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Global Cloud Cover and the Earth's Mean Surface Temperature

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Abstract The well-known 11-year cycle in low cloud cover amount for Solar Cycle Number 22 and the trend with time for Solar Cycle Number 23 are interpreted as being due to similar changes, but of opposite phase, in the mean global surface temperature of the Earth. An analysis of cloud amounts in two higher altitude bands shows that they, and the surface temperature, are roughly in phase with each other. The suggested mechanism to explain this result is that a warming of the Earth's surface causes low clouds to rise and to be reclassified in the next upper category. The energetics of the process are shown to be satisfactory for this to be the correct explanation.

Keywords Global cloud cover · Surface temperature · Energetics

1 Introduction

We consider here the long term variation of cloud cover over the last 25 years, and how this affects the Earth's global mean surface temperature. The claimed causal connection between the well-known correlation of the low cloud cover ('LCC'—cloud below 3.3 km altitude) from the International Satellite Cloud Cover Project (ISCCP) and the cosmic ray (CR) intensity has had many detractors, including ourselves (e.g., Sloan and Wolfendale 2008; Erlykin et al. 2009). However, the actual cause of the correlation has not been firmly established; solar irradiance (SI) changes have been favoured by some, including Khristjansson and Kristiansen (2000) , whereas others (Voiculescu et al. 2006) have considered a mixed origin—some regions of the Earth showing a causal CR, LCC correlation and others a causal SI, LCC correlation. Further problems of interpretation have

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been the observation of correlations of the opposite sense for clouds higher in the atmosphere: Middle Clouds (MCC—heights 3.3 to 6.7 km) and High Clouds (HCC—heights above 6.7 km). Indeed, the reason for a claimed change of mechanism for cloud production at a height of 3.3 km is by no means clear. The apparent slow decrease in the mean LCC over time is another difficulty, as also is the fact that the Solar Cycle (Number 23), which has just ended, appeared to show very little (if any) evidense for the 11-year solar cycle in the LCC compared with its predecessor, Solar Cycle Number 22.

In what follows we draw attention to what appears to be the controlling influence of clouds on the Earth's surface temperature and we put forward a mechanism which explains this.

2 The Relationship Between Low, Medium and High Cloud Cover

In previous work (Erlykin et al. 2009) we drew attention to the correlation between the magnitudes of the respective cloud covers, particularly between the LCC and MCC. The negative correlations with CR intensities were present for both long-term (deviations of monthly averaged values from the mean over the 25-year long period of July 1983 to June 2008) and short-term variations (deviations of the same monthly averaged values from the smooth curve obtained by using a polynomial fit for the time dependence). Specifically the updated negative values of the LCC, MCC correlation coefficient are as shown in Table 1. Turning to the correlation between HCC and MCC, there is a moderate positive correlation for both long-term and short-term variations.

3 Correlations with Surface Temperature

3.1 The Global Surface Temperature

Figure 1a shows the dependence of mean global surface temperature (T) on a monthly basis for the period indicated (from NASA temperature data 2009). Some of the features are of known origin. For example, the 0.4 degree reduction in 1992/3 is due to the Mount Pinatubo volcanic eruption and others arise from the effects of ENSO—the El Nino Southern Oscillation, that is the redistribution of thermal energy in the oceans, and its transfer, in part, to the atmosphere. An example of this is the spike in 1998.

The ISCCP cloud cover results for monthly averaged data ('D2 series) are shown in Fig. 1b–d. The smooth fits shown are five degree polynomials; the fits are relatively 'stable' in the sense that six and seven degree polynomial fits are very similar to the five degree fits. We are mindful of the need not to read too much into polynomial fits; they are given here mainly to guide the eye. Some features are regarded as significant, however, most notably the minimum near 1996–1997 for T, HCC and MCC and a 'peak' for LCC.

