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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Effects of cosmic ray decreases on cloud microphysics" *by* J. Svensmark et al.

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The manuscript Svensmark et al (2012), hereafter referred to as SES12, continues the work begun in an earlier study by Svensmark et al. (2009), in an attempt to analyze the effects of Forbush Decrease (FD) events on cloud properties. The authors have focused on cloud parameters from the Moderate Resolution Imaging Spectroradiometer (MODIS) dataset, claiming that significant changes in a range of globally averaged MODIS cloud properties support the hypothesized link between changes in the galactic cosmic ray (GCR) flux and cloud cover. After a detailed and careful analysis of the MODIS cloud fraction data we find that the results presented in SES12 are statistically insignificant and their conclusions are unsupported by the data. We attribute the author's significant results to a poor statistical handling of the data, and consequently recommend rejection of this work.

To construct composites based on FD events and establish statistical significance the authors used the following methodology: firstly, they linearly de-trended individual events (which normalized the data to zero). Separately, they calculated 100 randomly generated sample standard deviations over 36-day periods from the dataset (excluding the period of their FD events). They plotted their composite over a -15 to +20 day period and over-plotted the calculated standard deviation from their 100 random samples to estimate the 1 and 2 sigma level uncertainties, these sigma levels were normalized to an averaging period prior to the FD event (days -15 to -5 of the composite).

This procedure has several weaknesses. Firstly, the use of linear de-trending is inappropriate, as it will not account for mid-term variations (>2 week) in the data. This effect will increase the chance of any daily-timescale variation erroneously registering as statistically significant if it occurs during a peak of the mid-term variability.

Secondly, by adjusting the sigma levels to a base period (in SES12 the average of the day -15 to day -5) the chance of the values registering as statistically significant level will increase with time from the calibrated period. This effect can be clearly noted in Figure 1, which shows a comparison between the SES12 calculated two-sigma level and the correctly calibrated confidence intervals. A narrowing of the confidence interval during the base period can be seen (due to normalization of the data to this period), followed by a steady increase in both the 95th and 99th percentile values afterwards. The confidence intervals displayed in Figure 1 are produced from 100,000 Monte Carlo (MC) simulations of composites using the entire MODIS Terra Liquid cloud fraction (LCF) data (2000 – 2012), where the data have been linearly de-trended and normalized to a base period (day -15 to -5) prior to compositing (as in SES12).

To avoid the statistical shortcomings of SES12 and to properly evaluate fluctuations over the composite we have constructed a 21-day moving-average of the MODIS data and subtracted the daily averages from the moving-average (we will hereafter refer to these values as anomalies). A 21-day moving-average is appropriate, as it isolates the time-period within which one theoretically may expect a cloud response to occur from GCR flux variations. Our following analysis concerns the liquid cloud fraction (LCF) dataset (MOD_D3 Collection 5.1) as this cloud parameter showed the most significant response, however the statistical issues raised in this comment extend to all analyzed variables in SES12.

To assess the statistical significance of the composite variations we have used MC methods, generating 100,000 randomized composites of equal dimensions (time-period, and number of events) using the same methodology of data preparation (anomalies) as in our FD event analysis. From these data we then constructed histograms of the MC generated values and extracted the 95th and 99th (two-tailed) percentile values.

Our analysis of the LCF data, using anomalies for the five events selected by SES12, are presented in Figure 2. These data are plotted over both a $\pm$20 day period and a $\pm$100 day composite period (top and bottom panels, respectively), with the 95th and 99th percentile confidence intervals. We note a virtually identical pattern of LCF variations as in SES12, including a maximal reduction over the $\pm$20 day period on day +6 (of -0.95 %). However, as discussed in paragraph 4, we find the significance of this change to be markedly different to that presented by SES12: based on our MC

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distributions we calculate a two-tailed probability (p) value of achieving such a value to be p = 0.0068. Over a ±100 day period we note numerous excursions of equal and greater magnitude than the day +6 changes: statistically, over a composite of 200 events we would expect 10 (200 x 0.05 = 10) to be greater than the 95th percentile value, while 2 events (200 x 0.01 = 2) should be greater than the 99th percentile values. Examining Figure 2B we find 9 and 3 data points to be greater than the 95th and 99th percentile values respectively, in agreement with the standard statistical expectations.

