Paper 13.3

Diurnal Cycle of Clouds and How They Affect Polar Orbiting Satellite Data

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1. Introduction

Polar orbiting satellites have commonly been used for studying cloud cover. One criticism of using these satellites is that they fly in sun synchronous orbits and are affected by diurnal cycles in clouds. They sample at only one or two times per day which will cause biases in their reported statistics on cloud cover because they may be consistently observing at the high or low points in these diurnal cycles. Because of this problem the International Satellite Cloud Climatology Project (ISCCP, Rossow and Schiffer, 1999) used geostationary satellites gathering eight observation per day where these satellites were available. The diurnal cycles of clouds have been analyzed by Bergman and Salby (1996), Chen and Houze (1997), Kondragunta and Gruber (1994 and 1996), Cairns (1995), Hendon and Woodberry (1993), Duval (1989), Houze and Betts (1981) and Gray and Jacobson (1977),. These studies found significant diurnal cycles over land masses which appear to be driven by solar heating. The highest values in cloud cover were usually found just after solar noon. Some morning maxima were found in coastal areas. Over oceans the maxima usually occur in the mornings for low altitude marine stratus clouds. They appear to grow at night from radiative cooling and evaporate during the day from solar insulation. Diurnal cycles in high altitudeclouds tend to lag the lower clouds with late afternoon maxima (Wylie and Woolf, 2002). High clouds have diurnal cycles where solar insulation triggers deep convection. This commonly occurs in mountains and coastal regions during summer months. An except was found in the Pacific Ocean by Chen and Houze (1997) where high clouds exhibited a morning maxima probably due to infrared cooling at night at the tops of deep convective clouds.

2. Polar orbiting observations

NOAA series polar orbiting satellite data were analyzed for cloud cover by Wylie et al. (2005). This study reported the cloud cover from the 2 am/pm NOAA satellites because this orbit had a continuous record. The 8 am/pm orbit had large gaps in coverage of over a year in duration so it was not discussed in Wylie et al. (2005). However, a 10 year period of continuous coverage in both orbits occurred from 1986 to 1996. The differences in cloud cover reported by the two NOAA orbits were examined during this period.

The average cloud cover (all clouds at all altitudes) for this periods is summarized in Figure 1. White areas are where clouds are most frequent while in dark areas they are less frequent.

