

Interactive comment on “The environmental impact of the Puyehue-Cordon Caulle 2011 volcanic eruption on Buenos Aires” by G. B. Raga et al.

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We thank the referee for the comments and give detailed responses below.

Referee: 1. The description of the 2011 Puyehue-Cordon Caulle eruption should be improved. In particular the 2011 Puyehue-Cordon Caulle eruption was produced from the Cordón Caulle fissure while the authors write from the strato-volcano Puyehue (P1509 L6-P10).

Reply: This has now been corrected.

Referee: As authors are showing data from 1-2 July, they should add a description of
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the activity near the days of their measurements.

Reply: A brief description has now been included on the activity prior to the 1-2 July period of measurements in Buenos Aires. See the new text on the paragraph at the beginning of section 3. Results.

Referee: 2. The authors should clarify what “particle properties” mean (e.g. optical? Type of particles?). No data about shape and composition are given.

Reply: The word “properties” has been replaced by the word “measurements”.

Referee: 3. Fig.4 shows an high vertical profile of aerosol extinction associate to a lower value of PM10 (at the beginning of the measurement). A ceilometer should not be able to identify volcanic ash from other type of aerosols (e.g. SO₂) so the authors should add and discuss why they are sure to detect volcanic ash.

Reply: Actually, what we argue is that the ceilometer detects the presence of the volcanic plume, be it small ash particles or enhanced concentrations of sulfuric acid droplets (SO₂ as gas would not be detected by our ceilometer). Low PM10 concentrations only indicate that no particles with large mass were detected. Very large number concentrations of particles (such as those produced by gas to particle conversion, much less than 1 micrometer in diameter) would not show up as significant mass concentrations in PM10 measurements. Our condensation nuclei (CN) measurements do show enhanced number concentrations, since the counter is able to detect the presence of the small particles optically, even if they have very little mass associated.

Referee: 4. The authors should add other data that prove the presence of a volcanic cloud above Buenos Aires during the measurements (e.g. satellite images). An image of volcanic plume from MODIS on 2 July 2011 shows a volcanic plume direct toward the NW direction (<http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=51316>). It is possible that the plume moved and went above Buenos Aires but it should be verified and discussed.

Reply: The data from the MODIS instrument in the satellites Aqua and Terra were analyzed to confirm that the volcanic plume was indeed over Buenos Aires, and the retrieved Aerosol Optical Thickness (AOT) is reported in Figure 8 of the revised version of the manuscript. Moreover, there was actually ash reported at the surface in Buenos Aires during the first weeks after the initial eruption. We include the Terra image for 1 July 2011 (3AM UTC) (refer to Figure 1), where the ash product is highlighted in yellow. The plume has NOT yet reached Buenos Aires at the time of the satellite overpass, but it is clearly oriented towards Buenos Aires. Also please note that the synoptic analysis that was presented in the manuscript indicates the flow at the different altitudes in the atmosphere and are consistent with the advection towards and over Buenos Aires. We also include a graphical report of days when ash accumulated on the ground (for the period 4 June to 31 Dec 2011), provided by the VACC Buenos Aires (<http://www.smn.gov.ar/vaac/buenosaires/cenizaenargentina.php?lang=es>, click on "Ver imagen Año 2011"). It indicates that 22 days ash was observed at the surface in Buenos Aires. Refer to Figure 2. To further support our suggestion that the volcanic plume may have been a factor in the decreased surface temperature, we have estimated the climatological (1985-2006) average temperature (and standard deviation) for 1 and 2 July, to show that the diurnal evolution of the average temperature that we have presented in Fig 4f (in our manuscript). Refer to Figure 3 here. Note that these climatological values are consistent with the values presented in our study.

Referee: 5. The variation of temperatures looks very high. Variations of 0.5 and 1.5 were for example observed during the two years following the Pinatubo eruption (Yang and Schlesinger, 2002). Furthermore, authors should discuss the results of a paper of Okazaki and Heki (2012) on the atmospheric temperature changes in the 2010 Icelandic and 2011 Chilean cases that reports as "Post-eruption negative temperature anomalies at the 250 hPa plane were clearly observed in the Eyjafjallajökull eruption. In the Puyehue eruption, however, such anomalies were not so clear due possibly to insufficient accuracy of the forecast model". I suggest the authors to change the background (e.g. considering a wider time space without no volcanic ash cloud) and see if

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they find the same result.