The previous paragraph effectively indicated that small composite sizes suffer from issues of large mean variability. This is because the effects of individual events may dominate such composites. We can clearly see the effect of one event dominating the SES12 composite sample: by exchanging the second largest FD event in the SES12 list for the sixth largest event the composite looses all statistical significance above the 95th percentile level (Fig. 3A). Despite the event change the magnitude of the FD events is only reduced from 82 % to 76 % (according to the magnitudes ascribed in Table 1 of SES12). If we examine the LCF deviations of the largest six events it is clear that event #2 (19/01/2005) has a dominant influence in producing the day +6 reduction shown in SES12 (Fig. 3B). Furthermore, it is interesting to note that if SES12 wished to precisely test the effects of GCR reductions during FD events on cloud properties they should have excluded this event, as it is accompanied by a large solar proton (SP) event (Mironova et al., 2008), which would induce opposite atmospheric ionization changes to those produces by a reduction in the GCR flux.

SES12 have identified 13 strong FD events (SES12, Table 1), however they base their analysis only on the 5 highest magnitude events under an unsupported claim that noise dominates the expected GCR – cloud signal for the weaker FD events, making detection of a GCR – cloud link difficult. A plot of the full list of 13 events over a ±20 day period is shown in Figure 4 and indeed, the significant day +6 LCF reduction observed by SES12 is absent.

The SES12 argument of noise from weaker events possibly masking a GCR – cloud

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signal is reasonable, and has been noted by several authors (e.g. Harrison and Ambaum, 2010; Laken and Čalogović, 2011). However, upon examination of the change in the potential signal-to-noise ratio (SNR) of the composite samples we find that a hypothesized GCR – cloud signal should be more easily detected from a composite of the full 13 events (listed by SES12, Table 1) than from only the 5 largest events. We arrived at this conclusion by examining the 95th percentile values calculated from the generated distributions of 100,000 MC samples for the n = 13 and n = 5 LCF composites (found to be ±0.70 and ±0.44 % respectively with a difference of 37 %). Additionally, according to the FD magnitudes listed in Table 1 of SES12 the average magnitude of the FD events are reduced by 29 % by considering all 13 events (as opposed to the average magnitude of 5 largest alone). Thus, we argue that although the composite of 13 events has an average GCR reduction of 29 % less than the composite of 5 events, the SNR of the composite with 13 events is enhanced by 37 %, and consequently is more likely to detect a hypothesized signal. This enhancement is even greater if we take into account the fact that the most favorable GCR – cloud efficiency purported has been less than 25 % (Marsh and Svensmark, 2000); i.e. a 4 % change in the GCR flux has been suggested to alter clouds by 1 % at the most. Consequently, the lack of a significant LCF response in the 13-event composite significantly weakens the hypothesized GCR – cloud connection.

Our analysis has focused on the statistical significance of the results obtained by SES12 and does not cover the less important (yet notable) shortcomings of their manuscript. From our analysis the following can be concluded: 1) SES12 use an incorrect methodology and statistical approach leading to the false creation of significant results. 2) When correct methods are applied, analyzed cloud properties show no statistically significant responses following FD events. 3) There is no reason to claim that a GCR-related signal may be detected in just the largest five events, as the signal-to-noise ratio for the composite of the full thirteen events is larger (where even SES12 acknowledge no significant cloud anomalies are detected). 4) As a result of the insignificance of the SES12 results their discussion and conclusions are not valid.

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Figures

Figure 1. Correctly adjusted confidence intervals Using an identical method of data preparation as used by SES12 (i.e. linear de-trending, and normalization to day -15 to -5) we present correctly adjusted 95th and 99th percentile (two-tailed) confidence intervals (shown with the dashed and dotted lines respectively). These intervals were calculated from 10,000 Monte Carlo (MC) simulations from the MODIS liquid cloud fraction data (2000 – 2012). Red lines show the ±two-sigma confidence values projected by SES12. This figure clearly shows that during the period of normalization (indicated by the grey shading) our calculated confidence intervals are in close agreement to the SES12 two-sigma level. However, with increasing time from the normalization period the confidence intervals increase, and the two-sigma confidence interval of SES12 becomes incorrect.