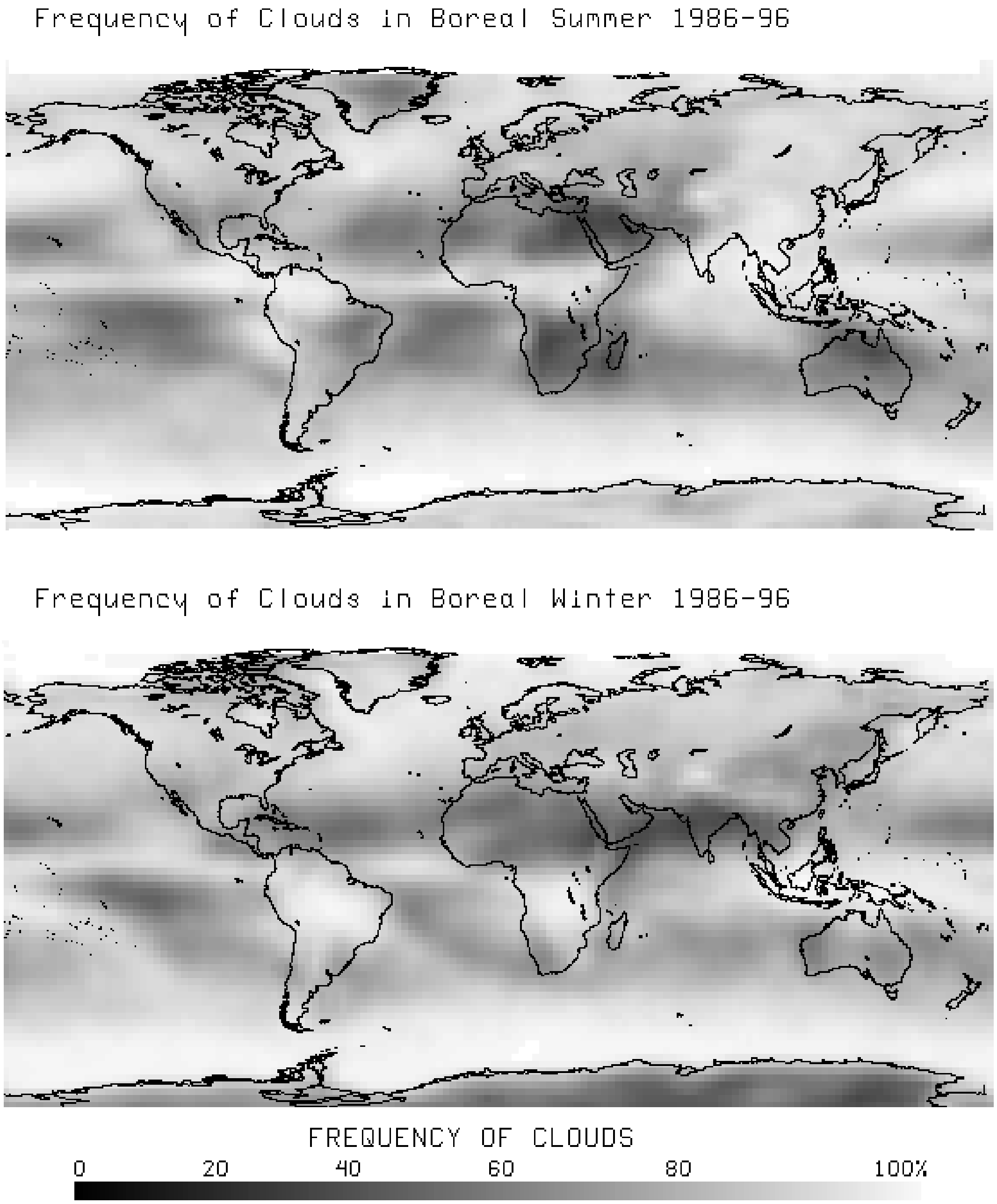
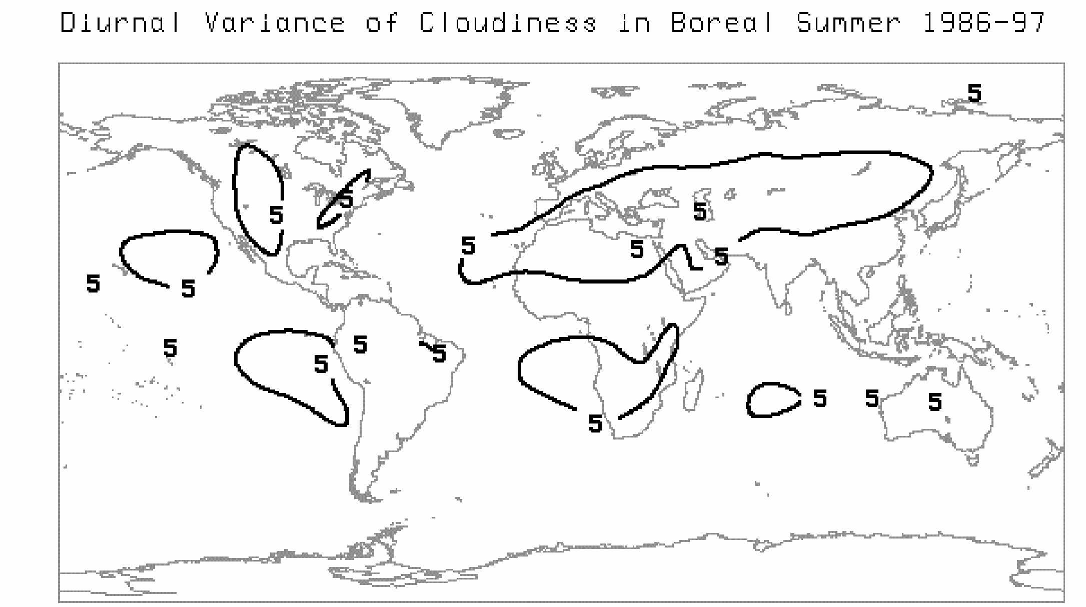


Figure 1: The frequency of all clouds from the HIRS NOAA polar orbiting satellite data.

