

Response to Referee #1

We thank the reviewer for the detailed review and very helpful comments and address the suggested changes in detail below. Comments by the referee are shown in *italic* font. In addition to the changes described below, note that the figures and Table 1 have changed slightly from the previous version of the manuscript due to having to redo some simulations to correct a minor inconsistency. None of the statements in the text had to be changed because of this correction. The simulations that were redone are CAM5-chem, CAM5-chem*, CAM5-chem MAM4, and SD-CAM4-chem.

In the abstract I am missing important findings from section 4, notably the general performance for tropospheric ozone and other important trace gases and aerosols (this is summarized in Section 6 only). 8877, 10-12: Mention underestimation of observational data for methane lifetime

We agree with the reviewer and will add a summary of the general performance of the model in the Abstract. The abstract is changed to:

“The Community Atmosphere Model (CAM), version 5, is now coupled to extensive tropospheric and stratospheric chemistry, called CAM5-chem, and is available in addition to CAM4-chem in the Community Earth System Model (CESM) version 1.2. The main focus of this paper is to compare the performance of configurations with internally derived “free running” (FR) meteorology and “specified dynamics” (SD) against observations from surface, aircraft, and satellite, as well as understand the origin of the identified differences. We focus on the representation of aerosols and chemistry. All model configurations reproduce tropospheric ozone for most regions based on in-situ and satellite observations. However, shortcomings exist in the representation of ozone precursors and aerosols. Tropospheric ozone in all model configurations agrees for the most part with ozonesondes and satellite observations in the Tropics and the Northern Hemisphere within the variability of the observations. Southern Hemispheric tropospheric ozone is consistently underestimated by up to 25%. Differences in convection and stratosphere to troposphere exchange processes are mostly responsible for differences in ozone in the different model configurations. Carbon monoxide (CO) and other volatile organic compounds are largely underestimated in Northern Hemisphere mid latitudes based on satellite and aircraft observations. Nitrogen oxides (NO_x) are biased low in the free tropical troposphere, whereas peroxyacetyl nitrate (PAN) is overestimated in particular in high northern latitudes. The present-day methane lifetime estimates are compared among the different model configurations. These range between 7.8 years in the SD configuration of CAM5-chem and 8.8 years in the FR configuration of CAM4-chem and are therefore underestimated compared to observational estimations. We find that differences in tropospheric aerosol surface area between CAM4 and CAM5 play an important role in controlling the burden of the tropical tropospheric hydroxyl radical (OH), which causes differences in tropical methane lifetime of about half a year between CAM4-chem and CAM5-chem. In addition, different distributions of NO_x from lightning explain about half of the difference between SD and FR model versions in both CAM4-chem and CAM5-chem. Remaining differences in the tropical OH burden are due to enhanced tropical ozone burden in SD configurations compared to the FR versions, which are not only caused by differences in chemical production or loss, but also by transport and mixing. For future studies, we recommend the use of CAM5-chem configurations, due to improved aerosol description and inclusion of aerosol-cloud interactions. However, smaller tropospheric surface area density in the current version of CAM5-chem compared to CAM4-chem results in larger oxidizing capacity in the troposphere and therefore a shorter methane lifetime.”

Section 1:

8878, 10: *Additional references would be desirable (e.g. Isaksen et al., doi:10.1016/j.atmosenv.2009.08.003).*

We agree and add the suggested reference.

Section 2:

8879, 26-27: *The term “data ocean” is not known to me. Re-formulate the sentence to “All model simulations are performed with prescribed sea surface temperatures and sea-ice distribution data for present-day climatological conditions, : : :”*

We agree with the suggestion and change the sentence accordingly:

“All model simulations are performed with prescribed sea surface temperatures and sea-ice distribution data for present-day climatological conditions, since we focus on the atmospheric component.”

8884, 5: *You may think about a different naming instead of “CAM5-chem*”. This term is also not searchable with Adobe Reader.*

Since the sensitivity experiment is not the focus of the paper, we prefer to continue using this naming.

8884, 10: *Replace “performance” by “setup and global model diagnostics”.*

We agree with the suggestions of the reviewer and changed the phrase accordingly.

Section 3: One could think of adding more surface station data to the evaluation data base, notably Ozone and other species or aerosol parameters from global or regional air quality networks, but this may be beyond the scope of the paper. At least the choice of evaluation data should be discussed for their relevance.

