Atmos. Chem. Phys. Discuss., 12, C7662–C7666, 2012
www.atmos-chem-phys-discuss.net/12/C7662/2012/

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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Received and published: 1 October 2012

Dear Benjamin Laken et al,

Thank you for your comments, which appear below in italics along with our answers.

> *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... ...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*

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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.

We agree that 21 days is a useful interval to remove long term trends. Please see our response AC C897, where we show that seasonal variations, while potentially problematic, have no significant impact on the result of our analysis.

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.

We acknowledge that this will cause the uncertainty to vary over the time interval investigated. Please see our response to comments SC C1000 where we apply a correction for this problem, and our final comment which also handles this issue.

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 distributions we calculate a two-tailed probability (p) value of achieving such a value to be p = 0.0068. Over a $\pm$100 day period we note numerous excursions of equal and greater magnitude than the day +6 changes: statistically,

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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.

You find a p = 0.0068 for finding the observed signal in figure 2A. In this probability you do not include the further constraints for detecting a physical signal, which are the constraints of localization and sign. This is explained in our comment AC C717, but to re-iterate: 1) The signal must occur within a reasonable timeframe after the actual FD event. We set this timeframe to 16 days giving a factor of 16/41=0.39 for this time interval. 2) The signal has to have the correct sign to make physical sense, which in this case is another factor of 0.5. So, using your p = 0.0068, the total probability of finding the signal in your Fig. 2. is 0.0068*0.39*0.5=0.13%, which is still significant. We approach this issue in another way in our final response.

Regarding your figure 2B, you seem to have made a mistake. The period from day -100 to day -60 appears identical to day -20 to 20. This makes it problematic for us to discuss the figure further. However, we note that the constraints of localization and sign, in this figure, gives a further factor of 16/201*0.5=4% to consider.

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).

It is peculiar that none of the data in your Fig. 3A is remotely close to crossing your

95th percentile line. And there is certainly not (1-0.683)*41=13 points above a line corresponding to half your 95th percentile, which should be very close to 1 sigma. When it is not clear what uncertainties appear on the figure it is difficult to comment on the significance of the signal, even though the excursion between days 5 and 10 is both the strongest and widest in the interval. With our uncertainties the signal remains above 2 sigma using event 1,3,4,5,6. Note also that event 2 is not equally important for all parameters, such as Emissivity. It is for this reason that we have combined the signal in the PCA (fig. 3 in the discussion paper), which is not greatly affected if event 2 and 6 are interchanged.

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.

Again we refer to a previous answer (in this case AC C591) where we discuss the effect of Solar Proton Events.

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 $\pm$20 day period is shown in Figure 4 and indeed, the significant day +6 LCF reduction observed by SES12 is absent.

Including all events could, supposing that there is a linear response, improve the signal-to-noise ratio. But since we have a limited sample size this is not necessarily true,

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due to statistical variability. Furthermore the weakest events could have no detectable signal at all due to other atmospheric processes. We do however include an analysis where all events are used in a new approach outlined in our final response.

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