Trends in High Clouds Over the Past 22 Years

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Background

The CO_2 slicing method has been used in operational processing of GOES (Geostationary Operational Environmental Satellite) and HIRS (High resolution Infrared Radiometer Sounder) data, and has been found to have accuracies of approximately 50 hPa for clouds at heights above 3 km. This technique to infer cloud-top pressure and effective cloud amount (the cloud fraction multiplied by the emittance at 11 microns) has been discussed in detail by Menzel et al. (1983) and Wylie and Menzel (1999). Error analyses for the method are provided in Wielicki and Coakley (1981), Menzel et al. (1992), and Baum and Wielicki (1994). The method takes advantage of differing partial CO_2 absorption in several of the HIRS infrared bands located within the 15-micron CO_2 band, with each band being sensitive to a different level in the atmosphere. The bands located closer to the center of the CO_2 band at 15 microns are sensitive to high clouds only, while the bands away from the CO_2 band center are sensitive also to the presence of midlevel clouds.

Retrievals are derived from ratios of radiance differences between cloudy and clear-sky regions at two nearby wavelengths using the upwelling radiative transfer equation. The strength of this technique is its ability to detect thin cirrus clouds with visible optical depths > 0.1. However the height derived for thin cirrus is below the cloud top by up to 60 hPa for the most transmissive clouds. Due to signal-to-noise issues and the altitudes which the CO_2 channels a sensitive, cloud heights inferred from method must be in the range from approximately 700hPa to the tropopause. If no valid retrieval is found in this pressure range, the 11-micron band is used to infer cloud pressure assuming the cloud is opaque.

In HIRS operational processing, cloud top pressures are calculated for the following ratio pairs:14.2/13.9 microns (band 4/band 5); 13.9/13.6 microns (band 5/band 6), 13.6/13.3 microns (band 6/band 7), and 13.9/13.3 microns (band 5/band 7). Four channel pairings are used but only one solution is reported. The most representative cloud pressure is chosen that best satisfies the calculation of upwelling radiance for all four channels. The final cloud pressure is chosen by minimizing the difference between the observed cloud signal (i.e., the difference between the clear-sky and measured radiance) and the simulated cloud signal calculated from a forward radiative transfer model (Menzel et al. 1983).

HIRS Data Reprocessing Effort

All HIRS data from 1979 to 2001 were reprocessed at the NOAA ETL, Boulder, Co, to form a consistent records of 22 years in length as part of the Pathfinder program.

The previous HIRS data processed at Wisconsin (Wylie and Menzel: 1999) used only data from 1989 to 1998. Other improvements also were made to the Pathfinder analysis over the previous Wisconsin analysis which are summarized in the table below. The Pathfinder analysis also used all HIRS data whereas the Wisconsin analysis sampled data to one of three pixels on scan lines and used only every third scan line. The Pathfinder analysis included all orbits over land. The Wisconsin analysis ignored the nighttime and morning orbits over land because it used surface temperature analyses from NOAA NCEP for identifying clear fields of view. The orbit elimination was previously used to prevent errors from the diurnal cycle of land surface temperature. The Pathfinder analysis used a different method for identifying clear fields of view (FOV). It was based on searching for low variance in space and time similar to the ISCCP procedure.

Current NOAA-Wisc. Pathfinder	***Earlier Wisconsin HIRS***
23 years	12 years
All orbits processed	2 am & 8 am LST orbits over land excluded
+/-18 degrees from nadir	+/-10 degrees from nadir
Contiguous fields-of-view processed	Every 3rd element of every 3rd line
Uses spatial variance cloud mask	Uses split window comparison with Tsfc [i.e., surface temperature]
Clear sky radiance calculated with biases removed from monthly statistics.	Clear sky radiances spatially extrapolated from 12 hour analyses
Temperature fields from NCEP/NCAR Reanalysis	Temperature fields from daily operation GDAS

