Point-to-point answers to 2nd referee on the paper "Continuous observations of synoptic-scale dust transport at the Nepal Climate Observatory-Pyramid (5079ma.s.l.) in the Himalayas" by Duchi et al.

AUTHOR INTRODUCTORY REMARKS: The main goal of the research presented is to investigate the influence of mineral dust aerosols due to long-range transport events on the seasonal variability of background aerosol properties in the high Southern Himalayas. With this aim, measurements of the aerosol size distribution derived from an optical particle counter (OPC) carried out during the first 2-years of continuous observations at the Nepal Climate Observatory-Pyramid GAW global station (5079 m asl) have been analysed. As shown by many other papers in this special issue, the NCO-P site is well representative of the tropospheric background conditions during night-time. For this reason, in order to identify only long-range dust transport events, in this work we considered the aerosol properties (size distribution, mass, SSA, AOD) observed at the measurement site during night-time (00:06 AM). Then, to evaluate specifically the impact of the identified dust transport events (DTE) on the Himalayan background atmospheric conditions, we compared aerosol properties during DTE with values observed during "dust-free" night-time observations.
Being based on a major experimental effort, this investigation allowed us to infer the first systematic identification of DTEs at 5000 m asl in the Himalayas, elucidating for the first time the influence of long-range dust transport on the temporal variability of aerosol concentrations and properties in the Himalayas. Moreover, the results represent a valuable resource for the validation activities of CTM or global models. Thus, the authors are strongly convinced that the paper actually represents a notable *"advance the existing knowledge of dust transport to Himalayas"*
(come prima)

REFEREE#2: This paper reports valuable observation data of aerosol size distributions and optical depth in the high-altitude Himalayas. Although the outcome of this effort is documented well, the authors do not give any information on what their new additional information is. Compared to several papers published by the authors, it is not clear what are newly reported in this paper. Given the below criticism, as a reviewer, I recommend "reject" for this paper as it stands now but highly recommend "resubmission" after significant addition of analysis and modification of manuscript. As a non-native speaker, this manuscript also should be checked by the native speaker.

AUTHOR REPLY: The authors wish to thank the second referee for his valuable criticisms Probably, we did not clearly express the paper's goals and the new additional information that it presents. Basically, apart from the earlier work by Carrico et al. (2003) based on the aerosol chemical composition in the years 1999-2000, no other systematic measurements of mineral dust in South Himalayas exist. Thus, our results contribute to filling an important gap of knowledge which will be fundamental to support future research on the evaluation of climate impacts of mineral dust in the Himalayan region (in terms of atmospheric radiative forcing, glacier surface albedo variability and aerosol indirect effects).

REFEREE#2: The authors select coarse dust particle events from 2-yr OPC measurements, and then identified the sources/origins of dust aerosols based on the back-ward trajectory calculations. How well the back-ward trajectories explain the origin of wind-blown dust particles? The approach for dust source identification is very simple and has potentially not recommendable, without additional information. An interpretation of backward trajectory is not straightforward. For example, how we can distinguish the dust source regions if the air mass pass over NA-AP-LT or TAK-TP. In this paper, the back-ward trajectories on the horizontal plane (i.e., latitude and longitude plane) are provided in Fig. 4, but this reviewer strongly suggest to show the vertical plane along the transport route to see the vertical movement of air mass.

