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Short Term Changes in Global Cloud Cover and in Cosmic Radiation

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Abstract

Galactic cosmic rays (GCR) have been suggested as a possible contributory mechanism to cloud formation. If these are significant then, in addition to the similarity between long-term(years) changes in GCR and cloud cover, there should also be a similarity over shorter(days) time scales. This paper reports an analysis of changes in global cloud cover and GCR recorded at three hourly intervals over 22 years. There is a significant correlation between short-term changes in low cloud cover over northern and southern hemispheres, consistent with about 3% of the variation arising from common factors. However, GCR is not a major factor responsible for cloud cover changes. There is an association between short-term changes in low cloud cover and galactic cosmic radiation over a period of several days. This could arise if approximately 3% of the variations in cloud cover resulted from GCR.

Keywords: cloud cosmic global correlation

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1. Introduction

This paper addresses two questions: firstly, do measurements of global fractional cloud cover show evidence of short-term (a few days) external or global influence? secondly, is there evidence of a short-term association between galactic cosmic rays (GCR) and fractional cloud cover?

The context of these questions is the possibility that galactic cosmic rays might affect the weather. Ney (1959) first made this suggestion and thought that ionisation by cosmic rays within the lower atmosphere could be a possible mechanism. It has been suggested that ionised particles could act as nuclei for cloud formation and hence be a plausible explanation for a correlation between GCR and cloud cover. Alternative explanations include the electro-freezing effect on clouds due to vertical currents induced by the interaction of the solar wind with the magnetosphere (Tinsley, 1996) , the indirect cloud modulation by UV- heating of the stratosphere consequent changes in global circulation patterns (Haigh, 1996) and changes in total solar irradiance (Kristjansson et al 2002).

Svensmark and Friis-Christensen (1997) used satellite data from the International Satellite Cloud Climatology Project (ISCCP) over the years 1983 to 1990 and made comparisons with the changes in cosmic radiation flux over the same period. Using other satellite data they extended the measurement period to cover 1980 to 1995 and concluded that there was a significant positive correlation between total cloud cover over the oceans and changes in GCR. The changes were about 3% over the solar cycles in both cloud and cosmic radiation. ISCCP data up to 1995 were used by Marsh and Svensmark (2000) to suggest that the greatest influence of GCR was on low cloud (<3 km) coverage. Marsh and Svensmark (2003) used the ISCCP monthly D2 data to extend their coverage up to 2001. They found a divergence from the earlier close correlation between GCR and low cloud cover which they attributed to problems experienced by ISCCP in inter-calibration of satellite measurements during 1994 and 1995. The approach adopted in the research now reported of looking at short term changes should minimise the effects of possible long term calibration problems.

The publications referred to in the previous paragraph gave rise to many criticisms. Most of this criticism arose from the conclusions that had been drawn about how the measured changes in cloud cover might affect global climate. Gierens and Ponater (1999) made several criticisms and pointed out that the correlation between cloud cover and cosmic radiation had only been made for data collected over the oceans and excluded data from the tropics. More recently Usoskin et al (2006) showed that spurious correlations can arise between cloud at certain levels and GCR as a result of the strong correlations between cloud cover at different levels. The effect of these spurious correlations varies geographically. These spurious correlations will not produce a correlation between GCR and cloud where none exists but they will make interpretation of geographically variable correlations very difficult.

Harrison and Stephenson (2006) inferred cloud cover over the period 1951-2000 by using the ratio of diffuse to total solar radiation and showed a correlation with days of high GCR. To avoid problems in the use of temporal data they used a scatter plot and a local polynomial fit to emphasize the non-linear relationship between diffuse fraction and GCR. High cosmic radiation flux was associated with an increase of 2% in the diffuse fraction and a 19% increased chance of it being an overcast day. Forbush events were associated with a decrease in the diffuse fraction. However, the cloud data were only recorded for the UK.

Research into how GCR might affect global climate is still a controversial area. Most of the research has been based upon correlations between cloud and cosmic radiation time-series. Unfortunately the attachment of an appropriate statistical significance to time-series correlation is difficult, although methods of dealing with this have been suggested. One of the difficulties is that the existence of a significant correlation does not imply any causal relationship between the two variables and indeed the correlation may be an artefact. A second difficulty is a particular problem when time series are correlated and concerns how to attach a statistical probability to the result.

