

Response to referee #1

We would like to thank the referee for the interest in our work and the helpful comments and suggestions to improve our manuscript. We have carefully considered all comments and the replies are listed below.

1. Abstract (P25052, L15-20): The authors state that “This phenomenon indicates that both slopes of Himalayas share a common atmospheric environment regime.” How is an area of the southern slope defined by altitude? Does this statement apply only to an altitude of the same order of magnitude as that of Langtang and NCO-P, or it can also apply to lower altitudes as well? The altitude values of Langtang and NCO-P should be provided here. The sentence “While OC, EC and other ionic species. . . . , such as Langtang and NCO-P” needs to be rephrased. My suggestion is to remove “While” and to rewrite the phrase as “. . . . in the monsoon season, similar to the trends of aerosol composition reported previously. . . .”.

Response: Yes, here the southern slope area refers to the comparable high altitude area with elevation more than 3000 meters, such as Langtang and NCO-P, which are relative far away from the populated area of Nepal. The exact altitude of Langtang and NCO-P can be found in Table 2 (the second column). The sentence mentioned above has been modified.

2. The second last paragraph of Sect. 3.1 (P25059, L4-10): In addition to the radiation forcing of organic carbon aerosols, the cause(s) of high OC/EC ratios observed on the Tibetan Plateau is suggested to be discussed.

Response: Now more explanations on this point were presented.

There are two potential reasons for the higher OC/EC ratios in this study (i.e. QOMS). The first possible explanation is a strong solar radiation over the TP, more secondary organic carbon (SOC) may be formed through photochemical reaction. Because of its high elevation, solar radiation on the TP exceeds 7500 MJ m^{-2} , only next to the Sahara Desert. The strong solar radiation could enhance the yield of secondary aerosol from their precursors. Another possible reason is the influence of biomass burning. Usually, the aerosols emitted from biomass burning have higher OC/EC ratio. For example, Watson et al. (2001) have reported an OC/EC ratio of 14.5 for forest fires. Cao et al. (2005) reported the OC/EC ratio of 12.0 for coal combustion, 4.1 for vehicle exhaust, and 60.3 for biomass burning. Considering the specific condition of this study, we think the second explanation is more likely, i. e. the strong influence of biomass-burning emissions. However, the exact reason is beyond the scope of the current study and needs a detailed study in the future.

3. The first paragraph of Sect. 3.2 (P25060, L1-7): In the summer monsoon season, the observed OC and EC concentrations are very low with high variability for EC, as can be seen in Fig. 4b. What is the detection limit for EC in micro gram per cubic meter? In addition, in spite of high temperature and humidity, photochemistry might not be so intensive due to reduced solar radiation associate with rains during the summer monsoon season. Moreover, WSOC was observed to be low in the summer monsoon season as shown in Fig. 3. Therefore, linking a high OC/EC ratio to substantial SOC formation in the monsoon seasons needs to be reconsidered.

Response: The detection limit for EC was estimated as $0.02 \mu\text{g m}^{-3}$ according to the real sampling air volume. For the cause of high OC/EC ratio in the summer monsoon season, we agree with the reviewer's comments. Not only the absolute concentration levels of WSOC are quite low in summer (Fig. 3) as the reviewer mentioned, but also the relative abundance of WSOC to the total OC (WSOC/OC) is not high, compared with other seasons (Table 1). Therefore, we modified this sentence. The relative importance of different sources merits a further study.

4. What are the time intervals of the data presented in Fig. 3 and Fig. 6? How about the regression result if the data point with the largest EC value (which seems to be abnormal) is skipped in Fig. 4 for the post-monsoon season?

Response: The temporal resolution of the sampling is every week. So we added "(weekly)" into the figure legends. If we exclude that data point with the lowest OC/EC ratio in Fig. 4c (for post-monsoon season), definitely, the regression result will become better. However, it does not change the main claim of this discussion part, i.e., during the pre-monsoon season, the high abundance of OC and EC have common emission sources and transport processes, which is clearly suggested by the significant correlation. Therefore, we intend to keep that data point in Fig. 4c.

5. Sect. 3.5: This section discusses about the transport mechanism of aerosols. However, not so much information on aerosol variations with transport at QOMS is provided. Specifically, the authors performed backward trajectory analysis, but variations in aerosols concentrations with different clusters are not discussed; they propose that local mountain wind system may play an important role in the transport of pollutants, but neither observed pollution tracer nor meteorological data is provided to support their viewpoint. Moreover, as they mentioned, carbonaceous aerosols observed at QOMS might be originated from northern India and Nepal, instead of Langtang and NCO-P areas, and thus other processes, such as wet removal during the summer monsoon season, should be considered for discussion.

Response: We understand the referee's concern on the aerosol transport process that proposed in this study (Section 3.5). Now we added more evidence to demonstrate

that the both side of Mt. Everest do connect each other. Because both QOMS and NCO-P have sun-photometers and participated in the AERONET project, the same instrument (Cimel 318), the same data process methods and simultaneous observation between QOMS and NCO-P make it possible to compare AOD data directly between the two slopes of Himalayas. As seen in the figure below, the daily AOD (500 nm) of QOMS and NCO-P varied in highly similar pattern (The correlation significant at $p < 0.001$), which is in agreement with our viewpoint that both slope share a common atmospheric environment regime. Furthermore, in the work by Lüthi, et al. (2014), the transport mechanisms of pollutants from IGP (the foothills of the Himalayas) to the TP was investigated using a high-resolution atmospheric transport model. They found some trajectories with low altitudes actually originate from the TP, flow down through valleys to the IGP during nighttime where they can mix with polluted air and are then lifted onto the TP again during daytime. For the vertical distribution of aerosols, two examples of such transport episode revealed by CALIOP satellite now were provided in the Supplementary Information (Fig. S3), which clearly showed the pollution plumes from South Asia could transport across the Himalayas.

