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Interactive comment on "Evaluation of near surface ozone over Europe from the MACC reanalysis" *by* E. Katragkou et al.

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We thank the reviewer for his/her comments. We responded to all of the points raised and changed the revised manuscript accordingly.

R1.1 "Throughout the manuscript, there is thorough discussion of both transport and chemistry, but none of deposition. Deposition is notably missing from both the Introduction and Discussion sections. Could deposition play a role in explaining the discrepancies between the MRE and observations?"

We agree that deposition is an important process. Additional tests performed currently in the C-IFS system indicate that surface O3 is sensitive to the dry deposition mechanism. In Figure 1 is shown how three different dry deposition schemes affect the annual

cycle of surface ozone over Europe in three, 1-year-long sensitivity experiments. These results indicate that the deposition can perhaps contribute to improvement of surface ozone seasonality, but cannot completely fix the spring ozone maximum problem over north Europe (left plot). Clearly, by improving the dry deposition scheme, the bias is decreasing, mostly over southern Europe in summer (right plot). The following text has been added in the revised manuscript "Ongoing work on the impact of dry deposition on surface ozone indicates that the new on-line dry depositions schemes currently tested in the C-IFS system improve the surface ozone positive bias, appearing mostly over southern Europe in summer, but cannot completely tackle the spring ozone maximum problem over north Europe (J. Flemming, personal communication, 2015)."

R1.2 "The model is sampled at vertical levels other than the surface to match altitude with observing sites, but this will also impact deposition. This issue should be discussed and the offset between surface and above-surface grid boxes should probably be evaluated."

In Figure 2 it is shown the modified normalized mean bias (mnmb) of the Austrian station Sonnblick (altitude = 3,106 m), evaluated i) with surface model data (Lev60, dots) ii) with data from level 46 (squares). Following the objective methodology described in section 2.2, it is shown that the bias is reduced, when adjusting o3 concentrations using atmospheric pressure as the correction criterion. The impact of deposition affects directly only the lowest model level (L60) and indirectly the higher leves of ABL. We have seen that concentrations of the lowest model level are not representative for stations with higher altitude.

R1.3 "The failure of the MRE to capture the spring peak in ozone that is noted by the authors requires further exploration, but it is fine with me for the authors to present it as a question for future work. One puzzling aspect is that many models do capture a springtime maximum in ozone, and particularly with the assimilation of column ozone observations, I would have expected long-range transport contributions to spring ozone [Parrish et al., 2013] to be captured."

As mentioned in Section 4.1 the shape of the observed ozone annual cycle (based on the ozonesondes) in lower free troposphere at 700 hPa and for the middle troposphere at 500 hPa is reproduced rather well by the MRE. The reasonable reproduction of the shape of the observed ozone seasonal cycle by MRE in the middle and lower free troposphere is consistent with transport processes from the lower stratosphere and the upper troposphere, as well as long-range transport being resolved adequately by the MRE. Hence, it is rather at near surface and within the boundary layer that MRE fails to capture well the spring peak. This mismatch could be related to a) overestimated photochemical ozone production within the atmospheric boundary layer, b) deposition, c) insufficient entrainment and mixing from the lower free troposphere into the atmospheric boundary layer. Here we discuss that overestimated local photochemical ozone production at near surface may actually mask the contribution of transport on the seasonal ozone cycle. We also discuss the role of deposition in MRE, indicating that the use of an online deposition scheme reduces the positive bias in summer at southern Europe. This can contribute to the improvement of near surface ozone seasonality, but cannot completely fix the spring ozone maximum problem over north –Europe.