Reply: We agree with the referee that perhaps the reduction in temperature is not only due to the reduction of solar radiation, which unfortunately the meteorological station at our site did not measure so we cannot fully support the assertion. However, in order to add support to the decrease in temperature observed, a new figure (Fig. 5) is now included in the revised version. This new Figure 5 includes the near surface temperature (from NCEP Reanalysis-2 data) and the MODIS aerosol optical thickness (2 independent estimates) for the case study presented of 1-2 July 2011. There is a very clear spatial correlation between these datasets, which obviously cannot be considered cause-effect but certainly are noteworthy. While the referee indicates that the reduction is large compared to Pinatubo, there seems to be an indication of decreased near-surface temperature in the regions where the ash plume is present. Please also refer to the reply about the study by Okazaki and Heki (2012), in page 8 of this document.

Referee: 6. Volcanic activity is very variable in time and in order to make a valuable comparison of AOT retrieved from different instruments, the same scene should be seen at the same time. This is probably why the authors find this inhomogeneity. Consequently, I suggest authors to delete the comparison of AOT if the volcanic plume is not retrieved at the same instant or very near.

Reply: An effort was made to determine de AOT from the variety of sources at the same instant. The AOT retrievals from MODIS (on Aqua and Terra) correspond to the overpass times at the location of Buenos Aires. We selected those same times (with a window of ± 1 hour) for the AOT retrievals from the AERONET sunphotometer and the ceilometer coincide in time. As we point out, we attribute the large variability in the retrievals to the spatial inhomogeneity of the plume.

Referee: 7. References about the eruptions, the synoptic description and about other works on this eruption should be added.

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Reply: We have included in the revised version a recent study by Collini et al (2013) and the recommended study by Okazki and Heki (2012)

Technical corrections

Referee: P1509 L7. In the reference SERNAGEOMIN (2011), the link doesn't work.

Reply: It seems that now the link is no longer active. We have contacted SERNA-GEOMIN and they have sent us a file with their daily reports, which can be sent to the referee if requested. We no longer cite the link in the revised version.

Referee: P1509 L9-L11. Authors state that the eruption column reached 10 km of height. They should specify if it is above sea level or above the crater rim.

Reply: We have now specified that it is above the crater rim level.

Referee: P 1511 L14. Specify the days.

Reply: The days are: 7, 8, 13 and 14 June and 1, 2, 7 and 8 July. They have been included now in the text.

Referee: P1514. Clicking at the website, there are data from 4 stations. You should add the station where data come from.

Reply: The PM10 data used in the study come from one monitoring station (Estacion Cordoba), closest to our experimental site and this is now included in the text

Referee: P1511 L22. Add the distance in km from the eruptive vent.

Reply: As listed in the text, Buenos Aires is located about 1400km from the eruptive vent.

Referee: P1512 L14. PSAP is for Particle Soot Absorption Photometer?

Reply: Yes, this has now been included in Table 2.

Referee: P1514 L14. Add the day of all four case studies.â€

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Reply: The days are: 7, 8, 13 and 14 June and 1, 2, 7 and 8 July. They have been included now in the text.

Referee: P1514 L15. Why are you showing only this case?

Reply: As stated, only one case is presented for brevity. The original manuscript with all four case studies included 27 figures, and was considered too long.

Referee: P1514 L16. Add also the day of this test case.

Reply: The dates 1-2 July are now included in the text.

Referee: P1514 L18-19. In "The synoptic situation in each case" authors refer to all four cases? If yes, authors should add the day and the synoptic situation for all the studied case.

Reply: The specific dates have now been included in the paragraph. And the wording has been changed to include "all four cases".

Referee: P 1515 L5. LST is for the local solar time?

Reply: We wanted to indicate Local time (LT) and now those words have been included for clarity.

Referee: P1515 L6. Add the hour.

Reply: All 24 hours for both days are included in the figure.

Referee: P1515 L20. If volcanic ash is "fallen" did authors or others collect or see volcanic ash on the ground?

Reply: Yes, ash was observed on the ground on 22 days (between 4 June and 31 December 2011, see map included as part of the reply to point 4 above). We did not collect ash as part of our study. We are unaware of other studies of ash collected in Buenos Aires. Colini et al (2013) indicate that ash collection took place in Puyehue, Villa La Angostura and Bariloche (up to 100km from the source) and indicate that the

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ash was coarse grained, from coarse lapilli to coarse ash.

Referee: P1515 L23-25. Authors should support this assertion adding other information (e.g. quantify the increase of wind velocity).

