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Some doubts concerning a link between cosmic ray fluxes and global cloudiness

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Abstract. Svensmark and Friis-Christensen (1997, henceforth SFC) showed a strong correlation between cosmic ray flux and ISCCP total cloudiness between 1984 and 1990. They concluded that ionisation by cosmic rays, more prevalent at times of lower solar activity, might explain apparent correlations between solar activity and climate through changes in cloud radiative forcing. We have extended SFC's approach with a study of the different cloud types, restricting our analysis to the period 1985 to 1988 during which the ISCCP calibration is believed to be stable. We find no clear relationship between individual cloud types and cosmic ray flux. Inclusion of data at high latitudes decreases the amplitude of the apparent correlation although ionisation by cosmic rays is greatest at high latitudes. Thin high cloud shows an increase throughout the period such that the combined effect of the changes in cloud types suggests an almost monotonic increase in cloud radiative forcing between 1985 and 1988 which is not related to cosmic ray activity.

Introduction

Cloud cover is an important factor controlling the way that radiation is absorbed and reflected by the Earth. Increases in cloudiness enhance global albedo, thus tending to cool the surface, but also trap thermal radiation, thus tending to warm it. Overall the cooling effect is believed to be dominant but this is a function of cloud height and type with, in particular, thin high cloud causing a net warming. Any factor tending to modify cloud cover will thus have an impact on climate so that it is important to understand the natural variability in cloud climate forcing (IPCC, 1994).

Using data from the International Satellite Cloud Climatology Project (ISCCP) SFC showed a variation in low- to mid-latitude total cloudiness between 1984 and 1990 that correlated strongly with cosmic ray flux and thus inversely with solar activity. During the period of minimum solar activity in 1986 total cloudiness was 3-4% higher than near solar maximum in 1990. From this they suggested that cosmic rays might enhance cloudiness, possibly through a mechanism involving an increase in atmospheric ionisation and formation of cloud condensation nuclei. This, they proposed, would cause a negative cloud radiative forcing, i.e. a tendency to cool climate, at periods of minimum solar activity. The correlation appeared to hold when three further satellite datasets were used to extend the analysis to the period between 1980 and 1996 although there may be problems of inter-calibration between these sets. Kuang et al (1998) confirmed the SFC analysis of the ISCCP total cloud data.

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The microphysical details of the proposed mechanism have still to be established. Cosmic ray ion-pair production rates are greatest near the tropopause in high latitudes. At low latitudes they have lower values and maximise in the middle troposphere but the higher energy cosmic rays, which are responsible for the low latitude ionisation, are not so sensitive to solar activity. Dickinson (1975) argued that, while it is unlikely that ionisation directly nucleates cloud droplets, it could be important for the formation of lower stratospheric aerosol. He speculated further that sulfuric acid aerosol thus formed could modulate high cloud nucleation, at least at middle and high latitudes. In this paper we discuss a new analysis of ISCCP data in which the cloud variation is decomposed into its low, medium and high components. In the context of climate change it would be useful to have an estimate of the magnitude of the proposed cloud radiative forcing so we also use our analysis to make an estimate of this.

ISCCP data

The ISCCP dataset (Rossow and Schiffer, 1991) comprises an archive of data over the globe from geostationary and polar orbiting satellites for the period July 1983 to December 1990. Cloud detection is based on visible (daytime only) and infrared thresholding techniques in 30km pixels. Cloud cover is then determined on a 280km grid based on the fraction of cloudy pixels. Infrared radiances are further used to determine cloud temperature and thus pressure (altitude) to derive three height categories: low, medium and high cloud. During the day visible data may be used to determine cloud optical depth and thus a further classification can be made into seven cloud types: cirrus, cirrostratus and deep convective (high types), altostratus and nimbostratus (middle) and cumulus and stratus (low).

The inter-calibration between the geostationary satellites was achieved using the polar orbiters, which regularly passed over the same areas as the geostationary satellites. Thus the absolute calibration of the NOAA polar orbiters is critical to the data. During the ISCCP data collection period three different polar orbiters were each used as the calibration satellite, introducing the possibility of systematic errors in cloud type classification. This has been investigated by Klein and Hartmann (1993) who showed that, while total cloudiness was not affected, the replacement of the polar orbiters in January 1985 and October 1988 caused discontinuities in derived cloud top temperature and, more particularly, optical depth. These resulted in significant artificial changes in the distribution of different cloud types but, because the cloud level discrimination depends only on the cloud top temperature, this was less affected than the division into cloud types. However, from January 1985 to August 1988 the operation of a single polar orbiter, NOAA-9, enabled a trend-free calibration during this period. It should be noted that, because of the intercalibration of the geostationary satellites with the polar orbiter data, use of just the geostationary data does not eliminate any residual calibration problems.