The problems in attaching a probability to a correlation coefficient between two time series were recognised a long time ago. A simple test of significance makes the assumption that the observations are normally distributed and that successive observations are independent. The first assumption has been shown not to be particularly important as tests of significance appear to be insensitive to variations in the frequency distribution of the data. However, the second assumption is rarely fulfilled in time series and it cannot be ignored. Orcutt and James (1948) considered the problem in the context of financial trends. Dawdy and Matalas (1964) considered it in the context of geological data and Mitchell et al (1966) applied it to climatology time series. Some authors (Usoskin et al 2006) have adopted a Monte-Carlo type analysis to randomise the time series and hence remove spurious correlations. However, depending upon the method of randomisation this technique can either overestimate the significance of serially correlated data or underestimate the correlation in the presence of strong periodicity in the time series. More recently Meko (2005) considered the problem of the correlation between successive observations to the problem of tree-ring time series. He adopted the approach of calculating an ‘effective’ sample size based upon the first moments of the autocorrelation functions of the two time series. All these papers appear to have been based in part upon the work of Bartlett (1935) in which the variance that can be expected by chance on the correlation between two time series is discussed. This is the method that has been adopted in this paper.

The continuity of data from the ISCCP project gives a growing data base that should enable some firm conclusions to be drawn. The purpose of the research described in this paper was to take a critical look at the suggested relationship between GCR and global cloud cover and to see if short-term correlations exist. Global data on changes in cloud cover and GCR at 3 hourly intervals over 22 years are analysed.

2. Methods

Data on cloud cover, GCR and geomagnetic variations were obtained at 3-hourly intervals over the period 1983-2005. In all cases the data were filtered to remove spurious correlations. A high-pass (4 cycles per annum) version of the data was derived in order to investigate short-term(periods between 6 hours and 3 months) changes in the variables.

2.1 Cloud

Data on global fractional cloud cover were derived from the data made available under the D1 project of the International Satellite Cloud Climatology Project (ISCCP, 2007) which was established in 1982. An international group of institutions has collected and analysed satellite radiance measurements from up to five geostationary and two polar orbiting satellites to infer the global distribution of cloud properties.

The D1 data is produced every 3 hours on an equal-area map of 280km resolution and merges the results from separate satellites with data on atmospheric humidity, temperature and on ice and snow.

The D1 data were downloaded from the British Atmospheric Data Centre (2007) and from the Atmospheric Science Data Center (2007). These data were downloaded for the period 1st July 1983 to 30th June 2005 and occupy 320 MByte per month.

D1 data contains 202 parameters for each of the 6 596 cells that cover the globe. The ratio of parameters 11(total number of pixels) and 12(number of cloudy pixels) was used to produce the fraction of cloudy pixels. The sum of parameters 28(number of IR-cloudy pixels $680<PC$(Cloud top pressure)≤800 mb or hPa) and 29(number of IR-cloudy pixels $800<PC\leq1000$ mb) as a fraction of parameter 11 was used to give the fraction of low cloud pixels (IR-cloudy pixels between 680 and 1000 mb). Low cloud top temperature was derived as the mean of parameters 111(Mean TC(Cloud top temperature) for IR-cloudy pixels $680<PC\leq800$ mb) and 112(Mean TC for IR-cloudy pixels $800<PC\leq1000$ mb). In all cases the parameters were calculated separately for the northern and southern hemispheres.

In order to reduce spurious correlations caused by the presence of a regular daily variation in all the measured parameters a band-stop filter was applied to all the data. This digital filter was applied in Matlab® and was applied to the fundamental frequency plus the first two harmonics and was a 5th order Chebyshev filter with a bandwidth of 4%. An anti-alias low pass filter was also applied to the data. In addition a high pass filtered version of all the data was produced in order to remove long term variations and isolate the short term changes. The filter applied was a 5th order Butterworth high-pass filter with a cut-off frequency of 4 cycles per annum. All data sets filtered in this way were given the extension _HP. A 10 day stretch of unfiltered and filtered data is shown in Figure 2(a).

2.2 Cosmic radiation

Proxy data on GCR were obtained from the Moscow neutron monitor (2006) as this gives continuous coverage over the period 1983 to 2005. The data were downloaded as hourly data and then an average of the counts per minute taken over 3 hourly intervals to give data in the same format as that for cloud cover. The intensity of GCR is a function of geomagnetic latitude with an approximately 10% increase from the equator to the latitude of the Moscow monitor (53^o N). The data downloaded was already corrected for atmospheric pressure variations and the same temporal filters were applied as were used for the cloud data to provide the derived parameters Cosmic and Cosmic_HP. These vectors were of the same length as those for the derived cloud parameters.

2.3 Geomagnetic variations

In addition to the data on cloud and cosmic radiation measurements of geomagnetic variation were also assembled in order to verify the expected correlation with cosmic radiation variations. Geomagnetic data were downloaded from the British Geological Survey site (2007). The planetary *Ap* indices were used to form a time series of 64 288 points at 3hourly intervals. The *Ap* indices are average values of the disturbances in the horizontal field component and have units of 2 nT. Because the distribution of this parameter is skewed about the mean the natural logarithm of the parameter was used. The mean value of this parameter was 2.34 (SD 0.87). The time series was filtered in the same way as for the cloud data to a produce a high pass filtered data set.