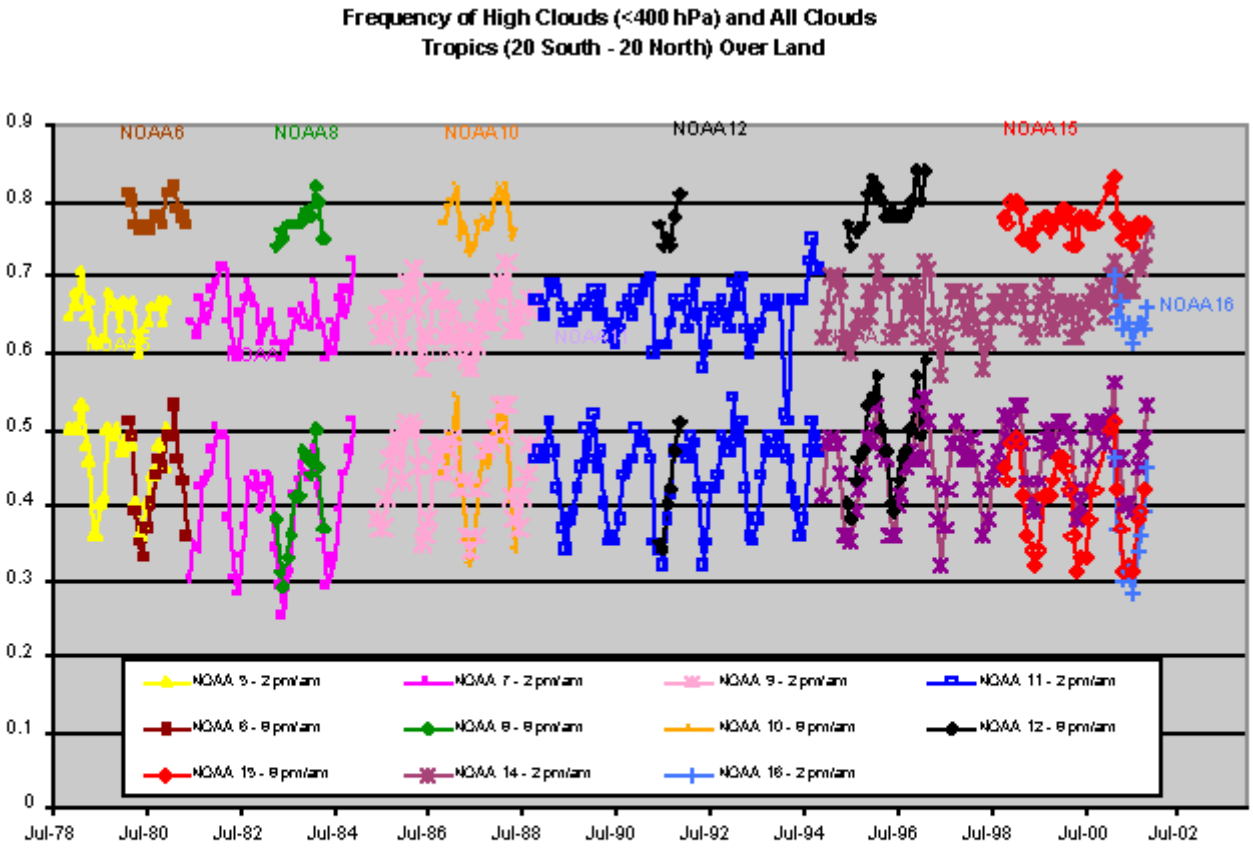
The HIRS Pathfinder analysis used three passes through the data. The first pass identified clear FOVs and compiled monthly averages of the differences between clear sky radiances estimated from forward radiative calculations and the HIRS clear FOV measurements. These difference averages were used to remove biases in the forward radiative calculations used in the cloud height analysis. The second pass estimated cloud top pressure and cloud IR emissivities. Data formerly classified as clear FOVs were included in the cloud analysis to see if thin cirrus (low IR emissivity) clouds could be identified. In the third and final pass through the data, the forward radiative calculation biases were recomputed eliminating all FOVs in which thin cirrus were found in the previous pass. Cloud top pressure were then re-computed using the corrected biases. This longer analysis improved on the Wisconsin method by including the cloud analysis for thin cirrus as part of the cloud mask.

Results

The frequencies of all clouds and high clouds (above 400 hPa) are shown in Figures 1 and 2 for the tropics, 20 south to 20 north latitude. The cloud frequencies over land (Fig. 1) show large annual cycles and differences between satellites from diurnal cycles and different local orbit times of each satellite. Satellites NOAA 6, 8, 10, 12 and

15 observed around sunrise and sunset (8 am and 8 pm local time), and 5, 7, 9, 11, and 14 observed at 2 am/pm local time. Over oceans, the annual and diurnal cycles were weak.