Figure 2. Liquid cloud fraction changes over ±20 and ±100 day period Composites of five largest FD events presented over a: A) ±20 day, and B) ±100 day period for anomalous MODIS Terra Liquid cloud fraction (90°N – 90°S). Values are anomalies from 21-day moving averages (i.e. mean of each day subtracted from 21-day moving average). Dashed and dotted lines indicate the 95th and 99th (two-tailed) percentile confidence intervals respectively calculated from 100,000 Monte Carlo simulations. Day +6 value is -0.95 %, probability of achieving this value at random is $p = 0.0068$. Grey shading in panel B indicates period analyzed by SES12 (day -15 to +20).

Figure 3. Liquid cloud fraction changes for alternative five FD events MODIS Terra liquid cloud fraction anomaly composite of the five largest FD events (panel A) substituting event #2 for event #6 (events taken from Table 1 of SES12). The individual events (including the excluded event #2) are shown in panel B, specifically, they are: 13/10/2003 (#1, line), 19/01/2005 (#2, red line), 13/09/2005 (#3, line), 16/07/2000 (#4, line), 12/04/2001 (#5, line), and 10/11/2004 (#6, line) DD/MM/YYYY (#X is rank number). Data show that it is the inclusion of event #2 that is responsible for the day +6 reduction. By replacing event #2 with event #6 we have only reduced the FD event

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magnitude from 82 % to 76 % respectively (according to the magnitudes ascribed in Table 1 of SES12). Despite this relatively small reduction in the GCR signal the composite has lost all statistical significance above the 95th percentile level. It can be clearly seen that the previously evident composite changes on day +6 were dominated by a single event (#2, 19/01/2005). Furthermore, this event should not have been included in the composite, as in addition to the GCR flux reduction it includes a strong solar proton (SP) event (Mironova et al, 2008).

Figure 4. Liquid cloud fraction from all 13 FD events Composite of MODIS Terra liquid cloud fraction anomalies from all 13 FD events listed in Table 1 of SES12. Dashed and dotted lines show the 95th and 99th percentile (two-tailed) confidence intervals respectively, calculated from 100,000 MC simulations. Day +5 shows a reduction of -0.45 % (p = 0.023).

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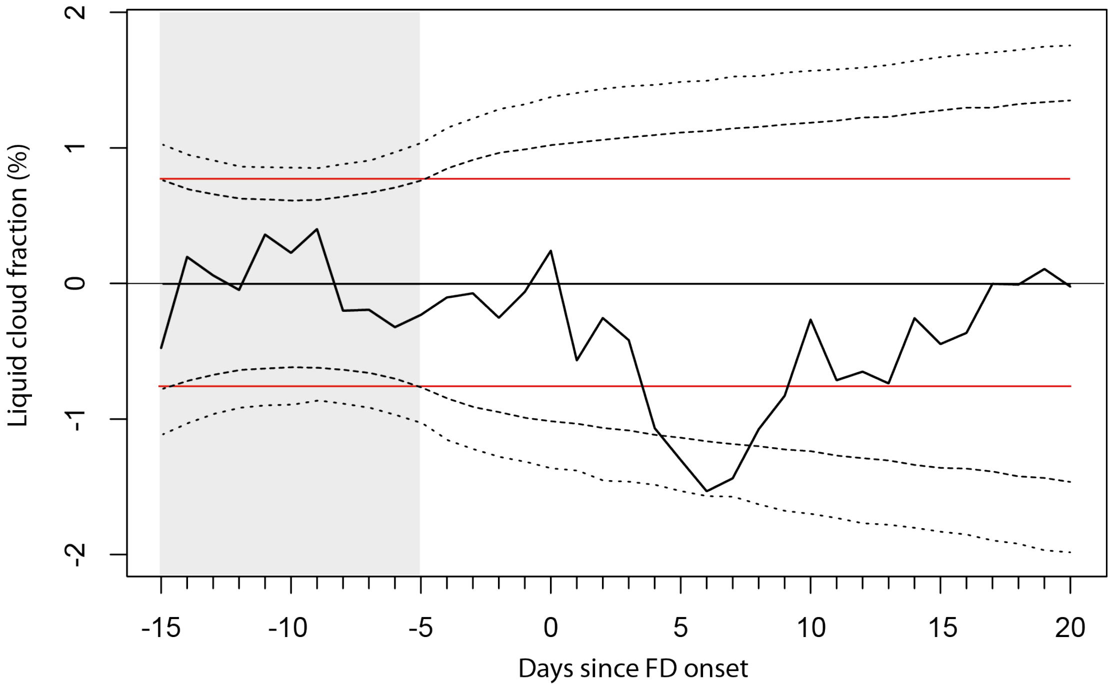