We thank the reviewer for pointing this out and follow the advice and add surface ozone observations to the evaluation in this paper. We perform a comparison of the probability distribution function of surface ozone stations over North America and Western Europe. For this we have added the new Figure 14 (see below) and add a description of the dataset and a discussion, see below.

8884, 22-25: *I found this very confusing. Why using MOPITT here? The sentence seems not to belong here.*

We agree with the review and moved the sentence to the next paragraph.

8886, 25-27: *Please clarify the meaning of a “profile-to-profile” comparison. How are observational data and model results matched in space and time?*

To clarify we change the following paragraph (line 16):

“For the comparison with model results one has to keep in mind that aircraft campaigns often do not sample climatological or background conditions of the atmosphere, since they are designed to target specific atmospheric conditions. Further, monthly-mean model results that are averaged over various years are not able to identify specific pollution plumes or structures of the atmosphere as observed in a particular campaign.”

To

“For each observed regional profile, monthly-mean model results are averaged over the location and months of the observations. It is assumed that these regional profiles represent typical background conditions. However, one has to keep in mind that aircraft campaigns often target specific atmospheric conditions that may not be captured in multi-year average model results.”

We further change “A profile-to-profile comparison between aircraft and model data is performed for ozone (O₃) carbon monoxide (CO), nitrogen oxides (NO_x), and peroxyacetyl nitrate

(CH₃COO₂NO₂ or PAN) and other hydrocarbons.” To
“A comparison is performed for ozone (O₃) carbon monoxide (CO), nitrogen oxides (NO_x), peroxyacetyl nitrate (CH₃COO₂NO₂ or PAN), selected hydrocarbons, SO₂ and sulfate aerosol for selected aircraft campaigns”

8887, 21-27: The first part of the sentence until “: : (Table 2)” is an unnecessary replication and can be skipped. Instead, another sentence to introduce the IMPROVE measurements would be useful.

We agree with the reviewer and change this sentence:

“In addition to a limited set of aircraft observations available for profile-to-profile comparisons to the model output (see Table 2), we use surface observations from the United States Interagency Monitoring of Protected Visual Environments (IMPROVE) dataset (<http://vista.cira.colostate.edu/improve/>), (Malm, 2004), for years 1998–2009, to compare sulfur dioxide and sulfate.”

To

“We use two sets of surface observations in this study. Surface observations from the United States Interagency Monitoring of Protected Visual Environments (IMPROVE) dataset (<http://vista.cira.colostate.edu/improve/>, Malm, 2004), is used for years 1998–2009, to compare sulfur dioxide and sulfate with the model results. The IMPROVE network includes 165 sites in the US. Major fine particles (with diameter < 2.5 micro meter) are monitored including aerosol species, sulfates, nitrates, organics, light-absorbing carbon, and wind-blown dust. IMPROVE sites are located in rural environments and therefore will not describe the conditions found in large urban areas.”

We further add:

“Ozone surface observations are used to evaluate daily ozone concentration in our model configurations. Daily averages from available hourly surface ozone data were derived from the Clean Air Status and Trends Network (CASTNET) (<http://java.epa.gov/castnet/>) and the European Monitoring and Evaluation Programme (EMEP) network in Europe (<http://www.emep.int/>) for years 1995-2010, as shown in Tilmes et al. (2012).”

Section 4: In section 4.2, the evaluation should be ordered strictly by species (groups). In particular, all CO evaluation should be placed after the ozone evaluation.

We agree with the reviewer and restructure the section in the following:

Section 4.2.1 Aerosols and Aerosol Optical Depth (AOD) (not changed)

Section 4.2.2 Ozone (including former section “Ozone column” and “Ozone profiles”)

Section 4.2.3 CO and hydrocarbons

Section 4.2.4 NO_x and PAN

We arrange the text accordingly, and rearrange the Figures as described below.

I cannot follow the argumentation when it comes to NH lower troposphere ozone differences between CAM5-chem and SD-CAM5-chem, as it is done in Sections 4.2.2, 4.2.3, and 5. From what is presented in the paper, the relation of BL tropospheric ozone to STE in the model configurations seems to be weak (or vague). A more stringent argumentation chain will be appreciated by the readers.

