WHAT CAN CLOUD OBSERVATIONS TELL US ABOUT CLIMATE VARIABILITY?

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Abstract. Clouds have a large impact on the Earth's radiation budget and hence have the potential to exert strong feedbacks on climate variability and climate change. These feedbacks are not well-understood, so it is essential to investigate observed relationships between cloud properties and other parameters of the climate system. Suitable cloud datasets based on surface observations and satellite observations are described and various advantages and disadvantages of each are discussed. In particular it is noted that significant inhomogeneities likely exist in the datasets which have important implications for studies of climate variability. Recommendations are made for the use of cloud data in future investigations.

1. Introduction

Cloudiness is one of the most important variables influencing the Earth's radiation budget, but our present understanding of its role in the climate system is limited. Current general circulation models do not consistently and correctly simulate cloud feedbacks internal to the climate system (Cess et al., 1996). Other large uncertainties are possible cloud responses to external forcings such as anthropogenic aerosol (Twomey et al., 1984; Albrecht 1989) or cosmic ray flux (Marsh and Svensmark, 2000). For these reasons it is important to examine past cloud variability and potential connections to other internal and external climate parameters. The two primary sources of cloud data are surface synoptic observations and satellite radiance measurements, each with its own advantages and disadvantages. Surface observations extend over a much longer period of record, but lack the quantitative radiative information and global coverage provided by satellites. Unfortunately, artificial inhomogeneities appear to exist in all cloud datasets, thus making interpretation and attribution of observed long-term changes in global cloud cover problematic.

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TABLE I
Cloud Datasets

	EECRA	ISCCP
source	synoptic weather observations	weather satellites
identification	visual, by synoptic code	radiance threshold
time period	1971–96 (land), 1952–95 (ocean)	Jul 1983 to Dec 1993
coverage	irregular	global
resolution	user-defined averaging	3-hourly, 250km x 250 km
parameters	total cloud amount low cloud amount low, mid, high cloud type	cloud amount cloud optical thickness cloud top pressure
advantages	identification of cloud type multidecadal time record unobstructed view of low clouds	quantitative radiative information global regular sampling unobstructed view of high clouds
disadvantages	no quantitative radiative information irregular and incomplete sampling obstructed view of high clouds cloud measured in sky-cover inhomogeneities	uncertain identification of cloud type short time record obstructed view of low clouds uncertain threshold for cloud inhomogeneities

2. Cloud Datasets

2.1. Surface-based

Surface-based cloud datasets suitable for studying climate variability are constructed from synoptic weather observations. Human observers on ships or at land stations visually measure the amount of total cloudiness and low cloudiness by eighths or tenths of sky-cover and identify cloud type and low, mid, and high levels following the synoptic code (WMO 1974). Note that the fraction of cloud covering the sky dome may not be the same as the fraction of cloud covering the earth. Warren et al. (1986; 1988) have averaged these observations to seasonal means at $5° \times 5°$ (land) and $10° \times 20°$ (ocean) resolution for the years 1971–1981 (land) and 1952–1981 (ocean). Much of the Southern Ocean and some land regions are poorly sampled. No global collection of land observations is available prior to 1971, and obvious inhomogeneities are present in the ocean observations prior to 1952. These data have been updated by Hahn and Warren (1999) in the Extended Edited Cloud Report Archive (EECRA) to 1971–1996 (land) and 1952–1995 (ocean). The EECRA is a quality-controlled collection of the original individual cloud observations and thus allows the user to define the averaging regions and time periods. Because the observers view from the surface, the EECRA is especially useful for examining changes in low cloud cover. Further information is summarized in Table I.

2.2. Satellite-based

Satellite-based cloud datasets are typically constructed from visible and infrared radiance measurements. The International Satellite Cloud Climatology Project (ISCCP) (Rossow and Schiffer, 1991) has the longest period of record available (1983–1993). It is derived from a succession of geostationary and polar-orbiter weather satellites and provides global coverage at 3-hourly and 250 km $\times$ 250 km resolution. The threshold method is used to identify cloudiness. Since clouds are almost always brighter and colder than the surface, the darkest and warmest pixels are identified as clear sky and pixels brighter and colder beyond a certain threshold are identified as cloudy. This has some uncertainty, and a decrease in the threshold from the C-series to the D-series of ISCCP caused observed global cloud cover to increase by 5% (Doutriaux-Boucher and Sèze, 1998). Cloud optical thickness and cloud top pressure can be calculated using a radiative transfer model. Due to their top-down view, satellite data are the best resource for examining high cloudiness. Since the threshold method used by ISCCP has difficulty identifying thin cirrus, the High Resolution Infrared Radiation Sounder (HIRS) dataset (Wylie and Menzel, 1999) may be a better resource for examining this cloud type. Because different datasets use different thresholds and other retrieval methods, information from two datasets cannot be combined into a homogeneous time series. Further information is summarized in Table 1.

3. Possible Inhomogeneities

In studies of cloud variability it is important to be aware of possible inhomogeneities in the data. These can arise from systematic biases that become more prominent as natural variability of opposite signs is averaged out. Thus, inhomogeneities are worst for the largest averaging intervals in space and time (i.e. multi-year changes in global cloud cover). Norris (1999) documented that changes in EECRA zonal mean total cloud cover and low cloud cover between 1952 and 1995 were positive at every latitude with sufficient sampling, but expressed uncertainty regarding the reliability of the trends. On the one hand no likely cause for an artifact was found, but on the other hand it was not clear what underlying physical mechanism would cause substantially different processes in the Tropics, subtropics and midlatitudes to all produce increasing cloudiness. For this reason it is important to corroborate observed changes in cloud cover with physically consistent changes in related climate parameters (e.g., Norris et al., 1998; Norris, 1999). EECRA variations can also be compared to ISCCP variations for the time period the two datasets overlap. Figure 1 shows that they do not agree, suggesting that the apparent increase in surface-observed global ocean cloud cover since the early 1950's may be largely spurious.