Fig. 1. Correctly adjusted confidence intervals (see end of text for caption)

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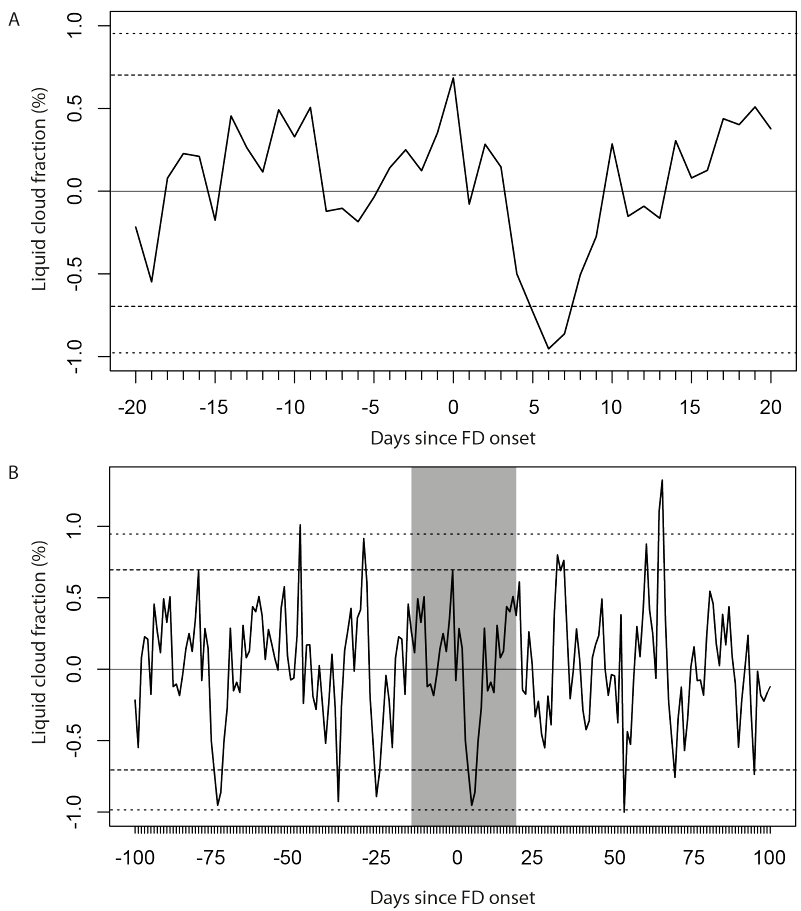

Fig. 2. Liquid cloud fraction changes over ±20 and ±100 day period (see end of text for caption)

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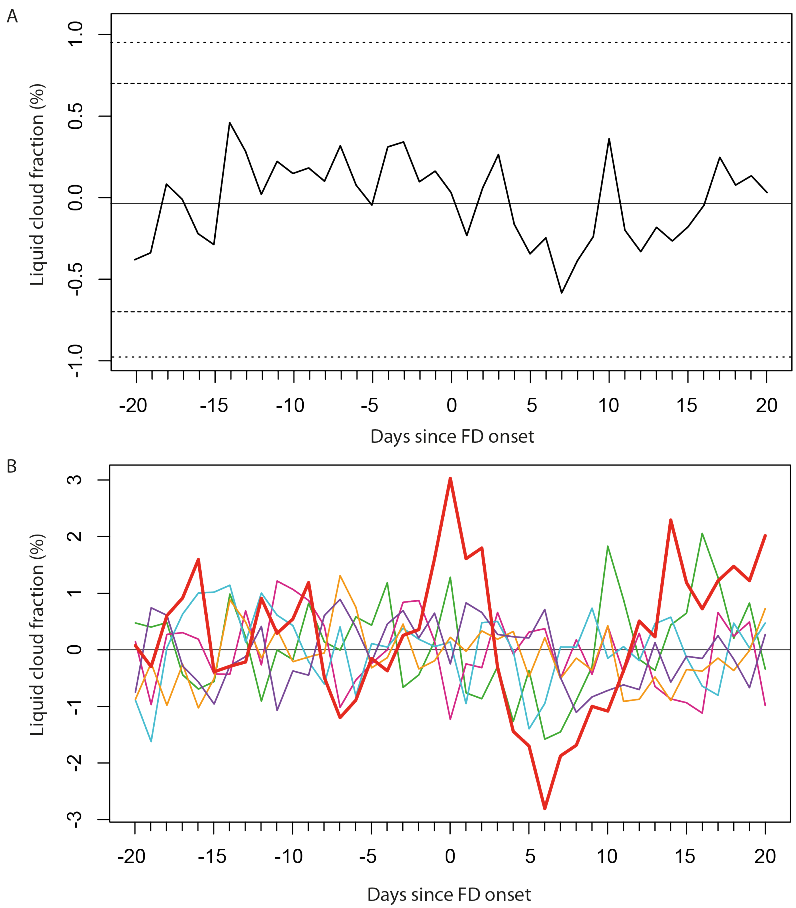

