Interactive comment on "Representing ozone extremes in European megacities: the importance of resolution in a global chemistry climate model" by Z. S. Stock et al.

We would like to thank both reviewers for their comments. We provide a response to comments and details of any changes to the manuscript below.

Anonymous Referee # 2

General Comments

The paper presents an interesting analysis of horizontal resolution effects on global atmospheric modelling ozone prediction. The paper is well written and easy to read and understand. The analysis findings reproduce results already published from other modelling studies and substantially confirms expected model behaviour, but it provides a systematic insight over the European area that can be useful for many issues concerning both global modelling and regional applications. Moreover it offers a specific analysis of resolution impact on megacities. Some aspects of the analysis need clarification and some further detail on technical aspect is worth to be added to complete the paper description and justify the proposed conclusions.

- We note similar comments from reviewer # 1 requesting the addition of further detail, especially regarding the model setup and potential differences in meteorological factors between the runs. In order to respond to both sets of comments we add a number of plots in supplementary material including monthly mean sea level pressure (MSLP) for July and November and monthly mean 10m winds over Europe. ERA interim data for 2005 is also provided for comparison. We discuss these plots and include further details of changes to the paper in our responses to the specific comments from both reviewers.

Specific comments

Page 27424 lines 23-26 In the abstract it is generally preferred to give a short resume of the paper results instead of mentioning what will be discussed in the paper.

- Following the suggestion of the reviewer we modify the final sentence of the abstract to highlight the main causes of differences between the HR and CR in this study. We adjust page 27424 lines 23-26 to "We find the observed differences in model behaviour between CR and HR configurations to be largely caused by chemical differences during the winter and meteorological differences during the summer."

Page 27426 line 15 The problem of averaging emissions from urban areas due to grid spacing limitation regards all cities and conurbation even smaller that megacities.

- We agree with the reviewer that the problem of averaging emissions is not exclusive to megacities. However, we make the example of megacities to highlight the problem in the context of our study. For clarity, we adjust page 27426 line 14 to "The

averaging of emissions in large grid cells presents a problem in representing emissions from megacities and smaller urban conurbations, as the coarse resolution of a climate model means the grid cells are often larger than the cities themselves."

Page 27427 line 26 HR latitude grid spacing is 0.5 deg. While in Table 1 is 0.56 CR has longitude grid spacing larger than latitude grid spacing while HR has longitude grid step smaller than latitude grid step. Is it correct?

- We thank the reviewer for bringing this to our attention. Line 26 is corrected to 0.56° x 0.375°. We also correct Table 1 as both in the HR and CR case the longitude grid spacing is larger than the latitude grid spacing. The HR grid spacing should therefore read 0.56° x 0.375°.

Page 27430 lines 2-6 It is mentioned that the convection parameterization causes differences between CR and HR model configuration. With no detail or explanation about the differences it is difficult to understand what can be the mentioned resolution effect. Later in the text it is mentioned NOx emission due to lightning. Is this the major resolution effect tied to convection? Is there any difference due to vertical mixing or wet deposition? Did you perform analysis of differences in meteorological fields? Some more detail would help the comprehension.

- Since this study focused on ozone extremes in megacities we have not produced the extensive model output required to do an in-depth analysis of tropical convection. However, we have done a similar analysis in a previous study which we can refer to. In order to address this point we have replaced and expanded page 27430 line 2-4 with "Previous studies looking at the impact of model resolution on tropical convection (Russo et al. 2011) have shown that higher resolution models have a better representation of convection, with more frequent deep convection occurring over islands and peninsulas, as opposed to neighbouring sea areas, and generally higher convective cloud top heights. Both of these features would contribute to differences in HR and CR lightning NO_x emissions in the tropics; this is because the amount of NO_x emitted is proportional to the convective cloud top height, and additionally, for a cloud top height of ~10km, lightning NO_x emissions are ~100 larger when lightning strikes over land compared to sea ".

Page 27429 lines 21-23 The HR run seems to produce lower/higher O3 column density over the polar/tropical regions with respect to the CR run. Is there a known reason for this behaviour?

- The reviewer's comment is interesting, although we do not know of a specific reason for this behaviour. In our general discussion of the global differences between the HR and CR runs we highlight lightning NO_x emissions and convection as likely causes of differences in the tropical O_3 column densities. As this study is focused on understanding the differences in European megacities we have not investigated the small differences in polar regions further.

