P6.7

View angle dependence of cloudiness and the trend in ISCCP cloudiness

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The International Satellite Cloud Climatology Project cloud analysis has a small view angle dependence in its cloud estimate. There is about 10% more cloudiness reported at 60^o view angle compared to normal views of the same scene. Over the twenty year ISCCP record, more geosynchronous satellites have been added to the analysis and the mean view angle over the globe has become more vertical. This systematic change in view point convolved with the view angle dependence in cloudiness produces much of the decreasing trend in ISCCP cloud amount, both regionally and globally. An empirical correction can be made to the ISCCP cloudiness time series which makes the data more useful for climate studies. This angular dependence is a real physical phenomena much like bi-directional reflectance for reflected sunlight from different surfaces. It should be incorporated in the conversion of instantaneous cloudiness at a particular view angle to averages over time and over view angle. Finally we discuss the impact on optical depth and radiative transfer in cloud fields.

1. Introduction

The International Satellite Cloud Climatology Project data set is a compilation of operational satellite observations analyzed for cloud frequency of occurance and the cloud radiative properties (Rossow and Schiffer, 1991). The analysis is available from July 1983 to September 2001. The basic analysis first constructs a background composite radiance and then assigns clouds to pixels significantly colder or brighter than the background. Cloud amount is then the frequency of pixels different from clear. It is a merger of AVHRR polar orbiter data two to four times per day with available geosynchronous observations superimposed. The geosynchronous satellite data are preferred because they provide evenly spaced observations 8 times per day. Figure 1 shows a monthly mean cloudiness for one particular month of observations. In this case only 3 geosynchronous satellites are available so the seams between geo data and AVHRR data are obvious. If trends of the 18 year data set are constructed, figure 2, one sees these seams as well. Qualitatively one suspects that different view angles are affecting the products.

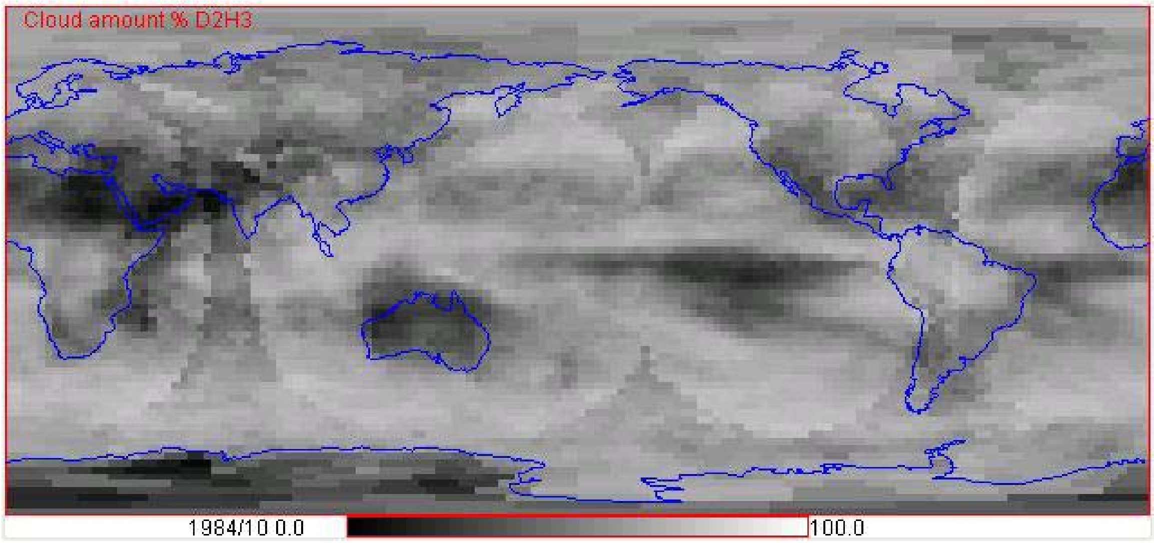

Figure 1: One month average () for a month with only 3 geosynchronous satellites available.