Table 1 Correlation coefficients between MCC and LCC, and HCC and MCC

	Long term	Short term
HCC, MCC	0.191 ± 0.053	0.370 ± 0.043
MCC, LCC	−0.869 ± 0.003	− 0.715 ± 0.014

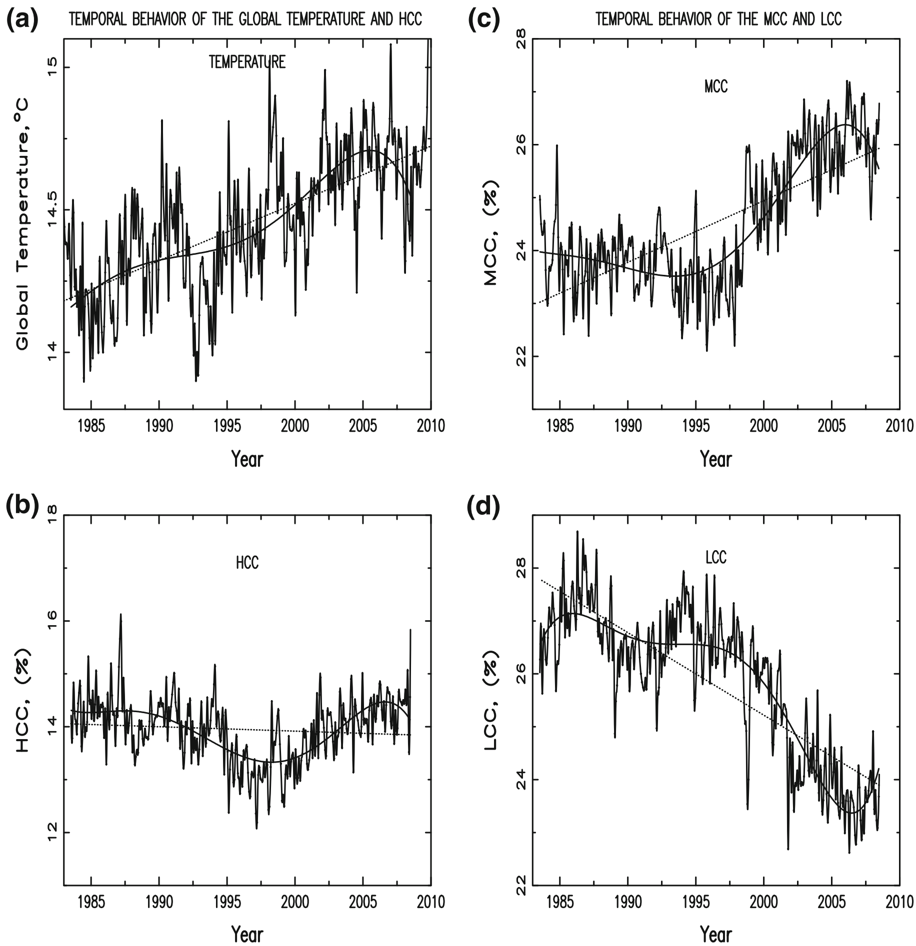

Fig. 1 Temporal behaviour of the global surface temperature and cloud cover variations. **a** Temperature (NASA temperature data 2009). **b** High Cloud Cover, heights above 6.5 km (data from ISCCP, Rossow and Schiffer (1999). **c** Middle Cloud Cover (heights between 3.2 and 6.5 km). **d** Low Cloud Cover (heights below 3.2 km)

The significance level is not high (0.5–1.5 standard deviations), but it is remarkable that the deviations from the linear fits occur at about the same time for all of them.

Interestingly, the near-linear trends for LCC and MCC are almost equal and opposite (which is the reason for the large-scale negative correlation referred to in Sect. 2). There is no linear trend in the HCC.

Figure 2a, b are more illuminating for cloud cover variations. They show the results for the summed cloud covers: HCC + MCC + LCC and MCC + LCC. The oscillation in HCC + MCC + LCC is seen to be very similar to that for T (Fig. 1a).

