

Interactive comment on “Validation of reactive gases and aerosols in the MACC global analysis and forecast system” by H. Eskes et al.

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Response to Anonymous Referee 3

This paper provides an extensive overview of the MACC global forecast system. The main aim of the paper is to document the data that is assimilated into the MACC system and to provide a detailed description of the methods and the data used for the validation of the modeling suite (VAL). The paper will be of particular use to the community that will be using the MACC data analysis and forecast system and those who are involved in the development of the MACC system. However, I feel it will also be of interest to wider modeling community. I believe the content of the paper is ideally placed for publication in GMD and recommend publication after the authors have addressed the relatively minor corrections below.

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We would like to thank the reviewer for the kind words, positive recommendation, and the very careful reading of the manuscript which has led to many small improvements.

Main comments: There is a large amount of data being assimilated into the MACC system and being used for validation so I believe the paper would benefit from a table that gives the reader an overview of the measurement uncertainties and an idea of the temporal and spatial frequency of the observations. This has been discussed during some sections in reference to specific observational datasets; however there are many observations whose uncertainties are not discussed specifically.

We have discussed this among the authors of the paper and with the modellers. We agree that especially the information on the uncertainty is useful. A table will be added to the revised manuscript, section 7, listing the measurements, the spatial and temporal characteristics and the estimated uncertainty. However, to our opinion it is outside of the scope of the present paper to list also the datasets which are assimilated. We will refer to the relevant papers for this.

My other main comment is that sometimes the language/sentence structure is a little mixed up and that the paper would benefit from a careful read through to check the English and grammar used. I have noted a few of these occasions below.

We have carefully gone through the whole document and made small modifications to the text. In particular, we have included the textual suggestions from all three referees, and in particular the ones listed below.

Minor comments:

Pg 1121, L22-28: Refer to the section numbers.

References to the section numbers have been included.

Pg 1123, L12-25: This paragraph is hard to follow. Please restructure and shorten to make a bit clearer.

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The first sentence has been reformulated, and a short list has been introduced. The text in the revised manuscript now reads:

For a good understanding of the quality of the MACC system it is important to consider which species in the global assimilation system are constrained by the observations, and which species are covered by the validation datasets used. This is summarized in Table 1. The MACC aerosol and reactive gas models contain on the order of 100 species with global coverage and ranging from the surface into the mesosphere. Clearly, only a small fraction of this is observed and constrained by the available observations.

- **Assimilation:** The MACC assimilation is focusing on aerosol optical depth (AOD), ozone, CO, NO₂ and SO₂. Note that the species are treated in a univariate way and correlations in background errors of different species are neglected (Inness et al., 2014). An analysis update of one trace gas will nevertheless influence others through the chemical reactions.
- **Validation:** The validation is also constrained by the limited amount of trace gas and aerosol properties for which validation data is available. Furthermore, validation is limited by the amount of external data that is available in real time or at least within a few weeks after measurement, and with a reasonable global coverage.

Pg 1124, L7-25: This paragraph is a bit hard to follow. It may be better condensed as a table?

We have turned the paragraph into a list in the revised manuscript, which improves the readability.

Pg 1129, L7: Add a reference for MOCAGE

This is dealt with in the revised manuscript by referring to the paper by Flemming where
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a list of references is provided for the three models. Introducing all these models is beyond the scope of our paper.

Pg 1135, L8: 'out through the Sahel,' – Check grammar.

Line replaced by:

A first example of a case study is shown in Fig. 2. In June 2014 a huge desert dust plume occurred that originated in the Sahara and traveled more than 6000 km over the Sahel and the North Atlantic, impacting the Amazon and the Caribbean.

Pg 1135, L10-11: Is it surprising that the MACC system can capture the MODIS AOD when it assimilates MODIS AOD? Maybe mention here that the comparison to MODIS is not totally independent whereas the surface sites are.

There is a subtle difference, because figure 2 contains MODIS DeepBlue data over land, which provides observations over bright land surfaces. The DeepBlue data is not assimilated in this version of the C-IFS system. So, in fact it is in part an independent check.

The following line is added to the text of the manuscript: "Note that the MODIS Deep-Blue data, which is providing aerosol observations over bright land surfaces, is used in the figure but not in the assimilation."

Pg 1135, L24: Add reference for uncertainty of ceilometer. Figure 3: Make labels clearer.

A reference will be added, and the figure will be improved in the new manuscript.

Pg 1136, L4-6: What do you mean by 'representativity' issues? Do you mean concentration bias or location bias? What improvements are planned?

This line is replaced by the following text:

"Many aspects influence the quantitative comparison, including uncertainties in the

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source strength (fire radiative power observation and aerosol mass produced) uncertainties in the transport over several days, removal processes, resolution of the model and local representativity issues. Part of these modelling errors may have been corrected by the assimilation of the MODIS observations."

Pg 1136, L19: Add reference to the other POLMIP studies – Arnold et al (2014) and Monks et al., (2015).

We feel that three references for POLMIP is out of balance. MACC has made significant contributions to the paper by Emmons.

Pg 1138, L4: Do you mean the number of observations being assimilated are more sparse in the SH so the model bias is larger or do you mean that the model has undergone little previous evaluation and therefore model improvements that benefit the SH?

We mean that there are only few GAW observations available for the evaluation.