Fig. 3. Liquid cloud fraction changes for alternative five FD events (see end of text for caption)

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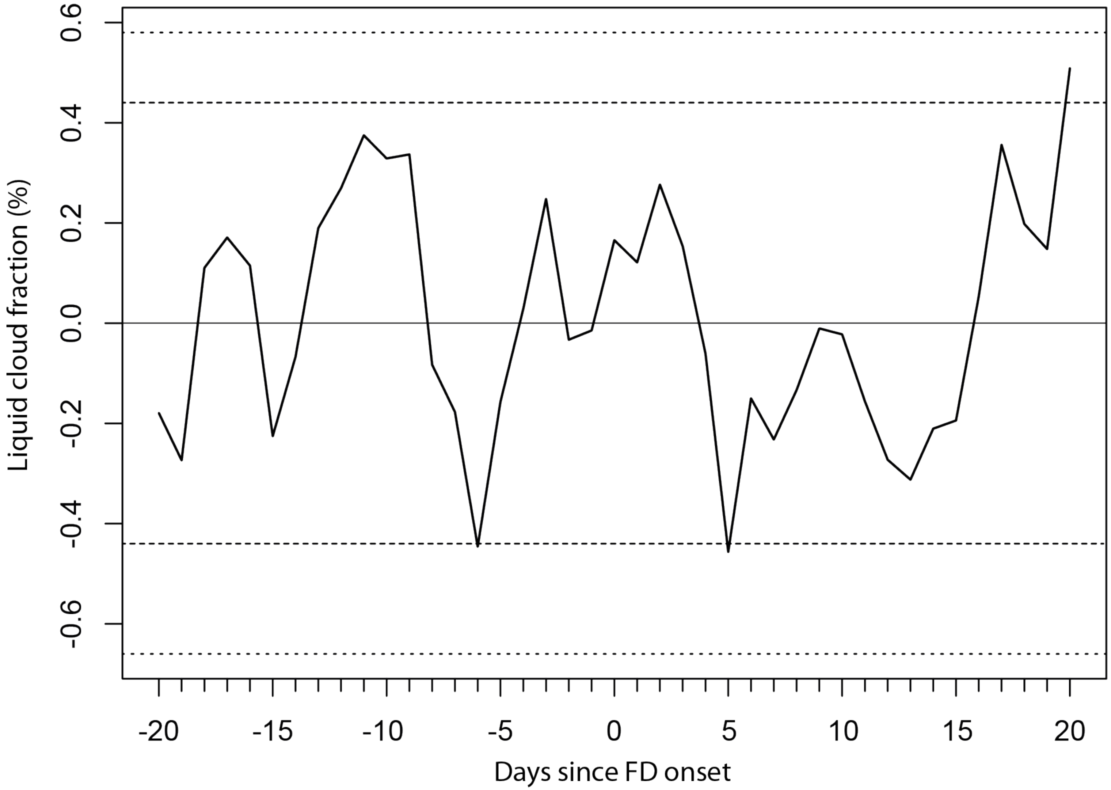

Fig. 4. Liquid cloud fraction from all 13 FD events (see end of text for caption)