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Interactive comment on "Aerosol properties and meteorological conditions in the city of Buenos Aires, Argentina during the resuspension of volcanic ash from the Puyehue-Cordón Caulle eruption" by A. G. Ulke et al.

Anonymous Referee #1
Received and published: 17 February 2016

We thank the referee for the helpful comments and suggestions . We include here the referee comments in black *and our replies in blue. The paragraphs of the manuscript are quoted and included in normal font type.*

1 General Comments

The quantitative study of resuspended or wind blow volcanic ash is a relatively new field and due to the potential for the ash to impact both on human health and the environment it is an important area of study. In this paper the authors focus on a single resuspension event which involved the transportation of volcanic ash from the Patagonian Steppe to Buenos Aires. The authors describe the meteorological conditions leading to and resulting from the advected volcanic ash as well as looking at aerosol properties within Buenos Aires. In addition they explored whether the resuspension event could be modelled using the HYSPLIT dispersion model with some modification to the surface properties utilised in the dispersion model.

The paper contains new observations of resuspended ash as well as discussion of the meteorological conditions leading to and resulting from the resuspension event and is, therefore, publishable. However, from a reader's perspective it feels as though the paper covers too many different observations/topics and as a result each area is only explained briefly. I think this paper could be greatly improved by some reorganisation of the text, as well as selecting topics/observations on which to focus and expanding the discussion on those topics. I've included some more detail on possible modifications below.

Answer to R1 general comments: Thanks for your suggestions and comments. In the ***revised*** *version of our* ***manuscript (RM)****, we reorganized the text and we also selected the topics and observations to focus on and we expanded the analysis in order to better highlight the achievements of our study.*

2 Specific Comments

To help the paper to flow better I would recommend that the authors move each method section next to the description of the results. For example if section 2.3 (the modeling

methodology) could be moved next to section 5 (the discussion) it would be easier for readers to refer to the details of the modelling while reading the results. A similar approach could be followed with the meteorology and the different observations.

*Answer to R1: We agree with the comments and suggestions and as the R2 did also suggest a reorganization of the sections we prepared the **RM** considering both recommendations. aiming to flow better the paper and help the readers to follow our study.*
*The **RM** will be structured as follows:*

1. ***INTRODUCTION***
2. ***MEASUREMENTS AND METHODOLOGY***
   - ***2.1. Geographical location***
   - ***2.2. Datasets***
3. ***ANALYSIS OF THE METEOROLOGICAL CONDITIONS***
   - ***3.1. Vertical Profiles***
   - ***3.2. Synoptic Analysis***
4. ***ANALYSIS OF AEROSOL PROPERTIES***
   - ***4.1. Surface-based measurements***
   - ***4.2. Satellite measurements***
5. ***ANALYSIS OF HYSPLIT SIMULATIONS***
   - ***5.1 Methodology and setup***
   - ***5.2 Analysis of modeling results***
6. ***DISCUSSION***
7. ***CONCLUSIONS***

The Figures will be re-organized accordingly and following this scheme.

Figure N° submitted manuscript	***Figure N° revised manuscript***
Figure 1	Corrected **Figure 1**
Figure 2	Corrected **Figure 2**
Figure 3 (extinction from ceilometer)	**Figure 5 (a)**
Figure 3 (surface wind speed)	**Figure 4** (surface wind speed and direction)
Figure 4	**Figure 3**
Figure 5	corrected **Figure 5 (b)**
Figure 6	Suggested replace by a new **Figure** as **5 (c)**
Figure 7	Corrected **Figure 7**
Figure 8	**Figure 6**

I'm not an expert on the observation techniques presented and I feel that the authors present a large number of observations but don't provide enough detail on the limitations of each observation type. I think the paper could be improved by reducing the number of observations presented but adding more detail on the detection limits, limitations, locations and interpretation assumptions for each of those observations. In addition for a number of the observation types it would be useful to see some indication of typical values for an urban area. This is particularly true in figure 5 where the peaks highlighted by the authors are modest.

Answer to R1: We agree with the referee comment. In general, the Southern Hemisphere (SH) has scarce observational data and our goal was to use a combination of observations in synergy with modelling results. But the variety and large number of information was somewhat confusing and therefore, we have reduced the number of observations and focused on the analysis of those that better illustrate and support our study.
In consequence, we concentrated in the analysis of the ceilometer observations, PM_{10} concentrations, AERONET information and CALIPSO retrievals.

*After considering R1 comments, we added the required information (the detection limits, limitations, locations and interpretation assumptions) for the measurements that we finally included where/when suggested or necessary in the **RM** and in the answers to the referee comments.*

1. *As regards the instruments at the research site we included the information about the ceilometer in the **RM** and the reference to Raga et al. (2013) when needed.*

   *The original paragraph: P5, L17 to L26 and P6 to P8 at the submitted manuscript: nhess-2015-311-discussions-typeset_manuscript-version3 (**nhess-2015-311-D-3):***
   "A detailed description of the instrumentation deployed at the Ciudad Universitaria (34°35' S, 58°22' W) during the field campaign to evaluate urban aerosol pollution is presented by Ulke et al. (2011) and Raga et al. (2013) and is only briefly described here. The particle properties measured were the number concentration of condensation nuclei (CN) larger than approximately 50 nm, the mass concentration of particle-bound polycyclic aromatic hydrocarbons (PPAH), the scattering (B_{scat}) and absorption (B_{abs}) coefficients at 530nm and the vertical profile of backscattered light from aerosols at a wavelength of 910 nm. For the purpose of studying urban pollution, the measurements of B_{abs} are converted to an equivalent mass concentration of black carbon (eBC) using a specific mass absorption coefficient of $6.5 m^2 g^{-1}$ (Bond and Bergstrom, 2006). The eBC concentration is an indicator of emissions from combustion by diesel engines, as are common in buses and trucks in Buenos Aires. Dust particles and volcanic ash (not only black carbon) can absorb radiation at 530 nm. However, the presence of dust and volcanic ash will typically not produce a PPAH signal, so the measurements can provide evidence of light absorbing particles that are not originated by diesel engines. The ceilometer backscatter measurements were converted to extinction coefficients using a least squares analysis with the in situ measurements of B_{scat} and B_{abs} (Raga et al., 2013). The vertical resolution of the ceilometer is 20m and the measurements are 10 min averages."

   *Was replaced by the following one in the **RM:***
   "The instrumentation deployed at Ciudad Universitaria (CU) (34.58° S, 58.37° W, 30 m a.s.l.) during the field campaign to evaluate urban aerosol pollution is described by Ulke et al. (2011) and Raga et al. (2013) including a discussion of uncertainties and limitations. However, for the purpose of this study, we will only concentrate on the data obtained with the Vaisala CL31 ceilometer, a remote sensing instrument located at the site that provides the vertical profile of backscattered light from aerosols at a wavelength of 910 nm. The vertical resolution of the ceilometer is 20 m, ranging up to an altitude of 7000 m. The measurement frequency of the instrument is 0.5 Hz, but the

data was averaged over 10 min intervals. The ceilometer backscatter measurements were converted to extinction coefficients using a least squares analysis with the in situ measurements of scattering and absorption, as described in detail in Raga et al. (2013)."

*In the submitted manuscript: (**nhess-2015-311-D-3**), we have referenced our previous paper (Raga et al., 2013) only for brevity because Table 2 presents the information of the array of instruments deployed at the research site.*

Table 2 (from Raga, G.B., Baumgardner, D., Ulke, A. G., Torres Brizuela M. M. and Kucienska, B., The environmental impact of the Puyehue-Cordon Caulle 2011 volcanic eruption on Buenos Aires. Nat. Hazards Earth Syst. Sci., 13, 2319-2330, doi:10.5194/nhess-13-2319-2330, 2013) is the following one:

2322 G. B. Raga et al.: Impact of Puyehue–Cordon Caule 2011 eruption

Table 2. Description of instrumentation deployed at the research site at the Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires (FCEN, UBA). The acronym UNAM corresponds to Universidad Nacional Autónoma de México.

