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DIURNAL AND ANGULAR VARIABILITY OF CLOUD DETECTION: CONSISTENCY BETWEEN POLAR AND GEOSYNCHRONOUS ISCCP PRODUCTS.

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There is a view angular dependence for cloud detection from the ISCCP cloud detection algorithm. Consistency can be demonstrated between polar and geosynchronous satellite observations. This leads to an angular correction model which can be applied to the either the geosynchronous or polar satellite data time series to correct for systematic angular sampling biases. Similarly there are diurnal sampling biases in the polar ISCCP observations, especially evident over the land areas. Using the ISCCP geosynchronous diurnal sampling, adjustments consistent with the polar ISCCP analysis are derived. Both these corrections lead to a more time consistent regional cloud amount time series from 1983 to 2001 from ISCCP.

1. Introduction

The International Satellite Cloud Climatology (Rossow and Schiffer 1991) project uses a combination of geosynchronous and polar orbiter data to derive cloud frequency of occurrence (cloud amount) and cloud properties. Mixing these observations together presents some problems because cloud amount detection is dependent on the view angle and each polar orbiter measures twice per day. Thus there can be view angle biases and diurnal biases depending upon which satellite data is used. There is an advantage to separating out the individual satellite observations because redundancy in overlap areas provide independent measurements and can be used for an error analysis.

Here we will show results just from the polar orbiter satellite observations which measure twice per day at different times in the day as the orbit equator crossing times drift over the years of observations. These polar observations require corrections for diurnal observation time, depending on the underlying geography (land or ocean or cloud type). We will demonstrate that the geosynchronous satellite data provides a good estimate of the diurnal cycle of cloud amount and can be used to correct the polar observations of ISCCP.

Similarly the individual geosynchoronous satellite observations have view angle biases. This shows though to the conventional D2 climatology because the view angles change when the experiment used different numbers of geosynchronous satellites.

Here I focus on the IR cloud detection products because they are available for both day and night observations.

2. Diurnal variation.

Figure 1 shows the geosynchronous observations of cloud amount for each of the 8 times per day of observation and for the 18 years for 7/ 1983 to 9/2001. Superimposed, as asterisks, are the AVHRR cloud amount estimates plotted at the local time of measurement. From this one sees that this typical diurnal cycle has just one maximum and one minimum. To zero order than, an average of two cloud amounts measurements 12 hours apart will eliminate the majority of the diurnal cloud amount bias.

