

Interactive comment on “Composite study of aerosol export events from East Asia and North America” by Y. Luan and L. Jaeglé

Y. Luan and L. Jaeglé

jaegle@atmos.washington.edu

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This manuscript provides a valuable contribution to the substantial body of work investigating the long-range transport (LRT) of air pollution. It's rather unique in two senses: (1) it compares Asia-to-North America (i.e., trans-Pacific) and North America-to-Eurasia (i.e., trans-Atlantic) outflow and transport; and (2) as a composite study covering 7 years and over 200 events, it provides one of the more comprehensive studies of the topic to date. It is generally well-written with the conclusions being well-supported by the data presented. Additionally, the figures do an excellent job of graphically displaying the most important results. I recommend publication of this manuscript pending an address of the following minor comments:

p. 21978, line 6 - At what altitudes (model levels) and during which season(s) is this
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statement pertaining to? *We have clarified that the bias is during summer. This statement is for the column AOD.*

p. 21978, line 11-12 - Regarding transport to the Arctic, what is the transit time (relative to the 6-8 days for trans-Pacific transport) and does this vary by season? The subtropical Pacific High mentioned is not a persistent annual feature, correct - during which season(s) is its impact most significant? *These points have been clarified in the revised text.*

p. 21978, line 15-16 - Again, what is the seasonality of the dipole structure of SLP anomalies? *This has now been clarified in the revised manuscript.*

p. 21978, line 21 - Explicit mention of sulfate and SO₂, but what about BC, dust, nitrate, organics, etc.? *The manuscript mostly emphasizes sulfate and SO₂. Thus this is what is highlighted in the abstract. Dust and organic sources are quite different from both continents.*

p. 21979, line 9, 26 - How does "organic carbon" differ from "carbonaceous aerosols"? Consider using consistent terms or discuss how they differ. *Carbonaceous aerosols include organic carbon (primary and secondary organic aerosols) as well as black carbon. We have modified the manuscript to be more specific.*

p. 21980, line 3-9 - Lofting by WCB's dominates during spring, correct? Again, seasonality of features should be discussed. *WCBs have been found to be important for all seasons. This has been noted in the revised manuscript.*

p. 21980, line 13 - What does "pollution" refer to here - anthropogenic only? Dust and biomass burning emissions included? *This is a general statement and to clarify this, we have removed pollution in the revised manuscript. The original manuscript did not define pollution aerosols, this has been corrected (see response to comments below).*

p. 21980, line 14-15 - It's not just deposition, but cloud scavenging right? This would be particularly important in interpreting MODIS retrievals. *We use deposition as a general*

term for dry and wet deposition (including in-cloud and below-cloud scavenging).

p. 21981, line 5 - Again, how is "pollution aerosols" defined? *In the context of our study, pollution aerosols refer to a mixture of urban and industrial pollution as well as biomass burning aerosols. We have defined this more clearly in the revised manuscript.*

p. 21981, line 5-9 - Other papers to consider citing and discussing given their relevance include Fischer, E.V., et al., GRL (2009), Vol. 36, L03821 and Yu, H. et al. Science (2012), Vol. 337, no. 6094, pp. 566-569. *We have added a description of the Yu et al. (2012) results to the revised manuscript.*

p. 21981, line 5-13 - A discussion of shortcomings of satellite retrievals is warranted (e.g., vertical resolution; deciphering cloud particles vs aerosols; etc.). *A statement to that effect has been added.*

p. 21981, line 19-24 - This is a very important point (i.e., validating models against obs) and is worth expanding on. One good source might be some of the results from the HTAP experiments (see, for example, www.htap.org). *We have expanded on this point and added references from the TF-HTAP 2010 report.*

p. 21982, line 1-3 - This could really benefit / bolster confidence in the conclusions if even *some* in situ observations were used to test not just the model's ability, but also the satellite retrievals. AERONET or other ground-based lidar data may be available, or CARIBIC/MOSAIC data collected aboard commercial aircraft. *This is a valid point. Several studies have conducted extensive comparisons of GEOS-Chem against aircraft and ground-based observations in the Asian outflow and N. American outflow. Instead conducting these comparisons again, we are addressing the concerns of this referee by adding a discussion of these previous studies in section 2.3. Similarly MODIS has been validated against AERONET comparisons by multiple authors and we are including a new discussion of their findings in the revised paper in section 2.1.*

p. 21982, line 15 - Throughout the paper, I kept wondering if we were always talking