2.4 Analysis

As discussed in section 1. there are considerable problems in the use of correlation coefficients in the analysis of time series where successive data points are not independent. In this paper this problem has been approached by using an 'effective sample size' (see Meko(2005)) N' given by:

$$N' = N\frac{(1 - r_{1x}r_{1y})}{(1 + r_{1x}r_{1y})}$$

where, N is the sample size and r_{1x} and r_{1y} are the first order autocorrelation coefficients of the time series x and y.

The statistical comparisons use a two-tailed t test.

3. Results

The data were analysed separately to identify first long-term(years) and then short-term(periods between 6 hours and 3 months) changes.

3.1 Long term changes in cloud cover and cosmic radiation

Long-term data were recorded at 3 hourly intervals over 22 years, with a band-stop filter applied to reduce daily variations and with an anti-alias filter applied. No high-pass filter was applied. Basic statistics on the cosmic and cloud derived parameters are given in Table 1. The names of the derived parameters given in the first column will be used throughout this manuscript.

If the cloud data were subject to a common, perhaps extra-terrestrial, factor then it seems reasonable to expect there to be a similarity between the changes found in the two hemispheres. In order to identify any similarity the correlation coefficients between the data for the two hemispheres were calculated. All cloud north and All cloud south give a negative correlation (-0.033) but the number of degrees of freedom is only 13, even though the number of data points is large (64 288). Low cloud north and Low cloud south give a positive correlation (0.071) with 213 degrees of freedom. Cloud temperature north and Cloud temperature south give a positive correlation (0.338) with 6 degrees of freedom. None of these correlations reaches a 5% level of significance because of the low number of degrees of freedom. The degrees of freedom were calculated using autocorrelation coefficients in the way described in the methods summary.

In order to identify any long-term similarity between GCR and cloud data correlation coefficients were calculated and are shown in Table 2. Again the calculated values of the number of degrees of freedom to be used are also given. The correlation between All cloud global and Low cloud global is significant with $p<0.01$. The correlation between Low cloud global and Cloud temperature global is also significant with $p<0.05$. None of the correlations between the cloud parameters and GCR reach a 5% level of significance. The correlation coefficient between low cloud global and GCR (0.252) has a p-value of 0.06. In order to check the consistency of this result the correlation coefficients were calculated for the first and second halves of the time series. These were 0.32 and 0.41 respectively.

In order to help understand the calculated correlations the Low cloud global and GCR data are plotted in Figure 1. The cross correlation function of the two data sets is also shown. It can be seen that the maximum correlation does not occur at zero time shift between the two time series. The maximum correlation is at a time shift of

403 days and corresponds to the changes in cloud cover preceding the changes in GCR.

3.2 Short term changes in cloud cover and cosmic radiation

The short-term(periods between 6 hours and 3 months) data is that recorded at 3 hourly intervals over 22 years, with a band-stop filter applied to reduce daily variations and with an anti-alias filter applied. In addition this data was also subjected to a high-pass filter at 4 cycles per annum as described in Methods. Basic statistics on the high pass filtered cosmic and cloud derived parameters are given in Table 1.

As for the long-term data, if the high-pass cloud data is subject to a common factor then it seems reasonable to expect there to be a similarity between the changes found in the two hemispheres. In order to identify any similarity the correlation coefficients between the data for the two hemispheres were calculated. All cloud north_HP and All cloud south_HP give a negative correlation (-0.071), the number of degrees of freedom is 10,025 and the result is statistically significant ($p<0.01$). Low cloud north_HP and Low cloud south_HP give a positive correlation (0.022), the number of degrees of freedom is 11,948 and the result is significant ($p<0.02$) . Cloud temperature north_HP and Cloud temperature south_HP give a positive correlation (0.050), the number of degrees of freedom is 14 827 and the result is significant ($p<0.01$). The total number of data points was in all cases 64 288 and the degrees of freedom were calculated using autocorrelation coefficients in the way described in the methods summary. The cross correlation functions of the above data are shown in Figure 2. Whilst there appears to be a positive short term(<1 day) correlation with zero time delay for all three cloud parameters there also appears to be a longer term(1-

3 days) correlation. This is particularly obvious as a negative correlation for the All cloud parameter.

In order to identify any similarity between the high-pass filtered GCR and cloud data correlation coefficients were calculated and are shown in Table 3. The correlation between pairs of the three cloud parameters show very significant correlations ($p<0.01$). However, only the low cloud changes show a significant correlation (0.029) with the changes in cosmic radiation ($p=0.04$). In order to check the consistency of this result the correlation coefficients were calculated separately for the first and second halves of the time series. These were 0.031 and 0.027 respectively. The possibility of a difference between the correlations for the northern and southern hemispheres with cosmic radiation was also considered. The correlations between low cloud and GCR for the northern and southern hemispheres respectively gave coefficients of 0.035 and 0.010.