The line is modified into: " The model is scarcely evaluated by the GAW network over the Southern Hemisphere."

Figure 4: You discuss comparisons to the other model simulations without data assimilation but they are not included in Fig 4. It would be interesting to see these model runs also.

These figures are available in the MACC validation reports. For the current paper we chose to show the regional dependence of the o-suite as example. Adding more curves would make the figure very crowded and we do not think this is a good idea.

Pg 1138, L14-17: You say 'The comparisons with SCIAMACHY/GOME-2 show that spatial distributions of tropospheric NO2 columns are well reproduced by all three NRT model runs throughout all seasons, indicating that emission patterns and NOx photochemistry are generally well represented.' I don't see this from the figures included (Fig 5). I'd say the models capture the seasonality, however, I wouldn't say they capture the

emission patterns as SCIAMACHY indicates larger NO₂ over Asia compared to Europe whereas the model indicates larger NO₂ over Europe. Are you referring to comparisons that aren't included or from one of the other scientific papers in the special issues? If so, say 'not shown' or reference the paper.

The text has been reformulated: "Comparisons to SCIAMACHY/GOME-2 monthly mean tropospheric NO₂ columns on a global map (Eskes et al., 2014a) shows that spatial distributions of tropospheric NO₂ columns are well reproduced by all three NRT model runs throughout all seasons, indicating that emission patterns and NO_x photo-chemistry are generally well represented. A general feature is the underestimation of NO₂ columns over the continents in general and particularly in China (the latter is also evident from Fig. 5), ..."

Pg1139, L21-28: You say there is an improvement when assimilating data (o-suite) . However when you look at Fig. 6, it seems the C-IFS run does a better job at capturing CO. The correlation coefficients are also better for this run than the o-suite run (pg1140, L1-2). Can you please check this paragraph and clarify why you think the o-suite run gives a better performance.

The improvement occurs for the o-suite, based on IFS-MOZART, and the free running IFS-MOZART. The general statements are of course not based on one location, but summarise mean results from the entire set of GAW stations.

C-IFS is a new and entirely different model which for the period shown in the plot was only operated in free running mode. The figure shows one example where the C-IFS free run improves the correlation as compared to IFS-MOZART free running configuration.

Figure 7: Say what data the correlations coefficients have been calculated for. Is it daily/hourly data within each month?

The correlation coefficients are based on consistent daily mean values, from all stations

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and when observations are available. This explanation is added to the text of section 9.5.

Figure 8: Make plot lines and text thicker to ensure quality of figures when printing.

New figures will be produced for the revised paper.

Pg 1141, L27: Check sentence structure: MACC o-suite captures almost all dust outbreaks tracking fairly well their spatiotemporal evolution over the North Atlantic and the Mediterranean.

Sentence has been somewhat reformulated

Figure 9: Caption – Define SD.

Replaced by "standard deviation".

Pg 1142, L23: Check sentence grammar: 'The impact of data assimilation at other locations is confirmed'. Do you mean 'the impact of data assimilation at other locations can be seen'?

Replaced by "can also be seen".

Pg 1144, L13: Check sentence: 'More research and technical work is needed to use e.g. the climatological aerosol composition and variation as used for AeroCom model'

Reformulated: " Additional research will be based on the climatological aerosol composition and variation (as used for AeroCom model evaluations) to obtain relevant information on the quality of the IFS forecast system."

Technical corrections: Pg 1120, L1: remove 'even'. Pg 1120, L14: remove 'to' before respond.

Both done.

Pg 1120, L: Define IFS properly in the following sentence - 'the numerical weather prediction forecasting system of ECMWF (IFS)'.

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Added " Integrated Forecasting System"

Pg 1123, L16: ranging -> range

Done

Pg 1128, L89: in case -> in the case

Done (2x)

Pg 1129, L5: insert comma after MACC.

Done

Pg 1130, L25: Insert 'of' after 'all'

Done

Pg 1131, L21: profiles -> Profiles

Done

Pg 1132, L 2-3: Check sentence structure and grammar.

This part was replaced by: " The validation activities in GEMS and MACC have been using ozone and CO from MOZAIC and IAGOS for ten years. Both the take off and landing profiles and the UTLS cruise part of the flights at northern mid-latitudes have been compared to the different model runs on a regular basis. Special events such as the summer 2003 heat wave over Europe (Ordóñez et al., 2010) and summer 2004 Canadian boreal forest fires (Elguindi et al., 2010) have been studied."

Pg 1132, 9: The second and final -> the second is the final

Not changed.

Pg 1132, L23: Assimilation O3 results → O3 results

Done

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Pg 1135, L19: I don't see the need for starting a new paragraph.

Done

Pg 1136, L8: which -> that

Done

Pg 1136, L20: Remove 'e.g'

Done

Pg 1138, L3: Insert comma after stations.

Done

Pg 1140, L21: , see Fig. 7 -> (see Fig. 7)

Done

Pg 1141, L15: Aeronet -> AERONET

Done

Pg 1141, L18: , see Fig. 8 -> (see Fig. 8)

Done

Pg 1142, L4: and -> an

Done

Pg 1142, L6: Add units (0.08 to 0.24)

Optical depth is dimensionless.

Pg 1142, L26: show always good agreement -> show good agreement Pg 1145, L10: remove 'model'.

Done

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