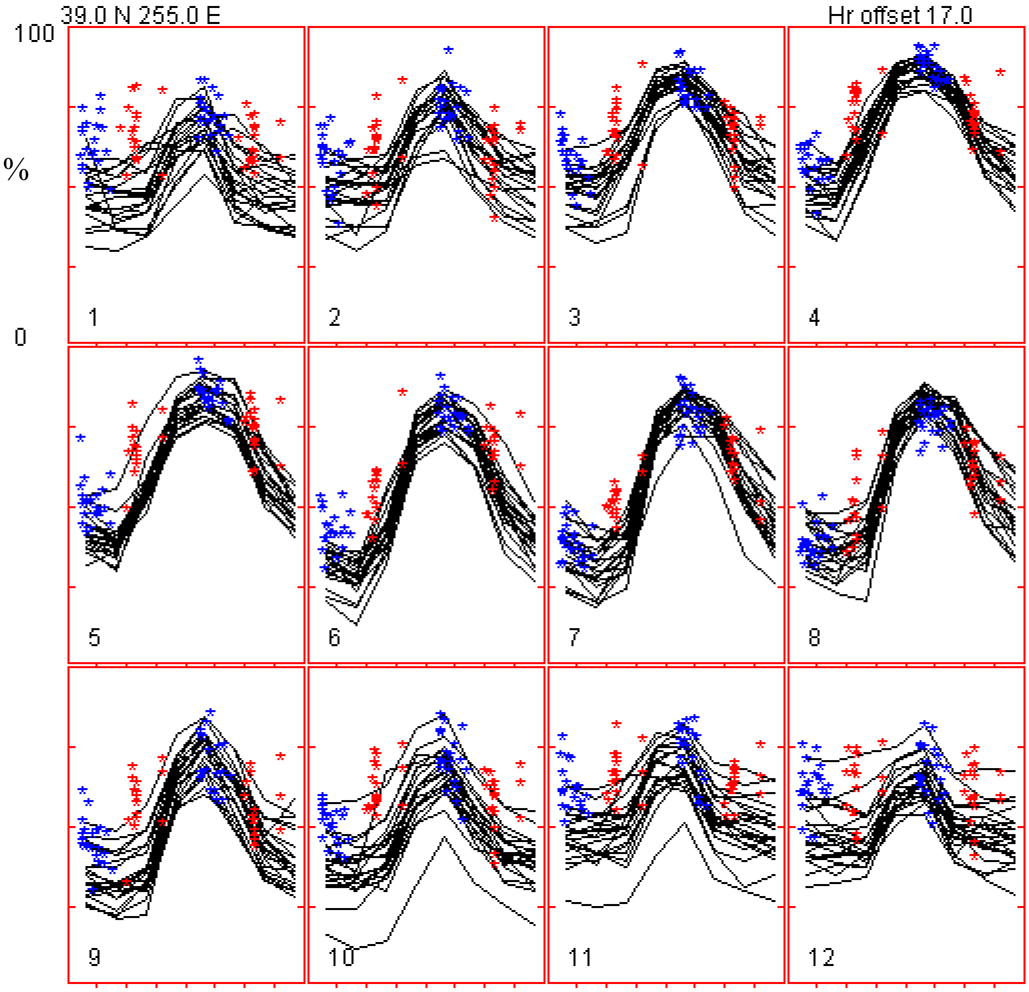


Figure 1: Diurnal cycles 12 months over western U.S. (40 N, 246 E). Each line represents the diurnal cycle for one year for each month. Local noon is at the center of each horizontal scale. Blue asterisks are AVHRR observations from N7, N9, N11, N14 and N16 satellites and red asterisks are AVHRR observations from N8, N10, N12 and N15 plotted at their respective local times. Data is included from 7/1983 to 12/2004.

From the consistency of diurnal cycles in the many years of observation, a mean diurnal cycle curve can be used as an interpolation function to make adjustments for measurements at one particular time. The first question is, should this be an offset at each time of day or a multiplicative factor to make the correction.

Since cloud amount is limited to the range 0. to 1., a multiplier factor with some kind of cut off at 1. is required. Our correction function is the ratio of the cloud amount at some time to the diurnal average as determined by the 8 geosynchronous observations:

Eq 1:
$F_{average} = F_{raw}(t)*\Sigma(G_{raw}(3hr))/(8G_{raw}(t))$

$F_{average}$ = estimate of 24 hour average cloud amount
$F_{raw}(t)$ = cloud amount at time t
$G_{raw}(t)$ = Interpolated cloud amount from nearest 2 times from the 8 G_{raw} observations.

This is calculated from the ISCCP D2 data base of 8 times per day cloud amount on a 280 km X 280 km equal area grid (6596 boxes) for each month of the year. This captures the geographical variation of the diurnal cycle. Only the 1998 to 2003 D2 data is used for this diurnal function, because there were consistently 5 geosynchronous satellites used and those satellites had no change in view angle in that period.

This is only applicable to mean statistics like monthly means of cloud amount. It could be applied to daily observations, but the weather will dominate the situation, and the diurnal correction will be small. One can see this in continental areas where it is often clear in the morning but 100% cloudy in the afternoon. One can also see from figure 1 that the year to year fluctuations in monthly cloud amount can be as big or bigger than the diurnal cycle.

This correction function can be used to convert cloud amounts from polar orbiter data or even a time series of geosynchronous data at just one time per day. Figure 2 shows the time series of AVHRR cloud estimates near 3 and 15 local time. The diurnal adjustments move the afternoon and morning values towards the means. As a secondary effect, making a diurnal correction has improved the time consistency of the time series of cloudiness at this one location. (The jump in 1995 occurred when there was a data gap and the NOAA satellite changed.) It is now possible to discuss variations from year to year in the cloud amount due to mean weather changes with out being overwhelmed by the diurnal sampling bias.