Parameter	Instrument	Institute	Detection limit	Accuracy	Frequency
Temperature, RH, pressure	Davis Inc. Weather Station	UBA	-50° to $+50^{\circ}$ 0 to 100 % 100 to 1024	$\pm 1^{\circ}$ ± 5 % ± 1 mb	1 Hz
Horizontal winds	Davis Inc. Weather Station	UNAM	0 to 50 m s^{-1}		1 Hz
Condensation nuclei	TSI CPC 3010	UNAM	0.02 µm	± 15 %	1 Hz
Particle-bound polycyclic aromatic hydrocarbons	EcoChem PAS 1000 photoelectric aerosol sensor	UNAM			0.3 Hz
Absorption coefficient	Radiance research particle soot absorption photometer (PSAP)	UNAM	1 M m^{-1}	± 25 %	1 Hz
Scattering coefficient	Radiance research nephelometer	UNAM	1 M m^{-1}	± 25 %	1 Hz
Backscattering vertical profile	Vaisala ceilometer CL-31	UNAM	20 m to 7000 m, with 20 m resolution		0.5 Hz

2. *As regards the required features of the air quality monitoring stations of the government of Buenos Aires city,*

*The original paragraph: Page 8, L11 to L18 at **nhess-2015-311-D-3:***
"The government of the city of Buenos Aires operates three air quality monitoring stations that report hourly concentrations of the coarse fraction of aerosol particles with aerodynamic diameters smaller than 10 µm (PM_{10}), according to USEPA regulations. The data from the station La Boca were selected since the station is close to the river and has similar geographic characteristics as the Ciudad Universitaria site. The data were digitized from the graphs displayed on the government web page: http://www.buenosaires.gob.ar/areas/med_ambiente/apra/calidad_amb/red_monitoreo/index.php?menu_id=34232."

*Was replaced by the following one in the **RM:***

"And finally, the official data from the air quality network of the government of the city of Buenos Aires (CABA) was analyzed to independently confirm the impact of the resuspended ash. The government of the city of Buenos Aires operates three air quality monitoring stations (Centenario (34.61° S; 58.43° W, 27 m a.s.l.), Córdoba (34.60° S; 58.39° W, 35 m a.s.l.) and La Boca (34.62° S, 58.36° W, 11 m a.s.l.)) that measure and report concentrations of the coarse fraction of aerosol particles with aerodynamic diameters smaller than 10 μm (PM_{10}) according to methodologies and calibration procedures established by the US EPA (Environmental Protection Agency) regulations. The instrument is the Thermo Scientific Beta Gauge Continuous Ambient Particulate Monitor (FH62C14) that measures continuously the attenuation of the C14 beta rays according to International Particulate Monitoring regulations. The data from the station La Boca (located ~ 13 km from CU)were selected since the station is close to the river and has similar geographic characteristics as the CU site. La Boca started to operate on May 2009 and measurements are available from 2010. Daily means and monthly reports according the CABA government and EPA regulations are freely available at http://www.buenosaires.gob.ar/agenciaambiental/monitoreoambiental. PM_{10} hourly concentrations for the analyzed period were provided upon request by the air quality division of the city government."

*As regards the urban typical values for PM_{10}, they were included in the **RM.** The following sentence was included in the **RM** in the case of the **daily mean** (which is the regulated one) and the corresponding typical **hourly** values for PM_{10} were included in a **new Fig.5** (see page 20 of this document).*

*The original paragraph (page P14, L3 to 5 in **nhess-2015-311-D-3**):*
"All the monitoring network sites in the city show increased concentrations of PM_{10}, and the La Boca station shows values in excess of 240 μgm^{-3} (for the daily average), much larger than the EPA standard of 150 μgm^{-3}."

*Was replaced by the following one in the **RM**:*
"All the monitoring network sites in the city show increased concentrations of PM_{10}, and the La Boca station shows values in excess of 240 μgm^{-3} (for the daily average) (GCBA, 2016), much larger than the CABA and EPA standard of 150 μgm^{-3}. The typical daily values (based on data from 2010 to 2015, excluding 2011) during October are 25 μgm^{-3} for the mean with a standard deviation equal to 9 μgm^{-3}."

3. *As regards AERONET information we have not included the detailed information on the procedures (detection limits, limitations, and interpretation assumptions) carried out by the AERONET team <u>for brevity</u> and because it is available at their site http://aeronet.gsfc.nasa.gov/. We only mentioned (P15, L16 at **nhess-2015-311-D-3**) that the information is the LEVEL 2 CEILAP-BA AERONET data. In order to facilitate the interpretation of the results, we included more information in the **RM.***

*The original paragraph: P6, L10 to L19 at **nhess-2015-311-D-3:***
"Additional information on aerosol optical properties was obtained from the AERosol RObotic NETwork (AERONET) sun photometer (Holben et al., 1998), maintained and operated by personnel at Centro de Investigaciones en Láseres y Aplicaciones

(CEILAP-BA 34 39' 35" S; 58 28' 08" W), located approximately four kilometers west of the Ciudad Universitaria measurement site. Although the AERONET sun-photometer measures at multiple wavelengths, only the aerosol optical depth (AOD) at 500 nm was selected for analysis. This wavelength is closest to the 530nm wavelength used in the instruments that measured the B_{scat} and B_{abs} and the 550nm used by MODIS that is carried on the Aqua (Parkinson, 2003) and Terra satellites. MODIS images were used to identify the resuspension events."

*Was replaced by the following one in the **RM:***

"Additional information on aerosol optical properties was obtained from the AERosol RObotic NETwork (AERONET) site CEILAP-BA (34.57°S; 58.5°W, 10m a.s.l.) which is maintained and operated by personnel at Centro de Investigaciones en Láseres y Aplicaciones and is located approximately four kilometers west of the CU site. AERONET is a global network of surface-based stations that provide continuous information for the study of aerosol properties. It was established by the National Aeronautics and Space Administration (NASA) and PHOTONS (PHOtométrie pour le Traitement Opérationnel de Normalisation Satellitaire; Univ. of Lille 1, CNES, and CNRS-INSU) and currently there are numerous collaborators worldwide. The data along with the detailed information on detection limits, limitations and assumptions for the retrieval, inversion algorithms and quality-control procedures is freely available at http://aeronet.gsfc.nasa.gov/.

The observations are made with sun photometers of type CIMEL at multiple wavelengths (340, 380, 440, 500, 670, 870, 1020 and 1640 nm) (Holben et al., 1998). The measurements are provided for three quality levels (level 1: unscreened; level 1.5: cloud-screened and level 2: cloud-screened and quality-assured after a seven-steps procedure) and their uncertainty ranges from 0.01 to 0.02 (Eck et al., 1999, Smirnov et al., 2000). Data intermittence is mainly due to cloudiness over the site and/or the detection of anomalous values on the basis of their temporal variance.

The Aerosol Optical Depth (AOD) is a measure of the extinction of a beam intensity by the presence of aerosols in an atmospheric layer through which the light is traveling and indicates the columnar aerosol load in the local atmosphere. Several quantities are obtained from the measurements using inversion algorithms based on the AOD spectral dependence (e.g. aerosol size distributions, single scattering albedo, refractive indices and asymmetry parameter, among others).

The Ångström exponent (Alpha) shows the variation of the AOD with the wavelength (λ) of incident light. The 440-870 nm Ångström exponent ($Alpha_{440-870}$) is computed from linear regression of ln AOD versus ln λ for all AOD data available between the wavelengths of 440 and 870 nm and provides important information on the particle size distribution (Dubovik et al., 2002). The larger Ångström exponents are due to higher spectral variation in AOD and are associated to smaller particles. Contrarily, the lower values of Alpha indicate dominance of coarse aerosol. Aerosol particles in the fine fraction are typical from urban/anthropogenic pollution (combustion products from fossil fuel or biomass burning) whereas those associated to natural sources belong to the coarse fraction (dust, marine aerosol, volcanic ash, bioaerosol).

The AERONET fine mode fraction AOD_{500nm} product (FMF) is the ratio of fine to total AOD obtained with the spectral deconvolution algorithm (SDA) using the

measurements from 380 to 870 nm. The detailed information and evaluation of the SDA along with the assumptions and errors is fully documented in O'Neill et al. (2001a, b, 2003). Specifically, the FMF is an estimation of the optical effects of the fine-mode particles based on the spectral curvature in the observed optical depths instead of a cutoff radius. It is more robust because it could be applied in the cases of mixed aerosols (e.g. desert dust + combustion aerosols, clouds + smoke, etc).
The quantities that were selected for analysis were the AOD_{500nm}, the FMF AOD_{500nm} and the Ångström exponent ($Alpha_{440-870}$) level 2 data."