Data analysis

SFC employed the C2 dataset which comprises monthly means of the cloud parameters on the 280km grid. Data acquired over land were excluded and twelve-month running averages were used to remove seasonal variations. Only geostationary data were included in the analysis, so that high latitudes were omitted, and analysis showed that low latitude cloud had little effect on the results. We too use the C2 data but, unlike SFC, we include both geostationary and polar orbiter data over land and sea. Because of the cross-calibration we could see no reason to exclude the polar orbiter data and, as they have better coverage at high latitudes where SFC suggest the cosmic ray effect is largest, should serve to enhance such a solar cycle effect. We have analysed the infrared low, medium and high cloud categories, and the visible/infrared sub-types, concentrating on the period July 1985 to February 1988 when the infrared and visible calibrations are believed to be robust. It is convenient that this period covers the solar minimum discussed by SFC.

Cloud anomalies

Figure 1 shows the global total cloudiness anomaly, relative to its mean value between February 1984 and July 1990, and its low, medium and high components determined by infrared thresholds. The magnitude of the decrease in total cloudiness from 1987 to 1989 is about 2%, somewhat less than the 3-4% shown by SFC. This decrease is almost entirely due to the inclusion of the polar orbiter data (separate analysis shows that the effect of including land pixels is much smaller). We acknowledge that there are larger uncertainties in cloud parameter retrievals over high albedo surfaces but our results suggest that the inclusion of high latitude data diminishes the effect, rather than enhancing it as might be expected from a cosmic ray flux mechanism.

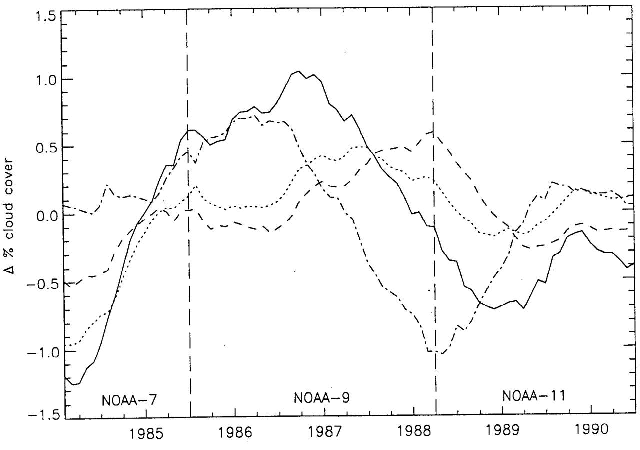

Figure 1. Anomalies, relative to the Feb 84 - Jul 90 mean, of twelve-month averaged global total percentage cloud cover (solid line), high cloud (dotted line), mid-level cloud (dashed line) and low cloud (dash-dotted line). The vertical dashed lines indicate the period within which the NOAA-9 calibrations are believed to be robust.

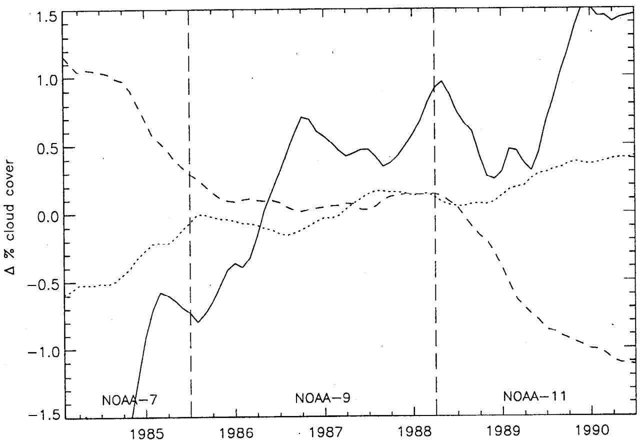

Figure 2a. As Figure 1 for high cloud types: cirrus (solid line), cirrostratus (dotted line), deep convective (dashed line).

None of the three cloud types in Figure 1 show the same time variation as the total cloud. The low cloud shows a maximum in early 1986 and a minimum in early 1988, the mid-level cloud a maximum in early 1988 and the high cloud a small maximum in late 1987. With data from satellites it is more difficult to quantify lower level cloud cover as only the non-overlapped portion is viewed and it is possible that an increase in high cloud could also be interpreted as a decrease in lower level cloud. Nevertheless the high level cloud retrieval is fairly robust and our analysis (Fig.1) shows that this does not vary in phase with cosmic ray incidence. Furthermore, if SFC are correct, then the cosmic rays are somehow influencing the cloud *that is seen as part of the ISCCP total* so if the changes in high cloud are not significant then there should be a clear signal in the other cloud types seen by the satellite. Again this is shown in our Fig.1 not to be the case. An increase in one cloud type coinciding with a decrease in another could also signify a degradation of the infrared calibration, such that the thresholds are shifting, but this is not happening in the July 1985 to Feb 1988 period. From the discussion in

