P1.4 Trends in High Clouds Over the Last 20 Years

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ABSTRACT

Global cloud cover has been monitored with multi-spectral observations from the eleven polar orbiting HIRS (High resolution Infrared Radiation Sounder) since December 1978. The HIRS longwave infrared data have a higher sensitivity to semi-transparent cirrus clouds than visible and infrared window techniques. Clouds are found in 71% of all HIRS observations from 65 S to 65 N; high clouds are observed in 33% of the observations. Closer investigation of the tropics indicates that there has been little overall change in the global total cloud cover. There is the possibility of a small increase in high cloud cover from the first decade to the second (about 2%) however orbit drift of some sensors and instrument differences may be part of this. Significant weather events such as El Nino Southern Oscillation or volcanic eruptions may also be influencing the trends local areas but show little signal in global averages.

Keywords: Remote sensing, Clouds, Cirrus, Climate

1. UW PATHFINDER HIRS CLOUD ANALYSIS

The TIROS Operational Vertical Sounder (TOVS) is the only long-term source of high spatial resolution global information pertaining to the temperature, moisture, and cloud structure of the atmosphere. Because similar HIRS and Microwave Sounding Unit (MSU) instrumentation has flown on operational satellites from 1978 to the present, data from these instruments can make an important contribution to our understanding of the variability of atmospheric and surface parameters as well as the correlations between spatial variations of atmospheric and surface quantities. In addition, the data can potentially be used to identify and monitor trends in temperature, moisture, cloudiness, Outgoing Longwave Radiation, and precipitation, provided that quantitative results can be obtained that account for differences in instrumentation on different satellites, as well as sampling differences in local crossing time. A prerequisite for such studies is an algorithm that does not change during the course of the processing.

The HIRS measurements in the carbon dioxide absorption band at 15 microns are used to detect cloud and calculate both cloud top pressure and effective emissivity from radiative transfer principles. The technique and details of its application with HIRS data are described in Wylie et al. (1994) and Wylie and Menzel (1999). This re-processing of the HIRS Pathfinder data set introduces a few changes from the referenced works (see Table 1). Clear sky radiances are culled using infrared window threshold and temporal and spatial variance tests (Jackson and Bates, 2001). CO_2 slicing is attempted for every field of view. The NCEP/NCAR Reanalysis is used for the cloud top pressure calculation. Radiance bias adjustments are made for every 2 x 2 degree lat-lon grid box using the clear measurements in order to keep calculated and measured radiances in concert. The HIRS data have a higher sensitivity to semi-transparent cirrus clouds than visible and infrared window techniques; the threshold for detection appears to be at IR optical depths greater than 0.05 (in general visible optical depths are twice the IR optical depth). Seasonal changes in global high cloud cover are well characterized by these CO_2 sensitive measurements.

Table 1: Differences in UW HIRS Cloud Processing

Current UW Pathfinder HIRS	Earlier UW HIRS
23 years	12 years
all orbits processed	2 am & 8 am LST orbits over land excluded
18 deg from nadir	10 deg from nadir
contiguous fovs processed	every 3rd element every 3rd line
uses IRW threshold plus and spatial & temporal variance cloud mask	uses split window comparison with Tsfc cloud mask
forward calculation	interpolates neighboring I(clear)
explicit radiance bias correction (NCEP/NCAR Reanalysis)	no radiance bias correction

The parameters measured by the HIRS all undergo a diurnal cycle. To obtain good diurnal averages, several measurements should be made each 24 hour day. A Sun synchronous satellite obtains one day and one night time measurement per 24 hours over most of the earth. The mean of these two observations yield an estimate of the daily averages for the parameters. When both morning and afternoon satellites are operating four daily measurements are available and the mean of these four will yield an improved daily average. However only one satellite is sometimes available, thus care must be taken in comparing one year to another year in which the observing times are different.

Since 1978 data has been available from eleven different NOAA satellites maintained in an orbit that produced either a morning (8 am local time) or afternoon (2 pm local time) local overpass. Table 2 indicates the morning and afternoon satellite instruments (prior to NOAA 17).