In order to gain insight into possible causes of the ISCCP time series presented in Figure 1, correlations between the Figure 1 time series and the time series of

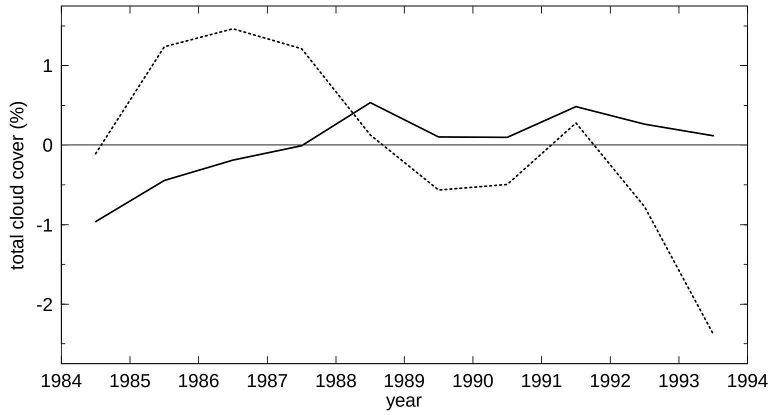

Figure 1. Annual mean ocean cloud cover averaged over 40°S - 60°N (where the EECRA has sufficient sampling). The solid line is EECRA and the dotted line is ISCCP D-series.

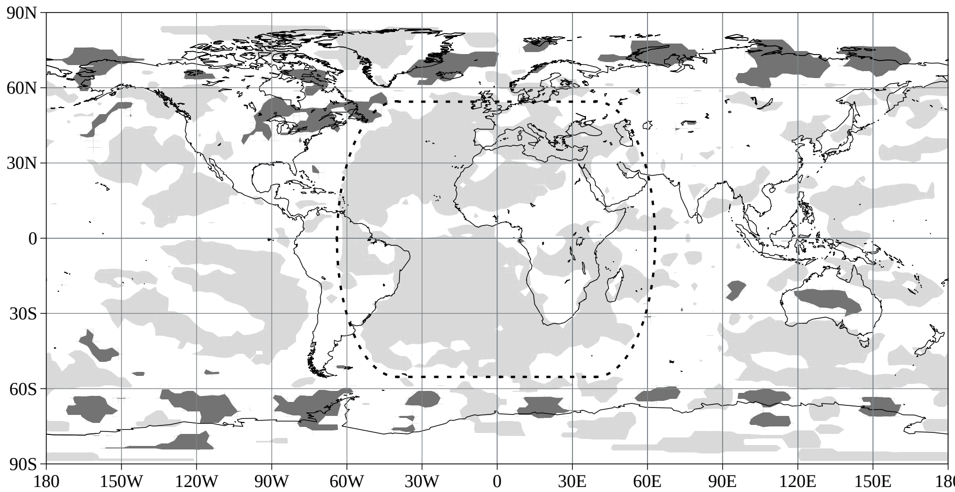

Figure 2. Correlation of ISCCP D-series gridbox time series with ISCCP time series in Fig. 1. Lighter gray indicates correlations above 0.4; darker gray indicates correlations below -0.4. The dotted line indicates the approximate footprint of Meteosat.

annual means at each grid box were calculated in hope that the spatial pattern of correlation coefficients (shown in Fig. 2) would suggest meteorological processes responsible for the variation in near-global ocean cloud cover. The most striking feature of Figure 2 is the circular patch of positive correlation centered on 0°N, 0°E. It seems unlikely that a natural process would produce such a regular pattern, but it is interesting to note that the pattern almost exactly resembles the footprint of Meteosat data incorporated into ISCCP (Meteosat is the European geostationary satellite). In particular, note the discontinuities in the western North Atlantic and South Atlantic. Some of the correlation patterns elsewhere around the globe are suggestive of other geostationary satellite footprints. The semi-regular patterns of alternating correlation sign seen between 60° and 70° latitude are also suspicious and may be related to polar-orbiter swaths. Similar features are observed for correlations with the time series of ISCCP monthly mean global cloud cover (not shown).

It has been known that instrument degradation and miscalibration between successive satellites created inhomogeneities in the previous version (C-series) of ISCCP data (Klein and Hartmann, 1993). The D-series ISCCP data used in the present study was generated using new methods to avoid the problems of the C-series, but it now appears that the attempt was not completely successful. The correlation patterns evident in Figure 2 suggest that the time series of ISCCP global mean cloudiness does not result from any natural process but is instead somehow related to systematic biases in the retrieval and/or processing of satellite radiances, though further investigation will be required to identify the exact problems. Accordingly, the ISCCP time series presented in Figure 1 is probably spurious, and any resemblance to time series of other parameters (e.g., Marsh and Svensmark, 2000) is merely coincidental.

4. Recommendations

The above results do not invalidate all uses of surface-observed or satellite cloud data, but rather enjoin caution. Natural variability is much greater on small space and time scales; hence, investigations of synoptic and regional variability in cloudiness should not greatly suffer from inhomogeneities. It is only when natural variability is averaged out in large space and time domains that the systematic biases become relatively strong. Some recommendations for studies of cloud-climate variability follow.

– Use extreme caution when interpreting cloud variability averaged over large space and time domains.
– Always check for the presence of unphysical variability in cloud data.
– Corroborate observed cloud variability with variability in other physically-related climate parameters.
– Look at geographical patterns of cloud variability since they provide more insight than large-scale means.
– Examine cloud type as well as total cloud cover since cloud type is a better measure of processes and radiative impacts.

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