Clouds are most frequent in the tropics especially over South America and Africa. This is the Inter-tropical Convergence Zone (ITCZ) and it moves north and south with the sun between seasons. Clouds are less frequent north and south of the ITCZ which is where the sub-tropical deserts occur over land and the subtropical high pressure centers occur over oceans. This is extensively discussed in Wylie et al. (1994 and 2005).

The NOAA polar orbiting satellites in the 2 am/pm and 8 am/pm orbits give four observations per day. While this sampling is less than the ISCCP, it shows the magnitude of the problem. The range in cloud cover reported by the four observations is shown in Fig. 2 below.



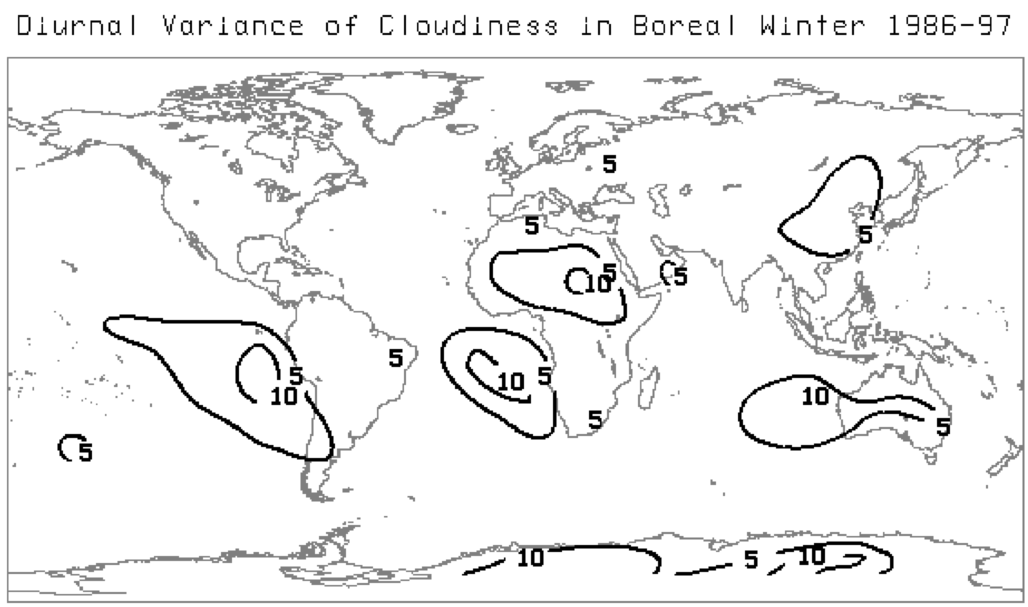


Figure 2: The differences in cloud cover averages between the four observations of the NOAA satellites. The Boreal summer is the months of June, July and August and the Boreal winter is the months of December, January and February.

In general the locations of significant amplitude diurnal cycles agree with the studies of Bergman and Salby (1996) and Kondragunta and Gruber (1996). The largest diurnal cycles appear to be over southern oceans during Boreal winter months and the Saharan desert. Here 10% differences in cloud cover were found between orbits. The northern subtropical oceans also found diurnal cycles during Boreal summer months of slightly smaller magnitude. Over land diurnal cycles were large over the Saharan desert, the Australian desert and over parts of Asia and North America. The North American diurnal cycle is primarily found during the summer season and absent in winter. Over Asia, diurnal cycles were found in both seasons.