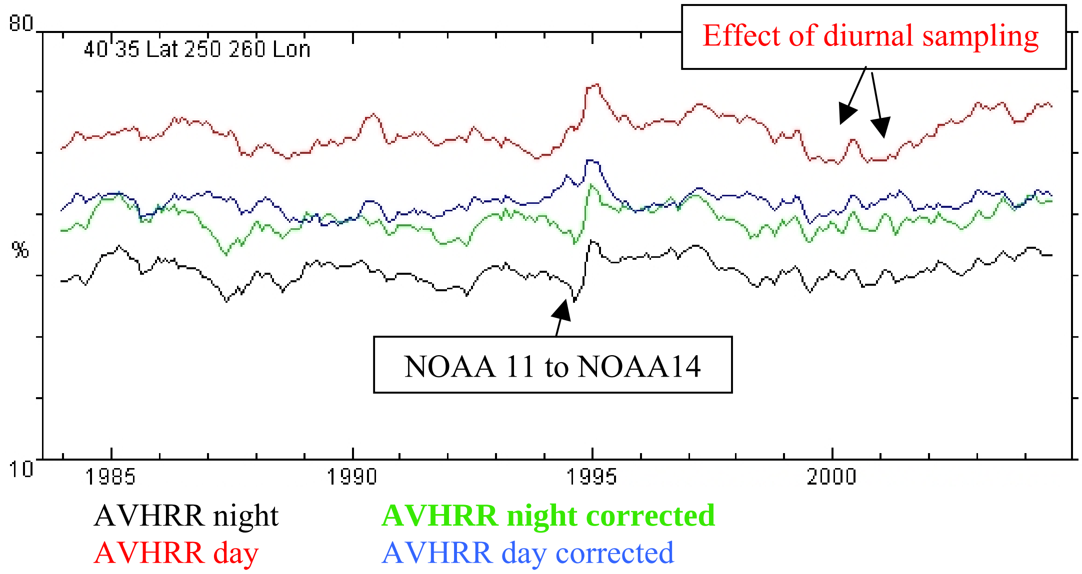


Figure 2: Time series: Central U.S. before and after correction.

Figure 3 shows the whole tropical area average before and after correction. Here the biggest effect is to decrease the night cloud amount towards the mean. Remember the diurnal correction is based solely on the geosynchronous observations. Since the morning and afternoon adjusted time series are very similar the adjustment is verified. For the tropics, averaging the day and night observations before and after correction produces nearly identical time series (correlation .98). In total, the diurnal correction makes only modest improvements in the time series of the day/night average after removing the seasonal cycle even for central North American with its big diurnal cycle.

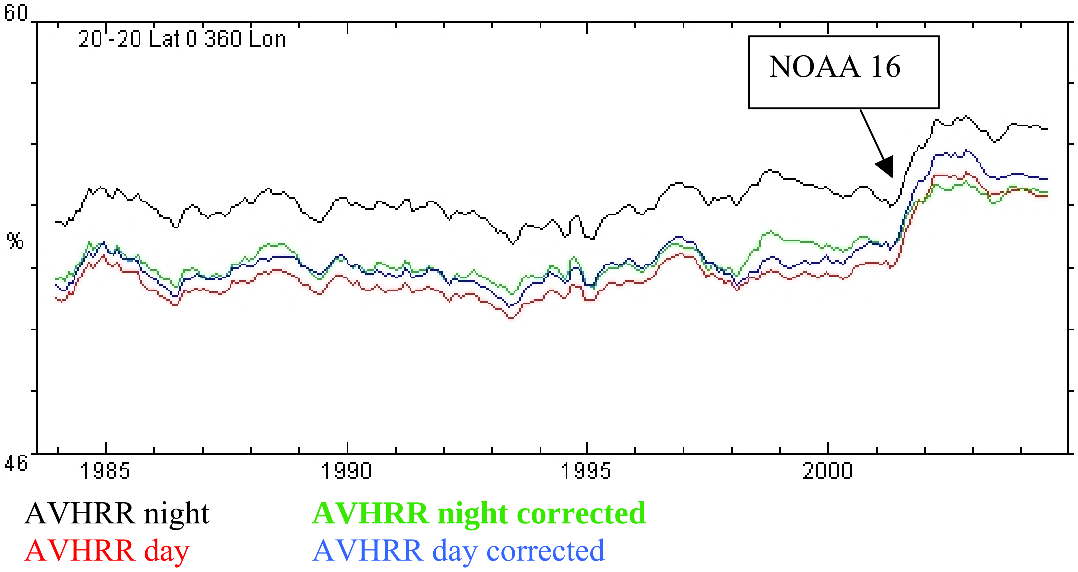


Figure 3a: Mean tropical average (20 N to 20 S) before and after correction. The change in 2001 occurred with the replacement of NOAA 14 with NOAA 16. An 11 month running mean filter has been applied.

