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Atmospheric Chemistry and Physics Discussions

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11, C9522–C9529, 2011

Interactive Comment

Interactive comment on "Possible effect of extreme solar energetic particle event of 20 January 2005 on polar stratospheric aerosols: direct observational evidence" *by* I. A. Mironova et al.

I. A. Mironova et al.

irini.mironova@gmail.com

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We thank Referee #2 for helpful comments and suggestions. The Referee's Comments are noted first and then we give our Reply to the comments in italic font. All the changes in text of the paper are highlighted by bold face.

General comments:

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Interactive Discussion

Discussion Paper

This manuscript deals with a possible effect of energetic solar particles on aerosols in the polar stratosphere. SAGE III and OSIRIS aerosols extinction profile measurements (and for SAGE III also spectral extinction measurements) during January 2005 are used to identify possible signatures related to the solar proton event that occurred between January 16 and January 22, 2005. Most of the results and discussions presented focus on the effects in the northern hemisphere, where SAGE III extinction measurements are available at latitudes of about 70 deg latitude. While the topic of this study very interesting and the interpretation of the observed effects presented is very tempting, the paper in its current form requires at least major revisions before it may become acceptable, in my opinion. The reason for this harsh judgement is that an alternative, but very obvious explanation for the anomalous aerosol extinction values in the northern hemisphere has been overlooked: Polar stratospheric clouds (PSCs). They are mentioned briefly in the discussion, but the obvious explanation of the results - formation of PSCs during a fairly cold Arctic polar winter, which has nothing to do with the SEP - is not considered or discussed at all.

To me, most of the reported results for the northern hemisphere can be well explained by the occurrence of PSCs:
1) Winter/spring 2004/2005 was a very cold winter in the Arctic lower stratosphere with relatively high PSC occurrence (e.g., Sonkaew et al., Atmos. Chem. Phys. Discuss., 11, 6555-6599, 2011) leading to large chemical ozone losses (e.g. Rex et al., GRL, 33, L23808, doi:10.1029/2006GL026731, 2006). SCIAMACHY, e.g., observed more PSCs during this winter than during any of the other of the winters from 2002/2003 to 2009/2010. Therefore, it is not surprising that apparently anomalously large aerosol extinction is observed during this period.
2) PSCs in the northern hemisphere are known to predominantly occur in the Eurasian sector, consistent with the results shown in Fig. 3 and also the zonal temperature variation shown in Fig. 7.
3) The altitude range where the enhanced extinction values occur are consistent with the expected PSC altitudes.

ACPD
11, C9522–C9529, 2011

4) The sudden drop in the Angstrom exponent seen in panel A) of Fig. 6 around January 25 may possibly be due to the formation of type II PSCs consisting of H2O ice. Type II particles are with sizes of $>$ 10 micron significantly larger than type I PSCs. My suggestion would be to study the temporal evolution of the polar vortex and the polar lower stratospheric temperatures in more detail in order to separate potential SEP effects from the 'usual' formation of PSCs associated with low stratospheric temperatures.

We agree that PSCs can be largely (if not entirely) responsible for the observed AEC changes in the polar Eurasia region (30W - 90 E) since DOY 25. However, neither the increase of α in the entire NH polar region on DOY 22 nor the increase of AEC in the SH on DOY 20 are consistent with the idea of PSC being the main reason for the effect. Another aspect is that soon after the event we found an increase of α in the entire NH polar region, indicating reduction of the effective size of particles. The effect of PSCs after DOY 25 is the essential decrease of α (viz. large particle size). Thus, the observed phenomenon before DOY 25 is unlikely to be directly related to PSCs. We have extended discussion of the PSCs in the paper.

Specific comments:

Page 14005, line 5: The third category, anomalous cosmic rays, has too low energy to ionize the lower atmosphere and is not considered here. It would be good to briefly mention what particles this refers to and what the source of these particles is. For many SEPs the majority of the particle population does not have sufficient energy to reach the lower atmosphere.