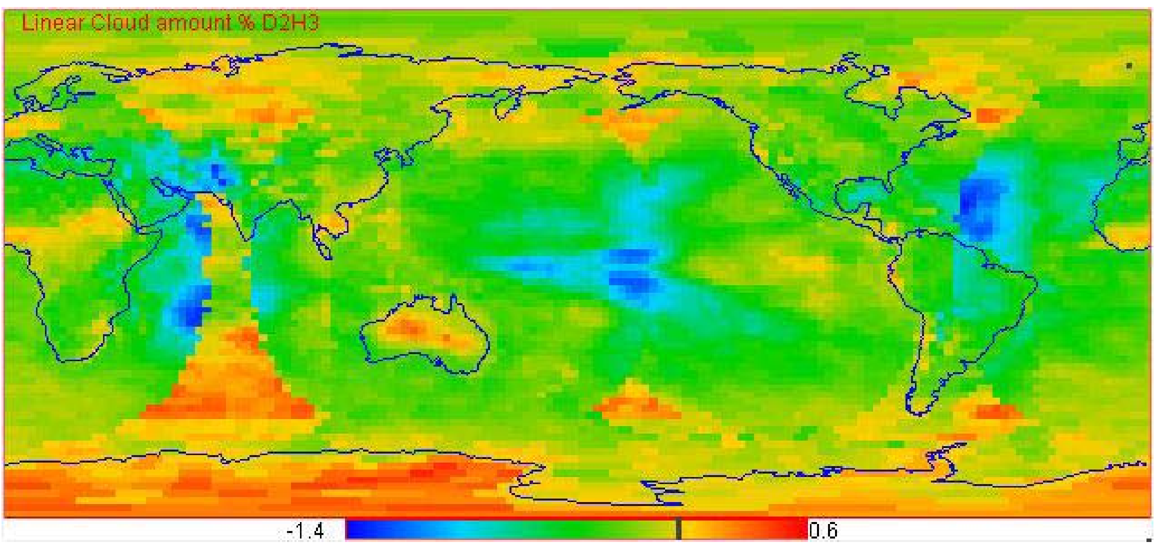

Figure 2: Map of the trend in cloudiness from July 1983 to September 2001. The trend was calculated at each ISCCP 280 km X 280 km grid box after removing the annual cycle (Rossow et al. 2003).

2. Angular dependence

There are a number of different ISCCP data products. Figures 1 and 2 were constructed from the ISCCP monthly mean product: D2. To look in more detail at the angular variation of the cloudiness the ISCCP DX product was averaged in a different way. The DX data contains the pixel level cloud flags (cloud/no cloud) and more important, each satellite is available separately. This allows comparisons between the overlapping observations. Figure 3 shows the monthly mean overlapping observations from all the available satellites for January 2001 for one latitude band. That month had 5 geo satellites and 1 polar orbiter available. One sees qualitatively that the cloudiness seems to increase at steeper view angles: locations farther from the geo. subpoints. The AVHRR in this case is the average of all view angles, but because the geo satellites have a fixed view points in time, at any particular longitude, the observations are all taken at the same view angle for the month.