Table 2: Local overpass times for the NOAA satellites since 1978. HIRS/2I channel 10 is at 12.5 micron instead of the prior HIRS/2 8.6 micron. HIRS/3 has improved signal to noise and stays with 12.5 micron for channel 10. The asterisk indicates both NOAA 11 and 14 drifted from 14 UTC to 18 UTC over 5 years of operation.

morning (8 am LST)	afternoon (2 pm LST)
NOAA 6 HIRS/2	NOAA 5 HIRS
NOAA 8 HIRS/2	NOAA 7 HIRS/2
NOAA 10 HIRS/2	NOAA 9 HIRS/2
NOAA 12 HIRS/2	NOAA 11 HIRS/2I *
NOAA 15 HIRS/3	NOAA 14 HIRS/2I *
	NOAA 16 HIRS/3

2. UW PATHFINDER HIRS REPROCESSING OF 23 YEARS OF CLOUD DETECTION

UW Pathfinder HIRS cloud statistics from 65 N to 65 S (for observations within 18 degrees of satellite nadir) since December 1978 are shown in Table 3. They are separated by cloud type into clear sky (infrared window optical depth $\tau_{IR} < 0.05$), thin ($\tau_{IR} < 0.7$), thick ($\tau_{IR} > 0.7$), and opaque ($\tau_{IR} > 3.0$) clouds and separated by level in the atmosphere above 400 hPa, between 400 and 700 hPa, and below 400 hPa. On the average for summer and winter, HIRS finds thin clouds in 19% of all observations, thick clouds in 24%, and opaque clouds in 28%. Thus these HIRS observations imply that clouds are found in 71% of all HIRS observations from 65 S to 65 N. High clouds are observed in 33% of the observations.

Table 3: UW Pathfinder HIRS cloud statistics from 23 years of measurements (within 18 degrees of nadir) between 65 N and 65 S from December 1978 through December 2001. All seasons are included. Measurements from eleven satellites are included. It should be noted that frequency of cloud observations at a given level of the atmosphere are percentages of observations only to that level. Effective emissivity refers to the product of the fractional cloud cover, N, and the cloud emissivity, ε, for each HIRS observational area (roughly 20 km resolution). Thin clouds have $N\varepsilon < 0.5$ and IR optical depths <0.7. Thick clouds have $0.5 < N\varepsilon < 0.95$ and IR optical depths from 0.7 to 3.0. Opaque clouds are opaque to the IR window with $N\varepsilon > 0.95$ and IR optical depths > 3.0. Comparisons with 1 km AVHRR data have indicated that the FOV is totally obscured by cloud when $N\varepsilon \geq 0.5$ and 72% obscured by cloud when $N\varepsilon < 0.5$.

	All Clouds	**Thin Clouds**	**Thick Clouds**	**Opaque Clouds**
High (<400 hPa)	**33%**	**15%**	**16%**	**2%**
Mid (400 – 700 hPa)	**21%**	**6%**	**10%**	**5%**
Low (>700 hPa)	**46%**	**1%**	**3**	**43%**
All Clouds	**71%**	**19%**	**24%**	**28%**

3. HIRS TROPICAL CLOUD TRENDS

Monthly averages of the tropical (20 N to 20 S) frequencies of cloud detection for each satellite are plotted as one continuous record in Figure 1. Several features are evident.

a) total cloud cover remains relatively steady over the 23 years
b) high cloud cover shows an annual cycle (January maximum and July minimum)
c) some satellite cloud detection seems out of family (NOAA 15 and NOAA 16)
d) morning and afternoon satellite cloud detections show modest differences (morning sees more total clouds especially over land)
e) high cloud cover has a modest increase in the second decade over the first decade (about 2%)
f) the 1982 El Chichon eruption along with an ENSO event may be connected with a modest decrease in high clouds
g) HIRS finds more clouds and high clouds than ISCCP

The transition from one satellite to another sometimes causes noticeable discontinuities in the trends. The largest inter-satellite changes were from NOAA 14 to 15 and 16. NOAA 15 began the HIRS-3 sensors. HIRS-3 has only small differences in the spectral locations of its channels from the HIRS-2 sensors that preceded it. But the data show the two highest altitude channels at 13.9 and 14.2 µm on HIRS-3 to be much colder than expected. This indicates a possible problem in the HIRS-3 calibrations which is being investigated. HIRS-2 and 3 sensors have been flying concurrently since 1999 so a substantial record is available to resolve these differences.