The zonal averages of cloud cover also show these diurnal cycles. An example is shown in Figure 3. The cloud cover averaged over the southern ocean from the equator

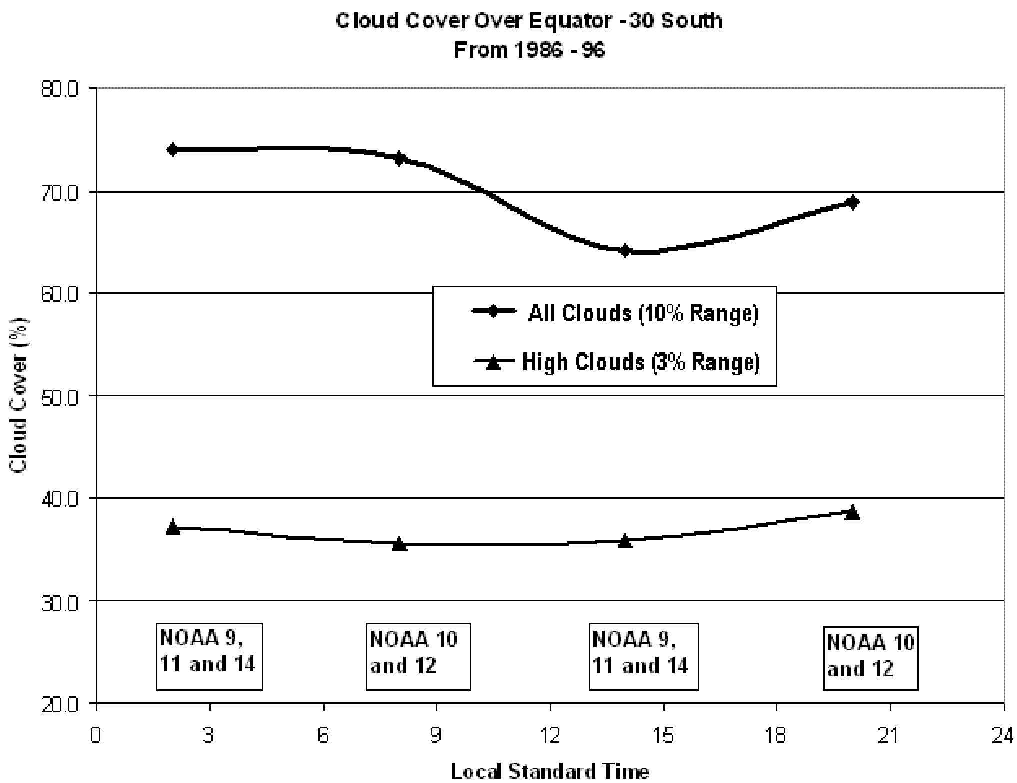


Figure 3: The cloud cover reported by the ascending and descending orbits from the NOAA satellites averaged over all longitudes from the equator to 30 south latitude over the oceans during Boreal winters.

to 30^{o} south latitude exhibits a 10% change between orbits. The apparent maxima occurred at 2 am and 8 am and the minimum at 2 pm. This is the largest diurnal cycle found in the NOAA satellite data.

High clouds had little diurnal cycle in this area with only a 3% range. This agrees with Wylie and Woolf (2002) which concluded that high cloud diurnal cycles were primarily in areas and seasons where deep convection occurred and absent or very week in all other areas.