4. *As regards the CALIPSO retrievals, they were described at **nhess-2015-311-D-3** from P6 L20 to P8 L10 (in the section 2.2) and from P16 L17 to P18 L28 (in the section 5). but as R2 asked for some explanation about them, we realized that our wording was misleading in some paragraphs and they were changed in the **RM**. We hope that the changes in these paragraphs and the reorganization of the manuscript will contribute to better present the procedures and outcomings of our work.*
In fact, we used the products provided by the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) freely available at http://www-calipso.larc.nasa.gov/. The products are distributed by the NASA Atmospheric Science Data Center and are listed in detail in the CALIPSO Data Products Catalog (Powell et al., 2013). A summary of the measurement uncertainties and capabilities and spatial resolution is also available at their site, which also provides the detail of the publications in journal articles, technical papers and manuals.

*The original paragraph: Page 6, L20 to L21 at **nhess-2015-311-D-3:***
"Measurements obtained by the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) are also analyzed."

*Was replaced by the following one in the **RM:***
"Products obtained from the observations of the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) are also analyzed. The products are distributed by the NASA Atmospheric Science Data Center and are freely available at http://www-calipso.larc.nasa.gov/. The detail of the products can be found in the CALIPSO Data Products Catalog (Powell et al., 2013)."

*In our analysis we use the browse images (Version 3.01) available in the CALIPSO web site and we applied a similar approach than Winker et al (2012) that was explained in P7 L23 to L28 (**nhess-2015-311-D-3**). That means that we identified the ash+dust by visual inspection of the CALIPSO browse images and considered in our analysis the values reported in the cited literature in the manuscript.*

The definitions of the variables from CALIOP lidar in the CALIPSO browse images that we use in our analysis are included here:

The total attenuated backscatter signal 532 nm (TAB) is the sum of the 532 nm parallel and perpendicular return signals. The volume depolarization ratio is the ratio of the perpendicular to parallel components of the TAB. The total attenuated color ratio is the ratio of the total attenuated 1064nm and 532nm backscatters.

The integrated attenuated backscatter is

$$\gamma' = \int_{\text{top}}^{\text{base}} \beta(z)T(z)\,dz,$$

where β is the total (molecular + particulate backscatter) and T is the atmospheric transmittance due to both molecules and particles, z is altitude and the subscripts ''top'' and ''base'' refer to the top and base of the feature as determined by the layer detection algorithm (Vaughan et al. 2009).
For further details please refer to:
http://www-calipso.larc.nasa.gov/resources/calipso_users_guide/browse/index.php.

*The definitions were included in modified paragraphs in the section 2.2 of the **RM**.*

*The original paragraph in P7 L9 to 15 at **nhess-2015-311-D-3:***
"To determine aerosol type, these algorithms use the integrated attenuated backscatter and the volume depolarization ratio measurements, as well as surface type and layer altitude. The volume depolarization ratio is used to identify aerosol types with a substantial mass fraction of aspherical particles (e.g., a mixture of smoke and dust). The integrated attenuated backscatter is used to discern instances of transient high aerosol loading over surfaces where this is not usually expected. The total attenuated color ratio is an independent quantity because it is not used in the subtyping algorithm."

*Was replaced by the following one in the **RM:***
"To determine aerosol type, these algorithms use the volume depolarization ratio (the ratio of the perpendicular to parallel components of the TAB) and the integrated attenuated backscatter (the vertical integral of the product of the backscatter and atmospheric transmittance due to particles and molecules between the base and the top of the detected layer), along with information on surface type and layer altitude. The volume depolarization ratio is used to identify aerosol types with a substantial mass fraction of aspherical particles (e.g., a mixture of smoke and dust). The integrated attenuated backscatter is used to discern instances of transient high aerosol loading over surfaces where this is not usually expected. The total attenuated color ratio (the ratio of the total attenuated 1064nm and 532nm backscatters) is not used in the subtyping algorithm and is an independent quantity that contributes to classify the features."

*The original paragraphs in P16 L17 to P17 L21, P18 L1 to 11 and L16 to L28 at **nhess-2015-311-D-3** will be in section 4.2 in the **RM**.*

*The original paragraphs in P16 L17 to L21 at **nhess-2015-311-D-3:***
"Figure 8 includes for each selected period a map that indicates the trajectory, the total attenuated backscatter (TAB) at 532nm and the derived aerosol subtype.
The TAB signal strength has been color coded such that cirrus clouds appear 20 in gray/red/yellow colors and mid- and low altitudes clouds in white/gray/red colors.
Aerosols show up as green/yellow/orange/red colored features".

*Was replaced by the following one in the **RM:***

"Figure 6 shows the CALIOP images corresponding to the total attenuated backscatter (TAB) at 532nm and the aerosol subtype for the times of the overpass of the satellite over the region of the present study. The TAB signal strength is provided by the CALIPSO team in a color code such that cirrus clouds appear in gray/red/yellow colors and mid- and low altitudes clouds in white/gray/red colors. Aerosols show up as green/yellow/orange/red colored features."

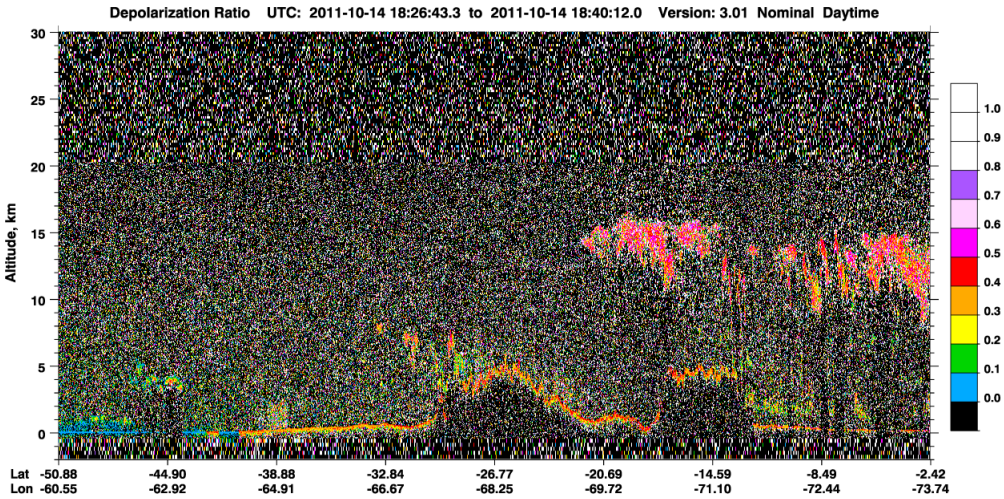
*The original paragraphs in P17 L15 to L21 at **nhess-2015-311-D-3:***

"On 14 October, the CALIPSO revealed a zone with TAB ranging from 2.5 x 10^{-3} to 4 x 10^{-3} km^{-1} sr^{-1} located over the Patagonian steppe (~39° S and 65° W, reaching 2 km height) (Fig. 8b). The vertical feature mask clearly discriminates this feature as aerosol and the aerosol subtype is dust (Fig. 8c). This zone displayed volume depolarization ratios between 0.3 and 0.4 and color ratios near 0.5 (not shown). This behavior is in agreement with the findings of Vernier et al. (2013) and Winker et al. (2012) for volcanic ash."

*Was replaced by the following one in the **RM:***

"On 14 October, the CALIPSO revealed a zone with TAB ranging from 2.5 x 10^{-3} to 4 x 10^{-3} km^{-1} sr^{-1} located over the Patagonian steppe (~39° S and 65° W, reaching 2 km height) (Fig. 6a). The vertical feature mask (not shown) clearly discriminates this feature as aerosol and the aerosol subtype is dust (Fig. 6b). This zone displayed volume depolarization ratios between 0.3 and 0.4 and color ratios near 0.5 (not shown). This behavior is in agreement with the findings of Vernier et al. (2013) and Winker et al. (2012) for volcanic ash."