The cross correlation function of the low cloud data used in Table 3 is shown in Figure 3. The positive peak is not very clear even though the zero delay coefficient is statistically significant. The curve shows a lag correlation with the maximum at a time delay of about 2 days, with the changes in GCR occurring before the cloud changes. The zero delay correlation of the lower curve could arise if approximately 3% of the variations in low cloud cover were the result of GCR.

3.3 Geomagnetic and Cosmic radiation variations

The cross correlation function between the high-pass filtered geomagnetic and GCR data showed a strong negative correlation (-0.25) with the maximum correlation at a time delay of 15 hours. This corresponds to the geomagnetic changes preceding the cosmic radiation changes

4. Discussion

The first question posed in the Introduction asked if there was evidence of a short-term(days) common or external influence on fractional global cloud cover. This question was addressed by comparing the changes in cloud cover over the northern and southern hemispheres. Statistically significant positive correlations were observed in both low cloud and cloud temperature but total cloud cover gave a significant negative correlation. Inspection of the cross correlation function (Figure 2) shows why this negative correlation arises. In addition to a very short-term positive correlation in both low and all cloud fractions, there is also a negative correlation over a period of a few days in the fraction of both low and total cloud. One possible explanation for this is the migration of large weather patterns across the equator perhaps linked to the Intertropical Convergence Zone. Such a migration might give transient opposing changes in the two hemispheres and so appear as a negative correlation. However, there are relatively few major weather patterns that cross the equator so this is an unlikely explanation for the negative correlations over a few days. An alternative explanation is seasonal cycles that would be in anti-phase between the two hemispheres. This cannot be excluded as a possibility although the negative correlation shown in Figure 2(b) only last for a few days which is a short period for seasonal changes to occur. Caution should also be exercised when interpreting the relative changes in low and total cloud cover in the light of the paper by Usoskin(2006) which was discussed in the Introduction.

There is a strong positive correlation in all three cloud parameters over a period of 3-6 hours. This is consistent with there being a common or external influence over both hemispheres over this time scale. The results can be interpreted as showing that approximately 4% of the short term variations in low cloud cover and 3% of the variations in total cloud cover are the result of an extra-terrestrial or global influence.

The second question posed asked if there was evidence that short-term changes in GCR are associated with similar global changes in cloud cover. Table 3 presents the relevant correlation coefficients. There was no significant correlation between GCR and total cloud cover but there was a significant positive correlation ($p<0.05$) between the global changes in low cloud cover and GCR. The associated cross-correlation function (Figure 3) shows that this positive correlation occurs over several days with the maximum correlation consistent with the GCR changes preceding the low cloud changes by about two days. The cross correlation function can be interpreted as showing that approximately 3% of the variations in global low cloud cover could be the result of changes in cosmic radiation.

There is evidence of an annual variation of about 1-2% in the intensity of GCR and that this variation occurs in antiphase in the two hemispheres. It is possible that there are also shorter-term out-of-phase changes. The correlation coefficient between Low cloud and GCR was indeed much more significant, 0.035 as opposed to 0.010, when the cloud variations for the northern hemisphere were used instead of the southern hemisphere. This may well be the result of using the Moscow neutron monitor data as the index of GCR. The presence of both in- phase and out-of-phase changes in GCR recorded in the two hemispheres makes the interpretation of any associated changes in cloud cover more difficult. However, changes in GCR intensity recorded at many sites correlate positively so the in-phase changes appear to dominate.

Interpretation of correlations is not easy. No conclusions concerning causality can be reached. However, the answers given to the two main questions do appear to be fairly robust. When the data for the period 1983 to 2005 was split into two halves very similar correlations were found for the correlation coefficients between the low cloud and GCR time series. Care was taken to exclude artefacts from the filtering and from edges of the data. Care was also taken to reduce noise on the data and to exclude spurious correlations resulting from daily and annual changes.

The unfiltered long term data does not show any correlations with cosmic radiation that reach a 5% significance level. However, the correlation between global low cloud and GCR (Table 2) is significant at the 6% level. Svenmark and Friis-Christensen (1997) and Marsh and Svensmark (2000) used data excluding the tropics and over land mass, whereas our data were for the whole globe. The fact that the cross-correlation function between global total cloud and GCR shows a maximum corresponding to the changes in cloud preceding the cosmic changes by 403 days is not consistent with a long term causal relationship. However, it is worth noting that peaks in the 11-year cycle of total solar irradiance(TSI) occur 1-2 years before the minima in GCR so that TSI could give a better zero-lag correlation.