Significant weather events such as El Nino Southern Oscillation or volcanic eruptions may also be influencing the trends, although the zonal average in the tropics shows little effect. Only zonal averages are shown here but regional changes are being investigated.

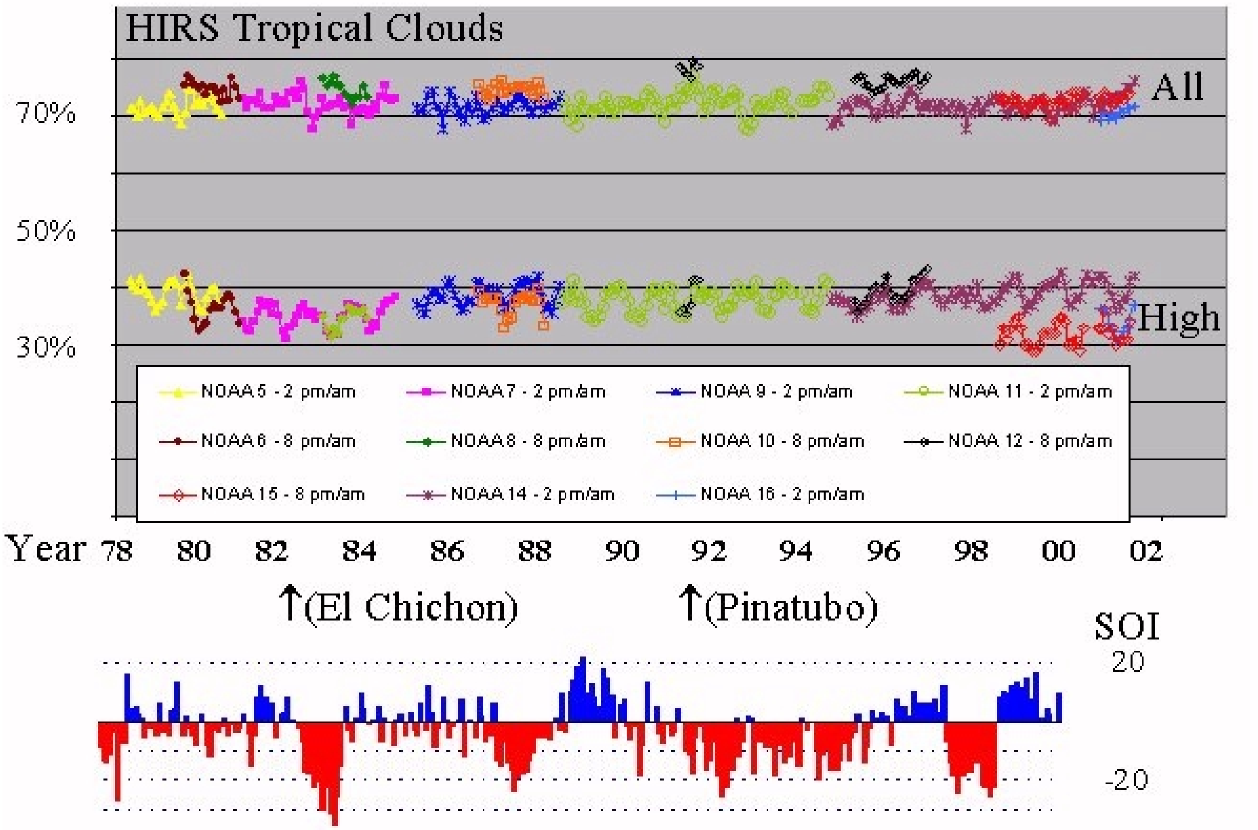

Figure 1: The UW Pathfinder HIRS detection frequency of all and high tropical clouds by individual satellites along with the Southern Oscillation Index (SOI) and significant volcanic eruptions from 1978 to 2001.