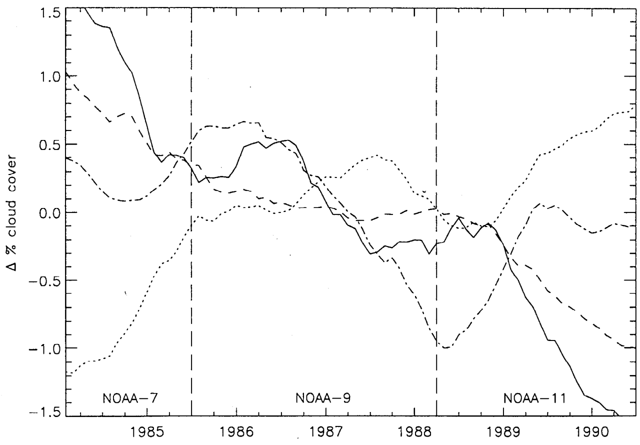

Figure 2b. As Figure 1 for mid-level cloud types: altostratus (dotted line), nimbostratus (dashed line) and low cloud types: stratus (solid line) and cumulus (dash-dotted line).

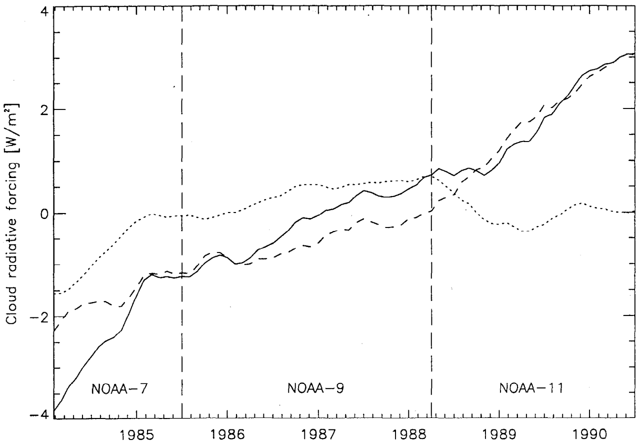

Figure 3. Anomaly in cloud radiative forcing (W m^{-2}): longwave (dotted line), shortwave (dashed line) and net (solid line).

the Introduction it would be expected that if cloud were responding to changes in cosmic ray intensity then high cloud, at least, would vary in phase with total cloudiness but this does not appear to happen.

Cloud radiative forcing

The effect of cloud on the radiation balance of the surface/troposphere system depends on the height and opacity of the cloud as well as the latitude and season. Ockertbell and Hartmann (1992) show that in the calculation of radiative forcing cloud type must be taken into account and gives estimates for global annual average values. Note that most clouds cause cooling but that thin high cloud tends to warm the climate.

Sub-classification of the high cloud types is shown in Figure 2a and that of the medium and low types in Figure 2b. These classifications are based on visible as well as infrared thresholding so that the total high, medium and low components are not identical to those in Figure 1; this is due to a cloud-top pressure correction in the day-time data (Klein and Hartmann, 1993). Figure 2a reveals large changes in thin cirrus. There are no changes of opposite sign in either of the other high cloud types so that the increase of ~1.5% in thin cirrus between July 1985 and February 1988 is unlikely to be due to artificial trends in optical depth brought about by degradation in the calibration of the visible channel. The reason for this increase in cirrus is not obvious; the peak late in 1986 might be ascribed to El Nino (Kuang et al, 1998), or it may be within the bounds of natural variability, but there does not appear to be a relation to solar activity.

We have used the radiative forcing values of Ockert-Bell and Hartmann (1992) along with the cloud types classified in the ISCCP data to estimate global average cloud radiative forcing over the ISCCP period. The anomalies in the longwave, shortwave and net radiative forcings, relative to their time means, are shown in Figure 3. The net forcing increases almost monotonically by about 2 Wm^{-2} between July 1985 and February 1988. This is composed of an increase in longwave forcing of about 0.8 Wm^{-2} and an increase in shortwave forcing of around 1.2 Wm^{-2}. During this period the longwave effect is largely due to the overall increase in cirrus, while the shortwave is largely due to the general decrease in low level cloud. There are no clear reasons for these trends; separate analysis of the Northern and Southern Hemispheres reveals no obvious difference suggesting that, if real, the increase in cirrus cannot be ascribed to enhanced air traffic. However, the lack of any anomalously negative value in late 1986 appears to discount any cloud radiative forcing anomalies due to cosmic rays.

Conclusions

The amplitude of the total cloudiness variation, seen in ISCCP data to occur in phase with cosmic ray incidence between 1984 and 1989, is reduced if high latitude data are included in the analysis. This acts counter to the suggestion that an increase in the incidence of cosmic rays during periods of lower solar activity might induce greater cloudiness since cosmic ray incidence is greatest at high latitudes. The correlation between global total cloudiness and cosmic ray flux is not mirrored in the distribution of cloud types although a physical explanation of such a correlation would require a similar correlation with the cloud types (possibly mostly in high cloud). The absence of this signature limits the confidence which can currently be placed in a cloud cover-solar cycle relationship. An estimate of cloud radiative forcing, taking into account the changes in the different cloud types, suggests an overall increase of about 0.4 Wm^{-2} between July 1985 and February 1988 which is not related to solar activity.

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