Data on geomagnetic variations was included in order to test the interpretation of the cross correlation functions. A strong negative correlation between variations in GCR and geomagnetic fluctuations was found but with a time delay of about 15 hours. This is consistent with the fact that, whereas the geomagnetic variations occur very soon after a sudden change in solar activity, the changes in GCR arise from the arrival of charged particles at the earth several hours after the solar events which have caused the changes.

The long term records of cloud and GCR shown in Figure 1 appear to show a reduction of 2-3% in the fraction of global low cloud over the period 1983 to 2005. Assessing the significance of this in the context of global temperature changes is not easy as clouds have both negative and positive effects on the global thermal balance.

It would appear that there is a significant correlation between the short term changes in low cloud and GCR. Possible mechanisms for this have been discussed by many researchers. The first to be raised was that of the Wilson cloud chamber (Wilson, 1912) which clearly links high energy cosmic radiation with droplet formation. However, it has been pointed out by Harrison and Aplin (2001) that the Wilson cloud chamber operates with air in a very highly supersaturated condition which is probably not found in the atmosphere. Wilson used a piston to produce an adiabatic expansion of water vapour saturated air at room temperature to produce a supersaturated medium. He used expansions of the order of 30% before particle tracks could be seen.

Alternative mechanisms for the production of cloud condensation nuclei by GCR have been proposed by Marsh and Svensmark (2000) , linked to the background aerosol distribution within the atmosphere. Harrison and Aplin (2001) showed some evidence for correlation between increases in the number of condensation nuclei and high ion concentrations, particularly in association with cosmic radiation events. Carslaw et al (2002) reviewed the physical mechanisms for the formation of cloud condensation nuclei. In particular they considered both a clear-air mechanism and a near-cloud mechanism whereby the presence of ions enhances the birth and growth of aerosol particles in the atmosphere. They quoted the rates of ion production by GCR, which will limit the rate at which GCR might influence changes in the concentration of condensation nuclei to a minimum of several hours. They stressed the need for further observations. Our observations of significant correlations over periods from about 6 hours to several days are consistent with the mechanisms proposed by Carslaw et al (2002). There is certainly neither, agreement on the ways in which GCR might affect cloud formation nor, on the significance of this to global cloud cover. Kirkby (1998) at CERN has proposed the CLOUD project in order to investigate water droplet formation inside a large cloud chamber simulating a range of atmospheric conditions. The CLOUD project is still in progress.

The conclusion of this analysis of the changes in cloud cover and GCR is that there is a statistically significant correlation between the short-term (between 6 hours and 3 months) changes in low cloud cover of the northern and southern hemispheres, consistent with about 3% of the variation arising from extra-terrestrial or global factors. However, the correlations with GCR do not suggest that this is a major factor responsible for the measured variations in cloud cover. None-the-less there is a statistically significant ($p<0.05$) association between short-term changes in low cloud cover and GCR over a period of several days. This could arise if approximately 3% of the variations in low cloud cover were the result of cosmic radiation. The correlations between the long-term (longer than 3 months) changes in cloud cover and GCR did not quite reach a 5% level of statistical significance in this study ($p=0.06$).

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Basic statistics on the cloud and cosmic parameters

Derived parameter	Description	Mean	Standard deviation	Coeff. of variation (%)
All cloud north	Total cloud cover fraction in the northern hemisphere	0.629	0.031	4.9
All cloud south	Total cloud cover fraction in the southern hemisphere	0.683	0.034	5.0
Low cloud north	Low cloud cover fraction over the pressure range 680 – 1000mb – north.	0.085	0.018	21.6
Low cloud south	Low cloud cover fraction over the pressure range 680 – 1000mb – south	0.139	0.025	18.1
Cloud temperature north K	Cloud top temp. – north K	158.9	3.9	2.5
Cloud temperature south K	Cloud top temp. – south K	148.7	3.7	2.5
All cloud global	Total cloud cover fraction	0.656	0.022	3.4
Low cloud global	Low cloud cover fraction	0.112	0.016	14.4
Cloud temperature global K	Low cloud temperature K	153.8	3.1	2.0
Cosmic radiation	Counts min^{-1} recorded at the Moscow neutron counter	8697.3	512.2	5.9
All cloud north_HP	High-pass filtered version of the above variables	0	0.023	3.6
All cloud south_HP	“	0	0.023	3.3
Low cloud north_HP	“	0	0.013	15.8
Low cloud south_HP	“	0	0.016	11.6
Cloud temperature north_HP	“	0	2.5	1.6
Cloud temperature southHP	“	0	2.3	1.5
All cloud global_HP	“	0	0.015	2.4
Low cloud global_HP	“	0	0.011	9.5
Cloud temperature global_HP	“	0	1.8	1.1
Cosmic radiation_HP	“	0	127.2	1.5

Table 1 The coefficient of variation is the standard deviation expressed as a percentage of the mean value of the parameter. In every case the variables were vectors of 64 288 points at intervals of 3 hours.