Reply: The sentence was removed from the revised version.

Referee: P1516 L10. What are these 8 days?

Reply: The days are: 7, 8, 13 and 14 June and 1, 2, 7 and 8 July. They have been included now in the text.

Referee: P1516 L27-28. Explain better the sentence.

Reply: The original sentence: "The CN and PPAH concentrations and the absorption coefficient (Figs. 4b–c) all increase well above one standard deviation on four occasions over this 2 day period" has been re-written. It now appears as: "The time series of CN (Fig 4b), PPAH (Fig 4c) and absorption coefficient (Fig 4d) in this 2 day period all show values above one standard deviation, related to the presence of the volcanic plume reaching the boundary layer."

Referee: P1518 L22. The authors write that "The plume was injected at an altitude of around 10 km" but when? The volcanic plume reached 12 km on 4 June. Add the reference.

Reply: The report form SERNAGEOMIN indicates 10km about the crater rim for the first eruption on 4 June.

Referee: P1518 L26-27. I am not really sure that this sentence is well supported.

Reply: Small particles that have grown from gas to particles (with diameters between 0.1-0.5 micrometers) are scavenged less efficiently than larger ones (Friedlander, 2000: Smoke, dust and haze: Fundamentals of aerosol dynamics)

Referee: P1520 L6. Chemical reaction with volcanic ash surface?

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Reply: The ash provides a surface and chemical reactions can take place on it. It would be equivalent to the presence of crystals in the polar stratospheric clouds catalyzing the destruction of ozone by halogen compounds.

Referee: P1520 L12 Metals are contained in volcanic ash in small proportion that could not justify a so increase of BC.

Reply: The study of Collini et al (2013) shows evidence of several metallic oxides (such as aluminum, iron and titanium oxides that absorb radiation in the UV and visible wavelengths) present in the samples taken in Patagonia after the explosion. In the manuscript we put forward a dual hypothesis for the enhanced values of the absorption coefficient: i) metals in the volcanic plume particles or ii) enhanced scavenging of soot particles by the presence of volcanic particles, which would accelerate the removal of soot from the surface layer where the measurements were being made.

Referee: P1522 L5. The authors assert that "There is consistency between the values of AOT derived from 5 AERONET, ceilometer and MODIS, since all three platforms were able to identify the volcanic ash plume simultaneously." This is not really true.

Reply: This conclusion has been revised to reflect only that all platforms detected the volcanic plume, not that they showed consistency.

Referee: P1523 L1. The authors should mention what type of compounds could cause the anomalous absorption coefficients.

Reply: Since we do not have independent measurements of composition, it would be somewhat speculative to mention particular compounds that may be absorbing

Referee: In the caption of Fig. 2 and 3, the square should indicate the right volcanic vent.

Reply: Unfortunately at the horizontal scale shown, the square is too large to accurately indicate only the eruptive vent.

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Referee: Fig. 4. May you add the hours in the plot? I also suggest to indicate the hour reported in the text.

Reply: Because there are many panels in the same figure, we have had to compromise to make legends and axes legible. Each tick mark in horizontal axis corresponds to 2 hours and this is now included in the caption.

Referee: Table 1. List of eruptive episode?

Reply: The word “eruptive” was included in the table caption

Referee: Table 2. The authors should add the wavelength as reported in the paper. They should explain UNAM in the table caption.

Reply: Included in the revised version.

Referee: UBA is University of Buenos Aires in the text while Facultad de Ciencias Exactas y Naturales in the Acknowledgements.

Reply: The revised version includes Universidad de Buenos Aires explicitly in the Acknowledgements.

Referee: References Yang F. and M.E. Schlesinger (2002), On the surface and atmospheric temperature changes following the 1991 Pinatubo volcanic eruption: A GCM study, *Journal of Geophysical Research*, 107, 0.1029/2001JD000373.

Okazaki I. and K. Heki (2012), Atmospheric temperature changes by volcanic eruptions: GPS radio occultation observations in the 2010 Icelandic and 2011 Chilean cases, *Journal of Volcanology and Geothermal Research* 245–246, 123–127.