Page 27430 line 18 Does "rural and background station" means "rural and urban background stations" ?

- The reviewer is correct that page 27430 line 18 refers to rural and urban background EMEP sites. For clarity we adjust page 27430 line 18 to "Monthly mean data for 2005 is gathered from over 100 different rural and urban background stations during the time periods chosen."

Page 27432 lines 3-8 It is stated that the presented statistics are computed using monthly mean computed and observed values. Does this mean that the correlation index represents a "space correlation" instead of the more usual time correlation? The order of the stations can influence results in this last case.

- The presented statistics are computed using a monthly mean across the stations and hence the correlation is in space rather than time. In this case the order of the stations does not affect the statistics calculated.

Line 9 Is it the mentioned RMSE calculation different from the standard one? If the difference is significant, it should be briefly resumed.

- The mentioned RMSE calculation is the same as the standard one. We include the reference of Borrego et al. 2008 for readers interested in the statistical parameters commonly used for evaluating air quality model performance and the formulas used for calculation.

lines 18-20 The sentence "Both resolutions..." explains why O3 has high values during the summer but it does not explain the overestimation obtained by both resolution runs. Is there any interpretation of this result? It could be interesting to verify if the overestimation of the average values is due to an overestimation of maximum daily concentrations or if it can be influenced by minimum nightly values. The verification of the reconstruction of the daily cycle is provided in a following chapter for London and Paris, but those cities are not located in areas where the overestimation of summer ozone is more pronounced (e.g. the Mediterranean area and eastern European continental region). The interpretation of the overestimation is of interest e.g. for the possible use of global models results to drive regional scale air quality simulations.

- The hourly output used in the construction of the daily cycle was only available for a small sub-domain including Paris and London, therefore we would not be able to comment on diurnal variations for the Mediterranean region. In a previous study (Stock et al. 2013), we show the UM-UKCA model to produce present-day ozone comparable to observations and to other global models (cf. Stevenson et al., 2006), although ozone is slightly over predicted in the Northern Hemisphere. The slight overestimation of ozone in this study over Europe is likely to be linked to the background ozone over prediction, possibly caused by the influence of a lower model top or an artefact of the emissions, as this overestimation is also found in the multi-model assessment of Stevenson et al. 2006. Although this is a well known feature, it has proved hard to pinpoint its exact causes in our current models.

Page 27434 Figures 4 and 5 show for both resolutions better performance over Paris than over London. What is the interpretation of this result?

- There could be a few explanations for why both resolutions appear to perform better over Paris than London in this study. Firstly, Paris is a denser city (in terms of NO_x emissions and size) than London. In the original megacity mask used to define megacities in this study (see Stock et al. 2013) Paris is captured by a single grid box whereas London consists of 5 grid boxes. Therefore the NO_x emissions in London are spread over a greater area and hence the peak in NO_x is diluted in the model. This leads both resolutions to overestimate ozone in London due to greater ozone production at lower levels of NO_x. Differences in meteorology and the air advected into the cities could also influence the ability of the model to capture ozone concentrations. London is noted to be located in a generally more polluted background than Paris.

Page 27435 lines 19-22 The proposed interpretation is quite generic, unless you can support it with meteorological modelling results analysis. Did you perform any comparison of the meteorological model model results with available reanalysis for the two simulated months?

- We intend lines 19-22 on page 27435 to simply provide suggestions on the reason why the probability of high ozone events in July are not particularly well captured by either model configuration. This effect is particularly apparent in the Paris PDF plot (Figure 5b). We highlight that the ozone precursor emissions or more extreme meteorological conditions could be possible reasons for the differences. Although we have compared the monthly meteorological conditions (see new plots in Supplementary material) we are reluctant to draw further meteorological details into the discussion at this point. The reason why the high ozone events in July are not particularly well captured by either model configuration remains unclear.

Page 27439 What is the reason of the higher BLH values obtained for HR simulation? It is reasonable to get higher values in coastal areas or where orography is better resolved, but is less straightforward to understand the differences over the eastern part of continental Europe, where the horizontal variation of topography and land-use is weak. Are there large differences in the meteorological fields over those areas?

- For a discussion on the differences in BLH between HR and CR we refer to the response of reviewer #1 specific comment, page 27439, line 9. Although the sensitivity of BLH to different land-use and meteorological factors is an interesting aspect, we have not attempted to investigate this further as the focus of the paper is on the chemistry produced by two existing climate model configurations.