We agree with the reviewer that the relation of ozone in the NH boundary layer and STE in the model configuration was not sufficiently supported. We decided to move this discussion to the model-to-model comparison section, and added a new Figure 3 (see below) supporting the

statements. The new figure includes the comparison of ozone, ozone production, lightning NO_x, CO, H₂O, and HNO₃, between different model versions. Based on this comparison, we can make the argument that higher ozone mixing ratios in high northern latitudes are not due to ozone production, but rather caused by stronger STE in CAM5-chem compared to SD-CAM5-chem. In addition to some other changes in Section 4.1 we add:

“The comparison of chemical constituents in the two model configurations further supports a stronger tropical vertical transport in CAM5-chem compared to SD-CAM5-chem and stronger STE in high latitudes (Fig.3). Stronger tropical vertical transport (mostly in deep convection) in CAM5-chem is evident due to higher mixing ratios in CO and lower mixing ratios of nitric acid in the upper tropical troposphere. The resulting higher CO mixing ratios in the upper troposphere together with increased LNO_x in mid-latitudes lead to greater ozone production, while reduced LNO_x in the tropical belt reduces ozone production. Furthermore, increased nitric acid in addition to higher ozone mixing ratios in high northern latitudes point to more STE. Additionally, lower NO_x and CO values in the boundary layer in CAM5-chem indicate that increased STE rather than chemical processing results in larger ozone mixing ratios in CAM5-chem than SD-CAM5-chem. Differences in low clouds between CAM5-chem and SD-CAM5-chem also impact chemistry and result in reduced ozone production in the boundary layer in CAM5-chem. Similar differences are present between CAM4-chem to SD-CAM4-chem, however, with smaller differences in STE in high latitudes compared to the CAM5-chem configurations (not shown).”

8888, 25-26: When TTL is defined by pressure levels 150-70 hPa, you can see from Fig. 1 both higher and lower ozone mixing ratios.

We agree and corrected the sentence to point to just the region around the tropical tropopause.

8890, 1-5: Write out COSMIC. These observational data, together with MLS and AIRS, need to be introduced before. Also, the observations give different cold point altitudes. All in all, Figure 3 is not really exploited. The whole paragraph (8889, 26 – 8890, 9) together with Figure 3 could be skipped.

We agree with the reviewer and remove the figure and corresponding discussion.

8890, 10: Fig.4. goes higher up than 30 hPa.

This was a typo, we changed it to 10hPa.

8890, 20-24: Instead of showing Fig. 5, AOA could be assessed by simply comparing AOA entries for a certain height, which can be given in Table 1.

AOA could be certainly expressed in a table picking a few values for different regions, like the tropics, and lower stratosphere in high latitudes. However, we do think, that details shown in the zonal mean plots are important, since for example they show differences in the shape of the age of air more clearly than what can be explained by a couple numbers.

8892, 13-16: CAM4-chem and CAM5-chem results are not shown in Fig.7.

We agree with the reviewer and added “not shown” at the end of this paragraph.

8892, 25-27: This is only true for free tropospheric SO₄. SO₂ is largely underestimated.

We agree and changed the sentence to: “In comparison to aircraft observations over Central Canada in July 2008, simulated SO₄ values in the free troposphere are in the range of variability of observations.”

8893, 9-13: I cannot see any significant and systematic differences between the model

configurations, at least from Figure 9. I suggest to skip these sentences.

We agree with the reviewer and removed the following sentences: “CAM4-chem and in part CAM5-MAM4-chem represent the influence from high BC plumes over the Pacific somewhat better than CAM5-chem. However, CAM5-MAM4-chem shows a stronger overestimation of background BC than the other models, especially in the upper troposphere.”

8894, 14-22: The whole paragraph would better fit to 4.2.4.

We agree with the reviewer, and have reorganized section 4.2 (as described above).

8894, 15: Is this total column or tropospheric column (as Figure 11 suggests)? In most studies, satellite CO used for evaluation is total column.

Here we have used the column below 100hPa and therefore approximately the tropospheric column. We have added the following information to the text: “CO columns are derived for altitudes between surface and 100 hPa”, and also add these information to the Figure caption.

8894, 17: It seems you were misled by the color coding in Fig. 11. There is no significant high bias for CAM4-chem for most of the year.

We agree with the reviewer and remove the statement and just state: “The tropical CO column agrees within 5% with the observations.”