Turning to the correlations of cloud cover with temperature, the values are given in Table 2. As could be expected, the correlations diminish as the cloud height above the Earth's surface increases.

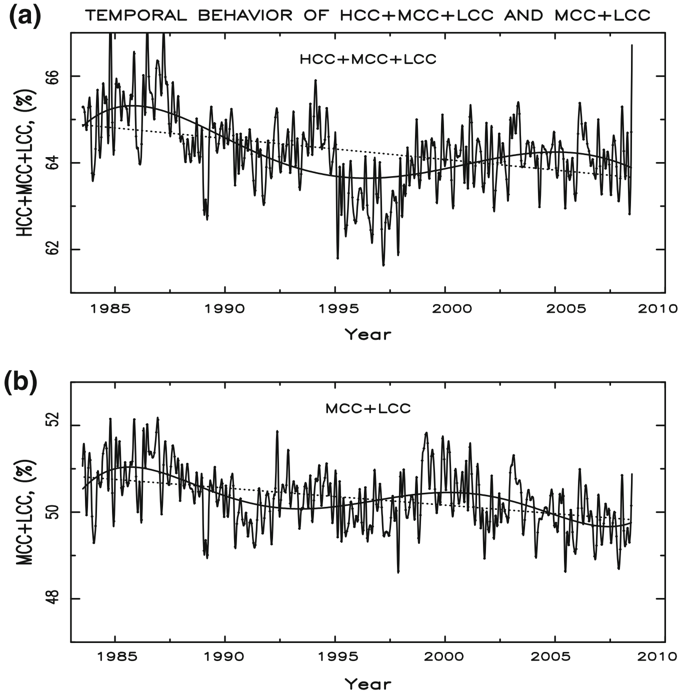

Fig. 2 Temporal behaviour of summed cloud cover variations. **a** HCC + MCC + LCC, i.e. total cloud cover. **b** MCC + LCC

Table 2 Correlation coefficients between CC, T and CR. The short term correlations relate to deviations of CC and T from their linear fits

	T (long term)	T (short term)
HCC	−0.065 ± 0.057	0.002 ± 0.058
MCC	0.509 ± 0.032	0.063 ± 0.057
LCC	−0.622 ± 0.022	−0.184 ± 0.054

3.2 The Significance of the Correlations with Global Surface Temperature

The reduced trend for MCC + LCC (comparing Figs. 2b with 2a) and the somewhat reduced peak-to-peak amplitude of the 'long term oscillations' are indicative of a transfer of cloud between LCC and MCC categories. Specifically, at times of high T there is an increase of mean height of the LCC so that some is classed as MCC.

The fact that the total cloud cover (HCC + MCC + LCC) oscillates roughly in phase with the mean surface temperature T shows that there might be also an effect of T on this quantity, i.e. the total cloud cover, as well as on its height distribution.

The results suggest that the phenomenon of the variation of the LCC is due to the height variation associated with temperature changes and, as such, has no relevance to CR-effects arbitrarily assigned to the 0–3.3 km air layer. The height variation can be deduced from the