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about **total column* AOD *at 550 nm**. It might be worth stating that it is (or is not) total column at 550 nm up front and then not having to continually re-state throughout, but it's an important point. What about cloud layers above aerosols - MODIS wouldn't capture these aerosols, but presumably GEOS-Chem would? *This has been more clearly noted in the revised manuscript. We have also added a statement that for comparison to MODIS, the model is only sampled on the days and locations when cloud-free MODIS observations are available.*

p. 21982, line 12-13 - Are there any differences, biases, corrections, papers to cite, comparing MODIS retrievals from the Aqua platform vs the Terra platform? Has anyone looked at retrievals from both? *We have included references to validation papers by Remer et al. (2008) and Levy et al. (2010) who have compared both Terra and Aqua MODIS AOD to AERONET observations.*

p. 21982, line 23 - It's unclear to me how a single pass "can represent daily averages" as they are mere snapshots in time. *We have removed this statement.*

p. 21983, line 4 - Is fine mode here aerosols with $D < 1\mu\text{m}$? Yes, *this has been clarified in the revised manuscript.*

p. 21983, line 16 - Are these 47 vertical layers still up to 0.01 hPa? Yes, *this has been noted in the revised manuscript.*

p. 21983, line 19 - Worth inserting a sentence or two about known strengths and weaknesses of GEOS-Chem broadly speaking (as it relates to the LRT of aerosols). *We have added a sentence on this.*

p. 21983, line 22-24 - It's worth discussing in a sentence or two how much SOA would be expected to be formed - can an estimate be provided or are there studies that have attempted to quantify this? *We have clarified this point later on in the manuscript. Inclusion of SOA formation from biogenic VOCs of land or marine origin is unlikely to explain the GEOS-Chem underestimate in MODIS AOD. This was shown in a study by*

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Lapina et al. (2011).

p. 21984, line 1 - What is meant by "resistance-in-series"? *This is one of the standard formulation for dry deposition where the deposition processes are treated in terms of an electrical resistance analogy.*

p. 21984, line 5 - What about non-convective scavenging - is it nominal? *Non-convective scavenging is part of the large-scale precipitation.*

p. 21984, line 7-10 - Am I understanding this correctly that over the 7 year study, the same year's (2000) emissions are used by that meteorological fields for all 7 years is used? While this might be OK for the US where anthropogenic emissions probably didn't vary substantially from 2004-10, the same cannot be said of Asian (anthropogenic, and probably not natural) emissions. If this characterization is accurate, a discussion of how this might affect the results is needed. If I misunderstand the inputs, further clarification is needed. *Yes, we do keep anthropogenic emissions constant for our 2004-2010 simulation in order to emphasize the variability in meteorology. Global anthropogenic emissions from the EDGAR 2000 inventory, scaled to the year 2006. This inventory is overwritten by the Zhang et al. (2009) inventory for the year 2006. Over N. America we use the NEI inventory for the year 2005. This has been clarified in the manuscript.*

p. 21984, line 22 - What are these "frequent pollution export events" driven by - WCB? strong winds over desert source regions? etc. *The driving forces behind these pollution export events are discussed in more detail as part of section 3.*

p. 21984, line 28 - Declaring that the model exhibits a "negative bias" *assumes* MODIS is ground truth, which is why either some discussion of MODIS validation from in situ obs is needed, or a direct comparison of obs here - if even briefly - would be warranted. *We have added a reference to the studies of Remer et al. (2008) and Levy et al. (2010) validating the MODIS AOD retrievals against AERONET observations in section 2.1.*

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p. 21985, line 2 - Is this a + or – 20% bias? or both? *This has been modified in the manuscript.*

p. 21985, line 15-16 - Why are BB emissions confined to the BL while other aerosol types are not? Spring isn't necessarily a big BB season in this box. It's a really big source from SE Asia (i.e., Indonesia) during spring, but it typically travels the Pacific south of the box. Perhaps the issue is using the same emissions database every year (see comment p. 21984, line 7-10). If this is really the case, GEOS-Chem and many models have a long history of inability to accurately capture the largest events (see, for example, Swartzendruber et al, JGR (2008), Vol 113, D10305; Reidmiller et al (2009), ACP, Vol 9, 557-572. *All surface emissions are typically injected in the boundary layer. Biomass burning aerosols are no exception. One aspect that makes BB emissions different is that the convection generated by fires can lead to larger altitudes for injections. This has been clarified in the revised manuscript.*

