Point-to-point answers to 1st 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 a.s.l. 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"*

REFEREE#1: My general feeling is that this paper does not advance the existing knowledge of dust transport to Himalayas except merely a reporting of 2-year of data which is also not presented as a time series to assess its quality, specifically the optical properties- AOD and SSA.

AUTHOR REPLY: As already expressed in the introductory remarks, the goal of the paper was the identification of synoptic-scale mineral dust transport episodes toward the NCO-P, the study of their seasonality, the identification of the principal desert regions that are sources of dust reaching NCO-P, and the evaluation of the impacts of synoptic-scale mineral dust transport on the background properties of aerosol in the Himalayas. The analysis of the time series of AOD and SSA data is beyond the scope of our work, considering that these series have already been showed and analyzed in two papers included in this ACP Special Issue (namely Gobbi et al., 2010 and Marcq et al., 2010). The time series of the data obtained by OPC were already presented in Bonasoni et al. (2010), expressed as number concentration of coarse and fine particles fractions, and in Marinoni et al. (2010), expressed as mass (PM_1 and PM_{1-10}) calculated from number distributions, assuming a constant aerosol density. Therefore, the authors deemed that a reading of these publications makes superfluous the presentation of time-series already discussed and analysed in other companion papers, in which the data quality was carefully also assessed. Moreover, in the paper we present the time series of coarse particle (particles with diameter greater than 1 μm), a well-known tracer used to identify mineral dust transport in clean environments (Van Dingenen et al., Atmos. Chem. Phys., 5, 2203–2226, 2005; Rajot et al., J. Geophys. Res., doi:10.1029/2008JD009906, 2008; Formenti et al., ACPD, doi:10.5194/acpd-11-2549-2011, 2011; Chun et al., Atmos. Environ., doi:10.1016/S1352-2310(00)00404-0, 2001, Murayama et al., J. Geophys. Res., doi:10.1029/2000JD900554, 2001). The submitted paper represents the first assessment of long-range mineral dust transport to Himalayas based on continuous systematic in-situ measurements at altitudes above 5000 m a.s.l. Thus, the presented research contributes to filling an important gap in the knowledge which is fundamental also to support further research on the evaluation of climate impacts of mineral dust on the Himalayan region (in terms of atmospheric radiative forcing, glacier

surface albedo variability and aerosol indirect effects). For this reason, the authors are still convinced that the submitted manuscript represents a significant advance in the existing knowledge!

REFEREE#1: For AOD sometime level 2.0 data is presented and other times level 1.5 which makes us to suspect the data quality. For the quality control of aeronet product please see Holben et al. (1996) and Dubovik et al.

AUTHOR REPLY: The authors wish to point out that the paper makes clear that the decision to consider Level 1.5 AOD data (for the period March 2007 – February 2008) was motivated by the unavailability of Level 2.0 AOD data for the same period. The Level 1.5 AOD data are already cloud screened using automatic processes, the difference with Level 2.0 data being the manual screening. Moreover, Level 1.5 AOD data have been previously used in published scientific literature (Papayannis et al., Geophys. Res. Lett., doi:10.1029/2006GL029125, 2007; Schaap et al., Atmos. Chem. Phys., 9, 909–925, 2009; Perrone et al., Atmospheric Research, doi:10.1016/j.atmosres.2004.12.003, 2005; and many others), and have been already used in the paper by Gobbi et al. (2010) presented in the same ACP special issue.
However, a comparison of the time series of the Cimel Level 1.5 and Level 2.0 data shows that they are very close for the periods selected as dust events. During the first year of measurements, when 2.0 data are present, the comparison between 2.0 and 1.5 data levels showed a mean deviation between the two time series lower than 5%. For the second year, however, it is expected to be even lower, due to the much lower number of outliers, probably due to failures of the automatic cloud screening performed at level 1.5.
Considering all of the above evidence, we are concerned (and rather surprised) that our reasonable decision to include Level 1.5 AOD data for the period when Level 2.0 AOD data were unavailable, generated doubts on data quality on the part of the Referee.

REFEREE#1: Table 3 shows, for monsoon season, during Dust Transport Events (DTE), AOD at 500 nm being significantly smaller than that during Dust free cases. The authors must explain this discrepancy given that their Fig 5 clearly shows higher concentration of coarse particles during DTEs.

AUTHOR REPLY: The authors thanks the referee for raising this point. The monsoon AOD data were presented in the manuscript to give a complete overview of the seasonal behaviour of AOD during DTEs and "dust free" conditions over the 2 years examined. However, as already reported in the paper:

- Section 3.4 : *"During the monsoon season, the smaller number of measurements available at the NCO-P lead to consider very carefully the fact that the AOD is higher when the measurement site is not affected by synoptic-scale transport of mineral dust".*

In fact, the majority of AOD data during DTE in the monsoon season were obtained during the June 2006 DTE (28 data with respect to 43 total data). Therefore the monsoon AOD data were deemed insufficient to determine a clear correlation between AOD data and synoptic scale mineral dust transports. Moreover, as reported by Gobbi et al. (2010, this issue) at NCO-P AOD maximizes during the monsoon due to the occurrence of elevated, coarse particle layers possibly originating from wind erosion from the surrounding peaks and hydrated/cloud-processed aerosols. This can hamper an accurate assessment of long-range mineral dust on total AOD. Probably, we were not clear enough in explaining these points.