We apologize for this confusing category and remove the sentence. Anomalous cosmic rays (ACR) consist of slightly ionized atoms, mostly heavier than hydrogen. They originate from neutral interstellar atoms that (1) enter the solar system, (2) get

ACPD

11, C9522–C9529, 2011

ionized by photo-ionization or charge exchange with solar wind plasma, (3) picked up by the solar wind and transported to the outer boundary of the heliosphere, where they (4) get accelerated to higher energy and (5) re-enter the heliosphere again. Since they have a peculiar composition and low energy (tens MeV) they are called anomalous CR, but in fact they form a sub-class of GCR. Since their energy and fluxes are low they do not produce any sensible effect in the atmosphere and are of great interest mostly for heliospheric physics as a probe for the termination shock acceleration. As it is not related to the topic of this paper, we remove this confusing sentence.

Page 14005, line 25: I'm not sure the Randel and Wu paper deals with the effect of SEPs on the atmospheric at all. The main focus is certainly not on this topic.

This reference appeared here by a mistake. We apologize. It is removed now.

Page, 14010, line 22 and Fig. 2: are zonally averaged extinction profiles shown here? This should perhaps be mentioned.

This is the available data, we did not average anything manually but, since the satellite's orbit scans longitudes, this plot is effectively a zonal average (66-72 N latitude range).

Same paragraph: The altitude of the aerosol extinction enhancement (14 – 26 km) is consistent with existing knowledge on PSC altitudes.

We agree - see our reply above.

Page 14011, line 7: One can see that the strong increase of AEC was detected starting day 21 but only in a limited longitudinal range from about 30W to 90E, while in other regions there is no notable effect. As mentioned above, this zonal modulation is

ACPD

11, C9522–C9529, 2011

consistent with PSCs.

We agree with this. Now we emphasize more the fact that a (more moderate) enhancement was observed in the entire NH polar region, not only in the 30W-90E range. We also note (as discussed above) that the enhancement of AE during DOY 21-25 implies reduced effective size of particles, which is not consistent with PSCs. The sharp and strong decrease of α in the 30W-90E long. range (not in other regions) is consistent with PCS. We have modified the text accordingly.

Page 14011, line 20: Interestingly, the slope of the spectrum remains largely unmodified .. I don't think this statement is entirely correct. Looking at the plots for 11 km, 14 km, and 18 km altitude and at wavelengths between 500 nm and 1000 nm I can see a clear change in the spectral dependence.

We have removed this Figure, as it is mostly related to PSCs.

Page 14011, line 21: The logarithmic slope of the AEC as function of wavelength is called the Angstrom exponent. I'm confused by the term logarithmic slope. The Angstrom exponent is the slope in a double-logarithmic plot, i.e. the wavelength axis has to be drawn logarithmically as well.

We have corrected this text.

Page 14012, line 16: A slight increase in alpha already started ... everywhere in the Northern polar region. Did it really occur everywhere in the northern polar region (the SAGE measurements only cover a very limited latitude range to start with) or only in the Eurasian sector?

The orbit of Meteor 3M/1 (onboard which SAGE-III is installed) is sun-synchronous, thus it covers the entire longitudinal range within 24 hours. Its latitude range is limited

ACPD

11, C9522–C9529, 2011

to 66-72 deg in NH. Therefore, we can securely say that the increase in α started simultaneously (within 24-hr) in the entire range of 66-72 deg northern latitude. We have modified the text accordingly.

Page 14012, line 20: Such low value of alpha indicates a sudden increase of the effective aerosol size up to several hundred nm or more (comparable to the wavelength range of the SAGE experiment), i.e. to the CCN size. We note that such a dramatic change is observed only in the region of NW Eurasia. As noted above this may be a consequence of the temperature dropping below the H2O frost point, leading to the formation of type II PSCs. This is speculation as well, of course, and would have to be verified.

We agree with this reviewer's statement and have modified the text.