*Here we include the images corresponding to the **volume depolarization ratio**, **color ratio** and **vertical feature mask** in order to show the mentioned values. We did not include them in our manuscript <u>for brevity</u> and because they are freely available at the CALIPSO homepage.*



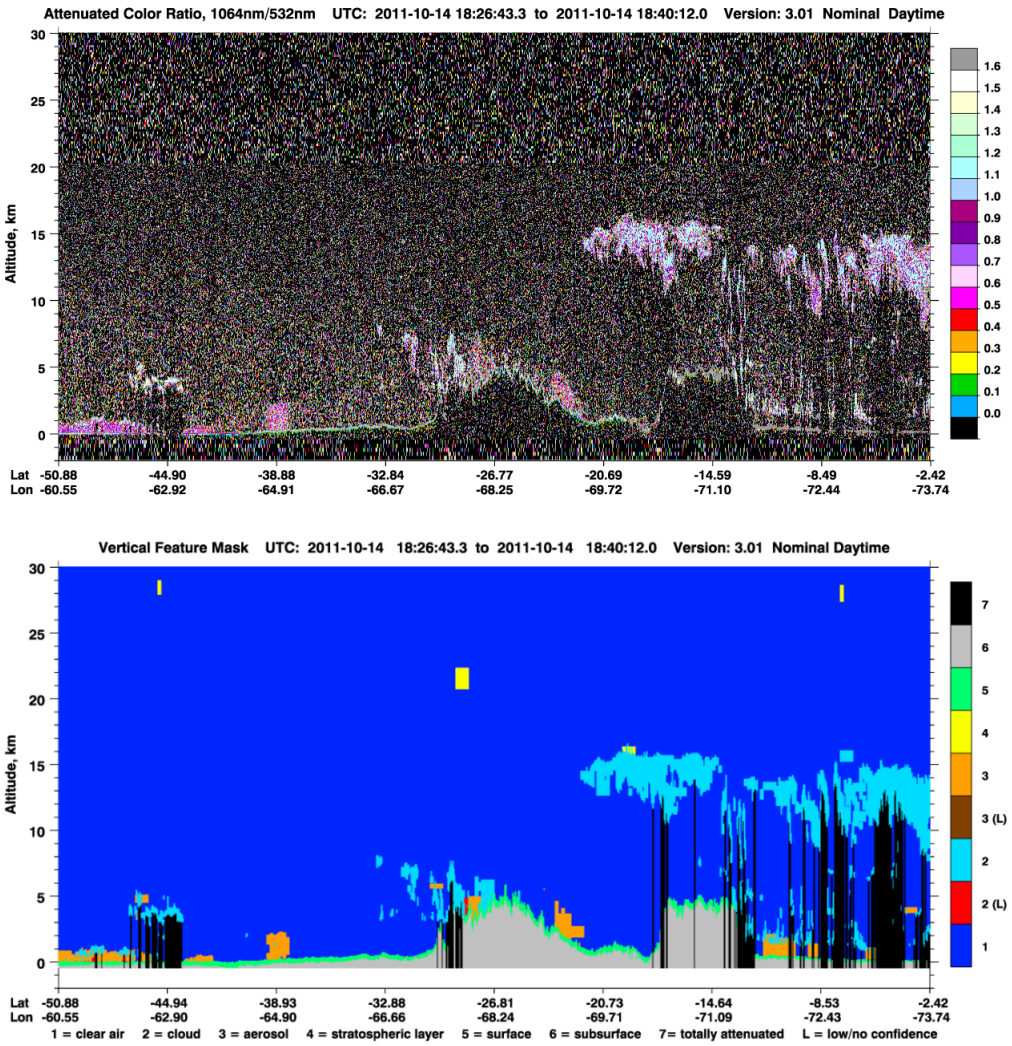


Figure I. Volume depolarization ratio (upper panel), attenuated color ratio (middle panel) and vertical feature mask (VFM) (bottom panel) from CALIOP along the track over the region of study on 14 October from 18:26:43 UTC to 18:40:12 UTC.

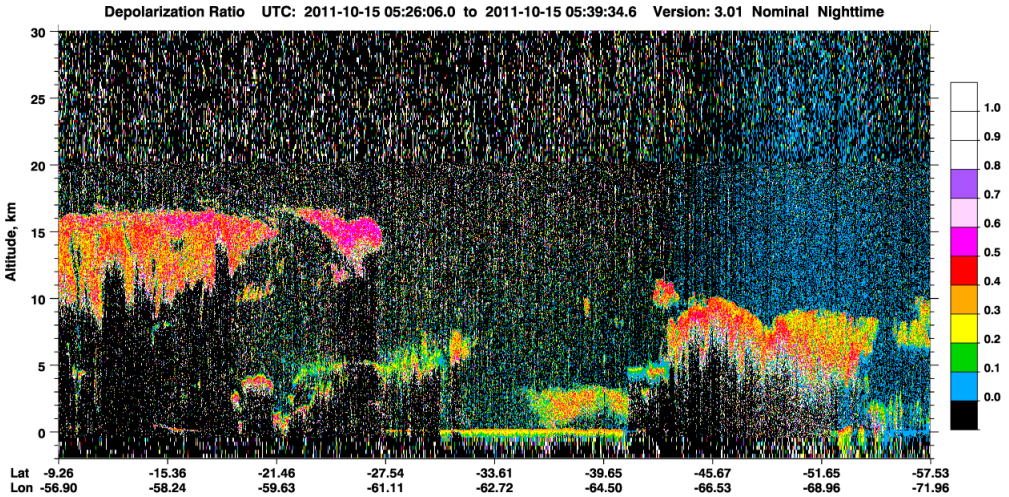
The original paragraphs in P18 L1 to L11 at ***nhess-2015-311-D-3:***

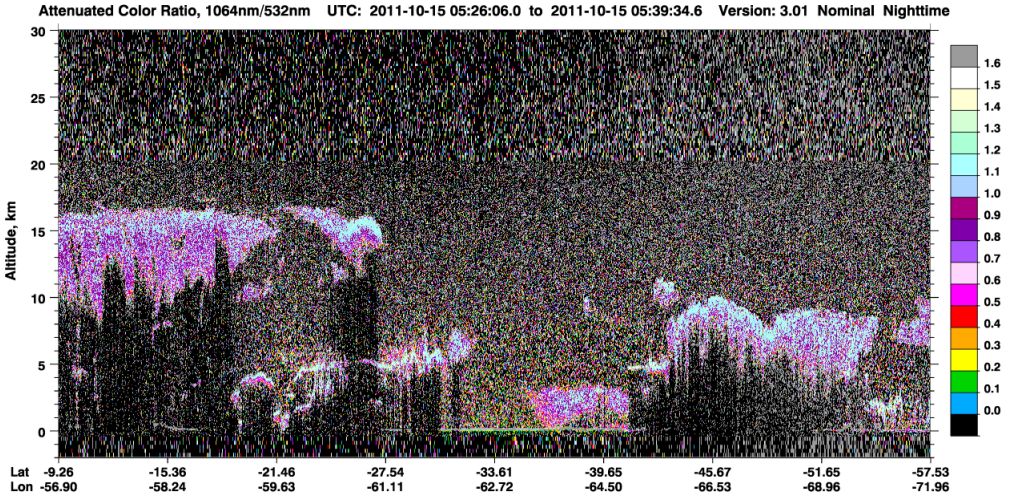
"The CALIOP lidar observations during the nighttime satellite route on 15 October depict TAB values ranging between 7 x 10^{-4} and 3 x 10^{-2} km^{-1} sr^{-1} at ~ 40° S; 64.5° W to 34° S; 63° W, rising up to 3 km above ground (indicated with the white arrow in Fig. 8e).

The depolarization ratios range from 0.1 to 0.5, where the predominant values are between 0.3 and 0.4 with a heterogeneous structure. The attenuated color ratio exhibits a majority of values around 0.5–0.6, but they also show magnitudes around 1, consistent with the presence of mixed clouds (water/ice) at southern latitudes, in coincidence with the vertical feature mask (VFM) (not shown). After applying the corresponding aerosol inversion algorithms, these features correspond to mostly dust, polluted dust and polluted continental as shown in Fig. 8f."

*Was replaced by the following one in the **RM:***

"The CALIOP lidar observations during the nighttime satellite route on 15 October depict TAB values ranging between 7 x 10^{-4} and 3 x 10^{-2} km^{-1} sr^{-1} at ~ 40° S; 64.5° W to 34° S; 63° W, rising up to 3 km above ground (Fig. 6c). The depolarization ratios (not shown) range from 0.1 to 0.5, where the predominant values are between 0.3 and 0.4 with a heterogeneous structure. The attenuated color ratio (not shown) exhibits a majority of values around 0.5–0.6, but they also show magnitudes around 1, consistent with the presence of mixed clouds (water/ice) at southern latitudes, in coincidence with the vertical feature mask (VFM) (not shown). Fig 6 d) shows that these features decoded by the CALIPSO aerosol inversion algorithms correspond to mostly dust, polluted dust and polluted continental."


