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Interactive comment on "Desert dust deposition on Mt. Elbrus, Caucasus Mountains, Russia in 2009–2012 as recorded in snow and shallow ice core: high-resolution "provenancing", transport patterns, physical properties and soluble ionic composition" *by* S. Kutuzov et al.

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We are grateful to the reviewers for their very helpful comments. All the comments have been addressed and corrections made in the text. The point by point corrections and alterations are presented below. The title has been changed as suggested by reviewer two.

Response to referee #2 comments

RC Specific comments:

RC As I understand, only dust events detected in the pit and the core were investigated, but no climatology of potential dust events from satellite images and air mass trajectories was obtained. This should be feasible for the short time period studied and would be fundamental for answering the question if glaciers can be used as reliable dust transport archives. Is every event preserved or only those for which precipitation is initiated by frontal activity?

AC Our analysis of the high-resolution satellite imagery for the 2009-2012 period allowed us to identify not only the dust events which reached Mt. Elbrus but also those which reached the Caucasus Mountains but passed further south of Mt. Elbrus. We also recorded a number of events originating from different sources in the Middle East which did not reach the Caucasus Mountains. There is a vast body of literature on the climatology of Saharan dust events. As it was out of the scope of our current study, we did not discussed those event which did not reach Mt. Elbrus. The Middle Eastern events will be investigated further in a course of a separate ongoing project and the results will be published elsewhere.

The overall majority of dust clouds indentified on the satellite imagery as reaching Mt Elbrus resulted in deposition and the dust layers in the snow pack and the shallow core. The corresponding dust layers were not identified in two cases only and both events are discussed in section 4.1. 'Uncertainties in Dating and 'Provenancing' Dust Deposition Events'. Thus the presented snow pit and shallow core record of dust events combined with the satellite imagery and trajectory analysis is mostly complete and confirms that ice cores are a reliable archive of dust deposition events. We acknowledge that it will be desirable to obtain snow pit and ice core records from the different sectors of the Caucasus Mountains, most importantly, from the south Caucasus and this comment has been added to the text (section 4.1.).

For all of the investigated events, meteorological conditions have been analysed. All

TCD
7, C1228–C1235, 2013

the events, apart from the two weak deposition events which have not been visually identified in the snow pit / core, were associated with frontal systems and wet deposition. This is stated in the text. One of the 'missing' events (13 June 2009) was likely to be associated with dry deposition and this is explained in the text.

RC How do you avoid settling of the coarse particles (30 m) in the sample when determining particle size distribution with the Coulter Counter? Our experience is that you can produce different results when stirring the sample or when different settling times are applied.

AC The following explanation has been added to the text:

The liquid sample in a covered accuvette was turned three times for dust homogenization, and analysed in the following 30 seconds to avoid large particles settling. This procedure was used with the same timing for all the samples. However, according to the measured dust size distribution in samples, the number of larger particles (>10 μm) was reduced so that settling does not affect a large number of particles.

RC Have you compared the accumulation from the shallow core with instrumental precipitation? Particularly in winter 2011/2012 there is low accumulation compared to the previous winters. Is this real or an artifact?

AC We have compared the accumulation from the shallow core with instrumental precipitation. Observational data from two meteorological stations Klukhorskii pereval, (WMO 37196; located 40 km to the west from Mt. Elbrus at the altitude of 2037 m) and Terskol (see text) show that annual precipitation in 2011 was a lowest on 1966-2012 record and 20% below1952-2012 average respectively. We have not added these comments to the text because the paper deals with a very short record only and the correspondence between instrumental observations and data from the deep Elbrus core will be discussed in a separate publication.

RC Are the concentrations of 89 to 253 mg kg-1 of dust comparable to other studies?

TCD
7, C1228–C1235, 2013

AC It is difficult to compare dust mass concentration with other studies because our results refer to individual events and most paper report dust concentration averaged over longer periods of time, i.e. years. Two papers, (Dong et al. 2009 and Wake et al 1994) report dust mass concentrations with higher temporal resolution, although the data are presented for different depth intervals and therefore averaging periods are not specified. The highest concentration reported by these studies is 90 mg kg-1 at Muztag Ata in Pamir which is comparable with our concentrations for individual dust events. The concentration of 253 mg kg-1 is one the highest reported in the high mountains. However, in order to produce valid comparison continuous measurements for longer period is required.