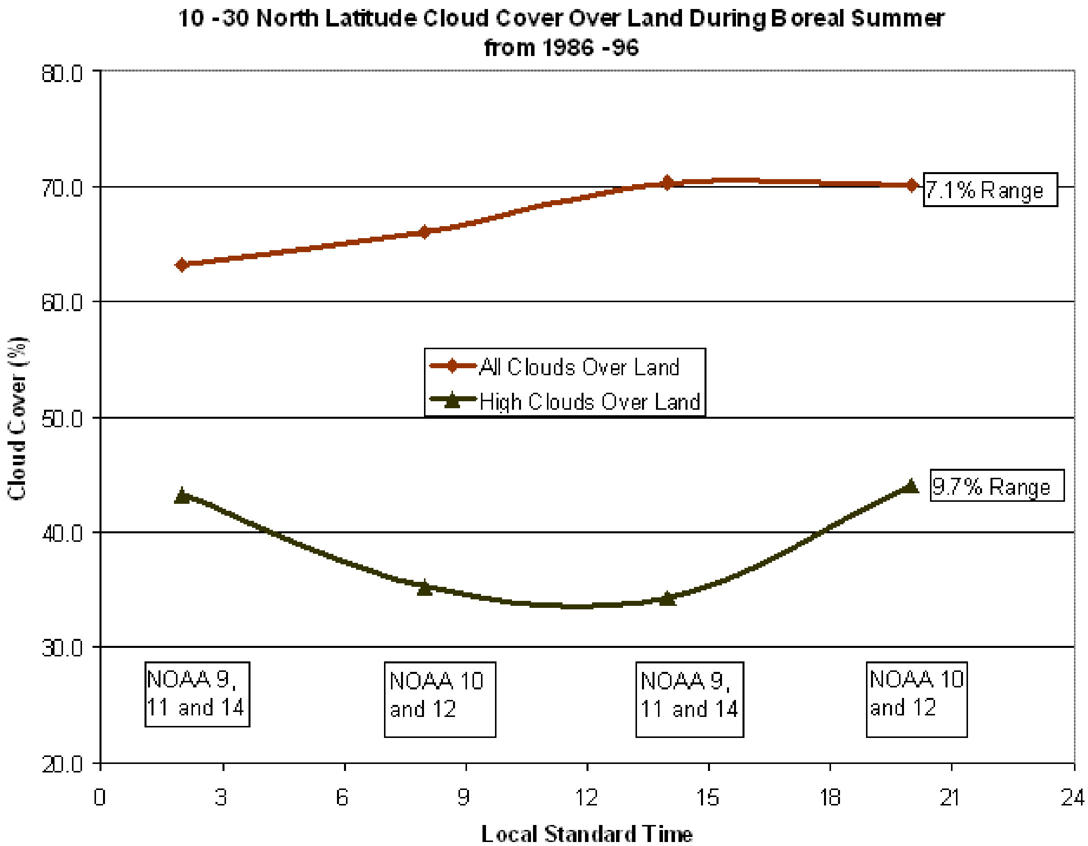


Figure 4: The cloud cover measured from the four observations of NOAA satellites averaged over all longitudes from 10-30 north latitude in Boreal summer months.

The land diurnal cycle (Fig. 4) shows the afternoon maxima with the high clouds lagging in time as discussed in Bergman and Salby (1996) and Kondragunta and Gruber (1996). The diurnal cycle of high clouds is stronger than the low clouds during the summer season.

3. Detailed study of high clouds

Wylie and Woolf (2002) employed the VISSR Atmospheric Sounder (VAS) data on the geostationary satellites operated by NOAA to specifically study diurnal cycles in high clouds. The VAS had partially absorbing CO2 channels which were used for detecting transmissive upper tropospheric cirrus clouds. It is hard to estimate the altitude of these clouds because they transmit terrestrial radiation and appear warmer than their altitude in satellite data. However, the partially absorbing CO2 channels used for making atmospheric soundings also can be used to refine cloud altitude measurements.

The VAS instrument scanned a limited area of the continental United States and some of its bordering oceans eight times per day. An additional tropical data set was collected over Brazil for a short period. This produced better diurnal coverage of upper tropospheric thin cirrus clouds that the ISCCP. The ISCCP uses visible reflectance measurements to identify altitudes of thin cirrus clouds which limits it to daylight data. The VAS provided a consistent data set of both day and night data.