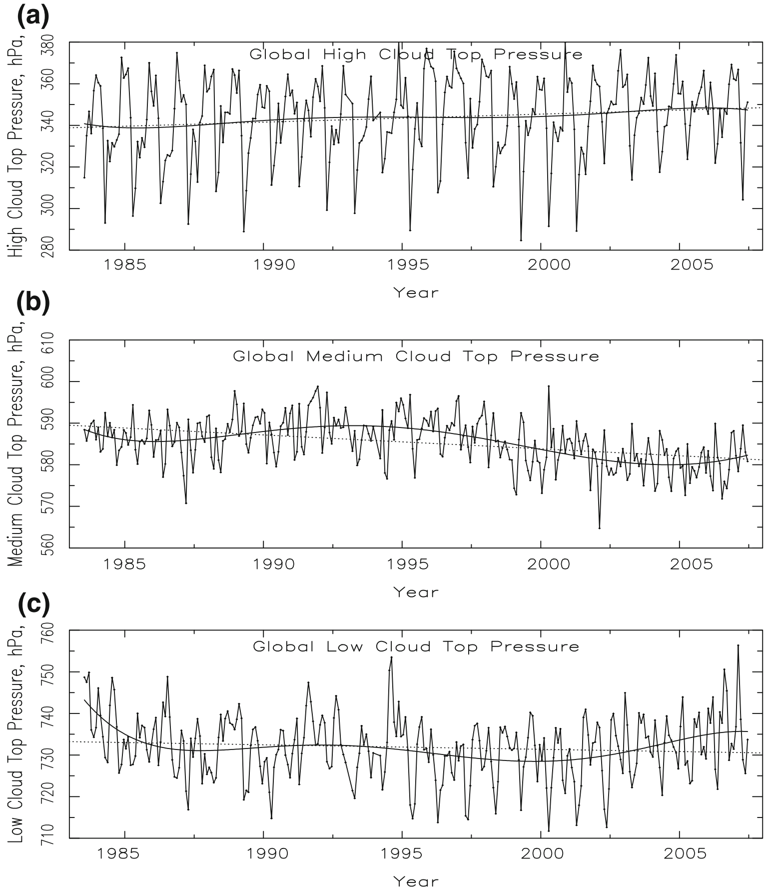

Fig. 3 Temporal behaviour of global top cloud pressure: seasonal variations are not removed. **a** HCC, **b** MCC, **c** LCC

Fig. 3, which shows variations of the Cloud Top Pressure for all types of clouds. Of course, the higher pressure corresponds to a lower height and vice versa. It can be seen that the only (barely) significant wave is that for the Medium Cloud Top Pressure, where the 25-year change is 9 mb and the peak-to-peak wave is 7 mb. Comparison with the total amount of cloud below this cloud top level (LCC + MCC) shows a 25-year change of 1% and peak-to-peak wave of 0.6%. The ratio of the peak-to-peak/25-year change are similar in the two cases: only MCC or MCC + LCC.

The influence of the temperature at the Earth's surface on the cloud heights is seen as seasonal variations for all types of clouds. The approximate coherence of the height variation for LCC and MCC indicates that the temperature varies at the heights of the LCC and MCC in the same way. The decrease of the absolute value of LCC with the contemporaneous increase of that for MCC is because with the rise of heights the input from LCC to MCC is larger than the output from MCC to HCC. The lack of a trend with time over the 25 years in question for HCC can be understood as due to its larger distance from the Earth's surface.

3.3 Other Contributors to the Surface Temperature

Moving on to an examination of the relation of T with solar effects, it is first necessary to study the variety of factors, besides solar irradiance, which contribute to the mean global surface temperature. They are, principally, ENSO, ozone, volcanoes and greenhouse gases. ENSO is the most important from the standpoint of potential effect on the variations of T. However, it has a periodicity of 2–3 years only and does not give rise to longer periodicities, such as the 11-year cycle, although, it can contribute to a displacement of the temperature pattern by a year or two.

A detailed analysis of the effects of the phenomena listed above has been made by ourselves (Erlykin et al. 2010), the work being largely based on Meehl et al. (2004), and only a summary needs to be given here. For 5-year averages, from 1900 to 2000, we find the following: a) The effects, i.e. contributors to T (with respect to a smoothly rising value), are roughly symmetrical about zero, with a median 'correction' of 0.045°C. b) The aggregate has a remarkable near sinusoidal distribution, with a period of about 50 years, with negative peaks in 1917 and 1965. The peak-to-peak value is about 0.15°C. This effect is presumably by chance. Again, it will not affect an 11-year temperature cycle significantly, even if it really exists, but only by way of a small displacement of the pattern.

Most important for the period of time 1983–2009 studied here is the effect of the Mount Pinatubo volcano (in June 1991). The ensuing aerosols injected into the stratosphere caused a global temperature reduction for 1992 and, to a lower extent, for 1993. These can be seen in Fig. 1a.