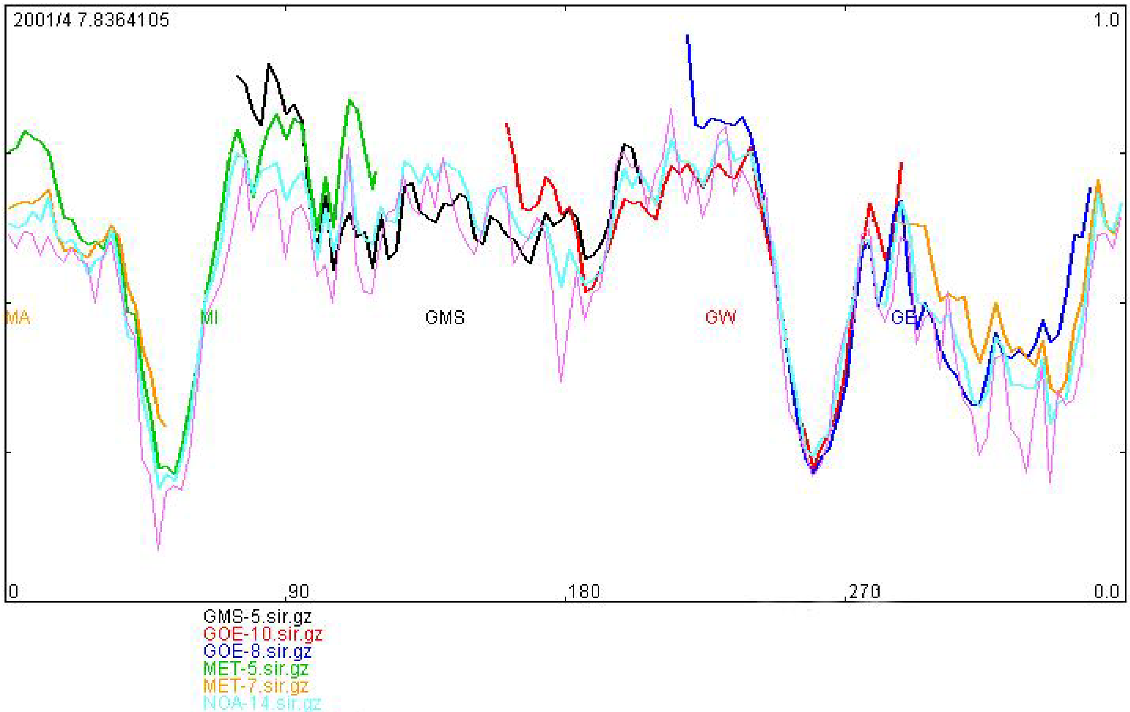

Figure 3: Transect (all longitudes) showing all the individual satellites contributing to ISCCP. April 2001 at 7^o north. MA: Meteosat 7 over Africa at 0^o East, MI: Meteosat 5 over Indian Ocean at 63^o East, GMS: GMS-5 at 135^o East, GW: GOES 10 at 225^o East and GOES 8 at 285^o East.

To explicitly look at angular variations, monthly means were constructed from the DX data for each satellite separating the averages into different view angle bins. After some experimentation, bins equally spaced in 1./cos(view angle) were chosen. For the AVHRR data, any particular view angle bin and particular latitude longitude and month, has considerable random variation in the monthly means because each bin has only about 1./6. of the pixel observations. Notice that we did **not** perform a new cloud analysis, we are just averaging the data in different categories based upon view angle and satellite. For the polar orbiter data, global maps of monthly cloud amount appear for each view angle. Differences in these maps tell us the angular variation of the cloudiness derived from the ISCCP algorithm. Figure 4 shows the grand average of this angular variation.

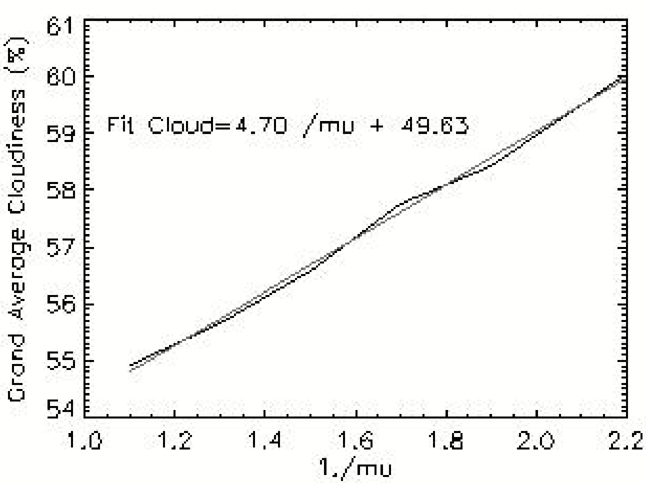

Figure 4. Average of all AVHRR maps of cloudiness for 7/1983 to 9/2001 for the region 50^o north to 50^o south. Six separate maps are included in the curve. The gray fit line is superimposed.

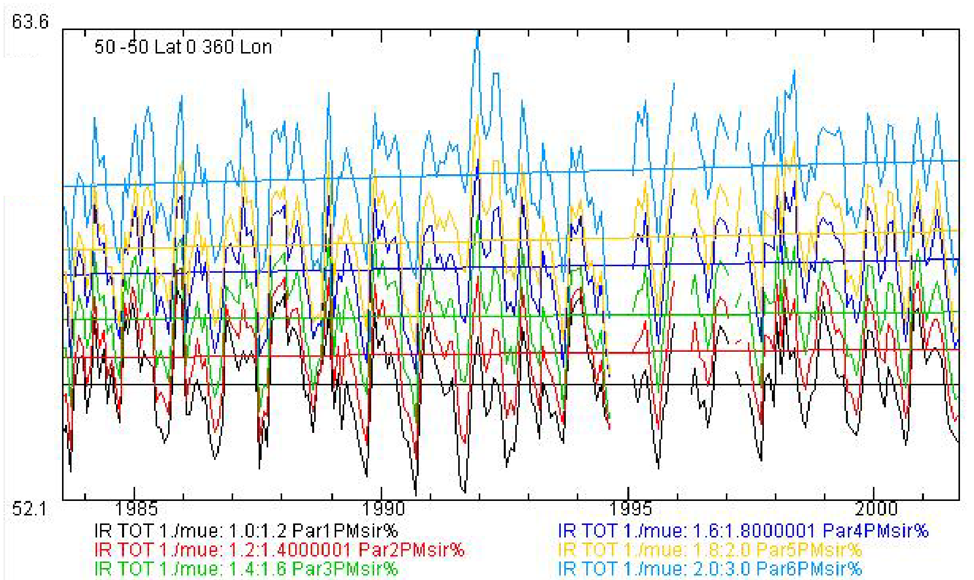

Figure 5. Averages of ISCCP AVHRR afternoon satellite, segregated into 6 different angular bins.