The time of the overpass influences the cloud detection especially over land. This can be seen more clearly in the frequency of cloud detection over land in the tropics shown in Figure 2. The sunrise/sunset satellites detect more than 10% more cloud cover than the afternoon/nighttime satellites; for high cloud cover the changes between orbits is not as noticeable. Moreover the drift of NOAA 11 and 14 from 14 LST to 18 LST over their lifetimes is increased the cloud detection by about 10% in the last year of each satellite's operation. This has a modest influence on the tropical cloud trends (modestly because only 10% of the tropics is land). Schreiner et al. (2001) report that the GOES Sounder found more clouds later in the afternoon over land (between 5 and 10 % more depending on season) in their one year study. The tropical high cloud detection over land is also showing a strong seasonal cycle with fewer clouds in June-July-August and more clouds in December-January-February.

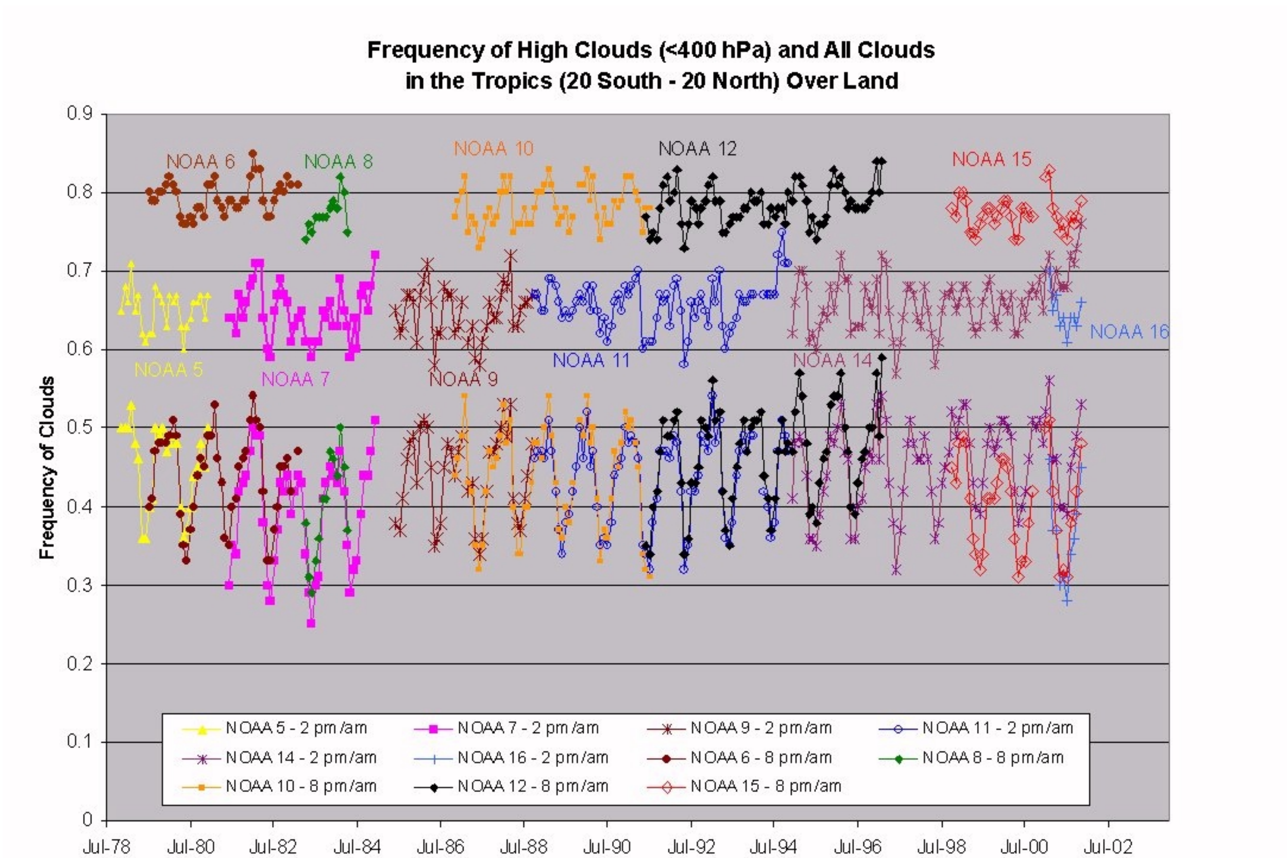

Figure 2: The UW Pathfinder HIRS detection frequency of all (upper plots) and high tropical (lower plot) clouds over land by individual satellites. The afternoon/nightime (2 am/pm local time) satellites NOAA 5, 7, 9, 11, 14, and 16 see fewer clouds than the sunrise/sunset satellites are NOAA 6, 8, 10, 12, and 15 (8 am/pm local time). NOAA 11 and 14 drifted 3 to 4 hours later into the afternoon during the five plus years of operation causing a slight increase in detection of clouds over land.

