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Cosmic ray decreases and changes in the liquid water cloud fraction over the oceans

Benjamin Laken,[1] Arnold Wolfendale,[2] and Dominic Kniveton[1]

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[1] Svensmark et al. (2009) have recently claimed that strong galactic cosmic ray (GCR) decreases during 'Forbush Decrease (FD) events' are followed by decreases in both the global liquid water cloud fraction (LCF) and other closely correlated atmospheric parameters. To test the validity of these findings we have concentrated on just one property, the MODIS LCF and examined two aspects: 1) The statistical chance that the decrease observed in the LCF is abnormal. 2) The likelihood of the observed delay (~5 to 9 days) being physically connected to the FD events. On both counts we conclude that LCF variations are unrelated to FD events: Both the pattern and timing of observed LCF changes are irreconcilable with current theoretical pathways. Additionally, a zonal analysis of LCF variations also offers no support to the claimed relationship, as the observed anomaly is not found to vary latitudinally in conjunction with cosmic ray intensity.

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1. Introduction

[2] A growing body of work has claimed that solar activity may indirectly influence cloud cover on Earth via a modulation of the GCR flux [*Svensmark and Friis-Christensen*, 1997; *Pudovkin and Veretenenko*, 1995; *Todd and Kniveton*, 2004; *Harrison and Stephenson*, 2006]. Some researchers have suggested that such a relationship may have even contributed a significant portion of the anomalous climate changes observed in recent decades [*Svensmark*, 2007]. Due to the enormous sociological importance of climate change it is essential to carefully examine such claims in great detail.

[3] A very recent study by *Svensmark et al.* [2009, hereafter SBS], has claimed to identify a global response of several atmospheric parameters to large daily timescale Forbush decreases. In their work, the strongest Forbush decreases from 1987–2007 were examined and a search made for associated changes in the atmospheric aerosol content using AERONET, the cloud water content using SSM/I, low cloud cover (hereafter referred to as LCC) using ISCCP and the liquid water cloud fraction (hereafter referred to as LCF) using MODIS. Interestingly these indicators gave very similar time profiles, and from these results SBS have concluded that a causal relationship exists between these parameters and the GCR flux. In this paper we will re-examine the findings of SBS and attempt to ascertain the validity of their conclusions.

2. Analysis

2.1. General Remarks

[4] The primary findings of SBS were drawn from only 5 of the strongest Forbush decrease events, specifically: 31/10/2003, 19/1/2005, 13/9/2005, 16/7/2000 and 12/4/2001 (ordered in terms of diminishing magnitude). The fact that the minima of the atmospheric parameters are not quite at the same times with respect to their associated FD event is not serious.

2.2. MODIS Results

2.2.1. Global Average

[5] We have examined the MODIS results in some detail from various points of view. Figure 1 shows the profile of the MODIS signal (LCF: liquid water cloud fraction) for the mean of the 5 events for an extended time period – our object being to see how frequently excursions similar to the claimed correlated dip occur. The results are plotted for ocean and land, in case of appreciable differences due to differing sources of initiating aerosols. The data covers the whole globe at a $1^\circ \times 1^\circ$ resolution, and values are given as an equal area adjusted simple daily average. An immediate problem concerns the datum level; in Figure 1 we take simple linear fits to the data.

[6] Following the onset of the FD events on the key date of the composite a decrease in the average LCF is immediately apparent over both ocean and land. This suggests that the dip may be genuine and not just natural variability, although it is strange that the dip should last longer over the ocean yet be of similar amplitude (≈1%). Most other variations with respect to the datum line are not coherent over ocean and over land. Dips of this magnitude are not uncommon, however there are 4 separate occasions where comparable decreases occur over the course of the composite period.