Reply: We have read these references recommended by the referee. The paper by Yang and Schlesinger (2002) shows temperature decreases that are averaged in space (zonal averages at different latitudes) and the anomalies would obviously be of a lower magnitude than what was observed at our site. Most of the emphasis of the paper is the longer timescale, rather than only a few days in the region within 1500km from the

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source, as in our case. The paper by Okazki and Heki (2012) presents evidence that relate two recent volcanic eruptions with anomalies in temperature at the 250 hPa level. However, part of the results show a large temperature anomaly in the South America sector displayed in their Figure 3 BEFORE the eruption. As the authors mention, it is likely that the NCEP values for 250 hPa may have a bias and may be responsible for the lack of evidence found in the case of the Cordon Caulle eruption. No results in their paper pertain to near surface temperature measurements, as are presented in Fig. 4 of our manuscript. In order to support our statement that the temperature decrease may be related to the presence of ash in the atmosphere blocking solar radiation, we have incorporated a new figure in the revised manuscript (new Figure 5). A similar figure is presented here (see Figure 4), as an illustration. The figure presents the near surface temperature (from NCEP Reanalysis-2) and the AOT derived from MODIS on Aqua and Terra. The leftmost panel shows the spatial distribution of the near surface temperature before the volcanic plume reached Buenos Aires. There is a noteworthy similarity in the spatial distribution of these variables from two very different databases. While this similarity does not imply necessarily cause and effect, it is nevertheless noteworthy. Note that while the study by Okazki and Heki (2012) did not show evidence of a decrease in the temperature at 250 hPa, the near surface temperature (now presented as the new Figure 5) shows lower temperatures in a spatial distribution similar to the spatial distribution of the AOT. All episodes listed in Table 1 were analyzed similarly.

Interactive comment on *Nat. Hazards Earth Syst. Sci. Discuss.*, 1, 1507, 2013.

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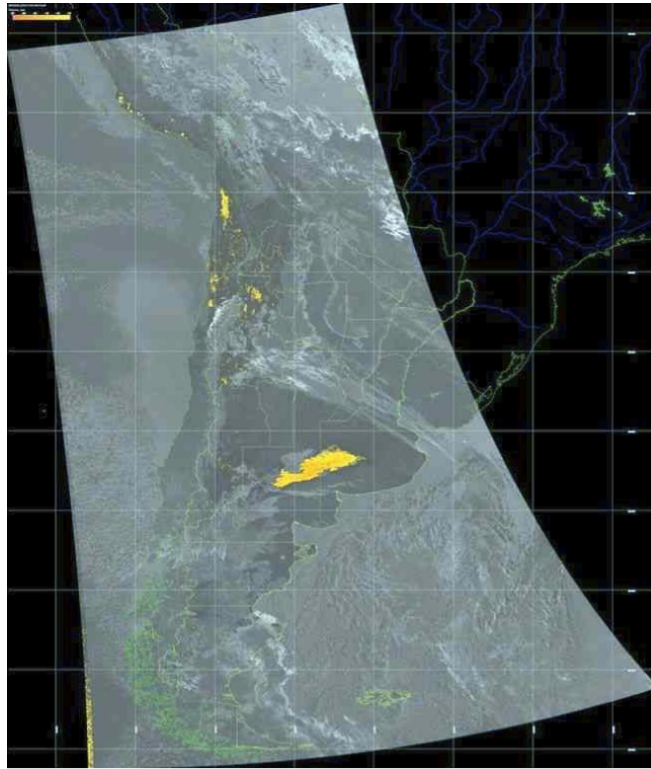


Fig. 1. Terra image for 1 July 2011 (3AM UTC), where the ash product is highlighted in yellow.

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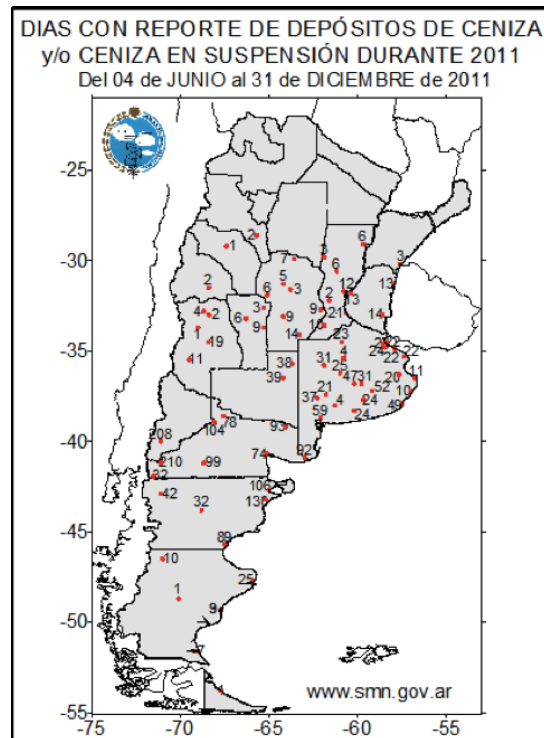


