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EVALUATION OF CLOUD AMOUNT TRENDS AND CONNECTIONS TO LARGE SCALE DYNAMICS

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1. INTRODUCTION

Recent studies by Wielicki et al. (2002) and Chen et al. (2002) provide evidence of a decadal-scale trend in the cloud amount (cloud fraction) in the tropics. Wielicki et al. use data from the Earth Radiation Budget Experiment (ERBE, Barkstrom 1984) to demonstrate a decadal-scale upward trend in the tropical mean long wave (LW) flux time series since 1985. They argue that this trend must be reflected in changes in the cloud amount in the tropics. Chen et al. use International Satellite Cloud Climatology Project (ISCCP, Schiffer and Rossow 1983) data to show that there was an overall change in the cloud amount in the tropical and subtropical regions over the same time period. Figure 1 shows one representation of how the global cloud amount has changed in the last 20 years.

Changes in the global cloud amount may have important climatic implications. Chen et al. provides evidence that these changes were associated with changes in vertical motion from reanalysis data that could be associated with the tropical Hadley/Walker circulation. Furthermore, while there is debate on the mechanism by which clouds feedback on tropical sea surface temperatures, there is general agreement that such feedbacks do exist and that they are important for understanding the climate system and its variability (Miller 1997, Pierrehumbert 1995, Lindzen et al. 2001, Lin et al. 2002, and others).

However, there is still some debate over whether the global cloud amount trend shown in Figure 1 is physical, or if it is simply some artifact of the satellites or the processing algorithm. Additionally, little effort has been expended to examine this trend thoroughly. For example, it has yet to be determined what kinds of clouds are experiencing the changes, where these clouds are located, and whether or not the trends are more pronounced at certain times of the year. Furthermore, previous studies have not attempted to examine mechanisms that might be driving such changes either on the local or global scales. All of these issues should be addressed in order to characterize the nature of the cloud amount changes in the climate system. This will improve our ability to model them and to understand their impact on the climate system.

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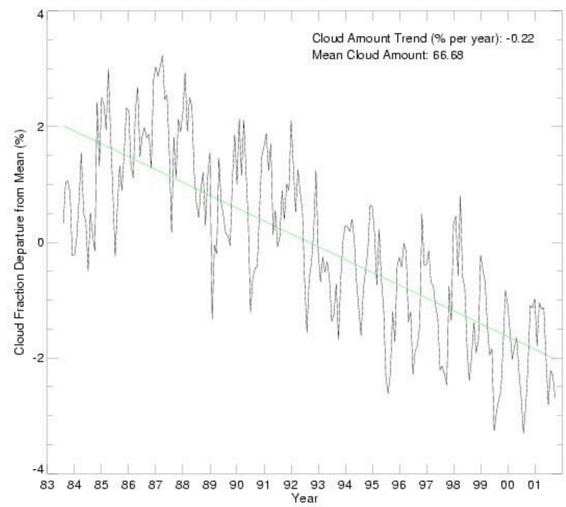

Figure 1: Time series of ISCCP D2 monthly mean cloud amount with the period mean removed. The total change from 1987 until 2001 is about 4%. The trend shown in green represents only that part of the data beginning in 1987.

This manuscript will describe efforts to characterize the nature of the global cloud amount trend and its interaction with the Earth's climate. Section 2 of this manuscript will detail the data sets used in this study. Section 3 will detail the methodology employed to conduct this study to date. Section 4 will present some of the results obtained prior to the submission of this manuscript, and section 5 will present a discussion of remaining tasks and possible future studies. For the most current figures and complete results to date, the authors refer you to their website:
http://reef.atmos.colostate.edu/ellis/AMStalk.html