8894, 26: The better agreement of SD models with observations for high latitudes cannot be derived directly from Figure 11.

We agree and remove this statement. However, we have added the following sentence in the next paragraph referring to stratospheric ozone column:

“SD configurations do not show the low bias in ozone column during the ozone hole season in both hemispheres, but instead slightly overestimate column ozone at that time. The reason for this is that temperatures in the SD configurations temperatures are slightly higher than for the FR versions especially the lower stratosphere in high latitudes.”

8895, 20-21: Be more honest here. Modelled ozone has deviations of up to 25% for larger world regions.

Based on comments by Reviewer 2 and to discuss the deviations between model results and observations with regard to the uncertainties and variability of observations, we have added two Figures, new Figure 13 and 16, showing the seasonal cycle of selected regions and different altitudes between models and observations. The mean deviations between modeled ozone and observations is still up to 25%, however, differences are for the most part within the standard deviations of the observations. We further added a probability distribution function comparison to surface observations, as mentioned above. We changed this section to:

“Ozonesonde observations (Sect.3.2), aircraft data (Sect.3.3), and surface observations (Sect.3.4) are used to evaluate the simulated tropospheric chemical composition in more detail. We use a Taylor-like diagram to illustrate relative differences between model configurations and ozonesonde observations, and correlations of the seasonal cycle for different regions, seasons, and different pressure levels, see Figs.12 and 14. In addition, seasonal cycle comparisons between model results and observations for specific regions are illustrated in Figs.13 and 15. A comparison of surface ozone is performed, showing probability distribution functions between model results and observations for Western and Eastern North America and Western Europe in Fig.14.

Near surface ozone at 900hPa is for the most part within the range of variability of ozonesonde

observations in both SD and FR configurations (Fig.12 top row). The high bias in summer over Eastern US and Western Europe, as reported in earlier studies (e.g., Lamarque et al., 2012), has been significantly reduced, due to an improved calculation of dry deposition velocities (Val Martin et al., 2014). In comparison to surface observations (Fig.14), in winter, FR model configurations slightly overestimate maximum ozone values for North America and Western Europe. SD configurations show a low bias for Eastern North America and Western Europe. In summer, all model configurations show a high bias of about 10-15 ppb. However, maximum ozone mixing ratios do agree with observations, whereas low ozone mixing ratios are overestimated. A high bias of about 10 ppb can be attributed to the coarse model resolution, which leads to an overestimate of ozone production, because of diluted emissions of ozone precursors and therefore an increase in the lower ozone mixing ratios of its distribution (e.g., Pfister et al., 2014). Ozonesondes are not compared to the model configurations at the surface. Those agree well to surface observations, besides they bias high over Eastern US in summer, as discussed in Tilmes et al., (2012).

In the mid-troposphere, model results agree well with ozonesonde observations at 500hPa (Fig.12, bottom row). The seasonal cycle is well produced, in particular for the FR configurations in mid- and high latitudes, with correlations around 0.95 compared to the observations. The somewhat higher bias in winter and spring over Western Europe and high latitudes in CAM5-chem in 500hPa contributes to the high bias in 900hPa, as more ozone is transported downward, discussed in Sect.4.1. The low bias in ozone in the West Pacific / East Indian Ocean is due to the stronger convection in the FR model configurations compared to SD, as also discussed in Sect.4.1. This bias is also shown in the comparisons at 250hPa, (Figs 14 and 15). At 50hPa, all configurations show a high ozone bias by at least 20% in the tropics during winter and spring. Mid- and high latitude ozone in the stratosphere is reproduced well for all configurations within the range of variability.

Comparisons to the aircraft climatology in the free troposphere (2-7km, Fig.17, top row) confirm the high bias of ozone in CAM5-chem and the low bias in the SD configuration at high latitudes, as well as the low bias in the Tropics in fall. Deviations from the aircraft climatology are much larger (up to 40%) compared to the ozonesonde observations (up to 25%).

In comparison to HIPPO aircraft observations over the Pacific, ozone mixing ratios are biased high in mid and high latitudes in both CAM4-chem and CAM5-chem configurations, mainly in fall and winter (Fig.18 first and second column). In addition, in spring CAM5-chem simulates larger ozone in the NH mid and high latitudes than the other models. The high ozone bias in both CAM4-chem and CAM5-chem in the remote region of the Pacific further points to a too strong STE in the FR versions. In the tropical troposphere, CAM5-chem reproduces observed mean ozone mixing ratios very well, while there is also the low biased summer and fall. However, SD configurations simulate larger ozone mixing ratios in winter and spring compared to ozonesondes and HIPPO observations.