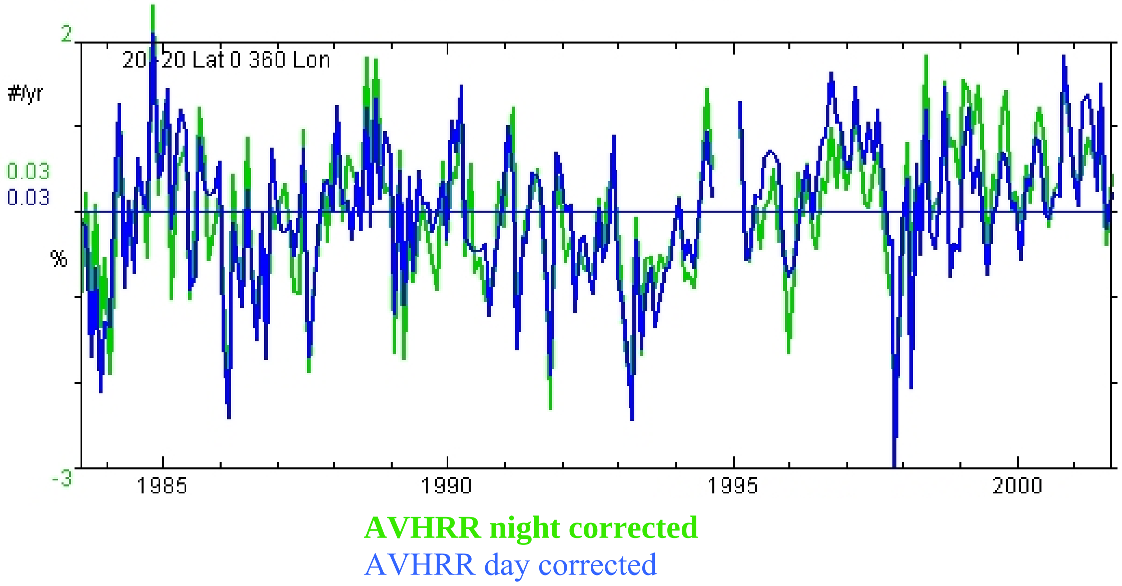
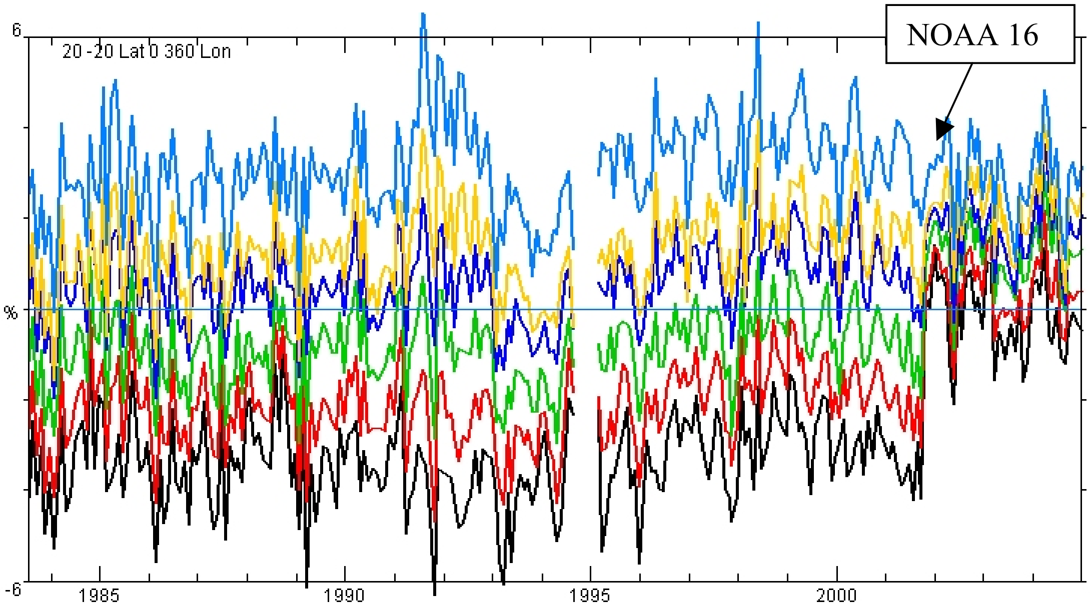