R1.4 "Some further justification is required in defining the subregions that Europe is broken up into. The authors argue that “Overall, the annual cycles of the observed data reflect the specific subregional characteristics: : :”. However, there are three counterarguments to this: 1) For some regions, the seasonal observed cycle varies substantially within the subregion. For example, in the Scandinavian subregion, the sites in the Baltic states and Denmark peak in the summer, while those on the Fennoscandian peninsula peak in the spring. This could be complicating the analysis of the offset in seasonality between modeled and observed cycles in the Scandinavian subregion. 2) All of the modeled seasonal cycles shown in Fig. 4 look much more sinusoidal than the observed seasonal cycles, so while the model is doing a reasonable job of the capturing the magnitude of the annual mean and seasonal amplitude, the shape and phase of the seasonality are not captured. "

In response to this comment, we performed a separate analysis for the Baltic (5 stations over Latvia, Estonia, Denmark) and the Fennoscandian (15 stations over Sweden, Norway, Finland) regions. Figure 3 shows the annual cycles for surface O3 over the Baltic (left) and the Fennoscandian (right) region, exhibiting both an observational spring maximum. This analysis justifies the grouping of all stations in a common subregion (denoted as SC), with similar seasonal characteristics.

R1.5 "The Mediterranean sites are broken into continental and coastal sites, but the other regions are not. There is likely a distinction in the observed seasonal and diurnal cycles between coastal and continental sites for the British Isles and Central Europe"

Indeed the geographical convenience was our initiative to split the regions and the fact the similar regions have been used in previous climate-oriented studies (Christensen, J. H. and Christensen, O. B.: A summary of the PRUDENCE model projections of changes in European climate by the end of this century, Clim. Change, 81, 7–30, doi:10.1007/s10584-006-9210-7, 2007). It has not be used a statistical cluster analysis to objectively discriminate regions with distinct ozone characteristics. This is part of our on-going work. However, in the case of ozone, there are a number of difficulties for an objective way to discriminate regions with distinct characteristic from station data. This is because even within a small region with similar large scale ozone features, the stations may differ significantly in terms of the ozone behavior depending on the distance from sea, the elevation and the distance for pollution sources. This becomes even worse for regions with small number of stations. A nice example is highlighter in the case of Mediterranean, with a small number of stations and with different ozone characteristics of the maritime rural EMEP stations from the continental rural classified AIRBASE stations. In our analysis we did a geographical compromise, when calculating ozone averages.

Specific comments: 1078L9: “Annual overall error” is a vague term in the abstract.

Done. Corrected to ‘fractional gross error’.

1080L7-11: Discussion of sources, chemistry, transport, but no discussion of deposition.

Done. Dry deposition was added as a removal process.

1081L19-21: In addition to stratospheric and column ozone, the MRE also appears to assimilate satellite observations of other relevant gases (CO, NO2) that will impact ozone chemistry [Inness et al., 2013].

That is correct. This note was added in the sentence. "The impact of assimilation on near surface ozone is only the "residual" of correcting the stratospheric and total ozone column, plus the assimilation of other relevant gases that impact ozone chemistry (CO, NO2) (Inness et al., 2013)."

1081L22-28: While the explanation of the configuration for the control run is clear, I am unclear on what is meant by the "control run is not a "clean" control analysis experiment"

Done. A proper explanation was provided.

1082L10-12: Is there a literature reference for the choice to use background stations for comparison to coarse-resolution model output?

A reference has been added in the revised manuscript. Schaap et al., 2014, Atm Env., text from Section 3 "Model performance evaluation": "…As it is fitted to catch background air pollution patterns with stations at a considerable distance from source areas in rural or remote regions, this network (EMEP) is appropriate to evaluate regional scale models performance with coarse resolutions (50 -150 km2)…"

1087L8-11: Why does assimilation make the seasonal cycle worse in some areas?

We attribute the deterioration of R to an inherent problem of the data assimilation procedure, related to the MLS bias correction, described in detail in the paper of Inness et al., 2013. The bias correction of MLS data, has caused drifts in the tropospheric ozone

concentrations between August 2004 and December 2007, an issue which have been tracked down and alleviated after year 2008 of the MRE. Comments are inserted in the revised manuscript. Figure 4 shows that temporal correlation of the MRE increases after bias correction (2008-2012).

1092L12: "Other PAN homologues (PANs)" I believe should be abbreviated APNs (standing for acyl peroxy nitrates).

Done

1106: Figure 2 caption. Describe the box and whisker structure in the figure caption in addition to its description in the text on page 1086.