To look at this in more detail, figure 5 shows the time variations of each of the view angle groupings.

Clearly from figures 4 and 5, more clouds appear from the analysis at steeper view angles. This can be summarized with the following empirical relationship eq 1:

Cloudiness(view angle) = C0 + C1/cos(view angle) eq 1

The cloud amount viewing straight down would have cos(view) = 1.: eq 2.

$C_{vertical}$ = C0 + C1 (54.3) eq 2

This function can be integrated over all possible view angles to give the radiometric average cloud amount, eq 3. An average like equation 3 should be **required for model** simulations of cloudy situations.

$$C_{total} = \int [C0 + C1/\cos(\theta)] \cos(\theta) d\cos(\theta) d\phi / \int \cos(\theta) d\cos(\theta) d\phi$$
$$= C0 + 2\,C1 \quad (59.0) \qquad \text{eq 3}$$

This is quite similar in concept to the bidirectional and directional functions used to convert radiances to fluxes in radiation budget analysis (Green et al. 1997). There is an important fundamental concept here. Cloud climatologies need to state the average cloudiness and the variation with view angle for any time average or region. Numerical models typically estimate radiation properties by doing vertical column calculation. Those formulations do not incorporate the concept of varying cloud amount with angle. The directional functions used to convert radiance to flux in cloudy situations contain some of this behavior because they were derived by compositing many different radiances in different angular situations.

3. Trends.

The real point of this paper is to look at the effect of this angular variation on maps and the trends. As the ISCCP project progressed, different numbers of geo satellites were available. This had the unforeseen effect of changing the average view angle as the data set has been accumulated. Figure 6 also shows the average 1./cos(view) as well as the mean cloudiness as a time series. Qualitatively one can expect that as fewer steep angle views are included in the analysis, that the cloudiness will decrease.

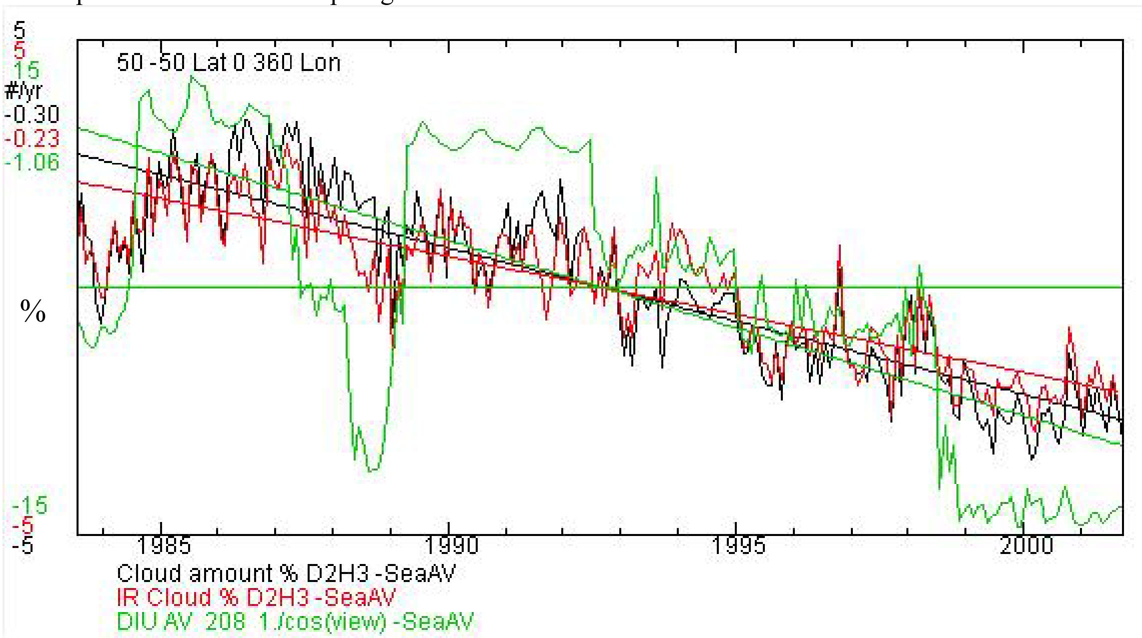

Figure 6: Time series with view angle averages. Black line shows the combination of IR and Vis clouds from the ISCCP standard D2 product. The red line is the average of just the IR cloudiness. The green line shows the average of 100./cos(view angle). The seasonal cycle has been removed from each series. For clouds amounts the scale is %.