2. DATA USED IN THIS EXPERIMENT

2.1 Cloud datasets

In order to ensure that the cloud amount trends obtained are not simply artifacts of the peculiarities of a particular dataset, two different sources of cloud data are used. The primary source of this data is the ISCCP D2 monthly mean cloud data. This dataset provides information on total cloud amount, as well as cloud amounts for different types of clouds. For the purposes of this study, the following types of clouds are analyzed: low cloud (cloud top below 680 mb), middle cloud (cloud top between 680 mb and 440 mb), cirrus cloud (cloud top above 440 mb, cloud optical thickness less than 3.6), cirrostratus (cloud top above 440 mb, cloud optical thickness between 3.6 and 23), and deep convection (cloud top above 440 mb, cloud optical thickness above 23). These divisions are further described in Rossow and Schiffer (1999). The temporal coverage of this dataset is from July 1983 until September 2001, and the spatial resolution is 2.5° X 2.5°. Since this is the primary dataset used in this study, all of the other datasets were trimmed so that they also only span this time period.

The Cloud Archive User Service (CLAUS) 2.5° x 2.5° brightness temperature dataset (Hodges et al. 2000) was also employed to provide some independent verification of the cloud amount trend by taking advantage of the different algorithm employed in their processing of ISCCP B3 data. This time series only spans the years 1983-1993, however since it overlaps 7 years of the downward ISCCP trend, it is sufficient for independent verification of the trends in the ISCCP D2 dataset.

2.2 Atmospheric Data

In order to further verify the trends in cloud amount as well as to evaluate the coupling between the cloud amount and climate, two independent sources of reanalysis data are used in this study: the National Centers of Environmental Prediction (NCEP) – National Center for Atmospheric Research (NCAR) 40-Year Reanalysis data (Kalnay et al. 1996) and the European Centre for Medium-Range Weather Forecasting (ECMWF) 40-year Reanalysis (ERA-40, Gibson et al. 1996; Gibson et al. 1997). These datasets provide global fields of monthly mean 200 mb winds and divergence, 850 mb winds and divergence, sea level pressure, and 500 mb heights at 2.5° x 2.5° resolution.

Precipitation data was also obtained from two different sources: the Global Precipitation Climatology Project (GPCP, Huffman et al. 1996) and the Climate Prediction Center Merged Analysis of Precipitation (CMAP, Xie and Arkin 1997). Both datasets are a combination of satellite-derived precipitation estimates merged with surface observations; the primary difference between them being that CMAP also ingests numerical model output in its algorithm to generate precipitation fields. Both of these datasets are also available at 2.5° x 2.5° resolution.

3. METHODOLOGY

The first part of this study involves characterizing the trends in the cloud amount (CA) data. First of all, upon inspection of Figure 1, it is apparent that the downward trend in CA begins in 1987. Therefore, in order to not diminish the slope of the CA trend, all trends are found by performing linear regressions only to the subset of data beginning in January 1987. In order to study how the CA trend varies with time of year, the time series is then partitioned into 12 subsets – one for each month – and then a linear regression was performed on each to describe the trends as a function of month. Finally, in order to study the types of clouds that are most affected by this trend, the clouds are separated into the five categories described in Section 2. Each was then studied to find how the total CA trend manifests itself as a function of cloud type.

The second and most important part of this study is the statistical verification of the ISCCP cloud amount trend by examining how it correlates with the reanalysis datasets. It is important to keep in mind that two independent datasets will show high correlations if both exhibit trends or variations of the same frequency regardless of whether the two datasets are physically related. Therefore, the following steps are taken to reduce this possibility. First of all, the downward linear trend in the cloud amount dataset is removed. The monthly climatology is then removed in order to eliminate any signatures of a seasonal cycle from the cloud amount data. The time series that remains simply describes the variance of cloud amount about the long-term trend and the long-term monthly climatological mean. This time series will hereafter be referred to as the detrended CA time series.

