiative modeling also predicted an increase in the retrieved cloud heights by $\geq$85 hPa for the high scan angles. The smallest changes were in the tropics and the largest exceeded 180 hPa at higher latitudes.

Modeling predicted the cloud densities ($N\varepsilon$) measured would increased by factors of 1.25-2.0 with scan angle. These changes generally followed a cosine function of scan angle and can be removed.

Acknowledgements

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Table 1: The frequency of clouds measured from April 1999 – March 2000 by the HIRS nadir data from 65° south to 65° north latitude and the change in frequency of clouds of the high scan over the nadir data.

	All Clouds	Thin ($N\varepsilon<0.5$) ($OD_{vis}<1.4$)	Thick ($N\varepsilon\geq0.5$) ($OD_{vis}\geq1.4$)	Opaque ($N\varepsilon>0.95$) ($OD_{vis}>6$)
Cloud Frequency (nadir data)				
>6 km	0.32	0.14	0.14	0.04
3-6 km	0.26	0.10	0.07	0.09
<3 km	0.40	0	0	0.40
All Levels	0.70	0.20	0.20	0.30
Change in Frequency (high scan – nadir)				
>6 km	+0.06	+0.04	0	+0.02
3-6 km	-0.04	-0.04	-0.01	+0.01
<3 km	+0.10	0	0	+0.10
All Levels	+0.06	+0.02	-0.02	+0.06

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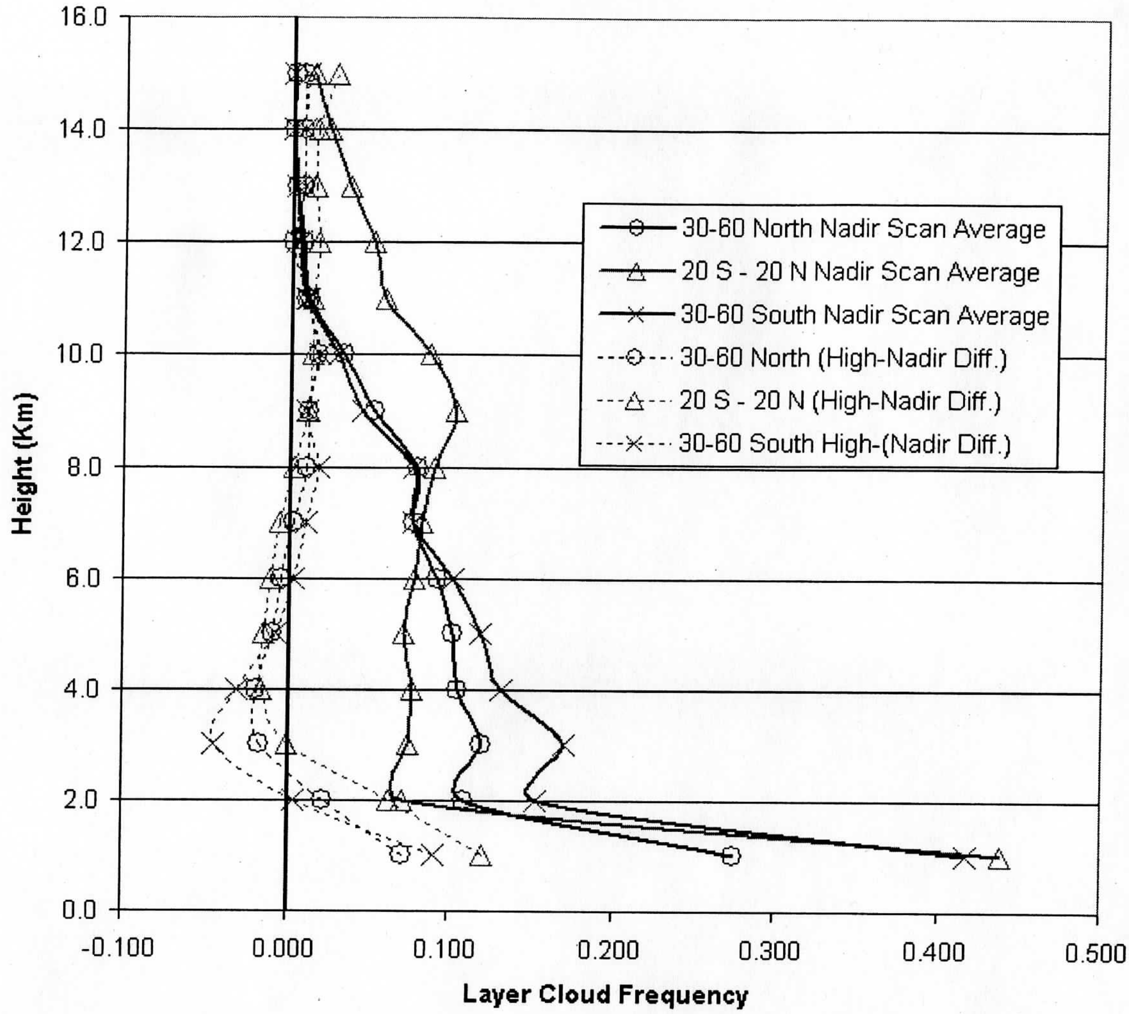