Long-term(years) correlations between the cloud and cosmic variables

	All cloud global	Low cloud global	Cloud temperature global	Cosmic
All cloud global auto corr. 0.9999	1			
Low cloud global auto corr. 0.9983	0.484 ** (n = 56)	1		
Cloud temperature global auto corr. 1.000	0.012 (n = 3.2)	- 0.315 * (n = 55)	1	
Cosmic auto corr. 1.000	0.061 (n = 3.2)	0.252 (n = 55)	-0.170 (n < 1)	1

Table 2. A correlation coefficient matrix for the three global cloud parameters and the galactic cosmic radiation parameter. In every case the first coefficient of the auto correlation function is given in the first column and n, the associated number of degrees of freedom, in the subsequent columns. The correlation coefficients that reach statistical significance are marked with a single asterisk if the 5% level is reached and with two asterisks if the 1% level is reached.

Short-term(days) correlations between the cloud and cosmic variables

All the data has been high-pass filtered	All cloud global	Low cloud global	Cloud temperature global	Cosmic
All cloud global auto corr. 0.8148	1			
Low cloud global auto corr. 0.8056	0.549 ** (n = 13 336)	1		
Cloud temperature global auto corr. 0.8256	- 0.202** (n = 12 579)	- 0.155 ** (n = 12 930)	1	
Cosmic auto corr. 0.9626	0.005 (n = 7 770)	0.029* (n = 8 130)	-0.020 (n = 7 353)	1

Table 3. A matrix of correlation coefficients for the three high-pass global cloud parameters and the high-pass cosmic radiation parameter. In every case the first coefficient of the auto correlation function is given in the first column and n, the associated number of degrees of freedom, is given in the subsequent columns. The correlation coefficients that reach statistical significance are marked with a single asterisk if the 5% level is reached and with two asterisks if the 1% level is reached.

Legends

Figures

Figure 1 Long-term(years) cloud and galactic cosmic radiation(GCR) data. (a) Low cloud global. (b) GCR. (c) Cross correlation function of (a) and (b). The zero delay gives a correlation coefficient of 0.252. This has an associated number of degrees of freedom of 55 and does not reach a 5% level of significance. The maximum correlation has a value of 0.304 and is reached with a time shift of 403 days.

Figure 2 Short-term cloud data. (a) The upper trace is of the unfiltered 3-hourly record of low cloud cover over the northern hemisphere. The lower trace is the same data but after filtering. See section 2.1 for a description of the filters applied. **(b)** The cross-correlation functions are shown between the northern and southern hemisphere cloud data. The lower curve appears to show a negative correlation over a period of a few days but a positive correlation for more rapid changes. Indeed all three curves show some evidence for both changes.