The effect on cloud cover is less clear cut, but it is unlikely that the excess in HCC + MCC + LCC for 1994 owes much to the volcano.

Returning to the temperature profile (Fig. 1a), omitting the data for 1992 and 1993 does not have much effect on the profile of the fitted line.

3.4 The Correlation of T with Sunspot Number (SSN)

A check on the application of the 5° polynomial fit to near-sinusoidal variations is afforded by inspection of Fig. 4a, which gives the sunspot numbers and the corresponding 5° fit, and Fig. 4b, which shows the same comparison for the CR intensity (Climax neutron monitor data). It will be noted that 1–2 year displacements of the maxima and minima are not uncommon, but the general shape of the long term variations is preserved by the 5° fit.

It is important to identify the origin of the global mean surface temperature variation, specifically, as to whether or not it is due to solar irradiance variations. There is the doubtless consistency of the minimum near 1996–1997 between T, CC and the sunspot number (SSN), but after that it is difficult to be certain as to whether or not the SSN maxima are reproduced by the data—the peaks in the best fit lines are too imprecise to allow an unequivocal answer to the question.

An analysis of correlations between T and SSN in the longer period of 1880–2005 does not reveal an appreciable 11-year periodicity in T (Erlykin et al. 2009). The short-term correlation coefficient for yearly means of these two variables is only 0.077 ± 0.088. However, as will be described later, there does appear to be an approximate 22-year solar-induced variation, many other workers (e.g. Crowly 2000) have drawn attention to the temperature, SSN (or proxy) correlation over the last 1000 years. In this period there have been several identified 'solar minima' (Oort, Wolf, Spörer, Maunder and Dalton minima). In what follows we *assume* that there is, in fact, an 11-year oscillation with a peak-to-peak magnitude 0.1°C following Lean et al. (2005) and others.

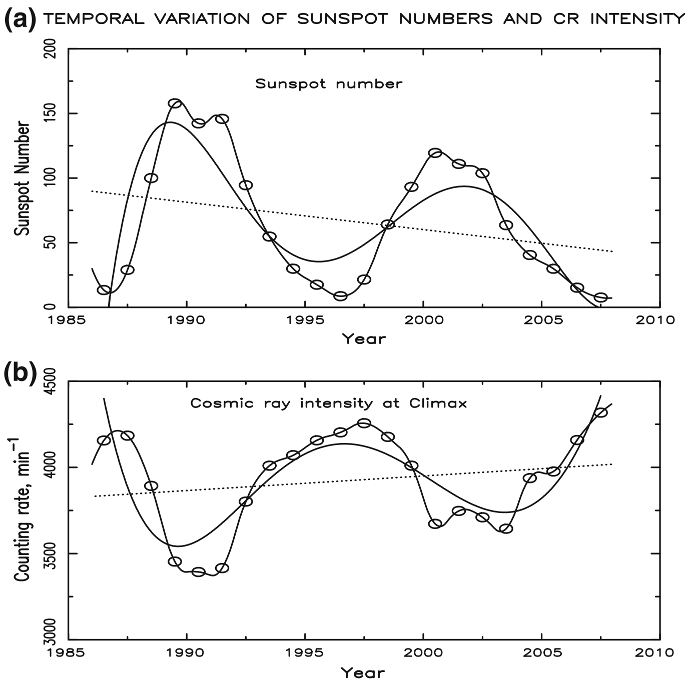

Fig. 4 Temporal behaviour of Sunspot Number and CR intensity variations. **a** Sunspot number (Sunspot Numbers 2009) and a 5° polynomial fit. *Dotted line*—linear fit. **b** Climax CR rate (Climax neutron monitor data) and a 5° polynomial fit. *Dotted line*—linear fit

3.5 Supporting Evidence for the Proposed Explanation for the Low Cloud Cover: Solar Irradiance Correlation from Energetics

It is well known that the idea that long term CR intensity variations cause the variations of LCC, rather than changes in the solar irradiance being responsible, suffers from an energetics problem: the energy of CR changes is some 10^{-8} times that of SI changes. Thus, it was necessary to invoke some magnification mechanism (i.e. positive feedback). Insofar as the mechanism for LCC variations suggested here—thermal heating of the atmosphere by the Earth's surface—is a straightforward mechanism, little positive feedback might be expected.