AUTHOR REPLY: The source/origins of mineral dust observed during DTE at NCO-P is based on a careful combined analyses of 3D back-trajectory ensembles (120 hour long) ending at the measurement site, as well as on analyses of mineral dust mobilization over the main source regions defined in Fig. 1. In their effort to simplify the paper's reading, the authors were probably not very effective in clarifying the adopted methodology, which we will try to improve on here. The source regions linked to a specific DTE were identified when back-trajectories passed at low altitudes over the said regions, so that mobilized dusts were likely to be caught from these desert areas. In particular, for one (or more) of the desert regions reported in Fig. 1 to be selected as source region for a specific DTE, the back-trajectories had to travel below a specific "critical" altitude (whose value varied according to the season) that was defined on the basis of the global climatology of dust injection layer heights presented in Liu et al. (2008a). Moreover, the mobilization of mineral dust over the source regions during the passage of the back-trajectories were further corroborated by the satellite analyses of OMI (aerosol index), MODIS (AOD @ 550 nm) and, when data were available, CALIPSO data. Thus, we disagree that our approach can be considered "very simple". Obviously, the adopted approach does not allow an accurate quantification of the respective roles played by different source regions to aerosol air-mass loading when multiple regions, identified as described above, concurred in a single DTE. In such cases, we assigned to each source region an equal "weight" in terms of aerosol contribution, by equally tagging the aerosol concentration observed at NCO-P to each source region. However, also considering the large number of DTEs presented in this work, identified thanks to the continuous monitoring activity, the authors are confident that the reported results are sufficiently robust.
A confirmation of the goodness of the selection methodology comes from the analyses of chemical signatures of PM_{10} samples collected at NCO-P, which were analysed by Decesari et al. (2010, this issue), as reported in the Section 3.2 of our manuscript: "different values of Ca/Al and Fe/Al ratios were found in function of different DTE source regions". These ratios have been used in the scientific literature as a fingerprint of dust origins (Kaspari et al., J. Climate, 22, 3910–3925, 2009; Rastogi and Sarin, Atmos. Environ., 43, 3481–3488, 2009; Kumar et al., Atmos. Environ., doi: 10.1016/j.atmosenv.2008.03.004, 2008).
Some uncertainties in the source area selection may arise from uncertainties related to the back-trajectory position that, according to Stohl (Atmospheric Environment, 32, 1998), can be roughly quantified as 20% of the travel distance from the end point. However, in this work we analysed back-trajectory ensembles and not single back-trajectories. In cases of coherent behaviours of an ensemble member, the accuracy of source region identification is further increased.
Information on the travel altitude is previously provided in Fig. 4.

REFEREE#2: In addition, the authors mention that the purpose of this paper is to evaluate and characterize the frequency and intensity of dust transport events and their influence on background atmospheric properties in the high Himalayas (L20-22 of P4233). However, I CAN NOT find the impact of dust aerosols on the background atmospheric properties in the high Himalayas in this paper. What the authors mean "background atmospheric properties" here?

AUTHOR REPLY: Along with the motivations that led to the definition of the data analysis strategy, the main aims of the paper are reported in our introductory remarks above. Probably, as mentioned earlier, the authors were not clear enough in explaining these points in the manuscript and in giving relevance to the results obtained. In fact, the impact of dust aerosols on background properties (in terms of size distribution, mass, AOD, SSA) in the high Himalayas is reported in Section 3, Tables 1-3 and Fig. 5, where aerosol properties during DTE are compared with aerosol properties during "dust-free" night-time (00-06 AM) periods. This nocturnal time-window has been defined as representative of the background conditions in several papers of the ACP Special Issue. Therefore, based on these points, we believed that a valuable information was already provided for describing how DTE can impact the background properties of the Himalayan troposphere (Section 3.2, 3.3, 2.4).

REFEREE#2: The logic for data analysis is not reasonable. The authors argue that only night-time OPC data were analyzed to minimize the effects of thermal valley wind circulation. But Cimel-derived AODs given in Table 3 are obtained in day-time observation (09:45). As the reviewer mentioned in the introduction, this reviewer strongly suggest analyzing and showing both day and night-time data to explain the impacts of dust aerosols on radiation budget and on snow-albedo effects in the high Himalayas. The mixing of long range transported dust particles with locally-emitted dust/pollution aerosols is also an important fact. For example, how the author explain the SSA with about 0.85 during dust events. This value of 0.85 is still quite low compared to the previous dust studies.

AUTHOR REPLY: All measurements presented in the paper were recorded during night-time (00:06 AM) in agreement with the DTE selection methodology that aimed to minimize possible interferences due to local/regional-scales transport along the Khumbu valley. In order to better define the night-time atmospheric conditions, we decided to consider also the Cimel AOD data observed in the very early morning (from sunrise to 09:45 AM), which are the first daily radiative measurements of aerosol optical depth available (after the nocturnal time). We already motivated this choice:

- Section 2.4 : *"Since the mean AOD measured at NCO-P is about 0.04 in the dry season (Gobbi et al., 2010), only direct-sun measurements were used in the present analysis, the inversions of sky radiance being unreliable in such conditions (e.g., Dubovik and King, 2000).".*
- Section 3.4 : *"As shown in previous sections, the synoptic transport of mineral dust can greatly affect the coarse aerosol number and mass concentration at NCO-P. During such events it is therefore reasonable to expect a significant change in the aerosol optical properties, possibly to the extent of determining a direct influence on the radiative properties of atmosphere. For this reason, in order to estimate the effects induced by the occurrence of DTEs on the optical aerosol properties at NCO-P, changes of aerosol optical properties were investigated in terms of SSA and AOD. The analysis concerns only the early morning AOD measurements from sunrise to 09:45 NST, which, by minimizing the influence of valley breeze circulation, can be considered more representative of the night-time synoptic-scale transport at the site".*

We agree that an assessment of the impact of dust aerosols on the radiation budget and on snow-albedo effects in the high Himalayas is an urgent issue, but it is well outside the goal of this paper, which aimed to provide accurate analyses of DTE seasonal climatology and its impact on aerosol properties. However, the authors think that the results provided in the submitted manuscript represent an important starting point for this kind of research, also representing a valuable resource for validation activity of CTM or global models.

As showed by Bonasoni et al, (2010) and many other papers in this special issue, the measurement site is affected by diurnal transport processes related to the occurrence of day-time up-valley and night-time down-valley breezes (from post-monsoon to pre-monsoon), able to trigger a strong diurnal cycle in trace gas concentrations and aerosol property (chemical and physical) variability. As reported by Marinoni et al (2010), this was also the case for the coarse aerosol fraction (especially from post-monsoon to pre-monsoon), which are characterised by higher values during day-time compared to night-time. More information about the general variability of AOD and SSA can be found in Gobbi et al. (2010) and Marcq et al. (2010). However, since the present paper sought identify long-range transport of desert dust, we decided to not analyse again the entire time series data-set in our work, but only to refer to other already-published papers. Perhaps this choice caused some ambiguity in our manuscript, which could be better clarified with a more complete discussion on diurnal cycle variability.

We agree with Referee#2 that “The mixing of long-range transported dust particles with locally-emitted dust/pollution aerosols is also an important fact”. It is for this reason that we adopted a very restrictive data-selection for minimizing the possibility that local/regional scale transport might invalidate the selection and the analysis of long-range DTE, which are the focus of the paper. A comparison between the role played by local/regional circulation and long-range circulation in transporting mineral dust to NCO-P is really important but, again, these aspects were outside the scope of this paper.

In the manuscript we reported, for DTEs, a SSA ranging from 0.84 to 0.89 as a function of season. On average, these values are larger than SSA typically reported at NCO-P for “dust-free” conditions (0.75 – 0.83), indicating that mineral dust plays a role in modifying (increasing) the low SSA usually characterising south Himalayas due to the presence of high amount of combustion products (e.g. BC, see Marinoni et al., 2010). However, we agree with the referee that the reported DTE SSA values are quite low if compared with other observations related to mineral dust (usually above 0.9 at 700nm, see Redmond et al., Aeolian Research 2, doi: 10.1016/j.aeolia.2009.09.002, 2010). However, SSA over India and East Asia/China during desert dust transport events greatly varied, with reported values from 0.75 to 0.99 (see Redmond et al., 2010 and references therein). In particular, some studies indicated SSA<0.75 for dust originating from the Thar desert (one of the most active dust sources for the NCO-P site) which, as reported by Moorthy et al. (J. Geophys. Res., doi:10.1029/2006JD007690, 2007), mobilizes the most absorbing dust particles in the world. Moreover, as shown by further analyses concerning the evaluation of eqBC during DTEs, residual influences from combustion emissions could influence our SSA estimated during the identified DTE, especially for DTEs originating in the Indo-Gangetic Plain and Thar desert.