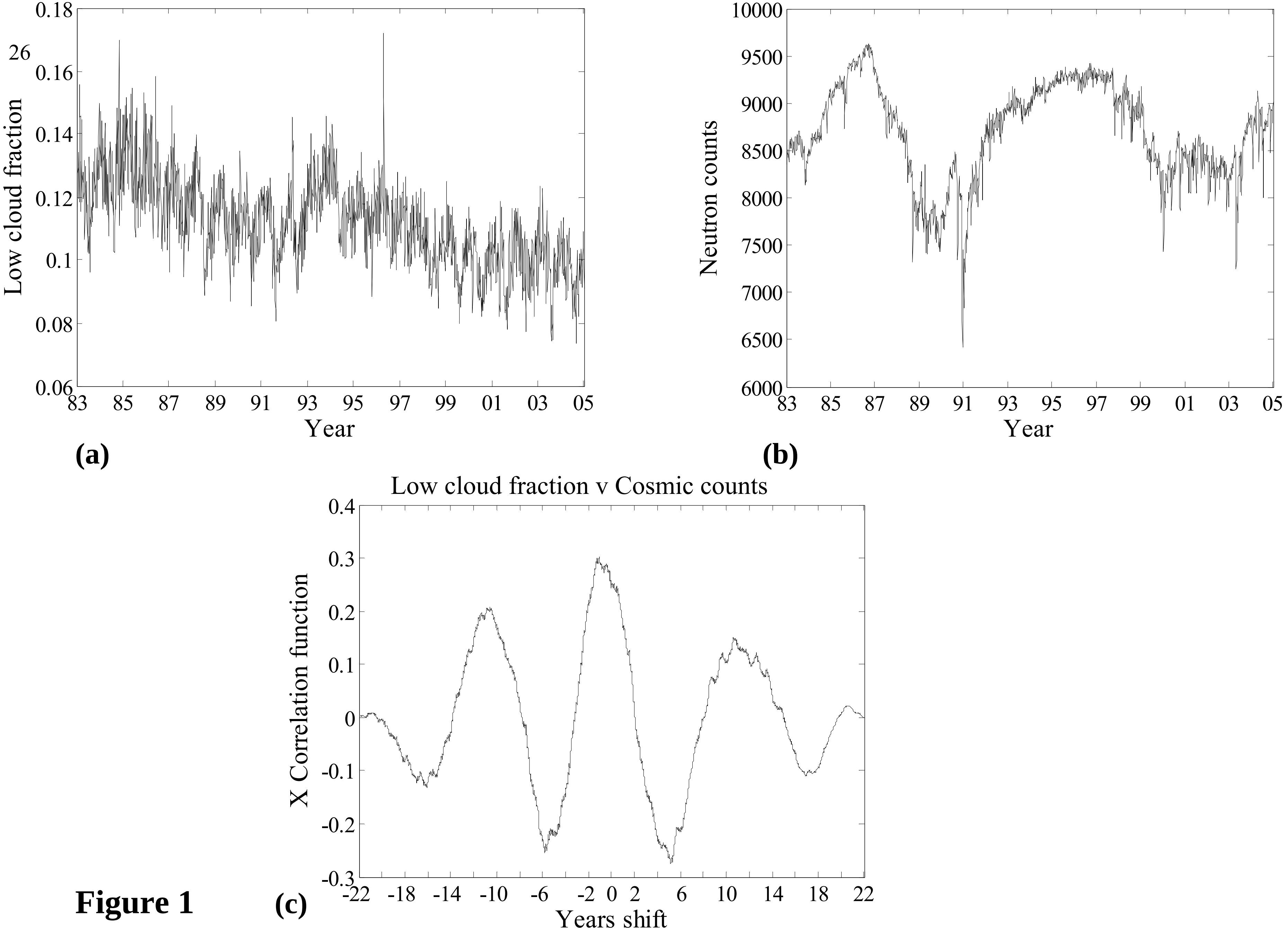
Figure 3 Short-term cloud and cosmic radiation changes. This shows the cross correlation function between Low cloud_HP and Cosmic radiation_HP.

Tables

Table 1 Basic statistics on the cloud and cosmic parameters. The coefficient of variation is the standard deviation expressed as a percentage of the mean value of the parameter. In every case the variables were vectors of 64 288 points at intervals of 3 hours.

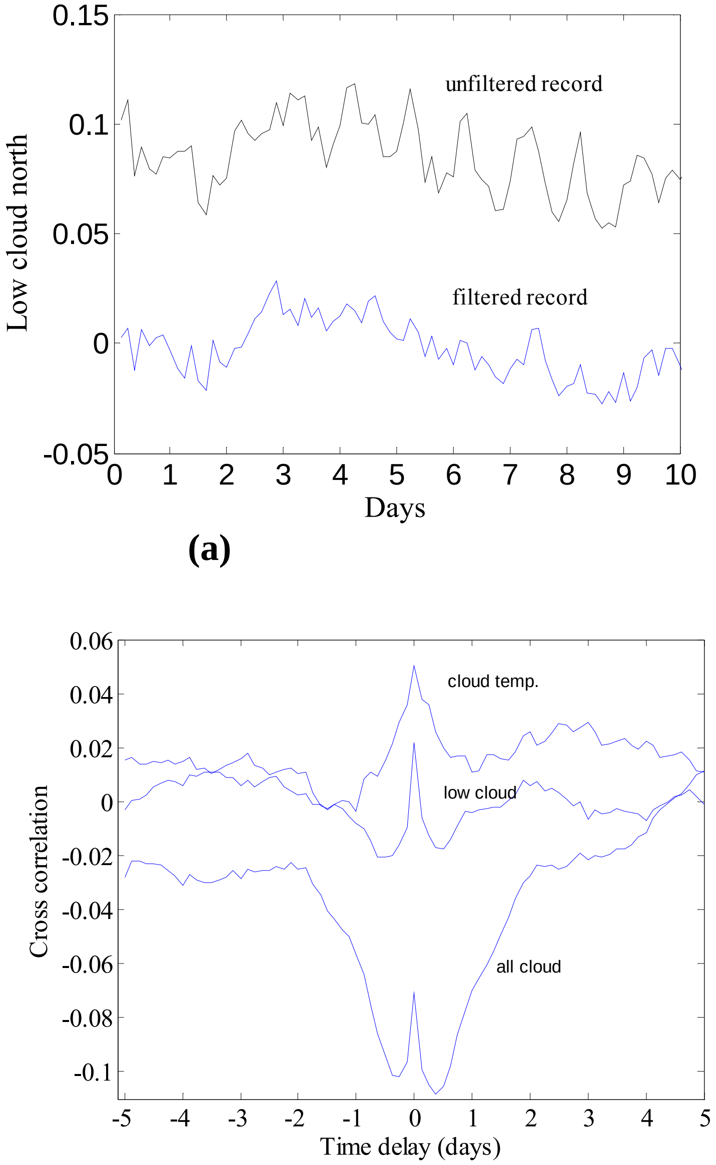
Table 2. Long-term correlations between the cloud and cosmic variables. A correlation coefficient matrix for the three global cloud parameters and the cosmic radiation parameter. In every case the first coefficient of the auto correlation function is given in the first column and n, the associated number of degrees of freedom, in the subsequent columns. The correlation coefficients that reach statistical significance are marked with a single asterisk if the 5% level is reached and with two asterisks if the 1% level is reached.