[7] The chance of there being a negative going signal which is in the allowed time window but has no connection with the FD can be quantified. If it is assumed that the negative-going excursion should start within 10 days of any datum time then it is observed that in about 33% of the cases such an excursion would occur. Another important aspect concerns the positive-going excursions; such excursions are obviously not connected with FD. It is observed that, in Figure 1, there are equal numbers of positive and negative 'signals'; again, a feature suggesting that the FD are unlikely to be genuine. For the moment we concentrate on the ocean data as oceanic air represents a relatively 'clean environment' containing less aerosols derived from

[1]Department of Geography, University of Sussex, Falmer, UK.
[2]Department of Physics, Durham University, Durham, UK.

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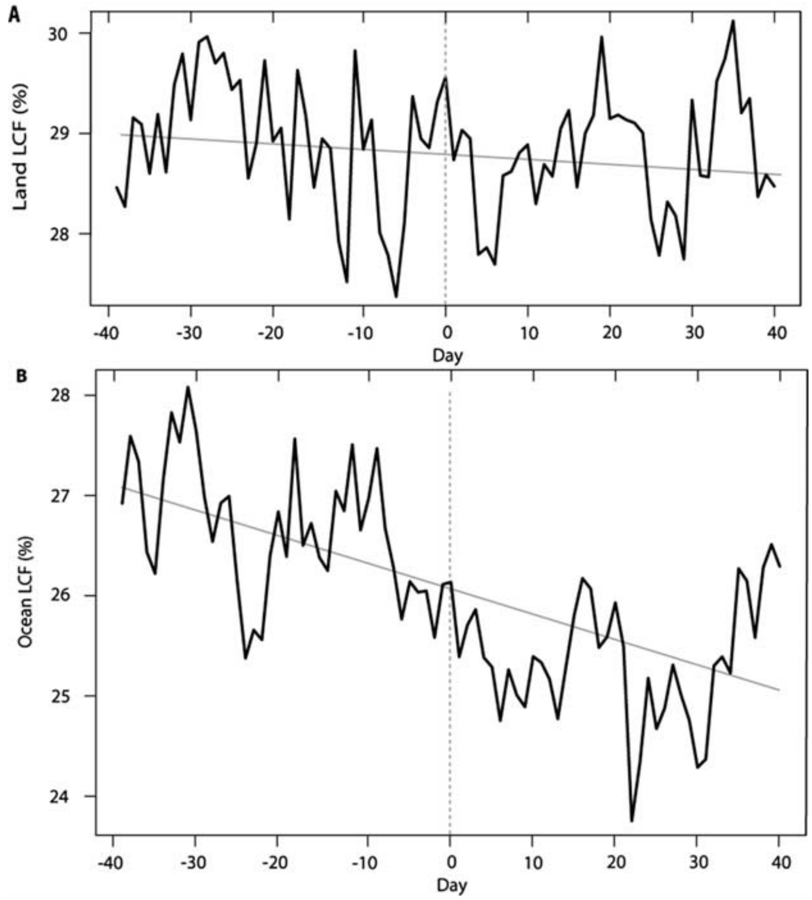

Figure 1. Daily average liquid cloud fraction for (a) land area only and (b) ocean area only (over the globe) during the five largest Forbush Decrease events. The vertical dashed line indicates the key date of each FD. The inclined lines represent the best linear fits over the range ±40 days.

anthropogenic and terrestrial sources than air over land and consequently may be more sensitive to variations in the GCR flux.

2.2.2. MODIS Profiles for the Five Strongest FD

[8] The validity of SBS's claim rests mainly on the signals from the 5 strongest FD events. Thus, an examination has been made of the individual FD (listed above, in section 2.1). The results are shown in Figure 2. Inevitably day to day fluctuations are greater than the sample mean. Principally, it is seen that the important decrease following day zero only occurs during one specific event, that of 19/01/2005. This FD was ranked the 3rd strongest decrease in SBS's ordered list. Although other dips can be seen there is no correlation with FD strength, (a similar result is, in fact, visible from *Svensmark et al.* [2009, Figure 3] for the 5 strongest FD). The widespread lack of agreement between individual events, and general incoherent nature of the observed post key date changes do not support the conclusions drawn by SBS. A further worrying feature is the different long period trends, i.e., the different slopes of the best-fit lines; these indicate that the results may be influenced by longer term variations underlying the dataset.