The better representation of tropical ozone in the SD configurations in summer and fall may therefore be the result of more realistic convection, or due to a larger production of LNO_x in this region. The observations further confirm that STE in winter and spring in mid- and high latitudes is slightly too strong in CAM5-chem compared to the other configurations.”

8896, 5-10: I am not convinced here. There are regions with reduced cloud fraction over the NH but also regions with larger cloud fraction. Also, the implications for ozone of cloud differences over Africa and the Middle East are not obvious. Wouldn't it be

more illustrative (also for the mid latitude differences) to show differences in modelled ozone production?

We thank the reviewer for the comment. A significant difference in the BL ozone as a result of differences in low clouds between the FR and SD configurations could not be confirmed. Differences in surface ozone production between the different models are not significant. We removed this discussion from the paper, including Figure 14.

8896, 11-15: Again, the model bias is up to 25% in Figure 13 and up to 40% for the aircraft data.

8896, 17-19: "Especially : : : observations". Skip this sentence or re-phrase.

8896, 23: Compliance of model results with aircraft observations over Europe and US is not shown.

8897, 9-10: The 250 hPa level is not stratospheric.

8898, 7-10: Specific campaigns are not shown directly by the figures.

We have changed the text in this section, see comments above.

8898, 19-21: HNO₃ nor NO_y are shown in Fig. 20. Fig. 15 does, but gives no clear answer.

We agree and have removed this sentence.

Section 5: 8899, 13-16: Re-phrase this sentence. "As shown in model intercomparison projects projects like : : :, the reason for differences cannot be easily ascribed : : :". Give references here, e.g. Naik et al. (2013) or Voulgarakis et al., doi:10.5194/acp-13-2563-2013.

We change "The reason for differences cannot be easily ascribed to specific processes in model intercomparison projects like the Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP), since various processes in models differ."

To

"The reason for differences cannot be easily ascribed to specific processes in models that contributed to the intercomparison projects such as the Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP) (Voulgarakis et al., 2013, Naik et al., 2013)."

8899, 22-25: This has been already described in Section 4.2.5.

We agree and removed this sentence.

8899, 27 – 8900, 4: Be more precise here and in Figure 22. Is it tropical CO burden or tropospheric CO burden or both. Similar for the Methane lifetime: Atmospheric or tropospheric?

We have added the information in the text and figure caption to make it clearer.

8900, 16 - 8902, 9: I guess that all burdens mentioned here are tropospheric burdens. This should be mentioned somewhere.

See comment above.

Section 6: 8902, 15-21: Overestimation of surface SO₂ and SO₄ for polluted regions points to an overestimation of emissions here?

We add to the text: "In this model version, anthropogenic emissions of SO₂ and SO₄ are emitted at the surface, which can lead to underestimated transport into the free troposphere."

8903, 9-11: *As said before, I don't agree with this conclusion: Deviations are up to 25% for ozonesondes (Fig. 13) and up to 40% for aircraft campaigns (Fig. 15).*

8903, 14-15: *Looking at Fig. 11, the bias looks more like 25-50% for the southern extratropics. We changed this bullet point to:*

“Tropospheric ozone in the tropics and the Northern Hemisphere is very well represented in all model configurations and agrees within the variability of ozonesonde observations of about 25%. Surface observations are well reproduced in winter. The summer high bias of all models over Western Europe and Northern America can be for the most part contributed to a high bias in low and medium ozone mixing ratios as a result the coarse resolution of the model configurations. In the free troposphere, FR configurations slightly overestimate ozone in mid and high latitudes and underestimate ozone in the tropical free troposphere in summer and fall, while SD configurations slightly overestimate ozone in the upper tropical troposphere and in part underestimate ozone in high latitudes. Southern Hemisphere tropospheric ozone is underestimated by 10-25% in all model configurations. The comparison to aircraft observations confirms the differences based on ozonesonde observations, but models show a large bias up to 40% compared to observations.