Table 3. Short-term correlations between the cloud and cosmic variables. A matrix of correlation coefficients for the three high-pass global cloud parameters and the high-pass cosmic radiation parameter. In every case the first coefficient of the auto correlation function is given in the first column and n, the associated number of degrees of freedom, is given in the subsequent columns. The correlation coefficients that reach statistical significance are marked with a single asterisk if the 5% level is reached and with two asterisks if the 1% level is reached.


0.18
0.16
0.14
0.12
0.1
0.08
0.06
Low cloud fraction
83 85 87 89 91 93 95 97 99 01 03 05
Year
10000
9500
9000
8500
8000
7500
7000
6500
6000
Neutron counts
83 85 87 89 91 93 95 97 99 01 03 05
Year
Low cloud fraction v Cosmic counts
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
X Correlation function
-22 -18 -14 -10 -6 -2 0 2 6 10 14 18 22
Years shift

(a) **(b)**

Figure 1 **(c)**


Low cloud north
0.15
0.1
0.05
0
-0.05
unfiltered record
filtered record
0
1
2
3
4
5
6
7
8
9
10
Days
Cross correlation
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
cloud temp.
low cloud
all cloud
-5
-4
-3
-2
-1
0
1
2
3
4
5
Time delay (days)

(a)

(b)

Figure 2

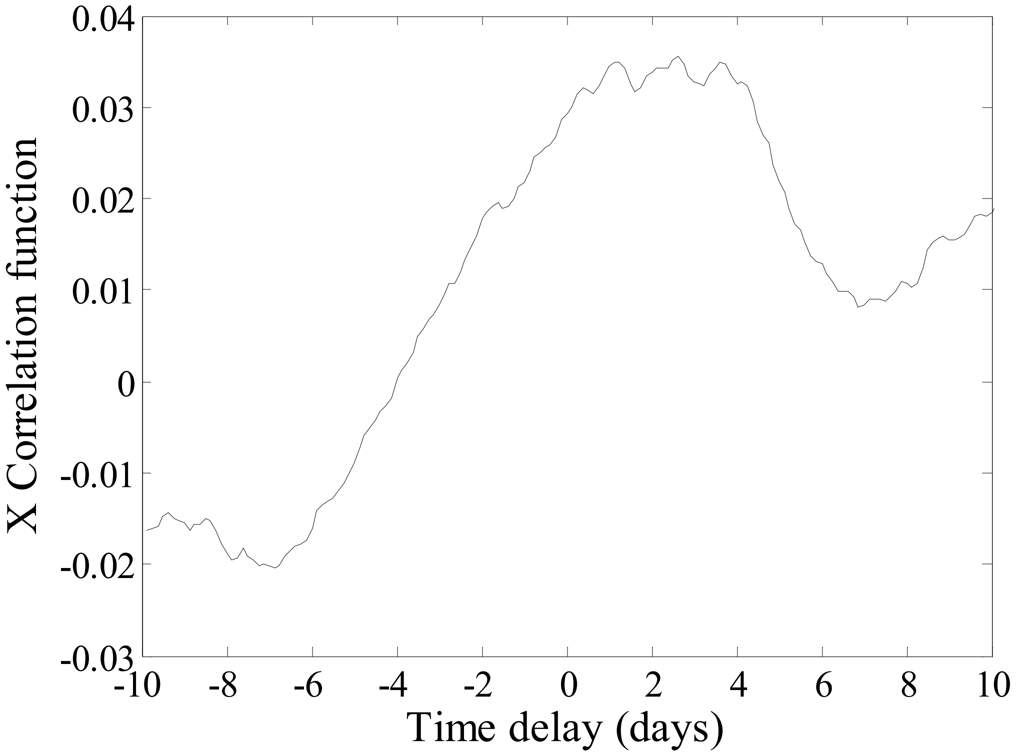

0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
X Correlation function
-10
-8
-6
-4
-2
0
2
4
6
8
10
Time delay (days)

Figure 3