[9] While the above does not completely invalidate SBS's claim, it does cast serious doubt on it. To further investigate the relationship between the LCF variations and the GCR flux, an analysis of the best-event (19.01.2005) will be given from a CR standpoint in a later section (2.3).

2.2.3. A Close-up of the Mean Profile of the MODIS Events

[10] Figure 3 shows the average LCF for the time region (−15 to +20 days) presented by SBS (i.e., a subset of Figure 2, but with a datum line fitted over the shorter period). The results are given for both ocean – and land. It is evident, and interesting in its own right, that the two are very similar, most notably both have a sharp negative spike at day 6. However, upon contrasting these variations with the longer term composite shown in Figure 1 it is clear the changes are not unique; rather the limited temporal perspective and inclined axis presented act to exaggerate the decreases, giving a false impression of an anomalously large decrease.

2.2.4. A Search for Evidence for a CR-LCF Over the Globe

[11] Theoretically, due to the form of the Earth's geomagnetic field strength at high latitudes, a correlation between increasing latitude an increasing anomalous LCF variations should be observed assuming, that is, that clouds are equally sensitive to CR changes at all latitudes. The latitudinal average LCF prior to and during SBS's anomaly has been studied for both the 5-event composite and individual (19/01/2005) event. No such correlation between increasing latitude and the magnitude of the LCF decrease was found. Instead, in both cases the greatest changes appear to be located around 20°N to 30°N which suggests

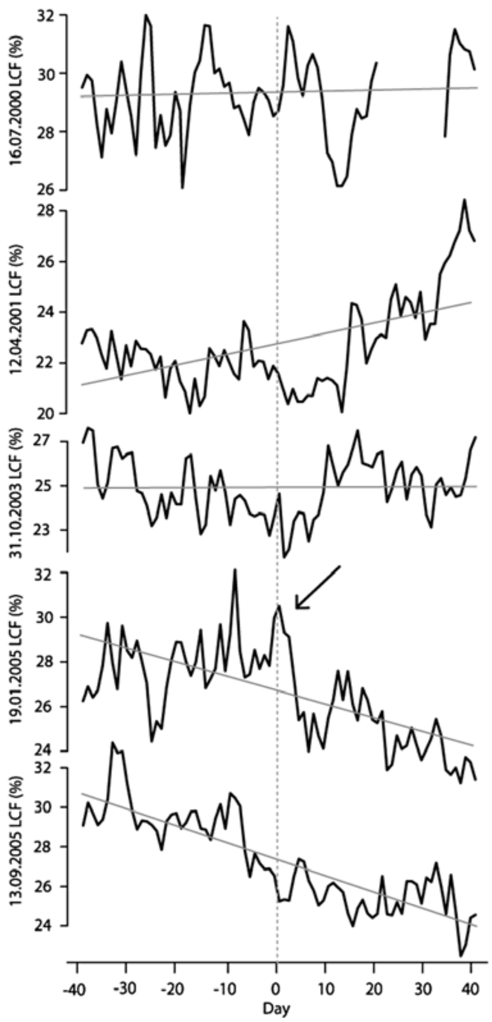

Figure 2. Individual daily average liquid cloud fraction variations during the five largest FD over the ocean area. The vertical dashed line indicates the key date of each Forbush Decrease. The arrow relates to the 'special event', which has the best chance of being genuine (see section 2.3).

a variance unconnected to a microphysical link to the GCR flux. Such findings complement the work of *Sloan and Wolfendale* [2008], who similarly find no correlation between low cloud cover and CR intensity over decadal timescales. Their technique of looking along lines of constant latitude but varying CR changes (due to Earth's magnetic dipole being inclined) was also adopted in an examination of the anomalous variations. No significant correlation was found here either.

2.3. "Special Event": FD, 19/01/2005

[12] The only FD event, for which there could possibly be a claim for CR-induction is the above event; a closer consideration of this event will now be given. Additionally, *Roldugin and Beloglazov* [2008] note that uniquely the event occurs during a possible decrease of the Schuman resonance amplitude. Such variations are usually connected to thunderstorm activity, and it has been suggested that a relationship exists between CR and thunderstorms [*Lidvansky and Khaerdinov*, 2009]. Therefore a more detailed consideration of this event is appropriate.