Page 14028, Fig. 7: the temporal resolution of the temperatures shown is only about 2 days, and the coloured striped are also not oriented in the vertical, but slightly inclined? Is there a reason for that? Why don't you show daily values?

Since the temperature data are linked to the satellite orbit (the point scanned by the instrument), the data look like a slightly inclined bar. The temperature is effectively daily values.

Page 14013, line 3: This cooling appeared slightly later than the corresponding increase in aerosol extinction. This is really very difficult to see from Figs. 3 and 7, I find, e.g. looking at the plots for 18 km altitude. Particularly given that the time resolution of the temperatures is only 2 days, I don't find this statement convincing.

We have revised this part of text. Time resolution of the temperature (at a given longitude) is one day, not 2 days. All the temporal changes are discussed with 24-hr *accuracy, related to the rate of the Earth's surface scanning by the satellite data.*

Page 14013, line 7: In order to exclude that the observed phenomenon is a typical midwinter/ summer effect due to, e.g., a change in insolation of the polar atmosphere, we have checked the period of 10 mid-summer/winter (January and July) for other years (1998–2003) using also POAM data (Cora Randall, personal communication 2010). I don't fully agree with this statement. Agreed, winter 2005 was quite cold, the Arctic vortex was stable, there was above average chlorine activation and chemical ozone loss. But the existence of PSCs is expected if the temperature is low enough, and there were also a lot of PSCs in the winters 2006/2007 and 2007/2008.

As this question has been raised also by Reviewer #1, we copy here the corresponding reply. In order to exclude a possibility that the observed phenomenon is a typical mid-(local)winter effect due to, e.g., a change in insolation of the polar atmosphere, we have checked the period of mid-winter (January in NH and July in SH) for other years 1998–2003 using POAM data. No similar change of the aerosol index have been found in all other years. We are aware that the winter 2004-2005 was not quite usual, but this at least suggest that such a change (increase of alpha) is not a typical mid-winter feature. Unfortunately, the POAM data cannot be directly used for January 2005 because of a calibration error (Cora Randall, personal communication 2010). We have clarified the text accordingly.

Page 14013, line 19: A peculiar region, NW Eurasia (30W-90E), can be identified, where this effect 20 was followed by an essential growth and sedimentation of aerosols related to the cooling of that region. Again, it is well known that PSCs in the northern hemisphere predominantly occur in the Eurasian sector.

We agree with this statement and have modified the text accordingly.

ACPD

11, C9522–C9529, 2011

Interactive Comment

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In addition we want to say that we realize that our interpretation of data is somewhat speculative, as is ascribing everything to PSCs. By interpreting all possible uncertainties in the interpretation to the effect of SEP we provide a conservative upper limit to the effect, which remains quite low. The true effect can be even smaller, we accept it, but we still believe that providing a reliable upper limit is important.

Section 4.2: The OSIRIS results are of course not affected by PSCs, and it would be interesting to analyse these observations in more detail, e.g., what is the longitudinal variability of the enhanced ACE on January 20? Can we exclude disturbing effects of in the south Atlantic anomaly possibly associated with disturbed geomagnetic conditions related to the SEP? My recommendation would be to provide a more detailed analysis of this dataset.

Unfortunately, the data from OSIRIS is poorer than for the SAGE instrument, in particular onle one wavelength is available which makes it impossible to calculate the Ångstrom exponent. No clear longitudinal pattern is observed beyond the data fluctuations, therefore we do not show them. We have mentioned it now. The South Atlantic Anomaly is not a case here, since we are focused on the data above 60 deg S latitude. On the other hand, an earlier study (Mironova et al., 2008) suggests that the effect is largest in the magnetic pole region, although the data were related to the columnar aerosol optical depth without altitudinal profile.

Typos etc.:

All minor typos have been straightforwardly corrected.

Interactive comment on Atmos. Chem. Phys. Discuss., 11, 14003, 2011.