Figure 3b: Removing the seasonal cycle from each corrected tropical time series shows the long term weather fluctuations are nearly identical in each (correlation = .84).

3. View angle dependence

There is another systematic bias in the ISCCP cloud products: as view angles increase from nadir to limb, the reported cloud amount increases. Figure 4 shows polar orbiter observations sorted by view angle. By lining up overlapping geosynchronous observations from ISCCP, one can see the same variation: more clouds are reported from the analysis at steeper view angles. In a month all the different view angles are sampled uniformly by the polar orbiter data, so one can arrive at mean view angle correction function, much like the diurnal correction function available for each ISCCP analysis grid box. This can then be applied to the monthly mean geosynchronous observations to arrive at a nadir view cloud amount. In addition the view angle effects decrease away from the equator so dependence on latitude must be included. Maps of the functional dependence were also constructed, but a single monthly set of data includes too much random weather variation to recognize any geographical variation. Again, this is evidence that the modest correction can only be applied to time and space means, not effectively to individual weather events.

From figure 4, it is clear that NOAA 16 has a different view angle behavior. This is not yet understood, so we will confine our discussion to the time interval: years: 1983.5 to 2001.7. An angular fit model can be constructed every month for each grid location, but this is noisy, with substantial variation over short distances.



AVHRR night 1.0:1.2 1/μ **1.2:1.4 1/μ** **1.4:1.6 1/μ**
1.6:1.8 1/μ **1.8:2.0 1/μ** **2.0:3.0 1/μ**

Figure 4 Cloud amount time series a different view angles from polar data. NOAA 16 began in October 2001 and has different behavior.

Since this correction is somewhat like a limb darkening correction, I will use the function form: eq 2 relating the cloud amount to the observation and view angle.

Eq 2: Cloud Amount (μ) = $A/\mu + B$
$\mu = \cos(\text{view zenith angle})$

To get comparable cloud amounts, one can calculate the nadir view cloud amount (A+B). From the ISCCP AVHRR observations we can derive A from the multiple monthly means at each location. Figure 5 shows the frequency distribution of the A values. With overlapping geosynchronous data it is also possible to estimate A for areas with two different view angles. There is a fairly wide distribution of A values so applying the correction should be confined to large scale statistics, not daily observations. Different pairs of geosynchronous observations show similar adjustment factor (A) distributions. The fact that about the same correction appears from both observation systems give some credence to the result. In addition the correction decreases away from the equator.

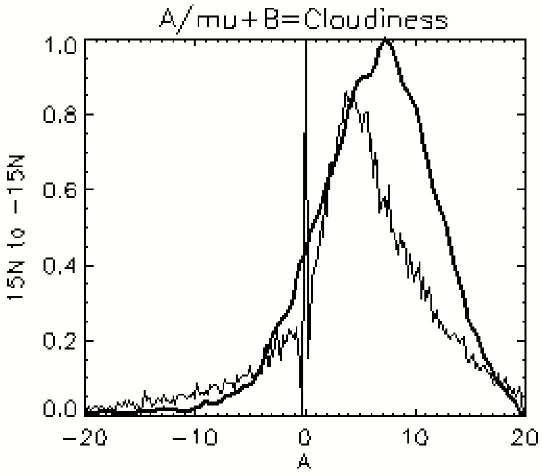


Figure 5. View angle dependence derived from AVHRR observations (thick line) and from overlapping GOES West and East monthly means (thin line).

4. Angular correction applied

As a first order angular correction I applied the formula: eq 3.