8903, 23-24: *A general underestimation of NO_x is not supported by Figs. 15, 19 or 20. Instead, both overestimation and underestimation can be found.*

Here, we do not agree with the reviewer. NO_x is for the most part underestimated, in particular in high latitudes. We added this information to the text.

Table 1: Exchange “model performance” by “global model diagnostics”.

Table 1: Add AOA as model parameter. Make sure that all burdens are atmospheric, otherwise say “tropospheric burden”.

We agree with the reviewer and add the information for tropospheric burden and lifetimes. As mentioned earlier, we would like to keep the AOA figure and do not add additional values into the table. The table caption is changed to:

“Overview of model experiments, setup between different simulations, and global model diagnostics. Lifetimes and burdens are calculated for the troposphere defined for regions where ozone is below 150 ppb.”

Table 3: Entries for the following abbreviations are missing: AERONET, AIRS, AMWG, CLM, COSMIC, MACCity, MOPITT, MOZART, WMO.

We have added those abbreviations to the table.

Fig. 1: How is SAD TROP in the stratosphere defined? You could mask this area in the top right panel.

In this version of the model SAD TROP contributes to the amount of SAD in the stratosphere, and therefore impacts the chemistry. More SAD in particular in the lower-most stratosphere in CAM4-chem contributes therefore to chemical ozone depletion. Since the model prescribes stratospheric SAD, this double counting of SAD in the stratosphere will be removed in future model versions.

Fig. 1: I guess differences in RH are relative differences, but this is not clear from the figure caption (also in Fig. 2).

Relative humidity (RH) is added to the figure caption.

Fig. 10: replace “Kinne (2009)” by “(Kinne, 2009)”. Add “(model – observations)” after

“Differences”.

Done

Fig. 11: Are tropospheric columns (as in the figure title) or total columns (as suspected from the text) shown?

We added “zonally averaged CO column below 100hPa”

Fig. 11: From the main text this is an OMI/MLS climatology.

We agree and changed this accordingly.

Fig. 14: Frames for aircraft campaigns are hard to see (also in Fig. 19), those are also not really needed for the paper. Re-Phrase the Figure captions.

We have removed this figure.

Fig. 15: It is not obvious how the temporal and spatial match between campaigns and model results has been achieved for this Figure (and Fig. 18).

We revised the text to explain this more clearly and point to the text in the figure caption for more details.

Technical corrections:

All technical corrections are implemented in the revised version of the manuscript if not stated differently below.

8879, 2: Reference for Liu et al., 2014 is missing.

8879, 9: replace “Strength” by “Strengths”.

8880, 2: Write out “CLM”.

8882, 1-2: Remove “chemistry including”.

8883, 8-10: Add reference: Rienecker et al., <http://dx.doi.org/10.1175/JCLI-D-11-00015.1>.

8883, 15: For clarification say “prescribed chemical fields for longer-lived substances”.

8883, 27: Add “with” before “lower”.

8884, 14: Replace “We are interested in: : :” by “We limit ourselves to: : :”.

Changed by “We use present-day ..”

8884, 22: Write out “MOPITT”.

8885, 15: Replace “TERRA” by “Terra”.

8885, 20: Write out “AERONET”.

8886, 6: Skip “between 1995 and 2010”.

We will keep this information to identify precisely what is included in the dataset.

8887, 10: Replace “: : : similar regions and different seasons : : :” by “: : : similar regions in different seasons : : :”.

8889, 28: Add “as” before “described”.

8890, 10: Replace “: : : are analyzed: : :” by “: : : is analyzed: : :”.

8890, 18: Replace “configuration” by “configurations”.

8892, 19: Add “free” before “troposphere”.

8892, 27: Data is shown in Fig. 8, bottom right panels.

8894, 7: Replace “Column” with “Columns”.

8895, 17: Add “ozonesonde” before “observations”.

8896, 26: Figure 17 must become new Figure 16, as it is introduced first.

8896, 26: Replace “Fig. 17 first and second column” by “Fig. 16, first and second row”.

8897, 5: Add “(Fig. 17)” after “biased high”.

8897, 8: Skip "(Fig. 16)".

8897, 21: Exchange "(Fig. 15)" by "(Fig. 18)". 8898, 7: Exchange "(Fig. 18)" by "(Fig. 15)". Figures have been reorganized as discussed above;

8898, 17: Add "free" before "troposphere".