To study how this time series is related to changes in large-scale dynamics, reanalysis data is used to generate maps of regression coefficients for each field described in section 2. In order to create these maps, the following steps are taken. Anomaly maps are created by removing the monthly climatology from each of the 219 monthly maps of a given field. Using all of these maps, a time series that describes how the anomaly field changes is generated for each point on the map. The detrended CA time series is then regressed onto and correlated with each of these time series. The map of regression coefficients shows where, and by how much, the field changes with a positive change in cloud amount. The map of correlation coefficients shows how the time series at each point correlates with the detrended CA time series. Using a 2-tailed Student's t-test at the 95% confidence level and 217 degrees of freedom, this map is then used to determine which regression coefficients are statistically significant. Finally, by taking the inner product of the regression map with each time step of the corresponding anomaly maps, the result is an expansion coefficient time series that shows how strongly the anomaly field for that month reflects the pattern of the regression map. This time series is important because, if the field in question is indeed related to the detrended CA time series, then the expansion coefficient time series and the detrended CA time series should be highly correlated. This procedure is then repeated for each of the reanalysis fields listed in section 2.2

4. RESULTS AND DISCUSSION

Figure 2 shows the spatial distribution of the global cloud amount trend shown in Figure 1. Of particular interest are the centers of action located in the tropical Pacific Ocean near the dateline and the positive trend located over Indonesia. The magnitudes of these trends are among the largest on the map, and it will be shown that these two centers of action appear regularly in most of the remaining analysis. Therefore, it is safe to say that these trends are robust. The spatial pattern of the trend near the dateline suggests that the cloud amount trends are symmetric about the equator, which suggests changes in the ITCZ cloudiness. This pattern also shows a possible trend in the South Pacific Convergence Zone (SPCZ). The gradient in the CA trend located near 60° East longitude appears to be suspicious, and is most likely due to limb darkening near the edges of the satellite field of view. Figure 3 shows the zonal mean CA trend as a function of latitude and a contour plot of how the zonal mean CA trend varies with time of year. From this plot, it is apparent that the negative CA trend is concentrated in the tropics and is most strongly negative in the winter and early spring. The CLAUS data, shown in Figure 4, shows a pattern that reflects the bimodal pattern of Figure 2 in that the centers of action are located over Indonesia and near the dateline and they have opposite signs.

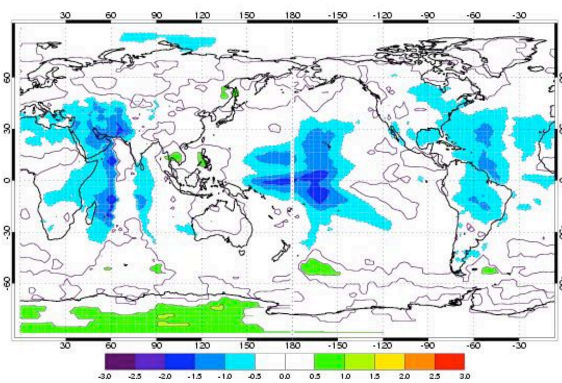

Figure 2: Map of ISCCP cloud amount trend for the years 1987-2001 as a function of spatial location. The map resolution is 2.5° x 2.5°. Contour units are in % cloud per year.

The CA trend manifests itself in different ways depending on cloud type, especially over the tropical Pacific. Low-level cloud shows only very slight trends, with a slightly negative trend over Indonesia and a near zero or slightly positive trend near the dateline. Middle clouds seem to change in a manner consistent with the patterns in Figure 2. Cirrus clouds appear to have the largest negative trend of all the cloud types over the tropical Pacific, but also show a negative trend over Indonesia. Stratocirrus clouds, however, seem to be strongly positive over Indonesia, but only slightly negative near the dateline. Deep convection also shows a weak negative trend on either side of the equator demonstrating that there may be a small change in the convection located in the ITCZ. These findings are not, however, obviously corroborated by brightness temperature trends from CLAUS data. There is an increase in brightness temperature over Indonesia, and a decrease near the dateline, neither of which obviously correspond to the changes as a function of cloud type. Further study is currently ongoing as to why this is the case. Figures for this portion of the study are available on the website.