Eq 3. $A = (7\%-|\text{Latitude}| *4\%/45.)$

This correction to the geosynchronous observations in the ISCCP D2 data set does not change the time variation character of the cloud amount over Africa or Europe because the Meteosat observations were made with consistent view angles through out the experiment. Similarly the western Pacific had uniform view angle sampling from GMS. But, in much of the rest of the globe the view angles of the geosynchronous satellites changed from year to year leading to changes in reported cloud amount not due to weather changes, but due to view changes. One can see this first in the time series shown in figure 6 where there was a sharp change in view angles in 1998 with the addition of Meteosat over India leading to a decrease in the reported cloud amount. After correction, the discontinuity is smaller.

Figure 7 shows a map of the trend of the time series of cloudiness from each region. After angle correction the some of the unphysical artifacts (Central Pacific, Indian Ocean and Atlantic) have been reduced. The Indian ocean area with its mixture of polar and geosynchronous observations get worse because a discontinuity in the transition from AVHRR estimates to Meteosat cloud estimates in 1998.

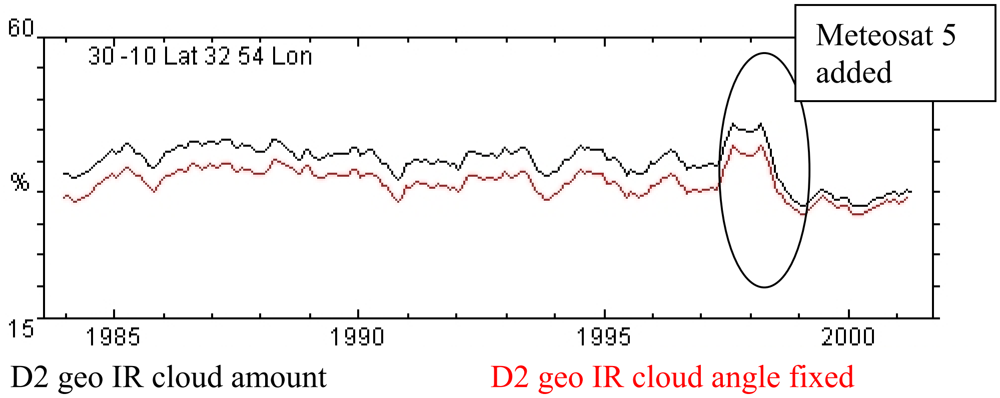


Figure 6: Cloud amount in the in East Africa before and after view angle correction
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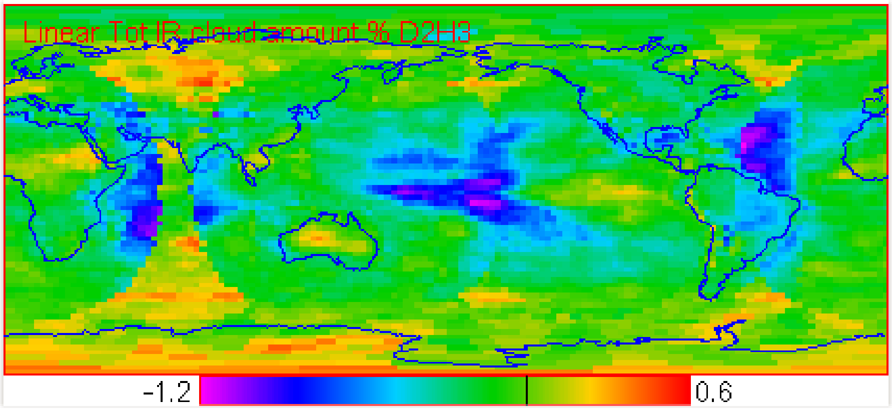
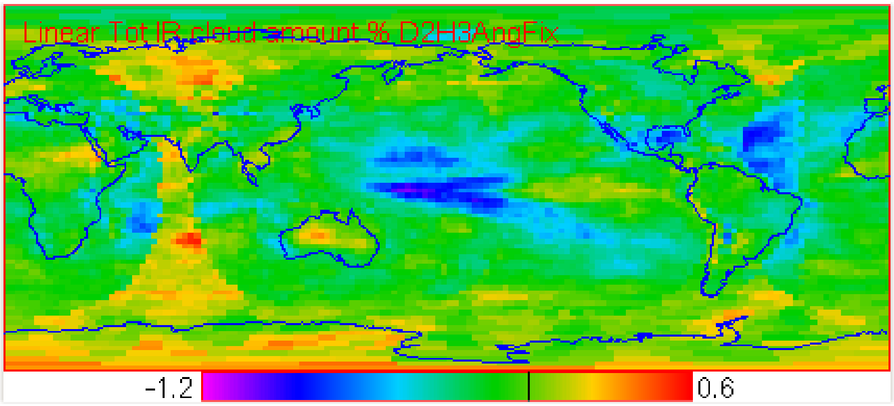
7a: 