8902, 2: Add "at" after "pointing".

8909, 3-5: Please use correct doi: "doi:10.1029/2004JD005537".

Table 2: Skip ", starting 1995".

Fig. 1: Exchange "SD-CAM4-cam" by SD-CAM4-chem" in the figure caption.

Fig. 3: Re-phrase figure caption: "Comparison between zonally (20_S-20_N) and annually averaged fields of : : around the tropical tropopause region, derived from : : : this figure was removed

Fig. 7: Replace "SD-CAM5-chem (blue) and SD-CAM5-chem (red)" by "SD-CAM4-chem (red) and SD-CAM5-chem (blue)".

New Figures:

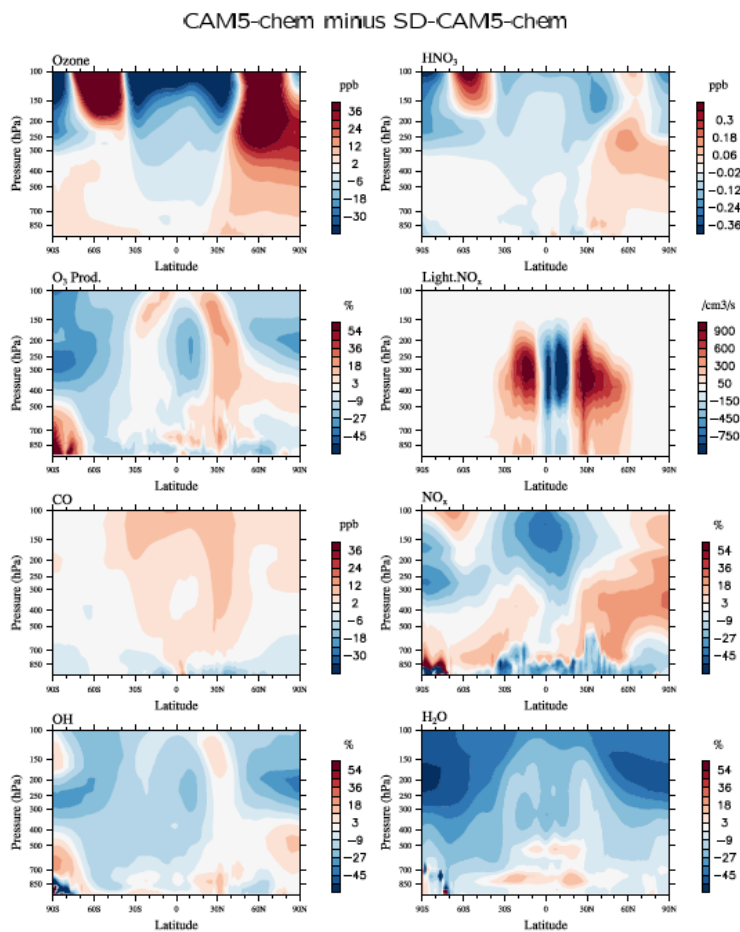


Figure 3: Comparison of ozone, nitric acid, ozone production, lightning NO_x, carbon monoxide, NO_x, hydroxyl radical, and water vapor, between CAM5-chem and SD-CAM5-chem.