The following paragraph has been added to the text:

Data on dust mass concentrations are limited to 2009 when the average dust mass concentration was 18 mg kg-1 and this was strongly affected by four dust deposition events (Fig. 11). Few studies report dust mass concentrations for short time periods or individual events. Wake et al. (1994) reported dust mass concentrations with higher temporal resolution for eight glaciers in Central Asia. The dust mass concentrations averaged over 1-3 year periods were 2-8 mg kg-1 which is considerably lower than the average concentration in 2009 in Caucasus.

RC Why are the number of particles obtained with SEM and CCM an order of magnitude different? Do you have an explanation?

AC This is due to the differences between the methodologies. In SEM particles were digitized manually avoid the problem of particle overlapping. And therefore the number of particles which were practically possible to measure was limited. Overall over 2000 particles were manually digitised for each sample at different magnitudes while CCM analysis allows to measure all particles in the sample.

RC There are two events with distinctly larger particle mode diameters (19/05/2011 and 12/02/2010). What is the reason for those large particles?

TCD
7, C1228–C1235, 2013

AC The possible reasons for such distribution in the sample N4(19/05/2011 event) were discussed in the text: “The dust deposition event of 19 May 2011 (No 4) was characterised by higher frequency of larger particles. This event was characterised by the highest modal value of 4.16 μm (Table 1) and particles with diameter of 10 μm and larger accounted for 17% of the total volume. In addition to sensitivity of particle size distributions derived from SEM analysis to the presence of large particles, high concentrations of fresh-water diatoms with equivalent diameter of 6-8 μm (Fig. 10) explained the atypical size distribution and comparatively high modal values.”

As for 12/02/2010 event, there is no obvious reason for such distribution.

RC I think Cl would be the better sea-salt tracer since the contribution of terrestrial sources is lower compared to Na.

AC Agreed, we will use Cl in future.

RC Technical corrections:

RC The title seems a bit long. Suggestion: Provenance of desert dust deposited on Mt.Elbrus, Caucasus in the years 2009 to 2012

AC The title has been changed to: ‘High-resolution provenance of desert dust deposited on Mt. Elbrus, Caucasus in 2009 – 2012 using snow pit and firn core records.’

RC Abstract, first sentence: This is not presented for the first time, but the first record, I guess.

AC Done

RC 1624, line 28: “While was research: ” sounds awkward, reformulate

AC Done

RC 1625, line 20: Please give a reference for the statement that significant seasonal melt is absent above 4600 m.

TCD
7, C1228–C1235, 2013

AC Reference added Mikhalenko, V.N., Kutuzov S.S., Lavrentiev I.I., Kunakhovich M.G., Tompson L.G.: Elbrus western firn plateau studies: results and prospects, Data Glaciol. Studies, (99), 185-190, 2005 (In Russian).

RC 1626, line 14: "a 12 m firn and ice core" Could you be more specific? Down to which depth was it firn? If there is no significant melt there should not be any ice even at 12 m depth.

AC It is indeed a firn core, we've corrected this throughout the text.

RC 1626, line 18: filters

AC Done

RC 1626, line 24: How was the density of the shallow core measured?

AC Following sentence was added: The density was calculated from the weight divided by the volume of each core section.

RC 1628, line 22: at LGGE

AC Done

RC 1631, line 16: Explain why you focused on the February–July and September–November periods.

AC It is indeed unclear so we deleted this

RC 1633, line 22: dust entrainment and transport. These vary in strength

AC Done

RC 1634, line 4: provided by chemical composition of the samples:

AC Done

RC 1637, line 11: affects particle number distribution, its effect on particle volume distribution

TCD
7, C1228–C1235, 2013

AC Done

RC 1637, line 24:revealed no systematic coarse particle mode:

AC Done

RC 1640, line 9: Biomass burning is not a significant source of SO2

AC Removed

RC 1642, line 7: stratigraphy

AC Done

RC 1644, line 24: predominantly of from

AC Done

RC Fig. 1: Could you add a map of the mountain with the drilling site indicated? What is the point 5642 m, the main summit?

AC The explanation has been added to figure caption.

RC Fig. 3: I do not understand the color coding: What do sources/km2 mean?

AC The colours represent the kernel density of the dust sources as calculated in ArcGIS 10. The results simply estimate points per unit area and in this case it is the points (dust sources) per km2.

The explanation has been added to figure caption.

RC Caption Fig. 5: (e): 4-8 May or March?

AC Corrected

RC Check reference list: Walter and Wilkinson, 1991; Brand and Brindley, 2012; Wilkinson,1991 are cited in the text, but are not in the list

AC Corrected

TCD
7, C1228–C1235, 2013

Interactive comment on The Cryosphere Discuss., 7, 1621, 2013.