Fig. 2. Report of days when ash accumulated on the ground (for the period 4 June to 31 Dec 2011)

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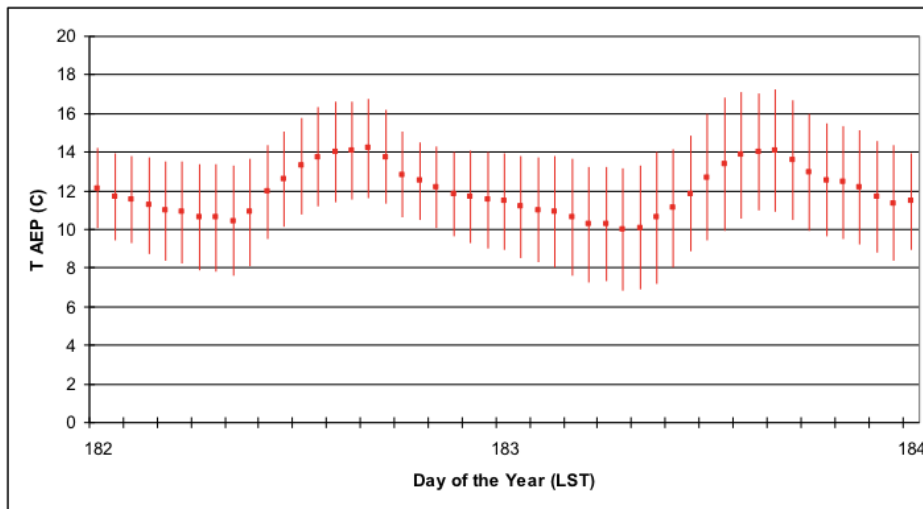


Fig. 3. Climatological values (1985-2006) of the average temperature for 1 and 2 July. The vertical bars correspond to the standard deviation

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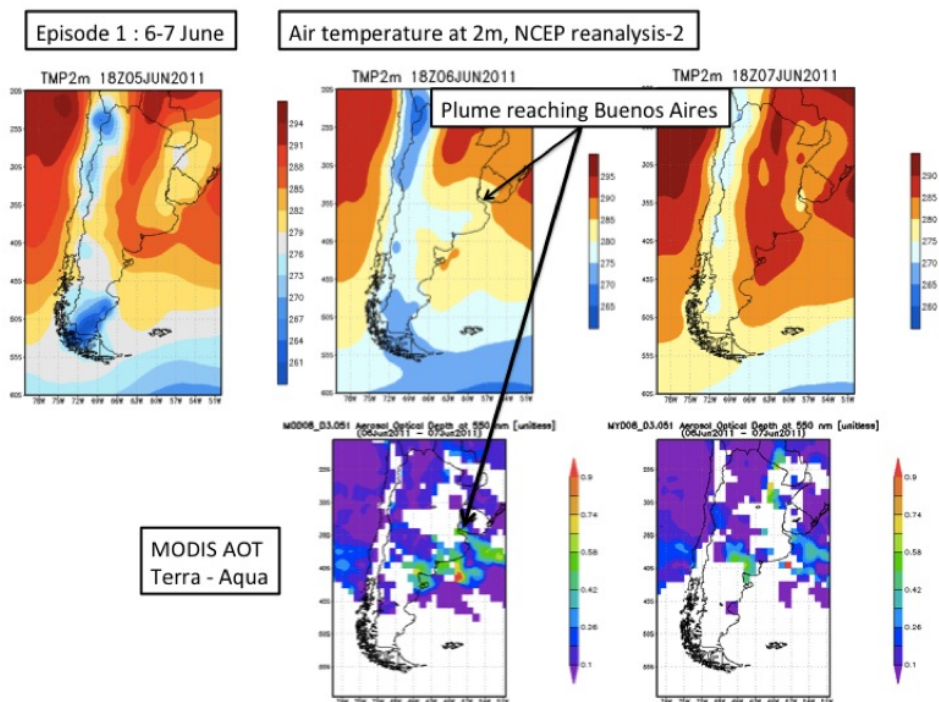


Fig. 4. Top panels: the near surface temperature (from NCEP Reanalysis-2) and bottom panels: the AOT derived from MODIS on Aqua and Terra corresponding to 6 and 7 June 2011.

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