[13] Figure 4 shows the CR intensity and the MODIS profile together for the time interval −12 to +12 days where the normalisation is at the onset of the FD, 17 January. It should be noted the vertical scales differ.

[14] It will be noted that the CR profile for the FD event has "structure", in the form of actually two Forbush decreases, on the 18th and 22nd January (really, this particular FD should not have been included by SBS in their set). It is thus, very unusual. Furthermore, there is a Solar Proton Event (SPE) starting at 07:00 on January 20 (see *Fluckiger et al.* [2005] for details of the Ground Level Enhancement (GLE) as well as the profile of the neutron monitor counts). Clearly the GLE and the FD act in opposition, but apart from the polar regions the FD dominates [*Usoskin et al.*, 2009].

[15] The situation so far is therefore that only one of the FD (the "special event") has a prospect of being in coincidence with a LCF dip – and even here the likelihood of such a change occurring by chance is approximately 33%. Somewhat smaller dips appear often and the question can be asked: why was this major dip not seen to any extent in the LCF responses of the other 4 events?

[16] However, to give the phenomenon every opportunity of being real we move on to examine the physics behind the CR profile of Figure 4 transforming into the observed LCF profile. It should be stressed that the profile of the special event is similar to that for the mean, presented by SBS.

3. Growth Times From Ions to Cloud Droplets

[17] The physics behind the process is, at first sight, straightforward. Cosmic ray ions adhere to molecules very quickly and thence to aerosols to form 'superfine aerosols'. By virtue of their charge they have an advantage in the pursuit of water vapour and then grow to form cloud condensation nuclei (CCN) which in turn form cloud droplets. The process (referred to as the direct or clean air mechanism) has been described in detail by *Harrison and Carslaw* [2003] and many others.

[18] In fact, there have been a number of studies pointing out the inefficiency of this mechanism, such as by *Pierce and Adams* [2009] and *Erlykin et al.* [2009]. Furthermore, many studies of growth times from ions to CCN have been made and from such studies two features are clear: 1) The maximum time is about 2 days (J. Kirkby, personal communication, 2009) or even as low as 6h [*Rycroft et al.*, 2008]. 2) The actual timing is highly variable across differing spatio-temporal domains. From these features can be concluded the time lag of approximately 6 days needed by SBS does not fit with the contemporary understanding of aerosol growth, and consequently there is no theoretical basis upon which SBS can justify their claims.

4. Discussion and Conclusions

[19] Although this study is able to broadly replicate the findings of SBS in relation to average LCF variations (Figure 3), we find no evidence to suggest that these changes are causally related to CR variations. Furthermore, we find no coherence between the 5 individual composite events; instead we find that the variations of a single event (that of 19/01/2005) dominate the sample, resulting in the false impression of a large decrease occurring across the