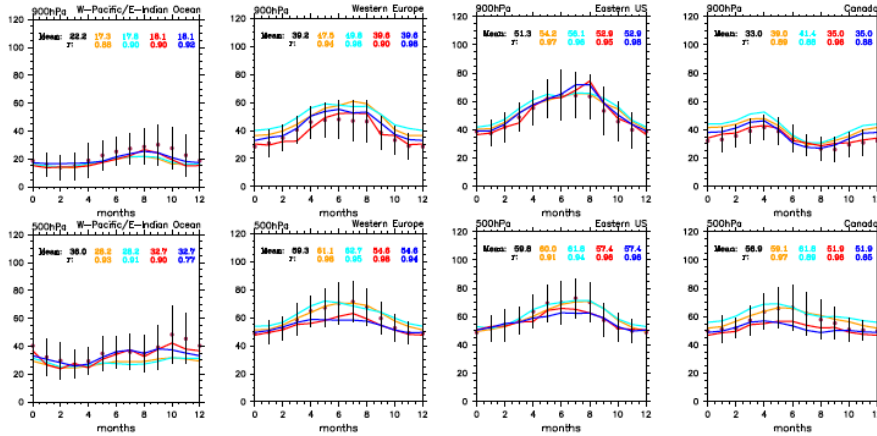


Figure 13: Seasonal cycle comparison between observations using a present-day ozonesonde climatology between 1995--2011 (black) and model results: CAM5-chem (cyan) and CAM4-chem (orange), SD-CAM5-chem (blue) and SD-CAM4-chem (red). Model results are interpolated to the same locations as sampled by the observations and for different pressure levels, 900hPa (top panel) and 500hPa (bottom panel) for selected regions. The standard deviation of ozonesonde observations is shown as error bars and the mean and correlation of the seasonal cycle between observations and models are printed on the top of each figure.

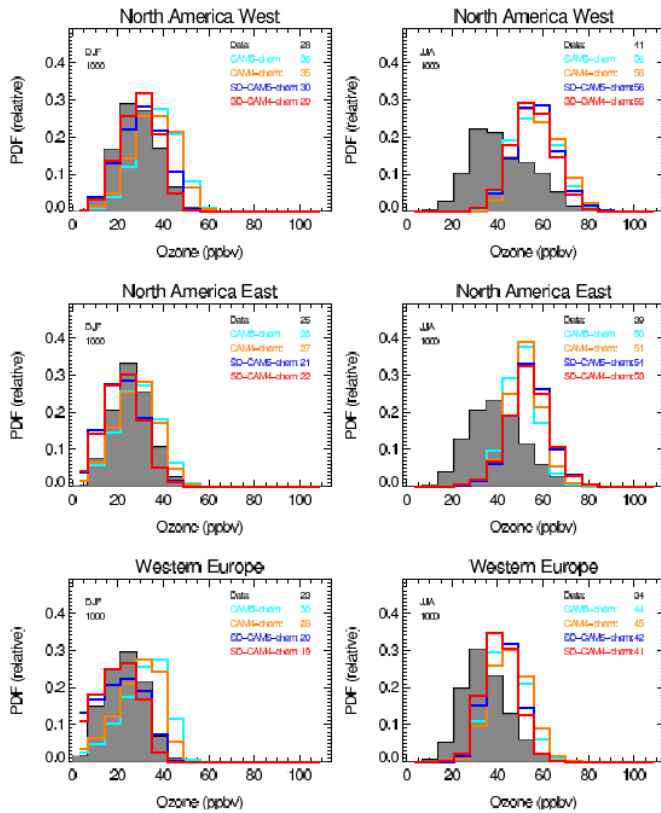


Figure 14: Probability distribution function (PDF) of the regionally-aggregated ozone distribution for Western North America, Eastern North America, and Western Europe from surface ozone observations (grey shaded area) in comparison to regionally-aggregated ozone distributions from

model results interpolated to the location of the ozone stations (different colors), for winter (left) and summer (right).

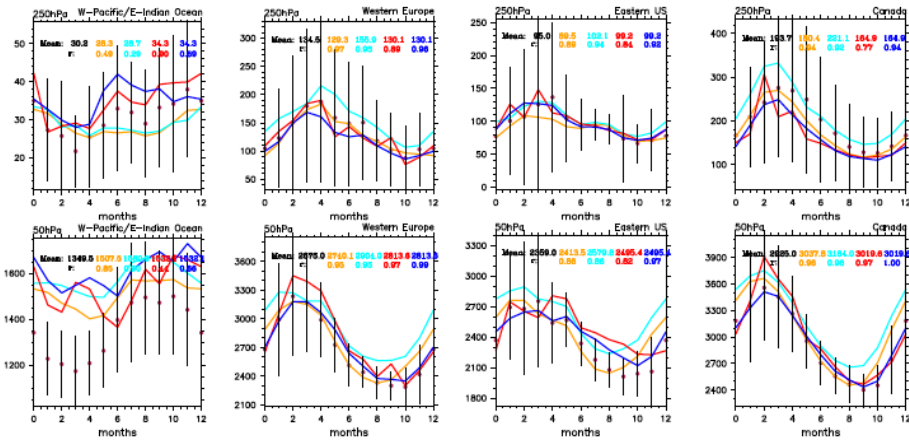


Figure 16:

As Fig.13, but for different pressure levels, 250hPa (top panel) and 50hPa (bottom panel).