A number of aspects are relevant. The first concerns the relationship between the increase in mean surface temperature for the last 25 years of 0.5°C and the 0.1°C peak-to-peak wave in temperature which we *assume* to be caused by SI variations. Insofar as there has been no significant increase in *mean* SI over the 25-year period in question (Lean et al. 2005) clearly SI cannot be responsible here. The peak-to-peak change in SI over a solar cycle of 0.1% for a temperature change of 0.1°C would mean that for SI to be responsible for the 0.5°C rise an increase of about 0.5% in SI would be needed. This is not possible: even the change in SI from the Maunder minimum to the present was only $\sim 2Wm^{-2}$, compared with 1 Wm^{-2} peak-to-peak for a contemporary cycle, This value comes from a summary of estimates given in Lean et al. 2005), which would give only 40% of the required temperature rise.

We consider the 0.5°C rise to be due to anthropogenically produced gases—such as carbon dioxide—as do most (but not all) workers. It is useful to consider the energetics of this process, too, from a very approximate point of view. The contemporary (2008) annual consumption of energy in the world, at $\sim 5 \times 10^{20}$ *J*, much of which eventually goes into heat, corresponds to $\sim 10^{-4}$ of the total annual energy delivered by SI. For the man-made energy the increase over the last 25 years has been $\sim$50% and it approaches now 2×10^{-4} of the actual SI reaching the surface of the Earth. The increase in terrestrial energy output has therefore been 0.003% of the total energy provided by SI and for this to yield an increase in temperature of 0.5°C it means that terrestrial energy sources must be 0.5%/0.003% $\sim$ 170 times more efficient than the Sun in causing a temperature rise for the same total energy input (assuming that our conversion value, namely that a 0.1% change in SI yields 0.1°C temperature change). The well known 'efficiency' of carbon dioxide in causing an increased greenhouse effect suggests that the energetics presented here are at least, 'reasonable'. Indeed, a doubling of the atmosphere CO_2 has been estimated to give an increase in surface temperature of about 4°C (IPCC 1990). A relevant fact is that with the terrestrial energy sources being, by definition, at the Earth's surface they are more effective than SI, much of the energy of which is absorbed before reaching the surface.

Turning to the cloud cover, examination of the variation in the LCC 'cloud top pressure' over the period 1983–2008 yields a mean height of 2.6 km and an uprise of about 40 m. The thermal expansion of the air amounts only to a change of about 1m. The change in cloud potential energy is thus $\sim$1.5%. For the (assumed) solar-induced change of LCC, the corresponding height change (peak-to-peak) is about 12 m, i.e. 0.4%, from the oscillations shown in Fig. 1 (showing mean global temperature and LCC variations). Taking the mass of water vapour in the atmosphere as 0.25% of the mass of the atmosphere (the mean of many quoted values) and an atmospheric mass of 5×10^{21} g (Allen 1973) the energy needed to cause this would be $\sim 5 \times 10^{18}$ J. The Earth's atmosphere absorbs ~ 15 Wm^{-2} ($\sim$1% of the Sun's radiant energy (Lean et al. 2005) i.e. 1.5×10^{24} J in 25 years, so that the fraction needed is $\sim 3 \times 10^{-6}$. Clearly, there is no lack of energy available to cause the effect discussed.

In terms of the fractional changes, we have a fractional change of SI of 0.1% causing presumably a fractional change in cloud potential energy of 0.4% i.e. a 4-fold increase (assuming linearity). This would mean that feedback effects must give some preference to the potential energy changes, in comparison with the many other recipients of the solar energy changes.