Figure 1: The frequency of clouds from the Wisconsin analysis of HIRS data (solid lines) and the change in cloud frequency of high scan angle over the nadir HIRS data (dashed lines).

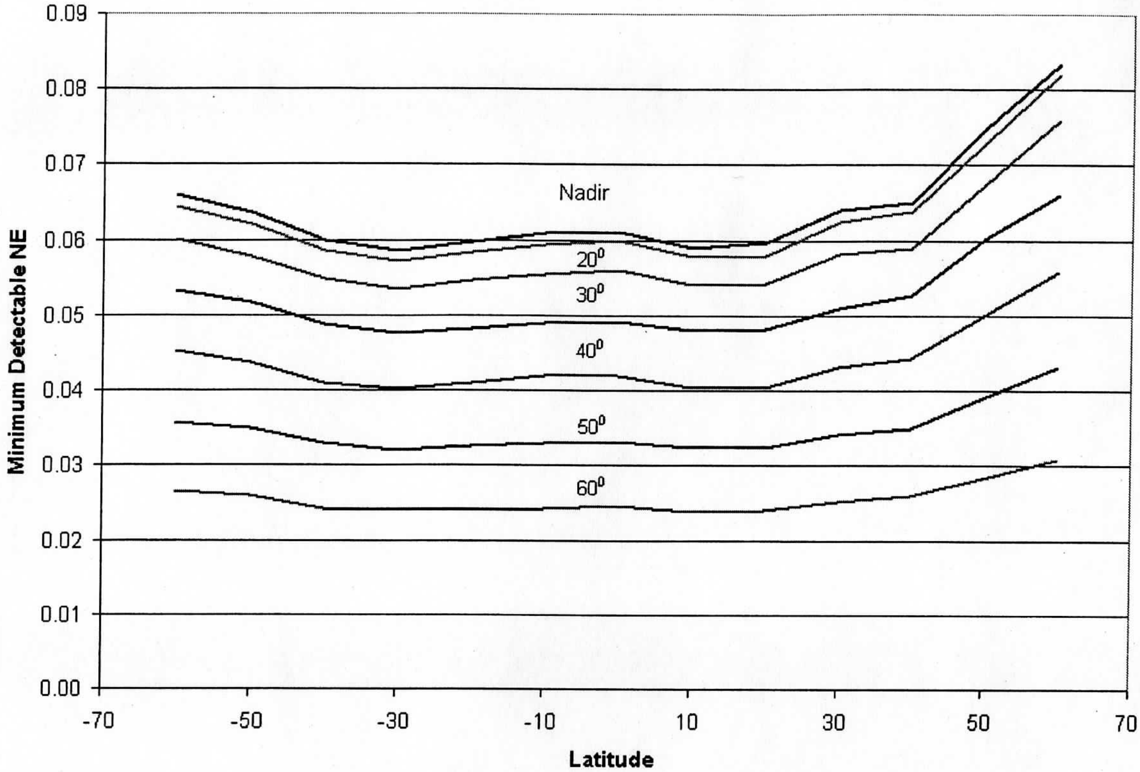

Figure 2: The minimum detectable effective emissivity for clouds retrieved from nadir HIRS