Figure 1:



Conclusions from HIRS CO2 Observations of Tropical (20N-20S) Cloud Cover over I

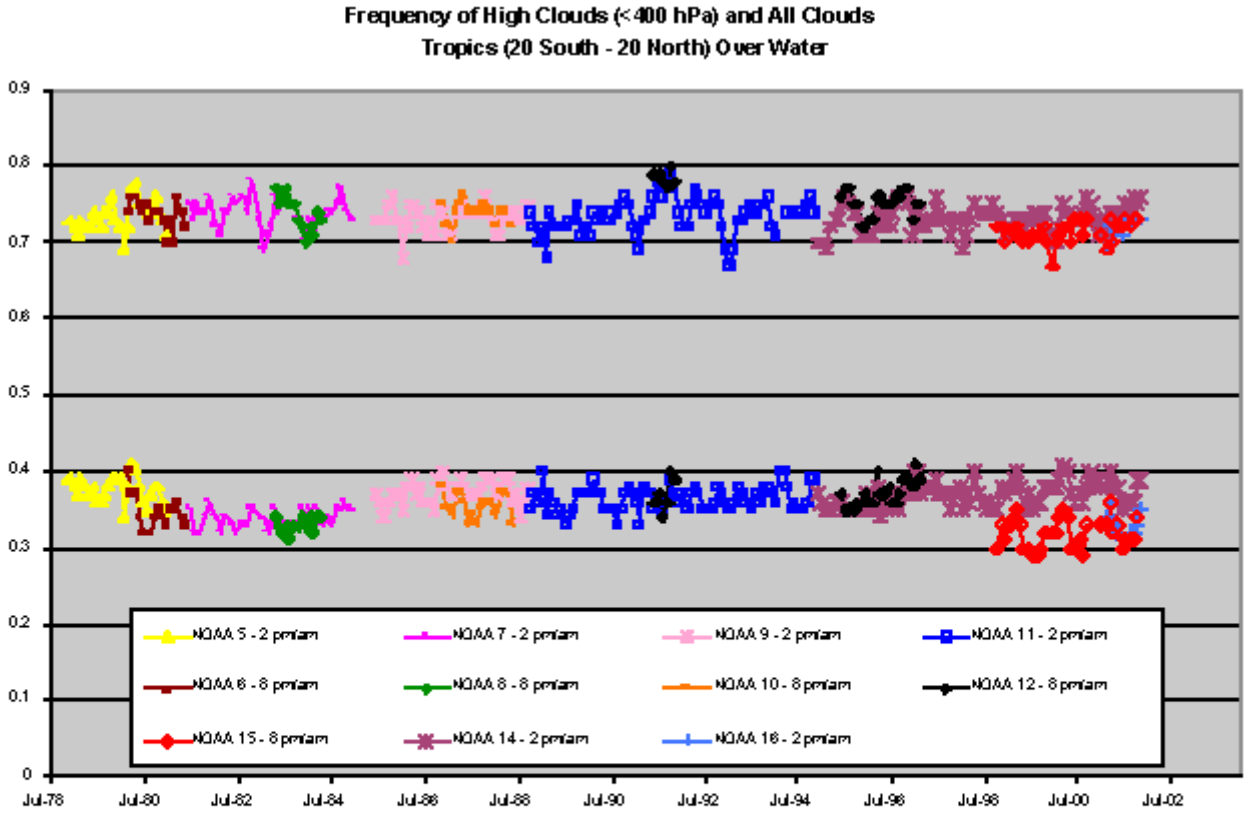
•HIRS high clouds show strong seasonal and diurnal cycle

*** All clouds remain constant while high clouds show modest fluctuations in 82, 96, an**

Land and ocean data were combined in Figure 3 which also denotes major climatic events that happened in this record; the eruptions of two tropical volcanoes, El Chichon and Pinatubo, which spewed ash into the stratosphere, and the Southern Oscillation Index (SOI) which shows the El Nino - Southern Oscillation (ENSO) events that started in 1983, 87, 91, and 97.

The HIRS Pathfinder analysis also was compared to the Eumetsat 3I analysis of HIRS and TOVS data in Figure 4. Similar cloud frequencies were found. Comparison to ISCCP analysis showed the HIRS Pathfinder reporting more high clouds especially in the tropics.