The results of Wylie and Woolf are summarized in Figures 5 and 6 below. The strongest diurnal cycles in high clouds were found in

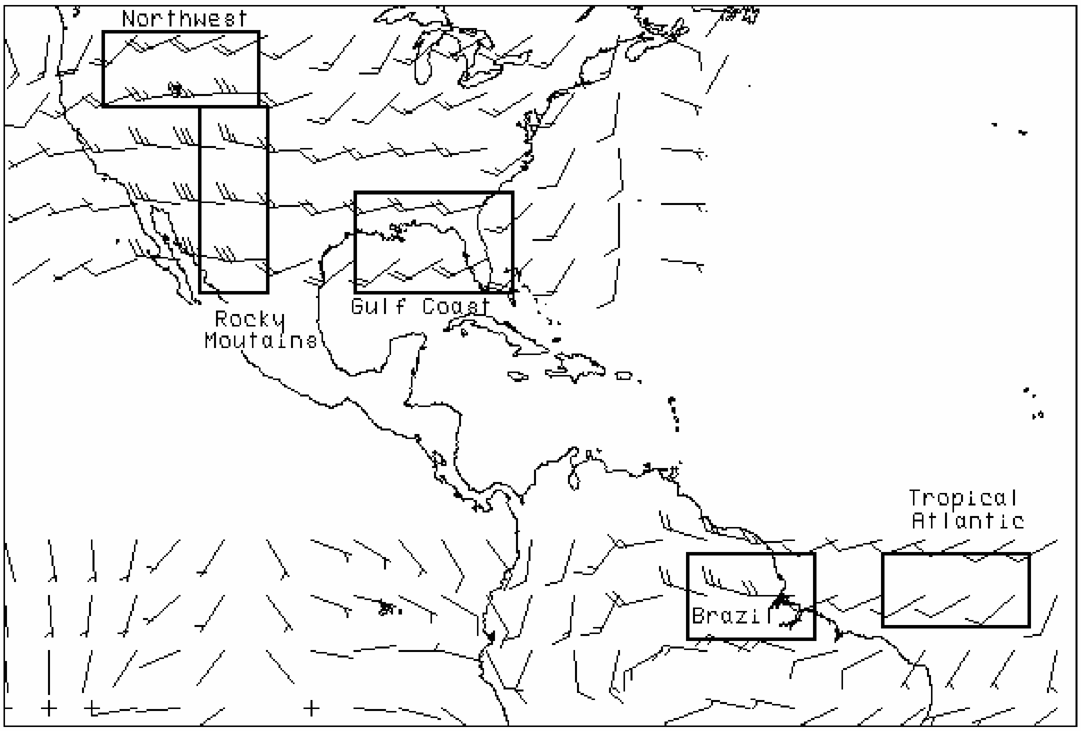


Figure 5: Boxes show the locations of areas analyzed for diurnal cycles from GOES VAS data by Wylie and Woolf (2002). The flags show the time and magnitude of diurnal cycles in upper tropospheric clouds. The direction of the flags correspond to a 24 hour cycle where flags from the south (bottom of page) indicate a solar noon maxima. Flags from the west (left) indicate a sunset maxima. (Reprinted with permission).

the Gulf Coast and Rocky mountains. Over oceans diurnal cycles in high clouds were small and sometimes absent. The mountain maxima occurred near sunset while earlier maxima occurred in the Gulf Coast region.

A comparison to the ISCCP data for the same locations and time periods also was made (Fig. 6). In general the ISCCP data exhibited similar diurnal cycles during daylight hours as the VAS but of weaker magnitude. The conclusion of Wylie and Woolf (2002) was that the ISCCP IR only data could be used to locate the regions of significant diurnal cycles in upper tropospheric clouds. However amplitude of these diurnal cycles were about one and one half times larger than shown in the ISCCP IR only data.