data and six scan angles from 10°-60° (angle from local zenith through the atmosphere).

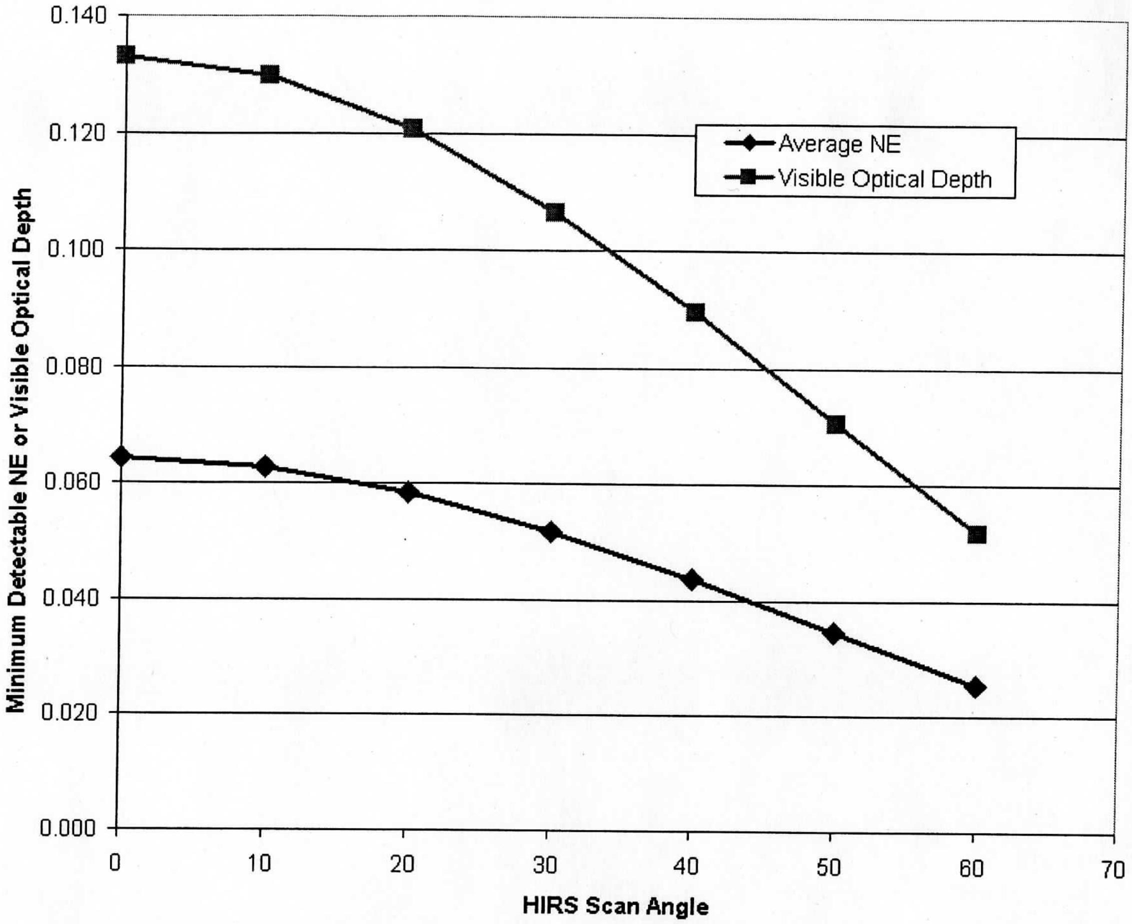

Figure 3: The latitudinally averaged minimum detectable effective emissivity as a function of HIRS scan angle (local zenith), and the visible optical depth estimated from the emissivity.