Figure 2:



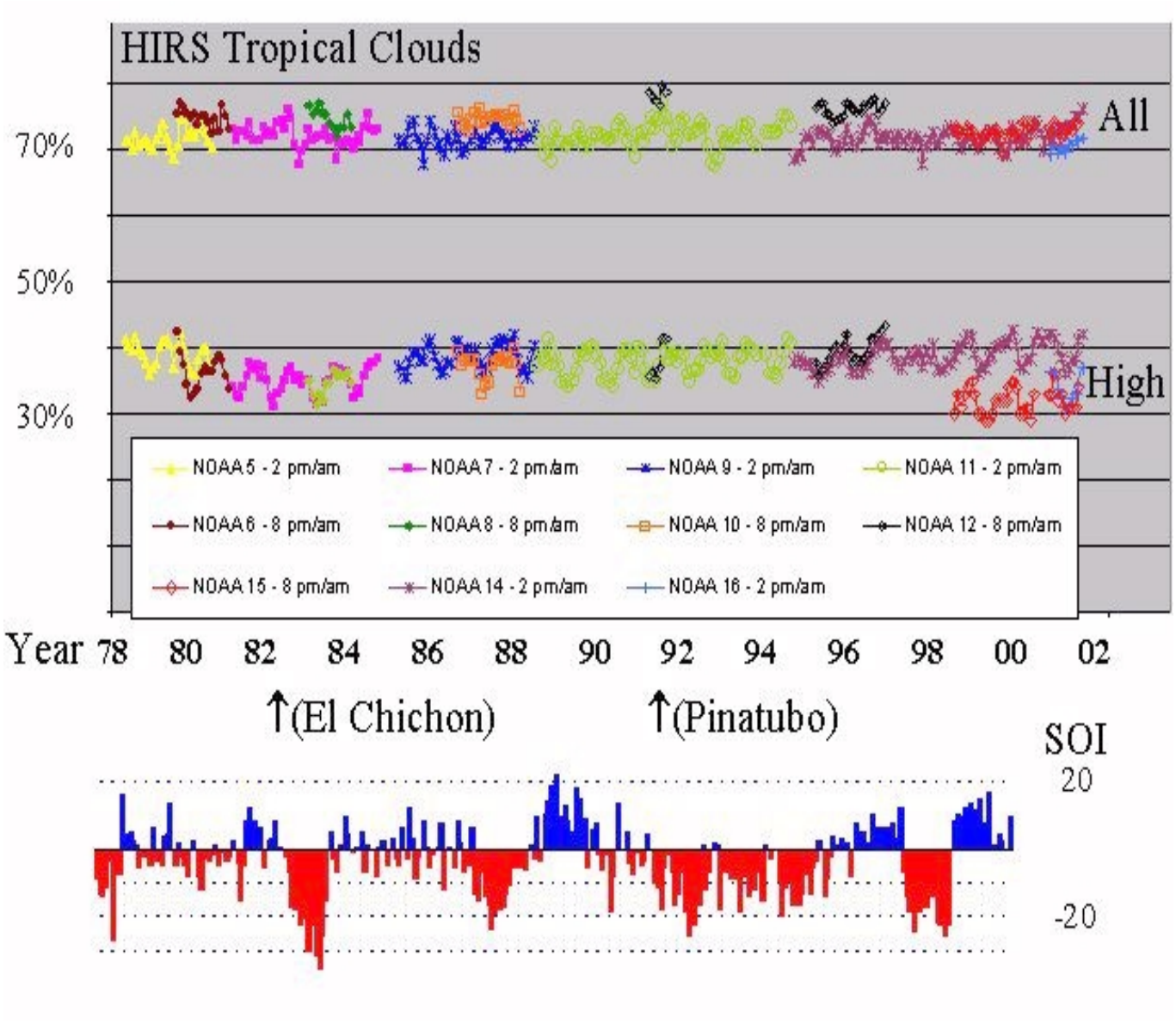
Conclusions from HIRS CO2 Observations of Tropical (20N-20S) Cloud Cover over Oc