Done

L1110: Figure 6. If possible, color coding the shaded envelopes to be consistent with the line colors would help to improve the readability.

Done. A new figure 6 is provided.

L1112: Figure 7. 24 subplots is too much for one figure! The profiles become very hard to read when that small.

Done. A new Figure 7 is provided.

1113: Figure 8 caption. Change "near surface ozone at 700 hPa" to "lower tropospheric ozone at 700 hPa" to distinguish from the "near surface" observations discussed throughout the rest of the manuscript.

Done

Technical corrections: 1079L12: Change "year-long experience" to "many years of"

Done

1080L18: "(even at near surface)" change to "even near the surface"

Done

1086L4-5: The line indicating the median in Fig. 2 is horizontal, not vertical.

Done

1090L9: “and the fail in MRE: : :” change “fail” to “failure”

Done

1090L10: Add “It” before “Is known that: : :”

Done

Interactive comment on Geosci. Model Dev. Discuss., 8, 1077, 2015.

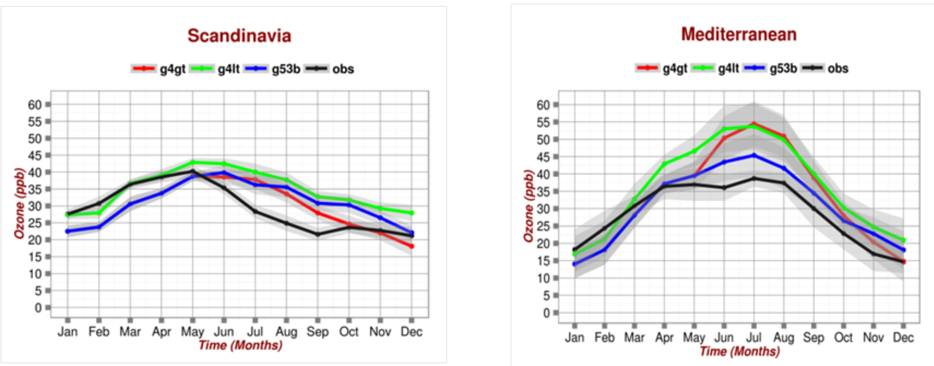

Fig. 1. Annual cycle of surface O3 for Scandinavian (left) and the Mediterranean (right) stations. Different colors indicate different deposition schemes tested in C-IFS.

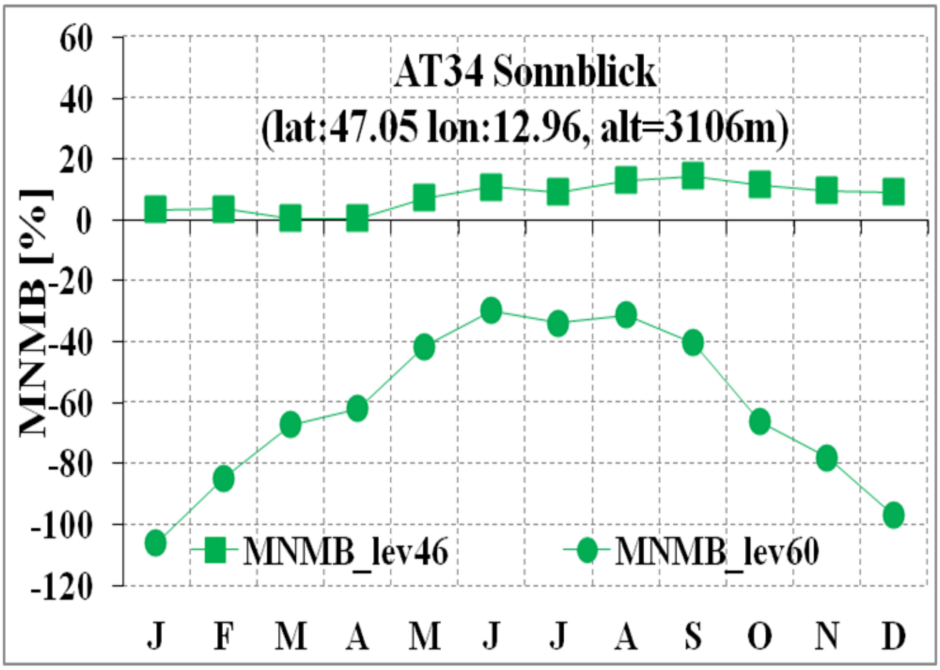

Fig. 2. Normalized Mean Bias for the Sonnblick station evaluated with model data from the surface model level and upper vertical model levels