Depolarization Ratio UTC: 2011-10-15 05:26:06.0 to 2011-10-15 05:39:34.6 Version: 3.01 Nominal Nighttime
Altitude, km
30
25
20
15
10
5
0
Lat -9.26 -15.36 -21.46 -27.54 -33.61 -39.65 -45.67 -51.65 -57.53
Lon -56.90 -58.24 -59.63 -61.11 -62.72 -64.50 -66.53 -68.96 -71.96
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0


Attenuated Color Ratio, 1064nm/532nm UTC: 2011-10-15 05:26:06.0 to 2011-10-15 05:39:34.6 Version: 3.01 Nominal Nighttime
Altitude, km
30
25
20
15
10
5
0
Lat -9.26 -15.36 -21.46 -27.54 -33.61 -39.65 -45.67 -51.65 -57.53
Lon -56.90 -58.24 -59.63 -61.11 -62.72 -64.50 -66.53 -68.96 -71.96
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0

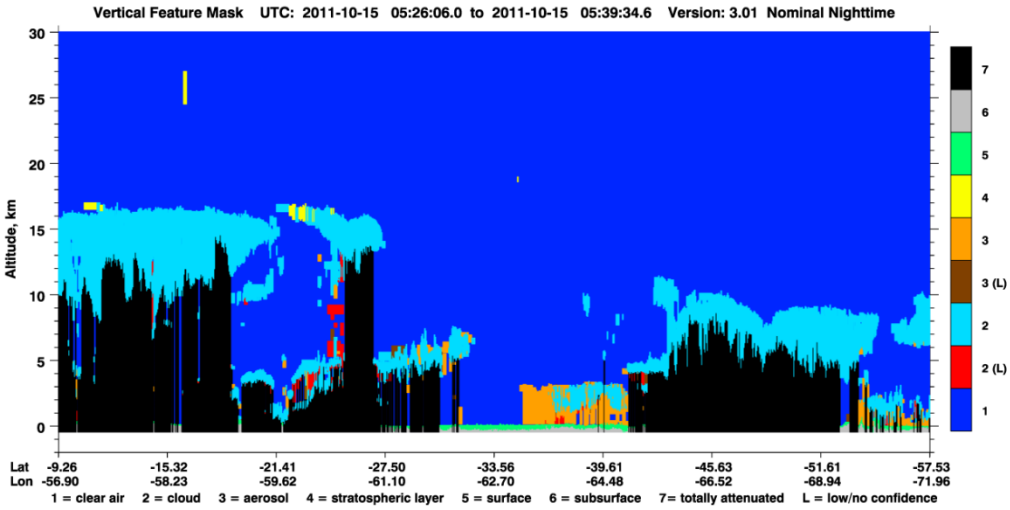

Vertical Feature Mask UTC: 2011-10-15 05:26:06.0 to 2011-10-15 05:39:34.6 Version: 3.01 Nominal Nighttime
Altitude, km
30
25
20
15
10
5
0
Lat -9.26 -15.32 -21.41 -27.50 -33.56 -39.61 -45.63 -51.61 -57.53
Lon -56.90 -58.23 -59.62 -61.10 -62.70 -64.48 -66.52 -68.94 -71.96
1 = clear air 2 = cloud 3 = aerosol 4 = stratospheric layer 5 = surface 6 = subsurface 7= totally attenuated L = low/no confidence
7
6
5
4
3
3 (L)
2
2 (L)
1

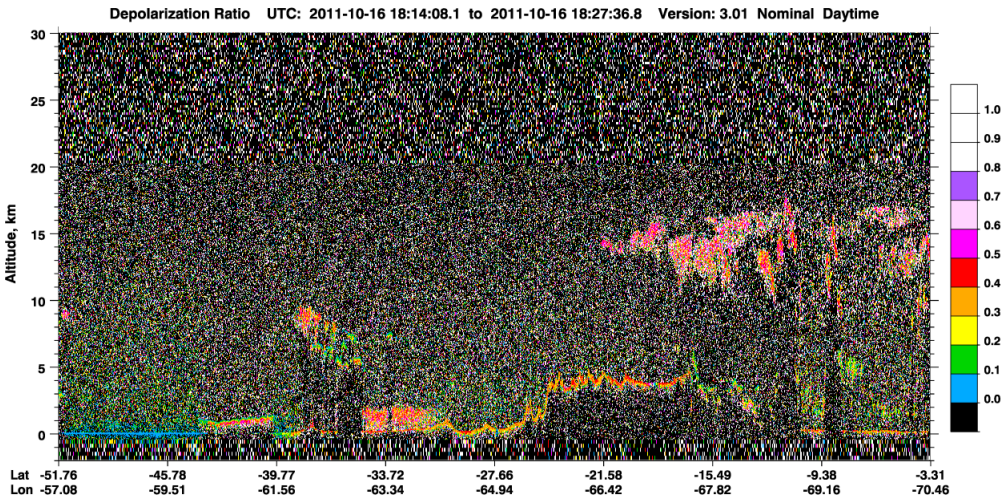
Figure II. Volume depolarization ratio (upper panel), attenuated color ratio (middle panel) and vertical feature mask (VFM) (bottom panel) from CALIOP along the track over the region of study on 15 October from 05:26:06 UTC to 05:39:34 UTC.

The original paragraphs in P18 L20 to L28 at ***nhess-2015-311-D-3:***

"For the daytime CALIPSO pass of 16 October, the lidar reported 532 nm total attenuated backscatter ranging from 1.5 x 10^{-3} to 2 x 10^{-2} km^{-1} sr^{-1} located at ~ 34° S; 63°W to 29° S; 64.5° W, with a vertical extent reaching 2500m (indicated with the white arrow in Fig. 8h). The gray colors are associated with clouds. The depolarization ratio is dominated by values around 0.4–0.5 (not shown) and the attenuated color ratio in the upper part of the signature, mostly corresponds to water (1) and below this layer a mixture of values from 0.5 to 0.7 is observed in coincidence with water and unknown values (the VFM has low confidence in discriminating the features/aerosols).The aerosol layer is identified as dust and polluted dust as shown in Fig. 8i."

Was replaced by the following one in the ***RM:***

"For the daytime CALIPSO pass of 16 October, the lidar reported 532 nm total attenuated backscatter ranging from 1.5 x 10^{-3} to 2 x 10^{-2} km^{-1} sr^{-1} located at ~ 34° S; 63°W to 29° S; 64.5° W, with a vertical extent reaching 2500m (Fig. 6e). The gray colors are associated with clouds. The depolarization ratio is dominated by values around 0.4–0.5 (not shown) and the attenuated color ratio (not shown) in the upper part of the signature, mostly corresponds to water (1) and below this layer a mixture of values from 0.5 to 0.7 is observed in coincidence with water and unknown values (the VFM (not shown) has low confidence in discriminating the features/aerosols). The aerosol layer is identified as dust and polluted dust as shown in Fig. 6f."