REFEREE#1: In the same Table SSA during Dust free monsoon season is reported as 0.75+-0.15. What could be the reason for such highly absorbing aerosol existing at altitude > 5000 m. The

authors explain it in terms of preferential scavenging of hygroscipic particles relative to black carbon during monsoon time which is far from convincing.

AUTHOR REPLY: The seasonal variation of SSA at NCO-P is shown and discussed in the accompanying paper by Marcq et al. (2010). In that paper (cited in our manuscript), the lower SSA average value (0.80) observed during the monsoon season is explained as :

- Section 4.1 : *"These variations reflect a higher proportion of absorbing material during the Monsoon that can either be related to preferential scavenging of more hygroscopic aerosol particles, such as sulphate and/or nitrate, or due to less-hygroscopic absorbing organic and BC material. It can also reflect changing emission source areas from long range transport of material from western regions of India and Pakistan in winter to more direct emissions from Indian and Nepal plains during Monsoon (summer) season (Bonasoni et al., 2010). Very low w_0 values (as low as ω_o 0.75) have been measured by several authors within the boundary layer in India (Ramanathan et al., 2001) and also at the Mukteshwar station where w_0 at 525 nm range from 0.74 to 0.85. Our study therefore adds additional evidence that strongly absorbing particles are efficiently transported to the high remote Himalaya regions.". **("Marcq, S., Laj, P., Roger, J. C., Villani, P., Sellegri, K., Bonasoni, P., Marinoni, A., Cristofanelli, P., Verza, G. P., and Bergin, M.: Aerosol optical properties and radiative forcing in the high Himalaya based on measurements at the Nepal Climate Observatory-Pyramid site (5079 m a.s.l.), Atmos. Chem. Phys., 10, 5859-5872, doi:10.5194/acp-10-5859-2010, 2010)**.

The in-cloud scavenging efficiency of black carbon is one of the lowest measured through separate cloud phase sampling by Sellegri et al.(JGR, 2003). Moreover, the preferential scavenging of other, less soluble chemical species, with respect to BC, is also considered as an explanation of the increase in the ratio of BC/PM1 during the monsoon season in Marinoni et al. (2010):

- Section 3.1.1: *"As shown in Fig. 3, the BC/PM1 ratio shows a maximum contribution of carbonaceous absorbing material to the fine particulate matter during the monsoon season (about 18% in July-August), while the minimum values characterizes the pre-monsoon season (less than 9% in April-May). This is plausibly due to a preferential scavenging by monsoon precipitation of the inorganic fraction of aerosol with respect to the less hygroscopic black carbon.". **(Marinoni, A., Cristofanelli, P., Laj, P., Duchi, R., Calzolari, F., Decesari, S., Sellegri, K., Vuillermoz, E., Verza, G. P., Villani, P., and Bonasoni, P.: Aerosol mass and black carbon concentrations, a two year record at NCO-P (5079 m, Southern Himalayas), Atmos. Chem. Phys., 10, 8551-8562, doi:10.5194/acp-10-8551-2010, 2010)**..

The presence of high concentrations of highly absorbing aerosol over 5000 m altitude and the analysis of the possible causes for such values are clearly illustrated in the papers by Bonasoni et al. (2010) and Marinoni et al. (2010), both of them already included in the ACP Special Issue. Both articles are already appropriately cited in our paper.

REFEREE#1: Asides the data no implications of these dust transport to higher Himalyas have been discussed.

AUTHOR REPLY: Evidently, we were not clear enough in explaining these points in the manuscript, as well as in giving the appropriate relevance to the obtained results. However, the effects of dust transport on the aerosol properties (size distribution, mass, AOD, SSA) in the high Himalayas are clearly 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 periods. Thus, we are rather surprised that the referee affirms that "no implications" have been discussed. Moreover, the significance of the variation of the optical properties caused by the identified DTEs and their possible impacts on the atmospheric radiative budget are expressed through appropriated citations (Kaufman et al., 2002; Engelstaedter et al., 2006; Lau and Kim, 2006; Lau et al., 2006).

REFEREE#1: In addition the size distribution measurements by GRIMM OPC has several issues compared to other techniques notably TSI APS etc. (see e.g. a classical paper by Reid et al. (JGR,

2003, Comparison of size and morphological measurements of coarse mode dust particles from Africa). The authors should have at the least discussed the potential limitations of their data set. No information is given.

AUTHOR REPLY: The authors are aware of the limitations of optical particle counters in determining the size distribution of coarse particles compared to other techniques, and agree with the referee that an appropriate indication of the limitation of the dataset should be included in the experimental description in the paper. For instance, the refractive index variation with different air masses and particle non-sphericty effects could influence the OPC response, both in terms of diameter and particle number. However, we would point out that several papers in the literature (e.g. Van Dingenen et al., Atmos. Chem. Phys., 5, 2203–2226, 2005; Rajot et al., J. Geophys. Res., doi:10.1029/2008JD009906, 2008; Formenti et al., ACPD, doi:10.5194/acpd-11-2549-2011, 2011; Chun et al., Atmos. Environ., doi:10.1016/S1352-2310(00)00404-0, 2001, Murayama et al., J. Geophys. Res., doi:10.1029/2000JD900554, 2001) have already used OPC size number distribution to identify mineral dust transport events.