In this connection it is interesting to note that the kinetic energy of the atmosphere is only $\sim$0.1% of the total energy, E, where E = internal energy + gravitational potential energy + kinetic energy + energy associated with phase transitions (Peixoto and Oort 1992), so that there is considerable scope for the transfer (positive feedback) from another form of energy to the required potential energy.

An estimate of the feedback needed can indeed be made by examining the data on the seasonal variation of the total atmospheric kinetic energy given by Peixoto and Oort (1992). The change of total atmospheric kinetic energy between December, January and February, and June, July and August amounts to 13%. The corresponding change in SI (due to the well-known eccentricity of the Earth's orbit) is 6.9% so that, if the process is linear, a 0.1% change in SI would be expected to give a change of 0.19% in kinetic energy. We are looking for a 0.4% change in potential energy, thus a feedback factor of $\sim$2 is needed if, as to be expected, the fractional changes in potential and kinetic energy are similar and also similar for atmosphere in general and clouds. This is within a factor 2 of the value (4) given above for the cloud top pressure analysis.

A larger factor appears in the analysis of Erlykin et al. (2010) in which it was shown that a 0.1% change in SI over the 11-year cycle gave temperature rises some four times those predicted from a simple pro rata model involving seasonal changes. In this case the reason advanced was that the 11-year cycle involved a variation in the important UV component which was more than 0.1% in the overall solar variation.

4 Discussion and Conclusions

The crucial role of changes of the Earth's global mean surface temperature in governing the variation, and division between cloud cover at various atmospheric levels, thus seems well founded. The reasonableness of the mechanism from the standpoint of energetics is clearly evident.

The distinction between SI and CR explanations of the actual mechanisms has been discussed in detail elsewhere. For example, the analysis of the detailed correlations of CC with both SI and CR by Voiculescu et al. (2006) and its further study by ourselves (Erlykin et al. 2010), showed that only the correlation of LCC with SI (actually the UV component) might be significant, and even this related to some 20–30% of the Earth's surface, only.

It remains to discuss the cloud cover versus time profiles in turn. Starting with the mean global temperature, the oscillation may or may not be solar-induced. The slow rise is presumably due to anthropogenic gases, in agreement with Lean et al. (2005) and many others, or to some unidentified geophysical phenomena.

Turning to cloud cover, the progression from LCC to MCC to HCC (both the mean slope and oscillation discussed) can be understood in terms of the effect of the heated Earth causing the low cloud to rise and the cloud to be reclassified. The reduction in temperature and total cloud cover (HCC + MCC + LCC) in the region of 1996–1997 seems well founded. It is possible that it has the same origin as those in 1910, 1930, 1950 and 1970 (Erlykin et al. 2010) where the temperature and SSN were smoothed with an 11-year running mean. The intention there was to examine the variability from one solar cycle to the next, ie the '22-year' Hale solar cycle. The reason put forward for the temperature dips was the pre-eminence of solar UV (and, perhaps, also the solar plasma incident on the Earth), which has a much greater variability than does the total SI, as already remarked.

The situation with respect to the 11-year solar cycle in surface temperature is that although the present work (Fig. 1a) has failed to confirm it there is some evidence in its favour. One such is the work of Lean et al. (2005) in which a small 11-year cycle in temperature was included in the fit to the observed mean global surface temperature variation. It is not clear, however, as to how essential this contribution was. Another approach was made by ourselves (Erlykin et al. 2009) through an analysis of the Fourier frequency spectrum of surface temperature for the period 1880–2005. Small peaks were found at 22, 12, 9, 5 and 3.8 year. It is tempting to attribute the first two peaks to the actual 22- and 11-year solar cycles.

Including our work referred to above (that 25–30% of the surface of the Earth responds to the 11 year cycle) the present results add just a little to the veracity of the claim for Solar Irradiance (SI) induced temperature change over the 11-year solar cycle.

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