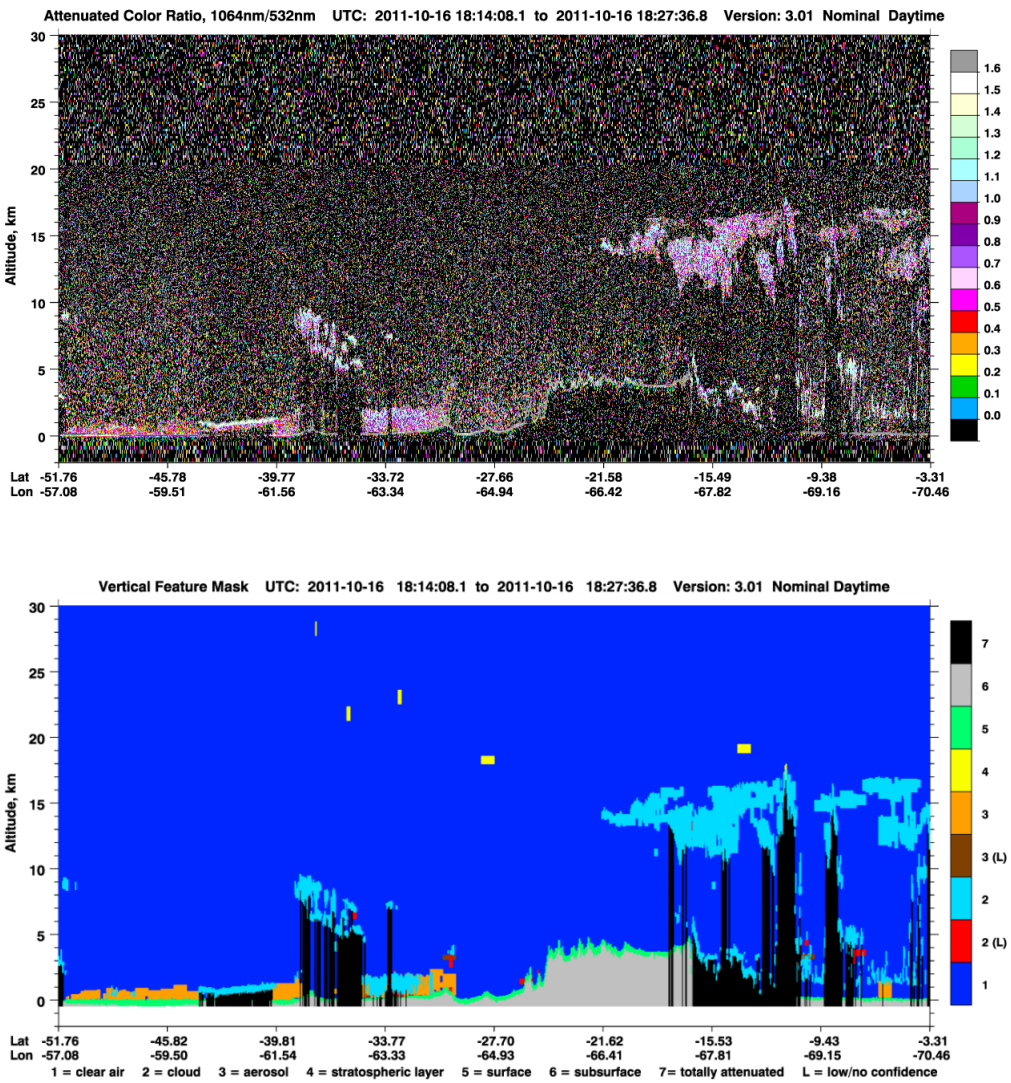


Figure III. Volume depolarization ratio (upper panel), attenuated color ratio (middle panel) and vertical feature mask (VFM) (bottom panel) from CALIOP along the track over the region of study on 16 October from 18:14:08 UTC to 18:27:36 UTC.

Section 2.2 – 1deg by 1deg resolution seems a little coarse given the distances involved. It would be good if the authors could discuss the limitations of using such a coarse resolution meteorology. For example, the impact of a new soil scheme at higher resolution than the meteorology is going to be limited by the resolution of the meteorology particularly in the determination of surface wind speeds and stresses.

Section 2.3 – It would be helpful if the authors could provide brief details of the dust scheme in HYSPLIT as they are critical to the results presented here. Given that the authors discovered that updating the soil classification scheme was essential to the model's performance it would be useful to have more details of the reclassification.

What was the resolution of the new classification? How much did it differ from the original classification? How big a difference did it make to model results presented in this paper?

Answer to R1: The reviewer's comment is actually relevant in order to clarify the text, where our wording about resolution confuses the reader. Responses to Sections 2.2 and 2.3 are related, so:

1°x1° meteorology resolution and the impact of soil classification scheme:

- *The Patagonian region is dominated by quasi-permanent, strong westerly winds and the prevailing synoptic meteorological conditions on the analyzed event are typical for the SH spring season. This environment is well reproduced by the 1°x1° GDAS files and in our opinion, the resolution of the meteorological data did not affect the determination of wind speeds as we corroborated in the analysis of the meteorology (Section 3 at* ***nhess-2015-311-D-3****).*
- *The Patagonian Steppe is an extended and semi-arid region (around 600,000km^2) with scarce native vegetation. The southern boundary is around 40°S and the northern border is variable. The temporal variability of the area is mainly due to the precipitation and temperature regimes (particularly, the winter accumulated precipitation). As the area comprises large extents of desert soil type, in our opinion and in this particular case, the resolution of meteorological and land use files (1° x 1° in both cases) are consistent and were enough to obtain satisfactory results.*
- *Our previous experiments with the* ***HYSPLIT DUST STORM*** *module were carried out using the NCEP reanalysis (2.5°x2.5° resolution). The modeled results did not reproduce the observed ash+dust plume pattern and also the modelled particle plume did not arrive at the cities of Buenos Aires, Cordoba, Rosario and Santa Fe (as documented by the satellite images and METAR reports). Hence, we decided to use GDAS 1°x1° meteorological data as is commonly implemented in the SH and documented in published research in our region (please see Stein et al., 2015 and references therein). Although we were confident on the GDAS representation of the meteorological conditions, unfortunately, we obtained similar results with the* ***HYSPLIT DUST STORM*** *module as the one with the NCEP meteorological fields.*
- *After this failure, we tried with the* ***Matrix Configuration*** *Module (running* ***HYSPLIT*** *in concentration mode), where we specified the emitting cells, filled each concentration grid with the required features for the particles using the coarsest meteorological field resolution (NCEP, 2.5°x2.5°) and the results were promising. In conclusion, we understood that the real problem we had in using the* ***DUST STORM*** *module was the miss representation of the soil type in the default-file (LANDUSE.ASC), within the Patagonian Steppe for this resuspension event.*
- *Hence, we modified the default land-use file (that has a similar resolution 1°x1° than GDAS meteorological fields) with the inclusion of desert soil grid points where appropriate (that means: in the location of the deposited ash). After modifying this file the experiment was successful in representing the displacement of the ash+dust particle plume. In order to illustrate the crucial inclusion of land-use modification, we show in a* ***supplementary document (SupplementaryMaterial.pdf)*** *the corresponding Figures) comparing the HYSPLIT results with and without this readjustment of the original file.*

We hope that these explanation would clarify the points about our approach. The original paragraphs regarding HYSPLIT model setup and simulations were modified in the re-

*organized **RM** in order to better explain the details of the model runs. Additional references were also included.*

2.1 Figures

I believe that figures should (to a certain extent) stand alone and that it shouldn't be necessary to read the detail of the text to find the figure description. Therefore I would find it extremely helpful if the authors could include descriptions of all the features in the figures in the figure captions. i.e.

*Answer to R1 comment: Thanks for your suggestion. We have included the description of the features in the figure captions and we have deleted the comments in the text of the **RM**.*

Figure 1: Please could the authors include a description of the triangle in the figure caption

Answer to R1 comment: We have addressed the issue.

Figure 3: Please could the authors mention that the white line denotes wind speed in the figure caption.

*Answer to R1 comment: As we have re-structured the sections in the **RM**, the Fig.3 in **nhess-2015-311-D-3** will be **Fig. 5 (a)** in the **RM.** The measured wind at the surface in Aeroparque will be **Fig. 4** in the **RM** and will include speed and direction. We have included the necessary explanations in the figure caption.*

Figure 6: It would be helpful to mention the cause of the gap in the data in the figure caption

*Answer to R1 comment: The cause of the gap in the data was partially included in the submitted manuscript (**nhess-2015-311-D-3**) (P15, L18: "only available at noon because of the obscuration by the ash layer"). Regarding the obscuration by the ash, Fig. I (MODIS image for 16 October 2011, at 10:50:56 LST) shows the presence of dust+ash aerosols and clouds over the region.*