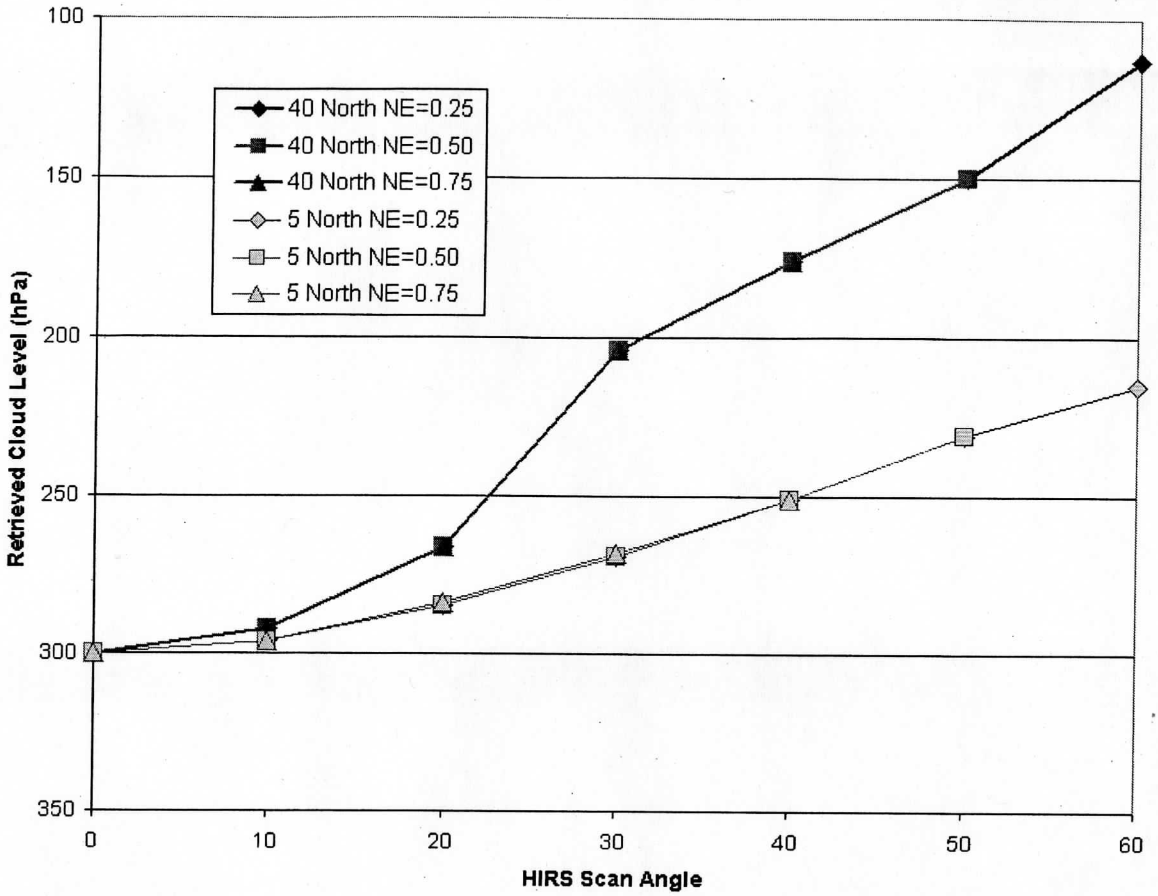

Figure 4: The change in cloud height reported by the Wisconsin HIRS analysis from changes in the HIRS scan angle through the clouds.