To test this quantitatively, each of the geo monthly means was adjusted by the relationship in equation 1. Figure 7 shows the monthly mean like figure 1 and qualitatively the seams between satellites have been reduced. Figure 8 shows the trend of the adjusted data. This shows some improvement, but there are still artifacts in the maps especially in the Indian ocean. Figure 9 shows the times series of the tropical averages 20^o north to 20^o south. Indeed the angular adjustment has reduced the trend from 0.3%/year to 0.2%/year. Particularly the jump in 1998 (Meteosat added over Indian Ocean) has been eliminated and the high cloud amounts in the mid 1980's (when there were only 3 goe satellites) have been reduced.

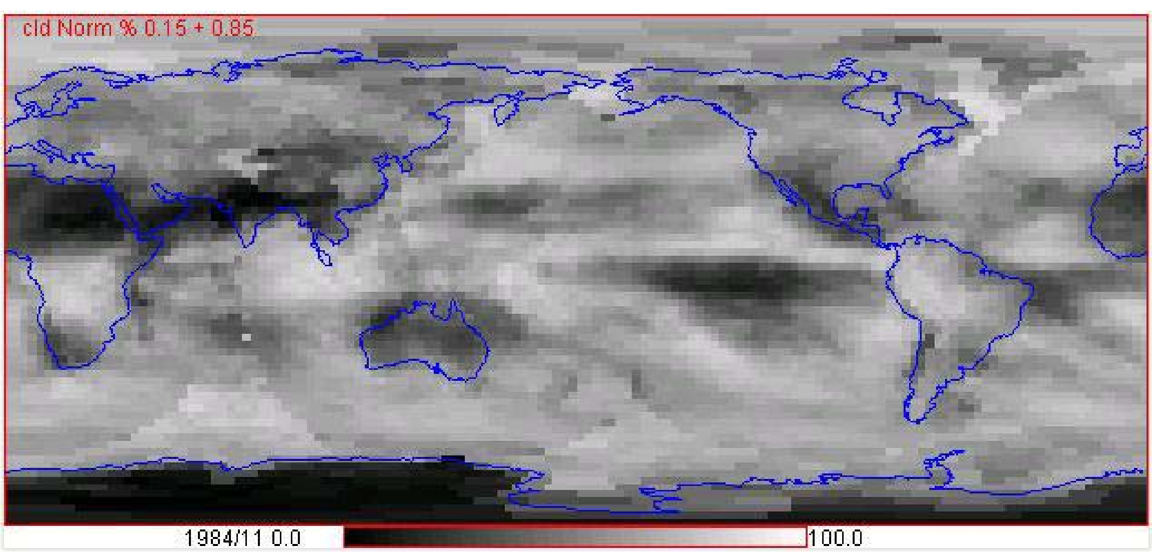

Figure 7: Month adjusted by equation 3, like figure 1.