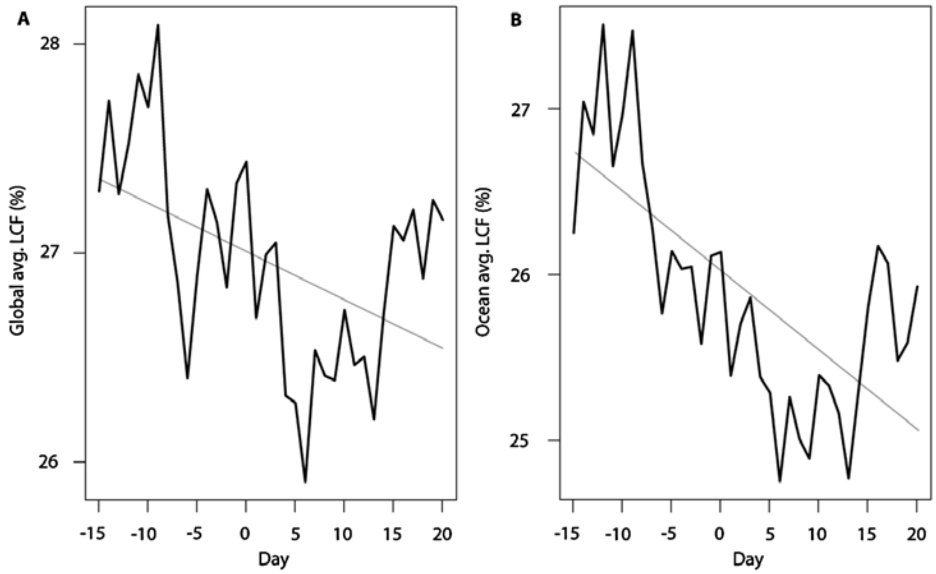

Figure 3. (a) Global average, and (b) Ocean only daily average liquid cloud fraction with comparable formatting to SBS except that the inclined reference lines are the best linear fits.

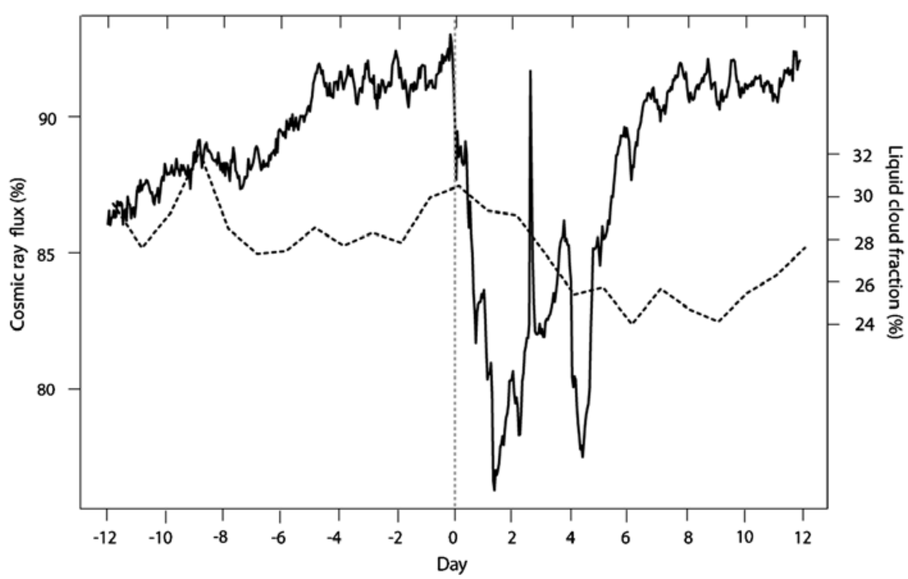

Figure 4. Cosmic ray flux (solid line; 100% being the long term average) and global daily average liquid cloud fraction variations (dashed line) occurring during the individual 19/10/2005 event. The vertical dashed line indicates the key date, the global average is adjusted to the onset of the associated Forbush Decrease event.

composite. An analysis of the latitudinal distribution of the LCF variations reveals that this decrease is predominately located at mid to low latitudes, whereas if the phenomenon were related to variations in the CR flux it should be predominately located at high latitudes.

[20] What is potentially interesting, however, is the event of 19/01/2005 which is found by others to have associated atmospheric electricity effects. Interestingly, electrical effects have been invoked as an indirect, though small contributor to CR effects on climate [*Harrison and Ambaum*, 2008]. It is not clear what the time interval should be between CR dip and water content dip but electrical effects appear to have time-spreads less than 10 h [*Rycroft et al.*, 2008], too short to give a ready explanation. A, further study of this particular event is warranted and although we reject the findings of SBS, we feel this area of Solar-terrestrial interactions is an important topic and should not be regarded as a closed book.

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References

Erlykin, A. D., G. Gyalai, K. Kudela, T. Sloan, and A. W. Wolfendale (2009), Solar activity and the mean global temperature, *Environ. Res. Lett.*, *4*(1), 014006, doi:10.1088/1748-9326/4/1/014006.