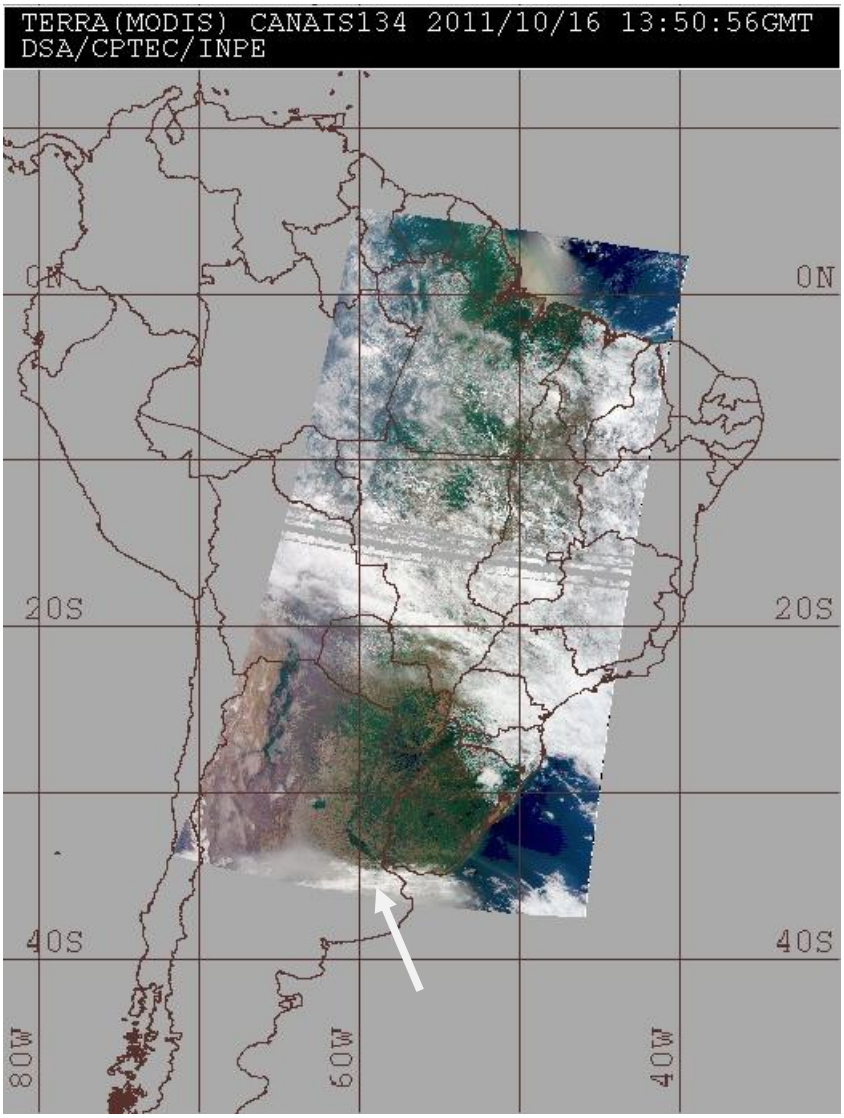


Fig. IV. MODIS (TERRA) image for 16 October 2011 at 10:50:56 LST in Argentina. The white arrow indicates the presence of clouds and the resuspended ash+dust over Buenos Aires. (provided by CPTEC/INPE, Brazil).

*We agree with the R1 comment about the variety of data used to document the event, and we have included the comments on Fig. 6 (**nhess-2015-311-D-3**) in a modified paragraph in the text of the **RM**.*

*The following sentence in P15, L15 to L20 in **nhess-2015-311-D-3:***
"Moreover, Level 2 AERONET measurements from CEILAP-BA indicate a significant contribution of the fine mode to the total AOD (Fig. 6) on 15 October, whereas the next day, the AOD data (only available at noon because of the obscuration by the ash layer), indicate that the coarse mode dominates in accordance with those reported by Papayanis et al. (2012) over Europe after the Eyjafjallajökull eruption."

*Was replaced by the next one in the **RM**:*
"Moreover, level 2 AERONET measurements from CEILAP-BA indicate a significant contribution of the fine mode to the total AOD on 15 October (the fine mode fraction (FMF) varies from 0.48 to 0.89, with a mean value of 0.69), whereas during the following days, the AOD data (only available at noon because of the obscuration by the ash layer), indicate that the coarse mode dominates (FMF ranged from 0.29 to 0.32 with a mean value of 0.30 on 16 October and between 0.37 and 0.47 with a mean of 0.40 on 17 October). On 16 October a few AOD level 2 data (from 07:00 to 08:00 LST) are available due to the presence of clouds + ash + dust over the site. These results are in accordance with those reported by Papayanis et al. (2012) over Europe after the Eyjafjallajökull eruption."

*In order to better depict the effect of the ash+dust plume on the aerosol features in Buenos Aires, we have prepared a new Figure (Fig. V) (which might be considered as **Fig. 5(c)** in the **RM**), that includes additional information along with the required typical values (long term means and standard deviations of the AERONET information, in this case the AOD_{500nm} and the Ångström exponent.*

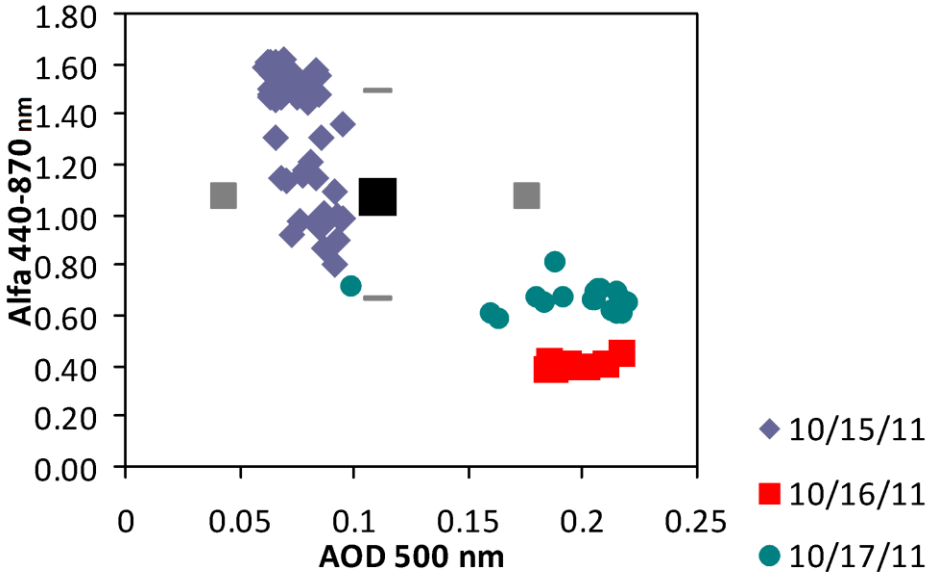


Fig. V. variation of the Ångström exponent (Alfa440-870nm) with the AOD_{500nm} from 15 to 17 October. The black square indicates the relation amongst the October long term means (1999 to 2012, excluding 2011). The grey squares indicate the AOD_{500nm} standard deviation and the grey slash the $Alfa_{440-870nm}$ standard deviation.

Figure V indicates that on 15 October the values of the Ångström exponent and AOD_{500nm} are typical of anthropogenic (mostly urban) sources, in coincidence with the greater proportion of fine aerosols. Contrarily, from 16 to 17 October, the small Ångström exponents are related to coarse mode aerosols in agreement with the fine mode fraction behavior. The elevated AOD_{500nm} coincides with the presence of the resuspended ash+dust on the atmospheric column over Buenos Aires. It is noteable how both parameters fall outside their mean values and standard deviations, particularly on 16 October. These results show similar behavior than those reported by Papayanis et al. (2012), Eck et al., (2005), (2010), Kim et al., (2011), Lyamani et al., (2015), among others).

*We consider that the inclusion of Figure V in the **RM** and the corresponding discussion would better support our study and its implications.*

Please could the font size be increased so that the figures can be properly understood? Figure 7: Please could the cross-sections be marked on parts (a), (d) and (g).
In addition many of the figures contain numbers and text which are too small to read.

Answer to R1 comment: We have addressed the issue with a new Figure and we also corrected and enlarged as possible the numbers and text.

In Figure 2: the pink profile in part (a) is Ezeiza not Santa Rosa and I think needs to be removed.

*Answer to R1 comment: Your comment is right we have made a mistake including a wrong profile in Fig. 2 (a). We have corrected the Figure replacing the profile with Santa Rosa measurements on 16 October. We have kept the correct profile because in our opinion the information that is provided is helpful for the analysis of the atmospheric thermodynamic structure and evolution. We have also corrected the text accordingly (see Section 3, 3.1 Vertical profiles, P10 L20 to P11 L7 on **nhess-2015-311-D-3**.*

*The original paragraph (page P10, L20 to 26 and P11, L1 to L7 **nhess-2015-311-D-3**):*
"The Santa Rosa thermodynamic profiles exhibit a warm layer located from the surface to ~1500 m compared to the mean temperature profile (Fig. 2a), throughout the period analyzed. Note that initially the near-surface temperature inversion is shallow (compared to the mean) and weakens with time. This evolution is mainly driven by the stronger radiative heating of the surface (almost bare soil covered with volcanic ash), not by advection or turbulent mechanical mixing. Above this layer, the quasi-isothermal profile evolves into an adiabatic lapse rate. The atmospheric humidity profile depicts layers of drying likely associated with the presence of a mixture of silica and dust in the air (Lathem et al., 2011). Schumann et al. (2011) and Miffre et al. (2012)also reported this atmospheric behavior in their analysis of the Eyjafjallajökull eruption. The relevant dynamic features of the vertical profiles are: i) between 14 and 15 October the wind speed is accelerating above 300m hence increasing in the potential to resuspend and transport the ash and ii) veering of the wind from west to southwest throughout the free troposphere during 15 and 16 October (see Fig. 2a)."