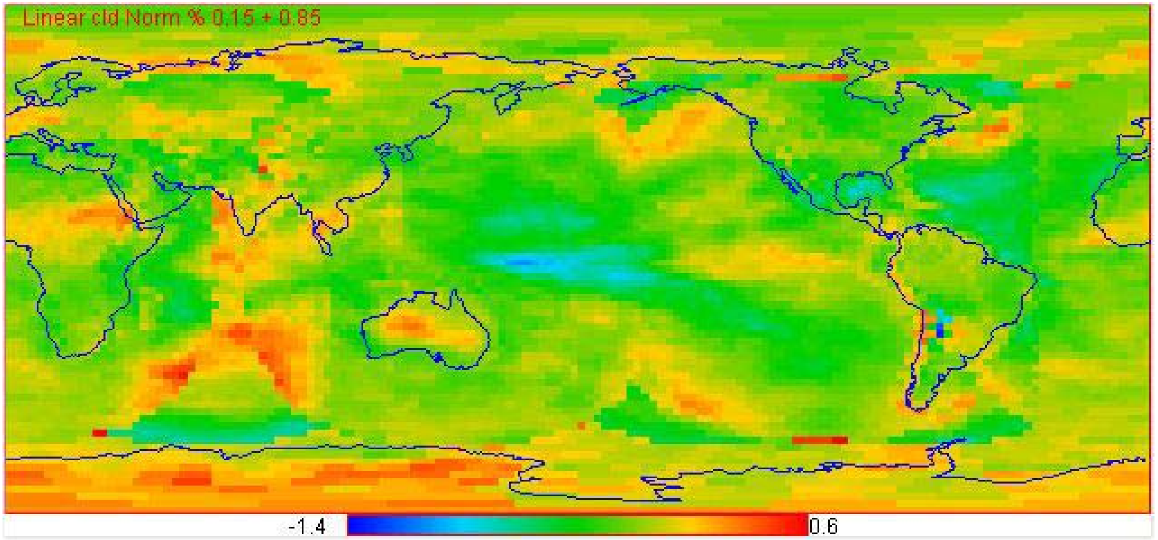

Figure 8: Trend map like figure 2 with view angle adjustments applied. Notice the absence of the negative areas shown in blue in figure 2.

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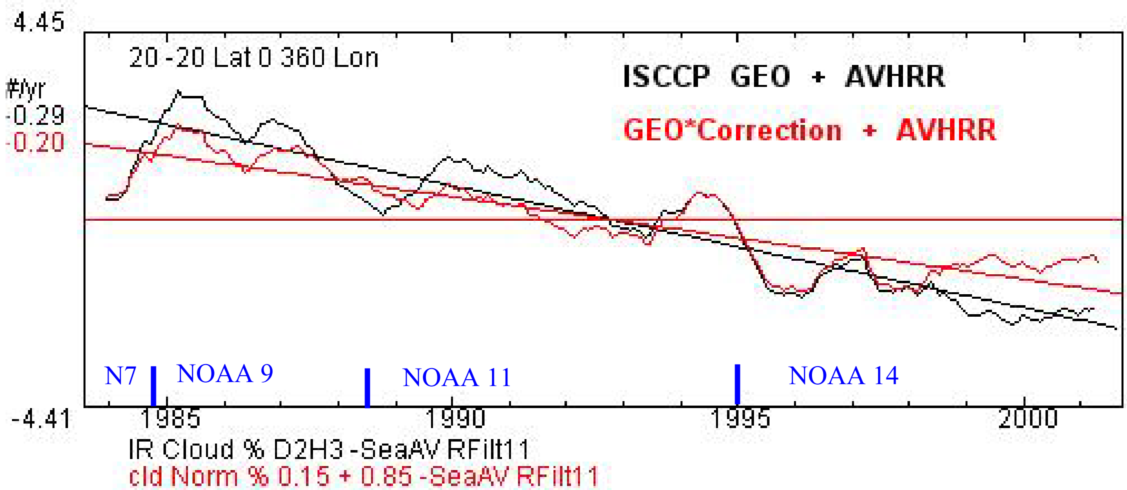

Figure 9: Trend time series like figure 6: Black the IR cloudiness and red the view angle adjusted cloudiness. An annual filter has been applied to eliminate the 2 to 3 month fluctuations in the averages.

There is still something suspicious about figure 9. There seems to be a discontinuity in 1995 in the average and that occurs just when the AVHRR satellite changed form NOAA 11 to NOAA 14. The basic calibration of ISCCP starts with a normalization of the NOAA AVHRR radiances to NOAA 7 (Brest and Rossow, 1992). Then each of the geosynchronous satellites is normalized to the concurrent NOAA satellite (Desormeaux, Y, 1993). We are now examining that to see if there is some calibration effect contributing to the trend.

There were some changes in the radiation budget as estimated by wide field of view detectors in the early 1990's (1991 to 1995) (Wielicki et al 2002). These changes are not mirrored in the large scale cloud amount although detailed cloud properties could have been changing to produce that change.

4. Conclusions

A substantial part of the ISCCP trend is due to systematic changes in the view angle over the 18 years of the data analysis. From an analysis of the AVHRR data alone, increasing cloudiness at steeper view angles is obvious. Using this empirical function to compensate for the geo view angles decreases the trend from .3%/year to .2%/year. This systematic cloud amount change with view angle must have an impact on radiative transfer calculations in model simulations of the atmosphere. Some interesting details about the trends in the ISCCP AVHRR data will appear in an up coming article in Science (Campbell and Vonder Haar 2004).

5. Acknowledgements

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