p. 21986, line 7-9 - Why is the focus solely on sulfate and not including dust and/or BB emissions, which are large contributors to LRT events? *See answers to comments from reviewer 1.*

p. 21986, line 11 - Any particular reason why 2007 was chosen? Is it representative of all years; is the "episodicity" characteristic of every year? *2007 is representative. This has been noted.*

p. 21986, line 17 - Where is the size distribution data coming from to support the assertion that the outflow timeseries is lognormally distributed? Or is lognormal referring to something other than size? *This simply means that the probability distribution function of the anomalies timeseries is fitted by a log-normal distribution. This has been clarified in the text.*

p. 21986, line 22-23 - How common are these multi-day outflow events - both in the model and in MODIS retrievals? *These events are fairly common in the model. About 40% of the events are multi-day events. It is more difficult to tell from the MODIS*

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retrievals because of the incomplete coverage due to cloudiness. This has been noted in the text.

p. 21986, line 25-26 - Can "reasonable correspondence" be quantified at all? *Out of the 33 events identified in the model, 22 correspond to peaks in MODIS fine AOD with another 5 events occurring within 1 day of a peak in MODIS. This has been added in the text.*

p. 21987, line 4 - This is a question throughout - when stating "pollution" is this anthropogenic only? sulfate only? *This point has been addressed in previous comments.*

p. 21987, line 7-9 - It would be interesting to see a figure of dust vs. sulfate contribution to AOD (if even only at 550 nm), and also BB - both Siberia and SE Asia are very large sources. *In order to reduce the number of figures, we have described the co-occurrence of dust and sulfate outflow events in the text.*

p. 21987, line 14 - "Seasonal averages" implies 90-day avg, no? But it was a 60-day running mean before, right? Yes, *this is correct. Using 60 or 90 days for the averaging does not affect the results.*

p. 21987, line 20 - "Agrees well with MODIS" - I disagree with this conclusion. The MODIS anomalies have far less spatial extent in all seasons and are concentrated west of the 150E line. *We have modified this statement to: "MODIS AOD composites on those same LRT+ days display a similar pattern, although not matching the exact shape of the modeled enhancement, possibly as a result of the patchy sampling of MODIS (Figure 4b)."*

p. 21987, line 27 - Again, the Fischer, E.V. et al (2009) study from GRL is worth citing here. *This study examines the interannual variability of dust and does not pertain the altitude at which dust is being transported, so it is not directly relevant in the context of the specific point of this paragraph.*

p. 21988, line 21 - Worth citing Lyatt's AGU presentation from several years back. I

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can't remember if it was turned into a paper, but it was one of the better visualizations of outflow processes I've seen and is worth citing. *As this study hasn't been published we are not citing it here.*

p. 21989, line 13 - Reidmiller et al., (2009), ACP, 557-572 and (2010) ACP corroborate Liang's findings and may be worth citing. *We have included a reference to the Reidmiller (2010) paper.*

p. 21990, line 1 - It might be worth citing some of the results from either the INTEx-B and/or ARCTAS field campaigns. *We have added a reference to the ARCTAS study of Matsui et al. (2011).*

p. 21990, line 7 - The multi-model, international HTAP report (www.htap.org) should be cited here. *Done.*

p. 21990, line 9 - What level is this 10-20% referring to? Total column? Is it relevant/important to surface air quality? *We have clarified that this is an enhancement relative to the total column seasonal mean AOD in the revised text. Examining the relevance of this enhancement to surface air quality is beyond the scope of this paper and has been addressed in many previous studies.*

p. 21990, line 15 - This conclusion regarding the MODIS AOD anomalies is a stretch. The MODIS panels look more like noise than any coherent pattern. *We have modified the text to qualify this statement.*

p. 21990, line 25 - Is the plume transported offshore? aloft? both? What about dust from due west? *The text has been modified to clarify this.*

p. 21991, line 19-20 - The seasonal dependency is very strong, so the 40% figure here is somewhat misleading. *We have modified the text to clarify that the 40% enhancement is on an annual mean basis and have further noted the largest enhancement during spring.*

p. 21991, line 23 - insert: "...precursors over E. Asia COUPLED WITH STRONGLY

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FAVORABLE METEOROLOGICAL CONDITIONS FOR EXPORT FROM EAST ASIA." *Meteorological conditions for export are favorable in spring for both continents as noted at the beginning of section 4: both regions are at the start of the storm tracks. So a priori, most of the difference is due to the much larger emissions. Later in the manuscript we highlight the difference in precipitation in mid-latitude cyclones which affects the vertical distribution of the outflow.*