*Was replaced by the following one in the **RM**:*
"The Santa Rosa thermodynamic profiles exhibit a warm layer located from the surface to ~800m compared to the mean temperature profile (Fig. 2a), throughout the period analyzed. Note that initially the near-surface temperature inversion is shallow (compared to the mean) and weakens with time evolving into an adiabatic lapse rate. This evolution is mainly driven by the stronger radiative heating of the surface (almost bare soil covered with volcanic ash), not by advection or turbulent mechanical mixing. The atmospheric humidity profile depicts layers of drying likely associated with the presence of a mixture of silica and dust in the air. Lathem et al., (2011). Schumann et al. (2011) and Miffre et al. (2012) also reported this atmospheric behavior in their analysis of the Eyjafjallajökull eruption. The

relevant dynamic features of the vertical profiles are: (i) between 14 and 15 October the wind speed is accelerating above 300m hence increasing the potential to resuspend and transport the ash and (ii) veering of the wind from west to mainly south throughout the free troposphere during 15 and 16 October (see Fig. 2a)."

In Figure 5: I'm not an expert in particle observations but these peaks don't look very big. It might be helpful if longer term means could be included in the background of this figure to help demonstrate that the peaks the authors point to are indeed anomalous.

Answer to R1 comments: Many thanks for your helpful comments and suggestions. La Boca PM_{10} hourly measurements and long term mean were included in a corrected ***Fig. 5 (b)*** *(see below). We made the* ***new Fig. 5 (b)*** *using the measured hourly values recently given to us by the Environmental division of CABA Government upon our request because the data we needed are not available from the web site. The previous Figure 5 in* ***nhess-2015-311-D-3*** *was done with the data extracted from the web page, which depicts the moving average over 8 hours minus the moving average over 8 hours during the previous 24 hours, and this is what the agency has to report according to the regulations. We realized that our estimates from the digitized data were incorrect after revising the original Figure and also comparing with the values plotted in Figure 11 in Folch et al (2014).*

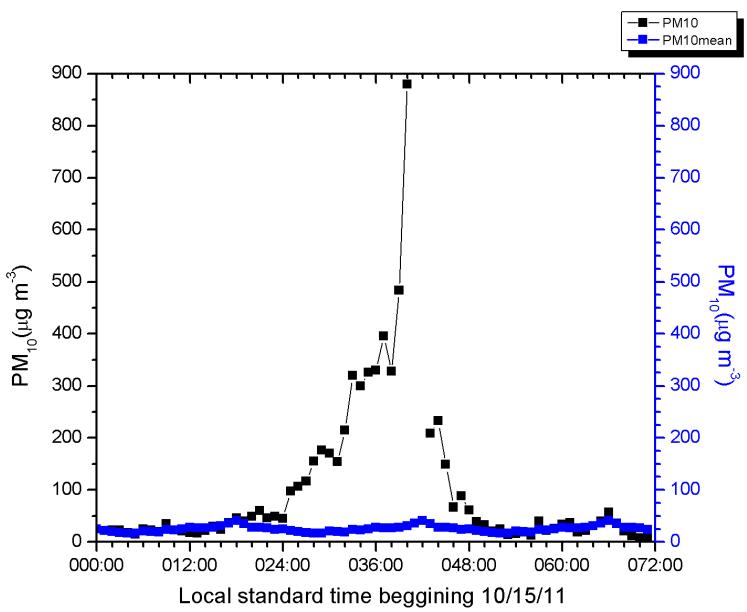


Figure 5. (b) Time evolution (LST) for the 3 day period from 15 to 17 October of the hourly PM_{10} concentration (black line and markers, in μgm^{-3}). The blue line and markers indicate the typical urban October mean values (in μgm^{-3}).

The original paragraph (page P14, L5to 12 in ***nhess-2015-311-D-3****):*
"Note that the PM_{10} concentration at La Boca, located ~ 13 km south of the research site, starts to increase earlier on the evening of 15 October, consistent with the resuspended ash plume arriving into the city. The average value of PM_{10} at this station for all other days during the month of October is only about 40 μgm^{-3}. The hourly maximum of PM_{10} is

observed between midnight 15 October and 1 a.m. 16 October (see Fig. 5b), a time not associated with high pollution, and is further evidence of the presence of the aged ash in Buenos Aires."

*Was replaced by the following one in the **RM**:*
"Note that the PM_{10} concentration at La Boca, starts to increase around midnight on 15 October, consistent with the resuspended ash plume arriving into the city. The average value of PM_{10} at this station for all other days during the month of October is only about 25 μgm^{-3}. The hourly PM_{10} concentrations show an important and fast built up on 16 October, from around 100 μgm^{-3} at 1 a.m. LST reaching the maximum in the afternoon and persisting until midnight. This behavior is consistent with the ceilometer measurements and that reported by Folch et al. (2014) for Córdoba-CABA monitoring site (see their Figure 11)."

*As regards the in-situ measurements, the reviewer is right. We reconsidered the magnitude of the measured peaks and we concluded that these measurements indeed did not give relevant information to justify their inclusion in the **RM**. We do not have a long term mean (in a climatological sense) because we only have carried out measurements for the 8 months that lasted the campaign. Accordingly, the comments about the campaign measurements other than the ceilometer profiles were deleted in the **RM**.*

In Figure 7: The release locations in the HYSPLIT model look very gridded. In my experience of dispersion models particles are normally released evenly across any grid square where the meteorological conditions are optimum for resuspension. In this figure it looks like particles are only released from one point within each 1 degree grid cell. Although it won't change the message provided by the results, if possible the authors should re-run HYSPLIT allowing particles to be released evenly across each grid box as this will greatly improve the look of the results. Alternatively if this isn't the case some explanation of the regular release pattern should be included in the discussion of the model results.

*Answer to R1 comments: We do agree with the reviewer, we used the public version of HYSPLIT which is somewhat inflexible with respect to some of the parameters that can be changed and how the plots are made. Moreover, in the description of the DUST storm runs READY HYSPLIT web site (http://www.arl.noaa.gov/) as well as in published research, we found a similar gridded look even with higher resolution meteorological and landuse files. We add here some additional references that will be included in the **RM.***
*The release locations are gridded because the **DUST STORM** module emits **dust** from the grid **only when the preprocessor finds desert soil and at this grid point the threshold wind velocity is exceeded**. This gridded "look" cannot be modified in this version and we selected for the Figures the particle display mode and not the concentration grid display, because we wanted to do qualitative comparisons with the images from the CALIPSO overpass. We considered that showing the horizontal and vertical structure of the simulated particle distribution obtained with HYSPLIT and their qualitative agreement with remote sensing observations will illustrate the applicability of a less demanding tool (from a computational point of view) in an operational framework. In fact a "calibration"*

procedure could also have been carried out in order to reproduce observed concentrations but this was not within the goals of our paper.
Regarding the regular release pattern, in this module the release pattern is governed by the driving mechanism of the dust emission, which is the exceedance of the threshold velocity over the desert type soil grid points. And this, in turn, is determined by the particular meteorological conditions. In this sense, our arguments and results are in agreement with the findings and conclusions in Folch et al. (2014).

The purpose of using the HYSPLIT model is related to its portability on Windows PC Systems. Technical personnel from different government agencies (e.g. Road Safety, National Parks, Civil Defense, County Offices, etc) could be trained in order to be prepared for this hazardous and not unusual event at the Patagonian Steppe. We want to remark that our numerical results were only qualitative as we do not have a dual-polarization lidar network or a dense air quality monitoring network to quantitatively evaluate the model results.

As stated above (see pages 15-16 this answer), the original paragraphs regarding HYSPLIT model setup and simulations were replaced in the RM.

3 Technical comments
Section 3.2, Line 18: suggest replacing 500/1000 thickness with 500-1000 hPa thickness as the "/" sign is suggestive of division rather than subtraction.

Answer to R1 comment: We have replaced by 500-1000 hPa thickness as suggested.

ADDED REFERENCES:

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