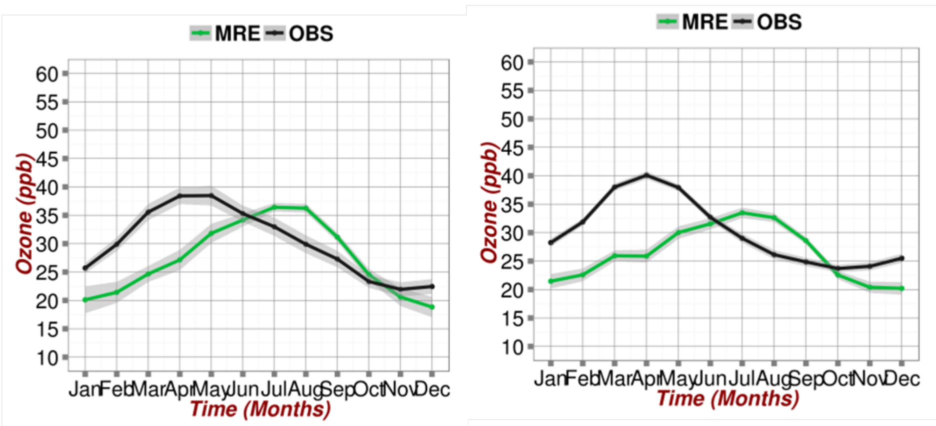

Fig. 3. Annual cycle of surface O3 for the Baltic (left) and the Fennoscandian (right) stations.

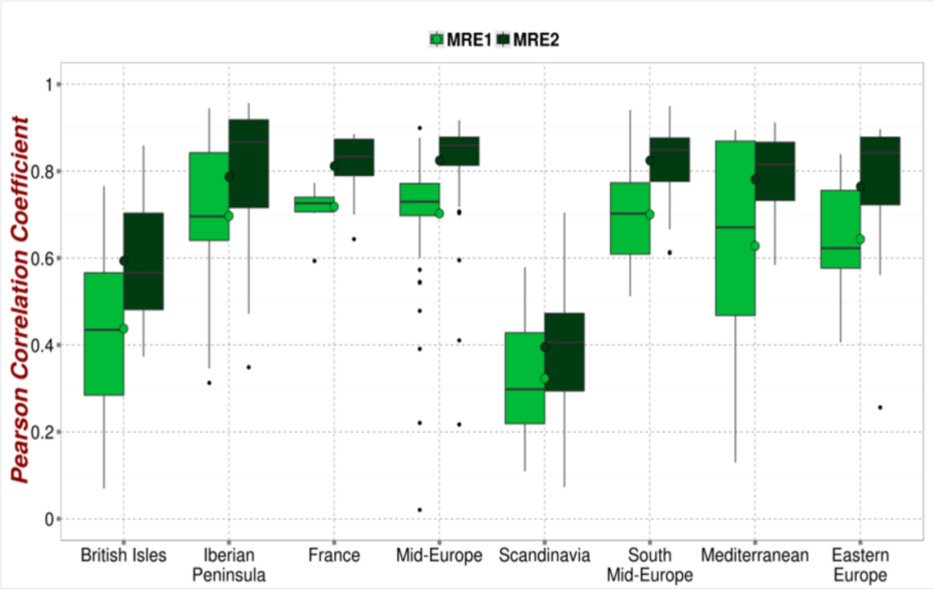

Fig. 4. Annual Whisker plots for surface temporal correlation for MACC reanalysis averaged over 2003-2007 with bias correction (MRE1, light green) and over 2008-2012 without bias correction (MRE2, dark green)