•All cloud cover is very stable

*** Clouds are detected in 75% of HIRS observations**

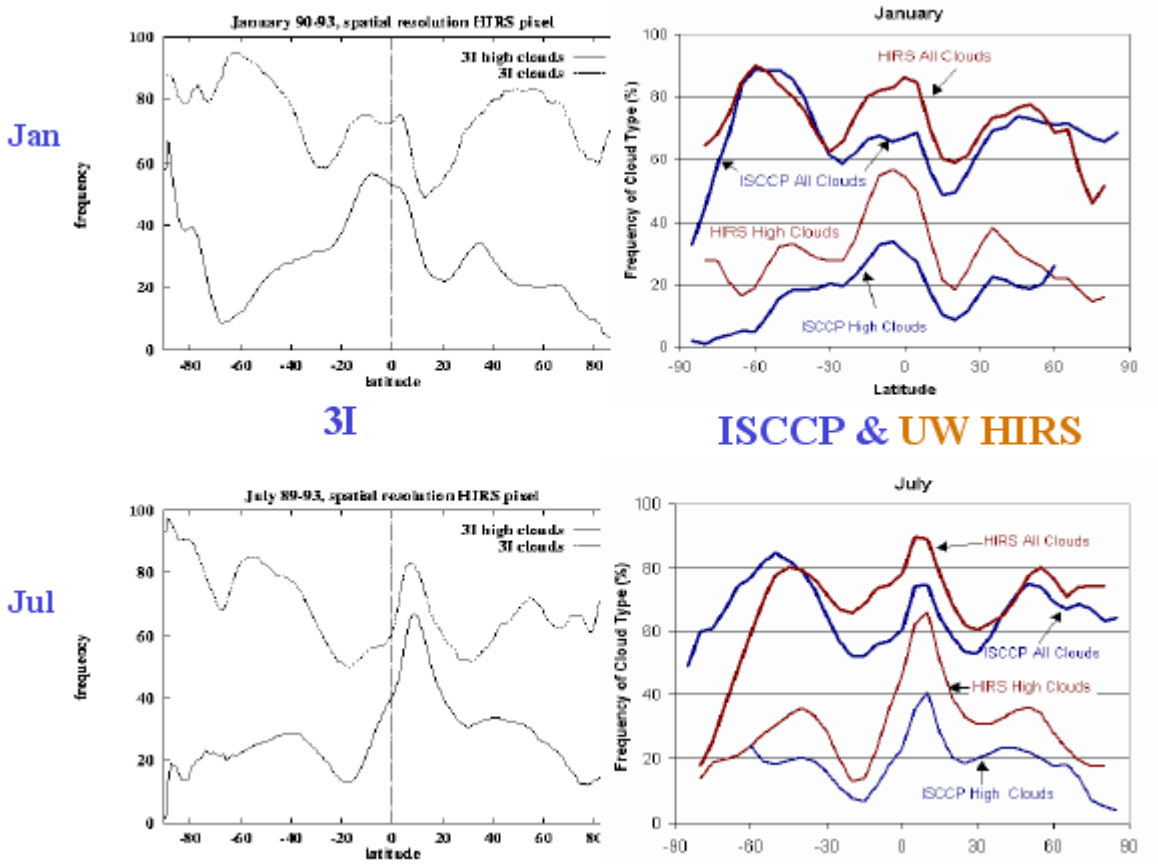
*** N15 is out of family (HIRS 3) starting 1998**

Figure 3: Frequency of clouds from the HIRS Pathfinder analysis of land and ocean combined in the tropics. Also shown is the Southern Oscillation Index and tropical volcanic eruptions.



The SOI (Southern Oscillation Index) is the barometric pressure difference between Tahiti and Darwin, Australia. It's used as an index with ElNino - ENSO. The SOI is an indicator of the strength of the trades in the west pacific.

Figure 4: Comparison of 3I, ISCCP, and HIRS:



Conclusions

- Clouds were found in more than 70% of HIRS observations since 1978, with high clouds found in more than 30% of the observations.
- 22-year trends in HRIS high cloud statistics reveal modest increase during last decade compared with previous decade.
- Volcanic eruptions and El Nino events disrupt trends.
- Orbit drift and satellite differences must be mitigated (differences in cloud statistics and their trends are consistent with changes in local solar times of orbits for satellites that drifted).
- The high cloud frequencies for NOAA 15 and 16 are lower because of changes in the spectral positions of two channels in the transition to the upgraded HIRS-3 sensor.
- Loop of monthly means shows latitudinal cloud cover follows the sun
- ISCCP finds 10% fewer high and all clouds in tropics.
- 3I agrees with UW HIRS on global high clouds.

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