

## ***Interactive comment on “New approach to monitor transboundary particulate pollution over northeast Asia” by M. E. Park et al.***

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First of all, we thank the reviewer for careful reading of our manuscript and constructive comments. We have revised the manuscript, following both reviewers' suggestions.

We have also removed/added/changed the words and sentences in the manuscript. The changed and added parts are painted in a red color in the text. Please, check them out.

(General comment) #1. The manuscript presented results of assimilating a new AOD data source from geostationary GOCl sensor with the CMAQ model and OI data assimilation approach. Assimilated AOD was used to monitor long-range transport of air pollutant over northeast Asia. The paper is overall well written although some result

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interpretation is too brief. Presented results have some implication for policy making. However, this reviewer had difficulty to find what new technical approach they have developed and what scientific questions the paper addressed. The authors claimed 'new approach', but it just used some relatively old DA technique to assimilate a new data source and produced un-surprised results. This reviewer does not see technical and scientific significance to grant the publication of this paper.

Reply) We think that this is the most important criticism to our work. Basically, this manuscript attempted to combine three major technical components: (i) chemistry-transport model (CTM) simulation including MET modeling; (ii) retrieval of aerosol optical data from geostationary satellite sensor (GOCl); and (iii) data assimilation (DA). Of the three technical components, the first two are the key components. The DA is a mathematical tool for combining the data from the first two components. Using the combined AOD data obtained from the first two components, we attempted to investigate transboundary PM transport over northeast Asia, where transboundary PM transport is a hot and debating issue among Korea, China, and Japan, since there have been no scientifically rigorous ways to accurately evaluate the transboundary PM transport between countries. We hope that the following explanations would help reviewer to better understand true motivation of this study and current technical status on this research issue in East and northeast Asia:

(1) The easiest and the most straightforward way to evaluate transboundary PM transport is to use CTM simulation. However, due to the large uncertainties in air pollutant emissions (particularly, from China) and incapability of the CTMs, not many policy makers or governmental people have trusted the evaluations only from the CTM simulations in East Asia (e.g. Arndt et al., 1998; Holloway et al., 2002; Wang et al., 2009; Yamaji et al., 2012). For example, several research teams have tried to evaluate transboundary PM transport, conducting the CTM simulations with and without the emission from a specific (source) country (e.g. China). But, these attempts have failed or have led to inaccurate estimations, because of highly non-linear nature of atmospheric chem-

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istry in addition to the uncertainties in the emissions from the source country (Chin and Jacob, 1996; Arndt et al., 1998; West et al., 1999; Yamaji et al., 2012). Due to the reasons mentioned above, to correctly estimate transboundary PM transport over northeast Asia using the CTM simulation only, is believed to be almost impossible (or extremely difficult).

(2) Of course, the best way to evaluate transboundary PM transport is to use “observation data” only. But, the observation data have also limitations. The limitations are twofold. Many science teams in Korea and Japan have made chemical measurements at several (super)sites in the Korean peninsula and Japan and several global research teams have measured the long-range transport (LRT) around the Korean peninsula, using aircrafts and ships (e.g., Ootshi, et al., 2001; Huebert et al., 2003; Jacob et al., 2003). However, these point and line measurements have given limited information of how often these sites and areas were influenced by the LRT events or how large impacts the LRT events can make “only around the measurement areas”. In the similar context, there have been attempts to show the long-range PM transport using satellite data. The satellite aerosol data have been retrieved from LEO satellite sensors such as MODIS, MISR, OMI etc. . . These attempts have again given us limited information, mainly because of two reasons. The first reason is temporal limitation. The LEO satellite sensors can only provide the data at most once per day. Even further, such aerosol data has spatial limitation that the aerosol data are not available at the cloud pixels, the pixels with high surface reflectance, and the pixels affected by sun-glint effects. But, as we mentioned in the text, these limitations can be mainly overcome, if we use the aerosol data from geostationary satellite sensors like GOCI. Therefore, the main driving force (i.e. motivation) of this study is this “availability” of the aerosol data from the “geostationary sensor of GOCI”.

(3) In order to overcome these limitations and to more precisely evaluate the transboundary PM transport in northeast Asia, we therefore attempted to mathematically combine the aerosol data from both the CTM simulations and geostationary satellite

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sensor (GOCI). These efforts are well described in the manuscript, we believe.

In the above context, the “new” in the “new approach” does not mean that this study developed new and/or advanced “technical” tools, but indicates that this type of attempt (approach) of combining the data from the CTM simulations with “geostationary satellite sensor data” in order to more accurately investigate/monitor transboundary PM transport is the first one of its kind. As far as we understand, no research team in the world has attempted to do this for this particular research purpose. In this sense, we selected the title of the manuscript of “New approach. . . .” (not “new technical approach”). We believe that our estimation from this “new” approach might have been the best and the most accurate one over northeast Asia. This approach will be applied further with the aerosol data that will be retrieved from upcoming geostationary satellite sensors around the Korean peninsula such as Korean GOCI-2 and GEMS in the future.