Fluckiger, E. O., R. Butikofer, M. R. Moser, and L. Desorgher (2005), The cosmic ray ground level enhancement during the Forbush Decrease in January 2005, in *Proceedings of the 29th International Cosmic Ray Conference*, pp. 101–104, Tate Inst. of Fundam. Res., Mumbai, India.

Harrison, R. G., and M. H. P. Ambaum (2008), Enhancement of cloud formation by droplet charging, *Proc. R. Soc. A*, *464*(2098), 2561–2573, doi:10.1098/rspa.2008.0009.

Harrison, R. G., and K. S. Carslaw (2003), Ion-aerosol-cloud processes in the lower atmosphere, *Rev. Geophys.*, *41*(3), 1012, doi:10.1029/2002RG000114.

Harrison, R. G., and D. B. Stephenson (2006), Empirical evidence for a nonlinear effect of galactic cosmic rays on clouds, *Proc. R. Soc. London, Ser. A*, *462*(2068), 1221–1223, doi:10.1098/rspa.2005.1628.

Lidvansky, A. S., and N. S. Khaerdinov (2009), Strong variations of cosmic ray muons during thunderstorms, *Bull. Russ. Acad. Sci. Phys.*, *73*(3), 397–399, doi:10.3103/S1062873809030356.

Pierce, J. R., and P. J. Adams (2009), Can cosmic rays affect cloud condensation nuclei by altering new particle formation rates?, *Geophys. Res. Lett.*, *36*, L09820, doi:10.1029/2009GL037946.

Pudovkin, M. I., and S. V. Veretenenko (1995), Cloudiness decreases associated with Forbush-decreases of galactic cosmic rays, *J. Atmos. Sol. Terr. Phys.*, *57*(11), 1349–1355, doi:10.1016/0021-9169(94)00109-2.

Roldugin, V. K., and M. I. Beloglazov (2008), Schumann resonance and amplitude during the Forbush effect, *Geomagn. Aeron.*, *48*(6), 768–774, doi:10.1134/S0016793208060091.

Rycroft, M. J., R. G. Harrison, K. A. Nicoll, and E. A. Mareev (2008), An overview of Earth's global electric circuit and atmospheric conductivity, *Space Sci. Rev.*, *137*(1–4), 83–105, doi:10.1007/s11214-008-9368-6.

Sloan, T., and A. Wolfendale (2008), Testing the proposed causal link between cosmic rays and cloud cover, *Environ. Res. Lett.*, *3*(2), 024001, doi:10.1088/1748-9326/3/2/024001.

Svensmark, H. (2007), Cosmoclimatology: A new theory emerges, *Astron. Geophys.*, *48*(1), 1.18–1.24, doi:10.1111/j.1468-4004.2007.48118.x.

Svensmark, H., and E. Friis-Christensen (1997), Variation of cosmic ray flux and global cloud coverage: A missing link in solar-climate relationships, *J. Atmos. Sol. Terr. Phys.*, *59*(11), 1225–1232, doi:10.1016/S1364-6826(97)00001-1.

Svensmark, H., T. Bondo, and J. Svensmark (2009), Cosmic ray decreases affect atmospheric aerosols and clouds, *Geophys. Res. Lett.*, *36*, L15101, doi:10.1029/2009GL038429.

Todd, M. C., and D. R. Kniveton (2004), Short-term variability in satellite derived cloud cover and galactic cosmic rays: Update, *J. Atmos. Sol. Terr. Phys.*, *66*(13–14), 1205–1211, doi:10.1016/j.jastp.2004.05.002.

Usoskin, I. G., A. J. Tylka, A. Kovaltsov, and W. F. Dietrich (2009), Ionization effect of strong solar particle events: Low-middle atmosphere, paper presented at the 31st International Cosmic Ray Conference, Univ. of Łódź, Łódź, Poland.

D. Kniveton and B. Laken, Department of Geography, University of Sussex, Falmer BN1 9QV, UK. (bal22@sussex.ac.uk)

A. Wolfendale, Department of Physics, Durham University, Durham DH1 3LE, UK.