p. 21991, line 24 - Again, is Fig 7c relevant for all seasons (see comment from p. 21991, line 19-20). *We have clarified that we are discussing annual mean AOD differences.*

p. 21992, line 8 - Has anyone looked at plugging in an SOA scheme in GEOS-Chem for N American export? If so, it's worth citing here. *We have clarified in the revised manuscript that the lack of SOA formation inclusion cannot explain the AOD underestimate. This is based on similar AOD underestimates found in a GEOS-Chem study including both a land biogenic SOA formation and marine organic matter formation (Lapina et al., 2011).*

p. 21992, line 10-13 - Why is the seasonality of export so much stronger in E Asia than N America? *We are not sure what this comment refers to.*

p. 21992, line 24 - "...events display a dipole structure SIMILAR TO THAT WHICH FACILITATES EXPORT FROM EAST ASIA, ..." *Done.*

p. 21993, line 24-25 (Fig. 10b) - These two pathways are very faint / not clear. Consider overlaying splitting arrows to depict this feature more clearly. *Done.*

p. 21993, line 25-27 - In situ observations from Mace Head, Ireland and/or Pico Nare site in Azores may show this concurrence and provide real confirmation. *We have added references to studies at PICO-NARE.*

p. 21994, line 16 - Re-state more clearly to read: "... sulfate during export FROM the boundary layer TO THE FREE TROPOSPHERE OFF East Asia compared to..." *Done.*

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p. 21995, line 6 - "Asian midlatitude cyclones [IN ALL SEASONS??] are usually..." *Corrected.*

p. 21995, line 14, 16 - Comparing NE China to Central China? *This has been corrected to China.*

p. 21995, line 18-21 - Worth citing ACE-Asia studies here? *Done.*

p. 21995, line 29-p. 21996, line 1 - This sentence on OMI seems out of place and just thrown in here. If deemed necessary to retain, specify which year this is referring to. *This sentence was removed.*

p. 21996, line 3 - "...NE Pacific Ocean at 3-6 km altitude DURING [SEASON, YEAR]." *Done.*

p. 21996, line 7-8 - Is it that there's more efficient export from the BL *OR* far more SO₂ emissions to begin with? I've seen no indication you can conclude it's one or the other, and therefore, BOTH factors should be attributed for the difference. *This is true in winter when oxidant levels are low (and is noted in our manuscript in the next sentence). For other seasons, H₂O₂ availability does not limit aqueous SO₂ oxidation.*

p. 21997, line 16-27 - It's worth saying something about the inability of MODIS and GEOS-Chem to capture this. What is this due to? clouds? *This has been added.*

p. 21997, line 23 - At what altitude (or total column?) is this 10-20% referring to? *This refers to column and has been clarified in the revised manuscript.*

Figure 2c - last line of caption: "A 5-day running mean was applied to the daily AOD FOR BOTH MODIS AND GEOS-CHEM." *Done.*

Figure 3top - This is a somewhat common problem with figures using a dotted or dashed line; they do not appear in the legend. *We have increased the line thickness and changed it to a dashed line to increase the visibility.*

Figure 3 (caption), last line - "Red triangles indicate the 33 enhanced Asian export

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LRT+ days AS DEFINED BY GEOS-CHEM (NOT MODIS) as described in Sect. 3.1."
. *Done.*

Figure 4c - Dotted liens do not appear in legend. *The dashed lines are indicated in the legend. We have viewed the pdf using acroread and preview and these lines do show up. We will work with the ACP editorial staff to make sure that these will appear.*

Figure 4ab - Make red line a different color (green or yellow) so it jumps out from figure more clearly. Amend caption text accordingly. *Done.*

Figure 4 - Does gray indicate that no data is available? Also in line 1 of the caption: "Seasonal composites of AOD anomalies (DEFINED AS ... EVENT - 60-DAY MEANS?) and extinction..." *Done.*

Figure 5 caption - line 2: are SLP anomalies events vs seasonal mean?; line 3: state wind FIELDS, so wind DIRECTION since arrow size indicates wind speed. *Done.*

Figure 7 - Again, dotted lines do not appear in legend. Also, worth stating in caption that these are AOD at 550 nm. *Done.*

Figure 9 caption - line 1: "meteorological field" should be singular not plural; line 3: state wind FIELDS, so wind DIRECTION since arrow size indicates wind speed. *Done.*

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