In technical aspects, regarding the first two components (CTM simulation and geostationary satellite data) we carried out the CTM simulations in a state-of-the-science manner, and retrieved aerosol data from the GOCI sensor using one of the most advanced aerosol retrieval algorithms. But, we have to admit that the DA was conducted using a relatively old DA technique (OI method). Although this is a relatively old one, we have thought that this method is still viable for our research purpose. In actuality, the OI has been still being used by many research groups for several investigations similar to this study (e.g. Collins et al., 2003; Yu et al., 2003; Adhikary et al., 2008; Chung et al., 2010), even if we are slowly moving to use ensemble Kalman filter-based DA technique for this type of study. Obviously, all the technical methods will be evolved continuously in the future: the CTM simulation will be further improved, together with two main drivers (emission inventories and MET fields); aerosol retrieval algorithm is being improved; and the DA technique may be switched in the future applications with aerosol data from GOCI, GOCI-II and GEMS sensors.

In order to clarify the abovementioned discussions, we put more texts into introduction and other parts. The added/modified parts are painted in red color. Please, check out

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p.3:line22-24, p.4:line2, p.14:line17, p.14:line19-21, and p.22:line10-16 in the revised manuscript.

(Specific comments) #1. Why only mentioned ASCAT? No other meteorological observations assimilated? Do NOT think ASCAT ocean wind is that important for the long-range transport process.

Reply) Actually, we skipped some detailed explanations for our MET model simulations, since it was discussed in other previous publications (e.g. Park et al., 2011a; Park et al, 2011b). First of all, several scientists have found that significant fractions of air pollutants are frequently long-range transported through the marine boundary layer (in case of regional-scale LRT events, not intercontinental-scale LRT events). This is one of the main reasons we carried out the data assimilation using the ASCAT surface wind data set over the ocean. China, Korea, and Japan are separated by three seas: Yellow sea, East China Sea and East Sea (check out p.6:line17-22). Secondly, Park et al. (2011a) also reported that the anomaly of vertical winds at the surface resulted from the anomaly of sea surface temperature (SST) may be able to cause relatively large anomalies of vertical winds in the upper levels.

#2. "4DDA" refers to 4DVAR or obs nudging? Better to add reference here.

Reply) Four-dimensional data assimilation (FDDA) refers to observational nudging (Grell et al., 1995; Chen and Huang, 2005). We added Grell et al. (1995) into References. Please, see p.6:line12.

#3. Section 2.4: better to briefly describe how 2D AOD analysis is partitioned into different 3D aerosol species.

Reply) In this study, we have regarded AOD as a proxy quantity to PM concentration. As discussed in Sect. 2.5, AOD shows good linear correlations with surface PM<sub>2.5</sub> and/or PM<sub>10</sub>. Regarding this issue, there have been numerous discussions (refer to Wang and Christopher, 2003; Engel-Cox et al., 2004; Liu et al., 2005; van Donkelaar

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et al., 2006; Choi et al., 2009; Schaap et al., 2009; Tsai et al., 2011).

#### Correction lists

1. p.17, line 9: Change "MEE values of" to "MEE values and hygroscopic enhancement factor ( $f_{ij}(RH)$ ) of".

2. p.23, line 10: Remove "Bentamy, A., Croize-Fillon, D., and Perigaud, C.: Characterization of ASCAT measurements based on buoy and QuikSCAT wind vector observations, *Ocean Sci.*, 4, 265–274, 2008."

3. p.23, line 37: Add "Daum, P. H., Kleinman, L. I., Newman, L., Luke, W. T., Weinstein-Lloyd, J., Berkowitz, C. M., and Busness, K. M.: Chemical and physical properties of plumes of anthropogenic pollutants transported over the North Atlantic during the North Atlantic Regional Experiment, *J. Geophys. Res.*, 101, D22, 29029–29042, 1996."

4. p.24, line 18: Add "Grell, G. A., Dudhia, J., and Stauffer, D. R.: A description of the fifth-generation Penn State/NCAR Mesoscale Model (MM5), NCAR Tech. Note NCAR/TN-398+STR, 122, 1995."

5. p.26, line 16: Add "Rajeev, K., Ramanathan, V., and Meywerk, J.: Regional aerosol distribution and its long-range transport over the Indian Ocean, *J. Geophys. Res.*, 105, D2, 2029–2043, 2000."

6. p.26, line 34: Add "Song, C. H., Han, K. M., Cho, H. J., Kim, J., Carmichael, G. R., Kurata, G., Thongboonchoo, N., He, Z., and Kim, H. S.: A Lagrangian model investigation of chemico-microphysical evolution of northeast Asian pollution plumes within the MBL during TRACE-P, *Atmos. Environ.*, 41, 8932–8951, 2007."

7. Figure 1: Add "Yellow Sea" and "East China Sea".

#### Further references

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Interactive comment on *Atmos. Chem. Phys. Discuss.*, 13, 15867, 2013.

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