The decadal trends are negligible for all cloud detection but small and positive for high clouds. Figure 3 shows the deviation of the 1990 to 2002 tropical high cloud detection from the mean of the 1978 to 1989 tropical high cloud detection; the out of family NOAA 15 and 16 observations were not included in this analyses. A gradual increase of 2 to 3 % is evident, due in part to the orbit drift of NOAA 14.

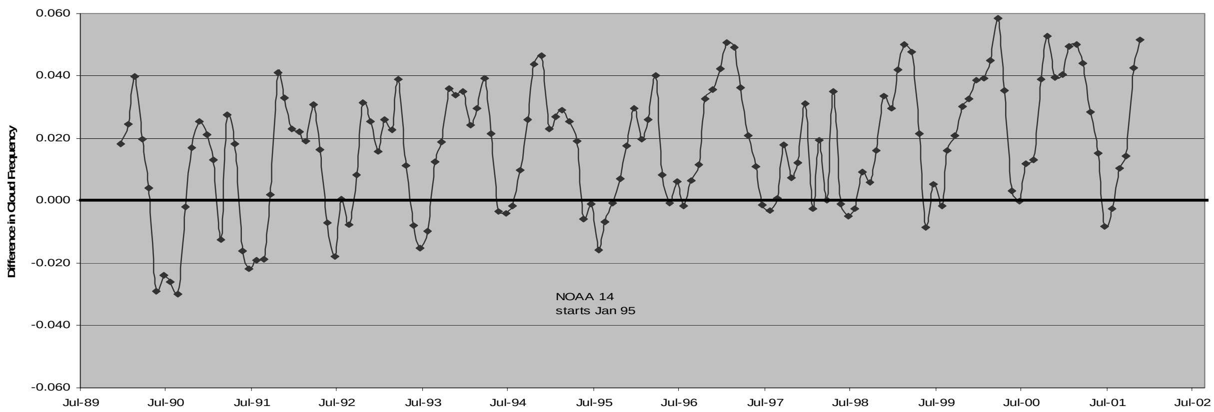

Figure 3: Deviation of 1990-2002 topical high cloud observations from the tropical high cloud mean for 1978–1989.

4. COMPARISON WITH ISCCP D2

The International Cloud Climatology Project (ISCCP) was initiated in 1983 and has been continually collecting cloud statistics from all operational geostationary and polar orbiting weather satellites since then (Rossow and Schiffer, 1999). ISCCP uses the channels common to all weather satellites - the visible channel at 0.6 microns and the infrared window at 11 microns - to detect clouds and measure their visible optical depths. ISCCP and UW Pathfinder HIRS cloud data sets were compared for 1983 through 1999.

ISCCP detects high clouds from (a) only infrared 11 µm window channel data where it misses some thin cirrus clouds because there is no correction for the transmission of terrestrial radiation through the clouds; and (b) infrared window data corrected for cloud semi-transparency using the solar reflection measurements at 0.6 µm with a radiative transfer model. The corrected data are reported in three categories: Daytime Cirrus, Cirrostratus, and Deep Convective Cloud Amounts. For this comparison, the cloud frequencies from the three daytime categories were added together to form ISCCP's best estimate of high cloud frequency. UW Pathfinder HIRS cloud detection uses four longwave infrared channels from 13-15 µm to detect thin cirrus; both day and night data were added to form UW HIRS estimate of high cloud frequency.