7b: 

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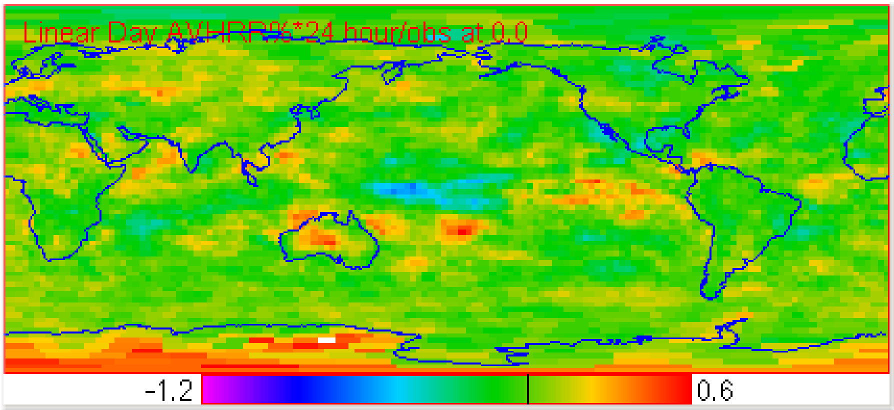

Figure 7: Maps of the ISCCP D2 trend (%/year) before (a) and after (b) the angular correction and the trend of the diurnal fixed (c) average ISCCP AVHRR diurnal corrected cloud field. These represent the **1983.5 to 2001.7** time period. The NOAA 16 change produces a tend in all fields.

Finally referring back to the diurnal correction, figure 7c shows the trends in the AVHRR PM time series corrected for diurnal sampling times averaging the morning and afternoon orbit halves. Almost no regional trends are left, although an amplification of the color scale shows up the central Pacific feature in figure 7b.

5. Discussion

One fundamental question not answered in this paper is whether the angular correction is a result of the particular algorithm for cloud recognition in ISCCP or a fundamental property of the Earth's clouds. Physically, it is reasonable to expect that photons leaving the Earth's surface have a higher probability of striking a cloud at angles off nadir vs straight up. Similar corrections have been discussed for human observed cloud climatologies looking up from the surface. One looks forward to the CloudSat observations to measure this effect directly.

The view angle or diurnal corrected ISCCP D2 product is still not the final word on corrections to the ISCCP time series. There are still apparent discontinuities in the record which occur when the geosynchronous satellites change. In my opinion, the diurnal corrected AVHRR time series is the most time consistent data set for climate studies from 1983 to 2001. Both the uncorrected and corrected (either geo or polar) time series detect strong events like El Ninos, but recognition of more subtle changes are confused by these systematic biases.

The ISCCP data now extends to the end of 2004. But there is a very distinct discontinuity in all the cloud amount time series in October 2001 when NOAA 16 AVHRR data replaced NOAA 14 data. This affects both the polar and geosynchronous components of ISCCP. A correction for that jump is still under discussion.

These corrections are modest in size. The trend in the Central Pacific is real and is a result of the sequence of El Nino events in that area. The change in Australia also appears real, but again associated with the El Nino.

The biggest utility of these corrections is that fact that they are small and do not explain all the artifacts in the ISCCP time series. This is demonstrated by the Indian ocean area where there is still an artifact when merging the polar and geosynchronous data together.

6. Conclusion

Including diurnal corrections to the polar orbiter cloud estimates from ISCCP improves the regional time consistency of that product. For large scale averages with land and ocean areas, the correction is small. For the geosynchronous contributions to ISCCP, angular corrections are needed where the satellite view points changed over the period of record. This is especially evident in the central Pacific and Indian ocean areas. Still the overall impact of these corrections in small and one must look elsewhere for explanations for the discontinuities in the ISCCP time series.

7. Acknowledgement

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8. References

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