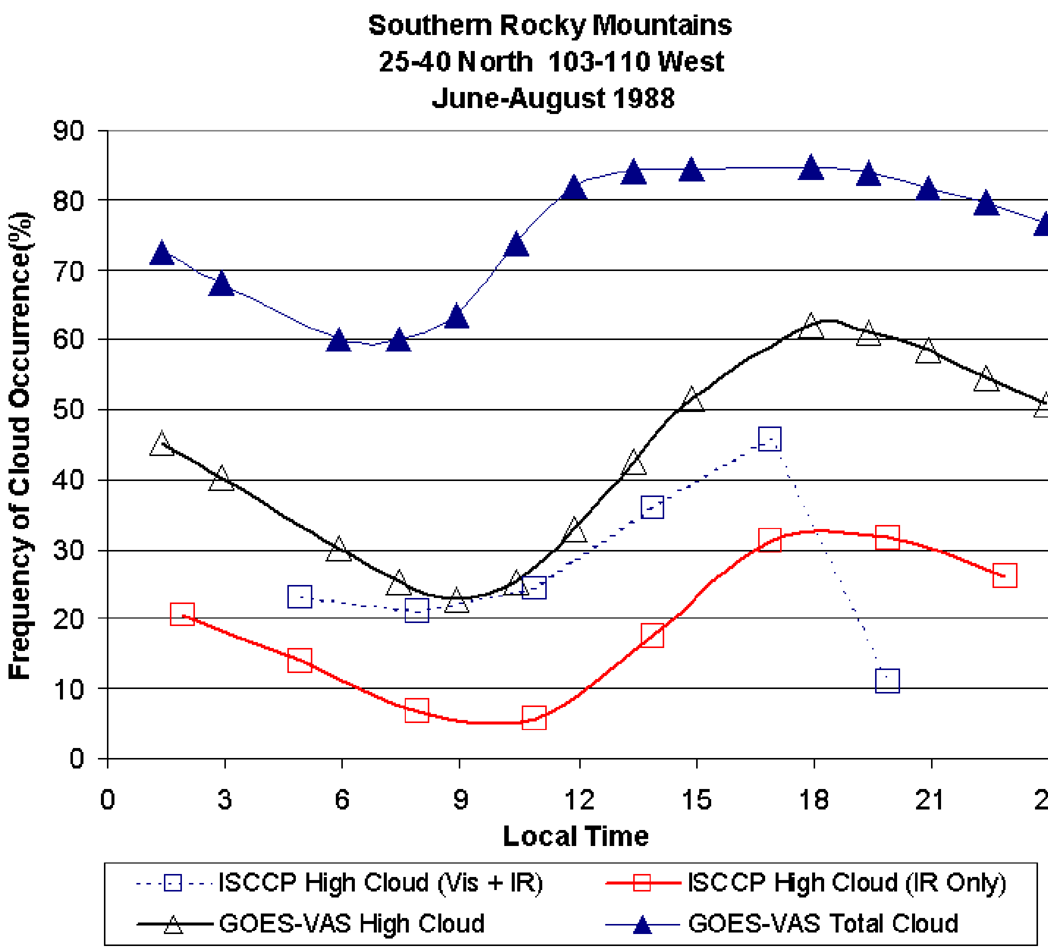


Figure 6: The diurnal cycle in clouds measured by GOES VAS and the ISCCP. Reprinted from Wylie and Woolf (2002) with permission.

4. Summary and conclusions

The diurnal cycles are significantly strong, being around 10% in amplitude in some areas. Zonal averages show these strong diurnal cycles if land and water are analyzed separately. However, these diurnal cycles may be missed if land and water areas are combined in zonal averages because maxima occur at opposite phases in time.

The averaging of both the ascending and descending NOAA satellite orbits reduces the affect of diurnal cycles in the cloud cover reports. The study of Wylie et al. (2005) averaged the 2 am and 2 pm orbits of the NOAA satellites together (NOAA 9, 11 and 14). This could be done only because long wave IR data were used and cloud cover, both high and low, were consistently measured during both daylight and night with these data. This averaging reduced the affect of sampling inside diurnal cycles.

However, the cloud cover reported by the 8 am/pm orbit satellites is not as symmetrical as the 2 pm/am satellites. Averaging of the ascending and descending appears to produce larger cloud cover values than the 2 am/pm orbits in Figures 3 and 4.

Wylie and Woolf (2002) show that the local times of minima and maxima occur in between the observations of the NOAA satellites. This detail is important if one desires to measure cloud cover with an accuracy of 1% or less.

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