We admit that the exact description of the local transport mechanism would require more study, not only the high-resolution model but also the simultaneous observation of air pollutants (like O_3 , CO and BC) between the two slopes of the Himalayas, especially on the ground level.

As to the influencing factor during the aerosol transport, like wet removal, it is difficult to evaluate based on the current observation results. In this work, we emphasize that although the air mass trajectories are similar in pre-monsoon, post-monsoon and winter, the difference of the carbonaceous aerosol abundance is mainly linked to the emission strength.

6. The authors are suggested to take into account and refer to a study recently published in ACP (Xu, C., Ma, Y. M., Panday, A., Cong, Z. Y., Yang, K., Zhu, Z. K., Wang, J. M., Amaty, P. M., and Zhao, L.: Similarities and differences of aerosol optical properties between southern and northern sides of the Himalayas, *Atmos. Chem. Phys.*, 14, 3133-3149, 10.5194/acp-14-3133-2014, 2014).

Response: This reference is now cited in the revised manuscript. As described above, we further analyzed the similarity of AOD temporal variation between QOMS and NCO-P (Fig. 11), to support our viewpoint.

References

Cao, J., Wu, F., Chow, J., Lee, S., Li, Y., Chen, S., An, Z., Fung, K., Watson, J., and Zhu, C.: Characterization and source apportionment of atmospheric organic and elemental

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- Lüthi, Z. L., Škerlak, B., Kim, S. W., Lauer, A., Mues, A., Rupakheti, M., and Kang, S.: Atmospheric brown clouds reach the Tibetan Plateau by crossing the Himalayas, *Atmos. Chem. Phys. Discuss.*, 14, 28105-28146, 10.5194/acpd-14-28105-2014, 2014.
- Watson, J. G., Chow, J. C., and Houck, J. E.: PM_{2.5} chemical source profiles for vehicle exhaust, vegetative burning, geological material, and coal burning in Northwestern Colorado during 1995, *Chemosphere*, 43, 1141-1151, 2001.

Response to referee #2

We thank the referee for the recognition on our work and the constructive review.

1. On what basis do the authors assume that the positive artifact due to VOC adsorption on the quartz filters was negligible (page 25056, lines 18-20)?

Response: Thank you for pointing it out. Now we modified the expression.

It should be noted that there are possible sampling artifacts by the adsorption/evaporation of gaseous organic materials on/from the quartz membrane. However there is no quantitative information available on such positive/negative artifact in this study, therefore, no correction was made for the data of carbonaceous components. These points were added in the revised MS.

2. The suggested causes for the high OC/EC ratios during the monsoon season (page 25060, lines 1-7) are reasonable, but it would be good if the authors could show some evidence for the intensive photochemical processes. Perhaps, aqueous-phase chemistry is even more significant during this wet season for SOC formation, while primary biogenic emissions are likely important during the warmer (and wetter) season as well.

Response: Regarding this point, Referee #1 also raised similar concern. After checking the OC/EC and WSOC/OC ratios in Table 1, we think, based on the current dataset, that it is hard to quantitatively attribute the high OC/EC to the different sources or formation process. Now we modified the expression into “The relative importance of different sources and/or formation process merits a further study.”

3. "polycyclic aromatic hydrocarbons (PAHs)" should be removed from this listing (page 25061, line 8), as they are non-polar, while other organic compound classes, such as resin acids, methoxy phenols, or methyl nitro catechols, could be added here.

Response: Changed.

Technical comments

1. The first 3 sentences of section 2.1 (page 25054, lines 19-25) need some rewording and corrections. For example "continues" (line 21) should be changed to "continuous", and the phrase "the Mt. Everest region (QOMS) is a typical representative of the middle Himalayas" is not logical.

Response: Changed. As to the phrase the reviewer mentioned, this argument is based on previous studies. More information could be found in the references we cited here.

2. The first two sentences of the last paragraph of section 3.4 (page 25062, lines 6-9) could benefit from some re-wording, e.g., changed to something like this: "The seasonal variation of biomass burning ions (K⁺) coincided with that of ions associated with fossil fuel combustion ..." or something similar.

Response: Changed as suggested.

3. The verb "deliver" is not fitting here (page 25062, line 26), and should be changed to "are derived" or "are advected".

Response: Changed.

4. The altitude numbers in Figure 1 are difficult to read.

Response: Changed. The altitude information has been moved into the figure legend now.

Response to referee #3

The authors wish to thank the reviewer for the constructive comments and suggestions.

1. Among the arguments of this investigation is that the air pollutants from the south of Himalayas can be transported over to the north slope. However, this argument was supported only by the common seasonality of air pollution. I think more evidence is needed for such a key finding. I didn't see how the aerosols identified as coming from the south of Himalayas, nor how the air mass moved over the Everest. Could the common seasonal variations in aerosol mass loadings be a result of common seasonality of human activities in that region?

Response: We agree. Now more evidences (e.g. daily AOD values and CALIOP results) were provided regarding the pollutant transport process in this region. Details have been presented in the response file to the Referee #1 and Fig. 11 and Fig S3. Actually, there are little anthropogenic aerosol emission nearby NCO-P and QOMS, especially in the pre-monsoon season. We believe that local human activities are not likely to impact the atmospheric environment.

2. Levoglucosan was used as a marker of biomass burning throughout the paper. Thus, Levoglucosan should be included in the data summary table, and the correlation between key components (OC, EC, WSOC...) and Levoglucosan merits presentation as a figure.

Response: Now the data of levoglucosan concentrations were added in Table 1. And the Supplement Figure S2 has been moved to the main text as Figure 8.