The average frequencies of ISCCP tropical all cloud and high cloud reports are shown in Figure 4. ISCCP finds fewer all cloud in the tropics (60 versus 70%) and many fewer high clouds (17 versus 35%); the high cloud difference is close to the 12-16% previously reported by Jin et al. (1996). ISCCP shows a noticeable decrease in all and high cloud cover from 1983 to 1999; UW Pathfinder HIRS shows nearly constant all cloud detection and a slight increase in high cloud detection.

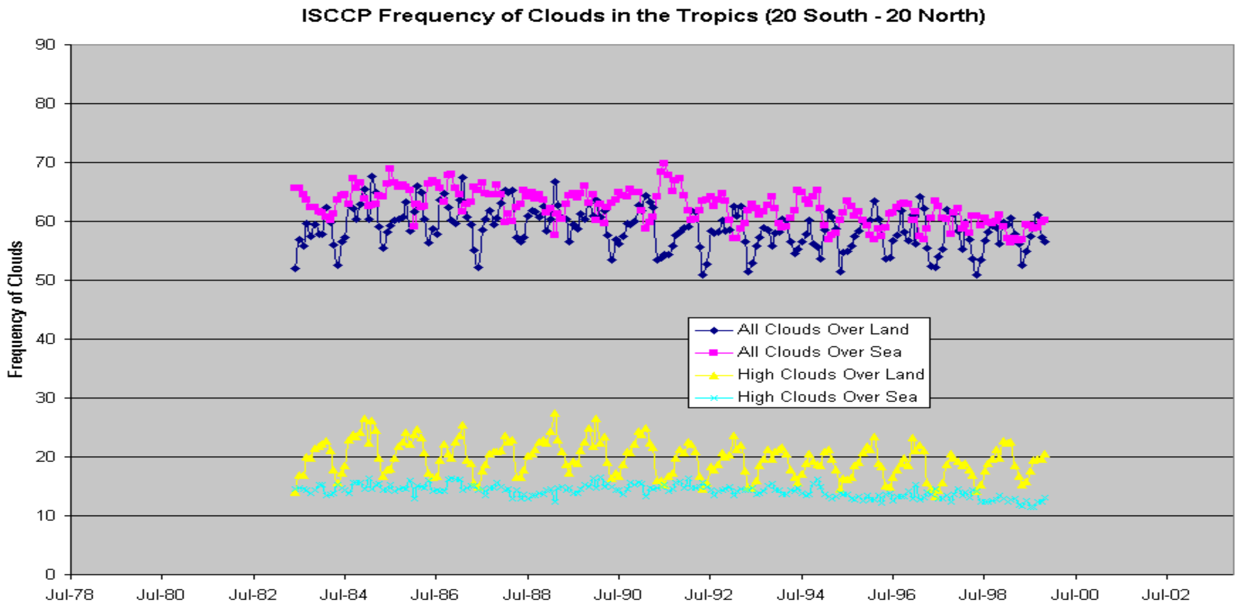

Figure 4: ISCCP D2 detection of all cloud (upper plots) and high cloud (lower plots) over land and sea in the tropics from 1983 to 1999.

6. CONCLUSIONS

UW Pathfinder HIRS cloud statistics extend 23 years. Clouds are found in 71% of all HIRS observations from 65 S to 65 N. High clouds are observed in on third of the observations. Closer investigation of the tropics indicates that there has been little overall change in the global total cloud cover; there is the possibility of a small increase in high cloud cover from the first decade to the second (about 2%). However orbit drift of some satellites and sensor differences may be part of this. Significant weather events such as El Nino Southern Oscillation or volcanic eruptions may also be influencing the trends. By comparison, ISCCP finds fewer clouds and has a decreasing trend in high cloud detection. Clearly more work needs to be done. The 23 year Pathfinder HIRS data set will be investigated more thoroughly and these and other effects will be isolated in order to discern a cloud trend can be confidently presented.

7. ACKNOWLEDGMENTS

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8. REFERENCES

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