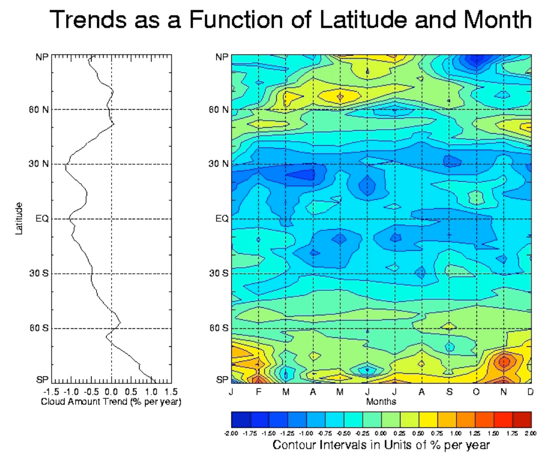

Figure 3: The zonal mean cloud amount trends as a function of latitude for the time period in Figure 2 (left), and as a function of latitude and month of year (right)

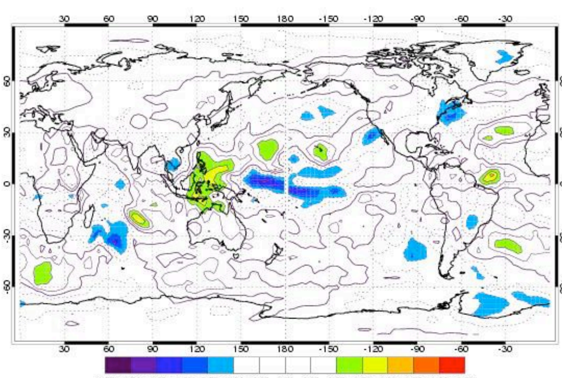

Figure 4: Map of CLAUS brightness temperature trends for the period 1987-1993 as a function of spatial location. The map resolution is 2.5° x 2.5°

Correlations to reanalysis fields are currently still being studied. However, some preliminary results seem to show evidence that there is a statistically significant correlation between changes in the tropical circulation and changes in cloud amount. For instance, for an increase in CA, there is evidence of increased 200 mb divergence and 850 mb convergence in the tropical Pacific near the dateline, and the opposite sign of both over Indonesia. Given this pattern, for an increase in CA it is likely that there is increased upward vertical motion over the tropical Pacific and decreased upward vertical motion over Indonesia. Increased 850 mb westerlies are also correlated with increased CA over the tropical Pacific. And not surprisingly, there is an increase in precipitation over the tropical Pacific near the dateline and there is a decrease in precipitation over Indonesia both of which correlate with an increase in the global CA. All of these features are statistically significant at the 95% level in all datasets. Therefore, there is ample reason to believe that the global cloud amount trend shown in Figure 1 is both real and robust. Since there are several figures for this portion of the study, the reader is directed to our website to examine the latest figures in support of these findings: http://reef.atmos.colostate.edu/ellis/AMStalk.html.

5. REMAINING WORK

At this point, there are still several questions that need to be answered. First of all, the correlation between CA and sea surface temperature (SST) needs to be explored, especially to verify if we can detect any cloud-climate feedback mechanisms in climate system. Secondly, it is important to examine the correlation between these CA trends and the El Nino – Southern Oscillation (ENSO) to examine how much of an effect ENSO has on the variability of cloud amount. The authors expect to see some correlation due to the fact that CA trends are significantly correlated with increased westerlies at low levels. Additionally, it would be instructive to study how the correlations with the reanalysis data vary as a function of time of year, especially since CA shows a strong seasonality. Therefore, the authors plan to generate maps similar to Figure 3 showing how the correlation and regression coefficients change as a function of latitude and time of year. Finally, since the data processing is nearly, but not yet complete, any examination of the possible climate feedbacks is premature at this time. However, by the start of the AMS conference, the authors hope to provide some insight into what, if any feedback mechanisms are detectable in the results of this study.

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