Review - Biogeosciences
Interactive trans-boundary contributions to ozone-induced crop yield losses in the Northern Hemisphere
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The authors of this study ("Interactive trans-boundary contributions to ozone-induced crop yield losses in the Northern Hemisphere" by Holloway et al.) examine the intercontinental contribution of NO_x emissions in different source regions to crop ozone exposure and corresponding yield reductions in the Northern Hemisphere (NH). The authors perform this analysis by calculating crop exposure to surface ozone (O_3) assuming a complete reduction of NO_x emissions in each of the major industrialized regions of the NH (North America, Europe, and Southeast Asia) using a global atmospheric chemistry model to simulate O_3 production and transport in each scenario. The authors then use different O_3 exposure metrics and dose-response relationships derived from field studies combined with global crop yield/area data to calculate associated crop yield reductions. This study finds that local NO_x emissions have a significant impact on O_3 exposure and crop yields downwind, with North American and SE Asian emission reductions resulting in the greatest trans-boundary benefit for crops. This study is extremely interesting and timely, and provides further incentive for international cooperation on tropospheric O_3 mitigation. I recommend this study for publication, but strongly suggest the authors address the following comments.

First, I agree with the other two referees that using the same growing season for all crops/regions in the Northern Hemisphere is unrealistic, and may lead to inaccurate results given the significant temporal and spatial variability of O_3 concentrations throughout the year. The May-July NH growing season assumption may hold relatively well for North America and Europe for most crops, but not for South and East Asia, and furthermore not for certain important crops (e.g. winter wheat). Although the paper in its current form is certainly illustrative of the potential intercontinental benefits of NO_x reductions in source regions, using more accurate crop calendars would make the results more robust. Growing season data has been published that could be utilized (see Sacks, W.J., D. Deryng, J.A. Foley, and N. Ramankutty (2010), Crop planting dates: an analysis of global patterns. *Global Ecology and Biogeography* 19, 607-620. DOI: 10.1111/j.1466-8238.2010.00551.x.), and international crop calendars for many countries are also available from the USDA.

Second, I additionally agree with referee #1 that calculating crop production losses and the associated economic impact, while not necessarily required for publication, would make the paper significantly more influential and interesting to policymakers. Similarly, calculating the benefit of NO_x emission reductions in various source regions on a national level, even if only for the major emitters/agricultural producers in the NH (e.g. the U.S., EU, China, India), could be a useful supplement to the study and more relevant from a policy perspective.

Third, I think the paper could have a greater impact (particularly in the U.S.) if results were also calculated according to the W126 metric, which was recently proposed by the

Environmental Protection Agency to be used to set the secondary O_3 standard in the U.S. (for the protection of crops and other sensitive vegetation). Although the proposed revisions were recently shelved, enactment of a secondary O_3 standard in the future will most likely be based on this metric, and therefore quantification of the potential contribution of NO_x emission reductions in various source regions to exceedance of the W126-based standard (as well as corresponding crop losses) would be especially interesting to U.S. policymakers.

Fourth, while the model evaluation is quite thorough, it would be constructive to see a comparison of model-simulated O_3 exposure with monitoring site data outside of just Japan and Malaysia for the SE Asian region. While I understand that hourly O_3 concentration data in this region are difficult to find, a monthly mean comparison may be possible in India and China (for a few sites), as well as for AOT40 during certain months in India (see for example the references in Van Dingenen et al. (2009) and Avnery et al. (2011a) as cited below).

A few more minor comments are noted as follows:

The paper could benefit from an enhanced discussion of the scalability of results to more realistic emission reduction levels (e.g. a 20% reduction in anthropogenic NO_x) given the complex nonlinear chemistry of tropospheric O_3 production.

On pg 8654, the last sentence in the last paragraph seems out of place and could be moved earlier in the paper as a part of the study motivation.

In the comparison of results section (pg 8661, lines 14-17), Avnery et al. (2011a) also use the same crop distribution data in their analysis of O_3-induced crop losses, so the differences between this study's results and those of Van Dingenen et al. (2009) appear to be due to the different models/emissions and growing seasons used rather than the crop data.

The sentence on pg 8666, lines 8-11 is unclear, I believe "may be reduced" is meant in line 10.

Generally the text meanders in places and could be tightened, and needs to be more thoroughly proofread.

Finally, a few key references have been omitted – several suggestions for additional recent literature citations include:

(1) The papers of Avnery et al. (2011), which should be cited in the introduction and elsewhere as they also quantify global O_3-induced crop losses in 2000 and 2030:

Avnery, S., Mauzerall, D. L., Liu, J., et al. (2011a). Global crop yield reductions due to surface ozone exposure: 1. Year 2000 crop production losses and economic

damage. *Atmospheric Environment*, *45*(13), 2284-2296. doi: 10.1016/j.atmosenv.2010.11.045

Avnery, S., Mauzerall, D. L., Liu, J., et al. (2011b). Global crop yield reductions due to surface ozone exposure: 2. Year 2030 potential crop production losses and economic damage under two scenarios of O3 pollution. *Atmospheric Environment*, *45*(13), 2297-2309. doi: 10.1016/j.atmosenv.2011.01.00

(2) In reference to stomatal flux indices (pg 8654, lines 20-22), tomato has additionally been parameterized. See:

Mills, G., et al. (2011). New stomatal flux-based critical levels for ozone effects on vegetation. *Atmospheric Environment* 45, 5064-5068.

(3) In the discussion of O_3 impacts below the 40 ppb threshold (pg. 8648, lines 17-20), the following paper could be cited:

Mills, G., et al. (2011). Evidence of widespread effects of ozone on crops and (semi-)natural vegetation in Europe (1990–2006) in relation to AOT40- and flux-based risk maps. *Global Change Biology*, *17*(1), 592-613.

(4) The new HTAP studies should also be cited in the discussion of intercontinental O_3 transport (pg 8649, lines 15-18), e.g.:

Dentener, F., Keating, T., Akimoto, H. (eds.). 2010. Hemispheric transport of air pollution. Part A: Ozone and particulate matter. Economic Commission For Europe, United Nations, Geneva.