REFEREE#2: The SSA derived from nephelometer and MAAP measurements is not enough to explain the contribution of dust particles on light absorption, because aerosol scattering coefficient measured particles less than 2.5 um in diameter. What is the size-cut of MAAP measurements? Why the authors do not provide the SSA as well as Angstrom parameter data from AERONT Cimel? The authors also proof the consistency of data quality between AERONET level 2.0 and 1.5 (e.g., compare AOD and Angstrom parameter for the periods when both level 2.0 and 1.5 data are available

AUTHOR REPLY: The authors are slightly confused by the referee’s comment, in that it is beyond the scope of the article to quantify the specific contribution of mineral dust to light absorption. We hypothesize that the following sentence is responsible for the referee’s comment:

- Section 3.4 : *“At NCO-P, higher SSA values characterised DTEs with respect to “dust free” conditions for all the seasons, indicating a more efficient scattering of dust particles and resulting in a relative weak contribution of mineral dust to the mean absorption coefficient.”*

The authors did not set out to quantify in the paper the contribution of mineral dust to the absorption coefficient: the meaning of the above sentence is that, although there could be a contribution of mineral dust to light absorption, the contribution to light scattering is greater than to light absorption, leading to an increase in observed SSA values during mineral dust transport events.
To complete the answer to the referee, there is no size-cut on the MAAP measurements, as the instrument’s inlet is linked to a Total Suspended Particles head.
The SSA and Angstrom parameter data from the AERONET Cimel were not presented in this paper because the Cimel-derived parameters come from the inversion of almucantars, which requires persistent clear-sky conditions. At NCO-P only few AERONET measurements allow such inversions, which are not enough to be considered reliable as a time series. A second reason, which is explained in the manuscript, is that because of the typical small values of the AOD, the derived

quantities are subject to a large error. Furthermore, the unknown vertical distribution of the aerosol makes it very difficult to infer ground properties from column measurements. As shown in Gobbi et al. (2010), the aerosol scale height, derived from ground and column extinction measurements, reach in some periods several hundred kilometres, thus indicating the presence of high layers which strongly contribute to the AOD, although not measurable at ground. Under such conditions, the optical properties derived from column measurements cannot be easily attributed to ground aerosol. As for the time series of the Cimel data, the level 1.5 and 2.0 data are very close for the periods selected as dust events. During the first year of measurements, when 2.0 data are present, a comparison showed that the mean deviation between the two time series is lower than 5%. For the second year, however, it is expected to be even lower. In fact, the AOD values show far fewer outliers, which are likely due to failures of the automatic cloud screening performed at level 1.5.

REFEREE#2: In Tables 2 and 3, it should be added that how many data are used for each categorized case. No information is given. In table 3, it will be greatly helpful if the authors provide aerosol volume size distributions retrieved from Cimel.

AUTHOR REPLY: The authors agree with the referee on the inclusion of the number of data used. Regarding the Cimel data they were not included in the table because of the unreliability of Cimel-derived parameters (as reported in the above reply).

MINOR COMMENTS

REFEREE MINOR COMMENT: "mineral dust may strongly affect the balance of tropospheric O3 (a powerful regional greenhouse gas), thus having a further indirect effect on climate". Please provide relevant reference(s).

AUTHOR REPLY: The authors agree with the referee.

REFEREE MINOR COMMENT: The uncertainty of SSA at 700nm should be mentioned, although details are given in Marcq et al.

AUTHOR REPLY: The authors agree with the referee.

REFEREE MINOR COMMENT: The "Decesari et al. (2010) showed that PM10 samples collected during DTEs from LT and TP were characterized by enhanced calcium content (up to 487 μg m-3)". The value of 487 μg m-3 is extremely higher than the values reported in this study (Table 1). More explanations are necessary.

AUTHOR REPLY: This was a typesetting error: the calcium content is 0.487 μg m-3.

REFEREE MINOR COMMENT: The MODIS AOD images do not provide any meanings. Why the authors showed? In addition, what level of MODIS data is used here? MODIS Collection 5.1 data and or MISR AOD data are recommendable to see AOD over the bright surface area.

AUTHOR REPLY: The MODIS AOD images refer to the two most significant episodes of synoptic scale dust transports over the two years, in terms of coarse particle concentration (June 2006 DTE) and number of consecutive days affected by the event (April 2007 DTE). These images have been included in the manuscript with the aim of providing two "textbook" examples of DTEs occurring at the NCO-P.

The images shown were obtained using MODIS Level 3 Data, from Collection 5 (the one available at the moment when the images were gathered): however, the images obtained from Collection 5.1 (now available) do not show any remarkable difference with that shown in the article.