Note: Reviewer's comments are presented in black font; authors' responses are presented in blue plain font; manuscript text quotations are presented in blue italics font.

Anonymous Referee #1

We would like to thank Reviewer #1 for his/her time devoted and the constructive and helpful comments.

General

This manuscript describes a deep stratosphere-to-troposphere event over Europe in 2017 winter that has been well captured by CAMS global and regional forecast models. The authors illustrated the simulated winds, geopotential height, PV, water vapour and ozone during the event. They compared the simulations with satellite data of water vapour , radiosonde, ozonesonde and aircraft observations. By putting all of the simulated and observed meteorological and chemical data together, the authors depicted the evolution of this event in detail and showed strong performance of the CAMS global and regional models.

Overall, this study is well conducted and has contributed to enhancing our knowledge of ozone transport from the stratosphere to troposphere. The presentation is overall clear. However, I have the following points for the authors to consider when revising their paper.

We thank the Reviewer for the comments, to which we will respond point by point.

1. While the CAMS showed strong performance in capturing the stratospheric intrusion event, it is not clear (1) what are key schemes in the models that are responsible for the performance and (2) what advance this study has made comparing with earlier studies. Can the authors provide some assessments on the model prediction of ozone intrusion events? Do the models tend to overestimate or underestimate occurrence of these events?

(1) The simulation of the intrusion is mainly driven by model dynamics. An important aspect is also the vertical model resolution; increasing the number of vertical layers, theoretically would improve the forecast evaluation metrics. (2) This evaluation work is the first in its kind, since the IFS system has not been evaluated before for stratospheric intrusions. It is a process oriented evaluation study which is complementary to the standard evaluation work performed within the CAMS84 service. This work is also original because we compare the global (IFS) with the regional European air quality forecasts, the latter driven by IFS. Therefore we give insight into a comparative model performance, and present the range of uncertainty in the regional ensemble.

As mentioned above this is the first study about the IFS performance for stratospheric intrusions, so there is not yet a systematic study on the IFS performance for such events. Although this is out of the scope of the current work, it is quite an interesting aspect for future work.

2. There are more than one ozonesonde stations in Europe. The authors are encouraged to take advantage of the ozonesonde data from more ozonesonde stations to validate the model performance. In these validation, such as those in Figure 10, humidity can also be validated so to provide additional confidence on the model performance.

We agree with the Reviewer's suggestion to include also humidity in the vertical profiles of ozone to increase confidence on the model performance. Apart from Figure 10 (Prague), we extended this suggestion also for Figures 5, 6, 7 and 9 (Norderney, Muenchen, Trapani and Heraklion) including relative humidity as a stratospheric tracer. The following figures present the updated vertical profiles including the observed and ifs relative humidity:

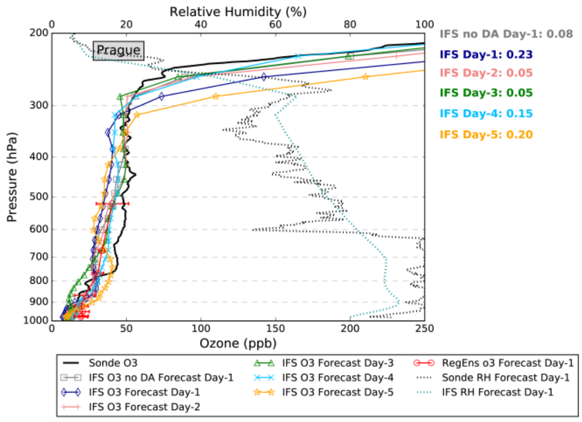


Figure 10a

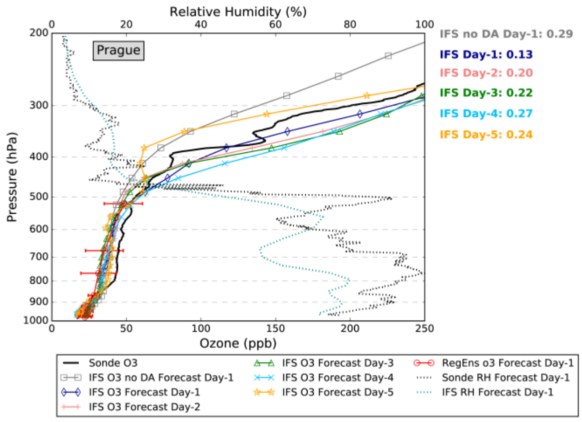


Figure 10b

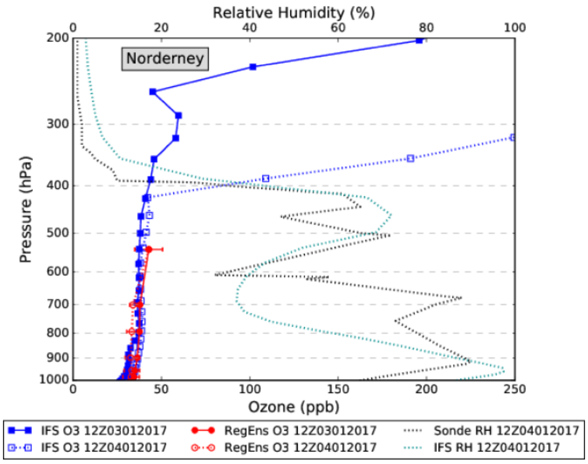


Figure 5

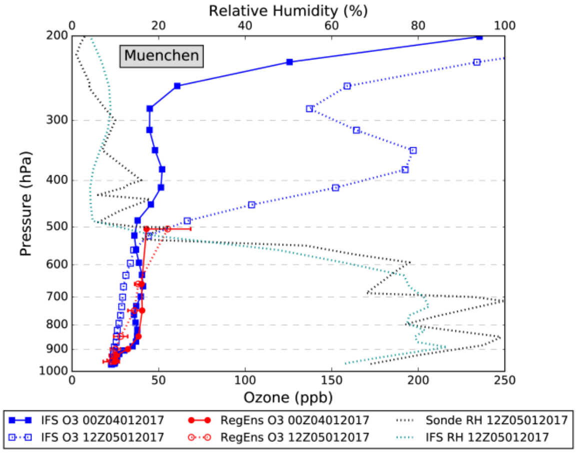


Figure 6

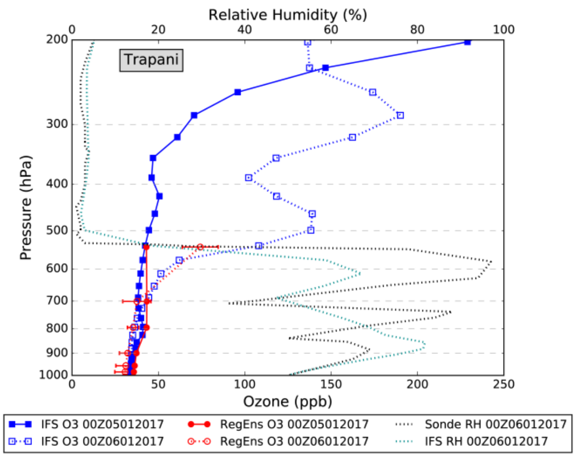


Figure 7

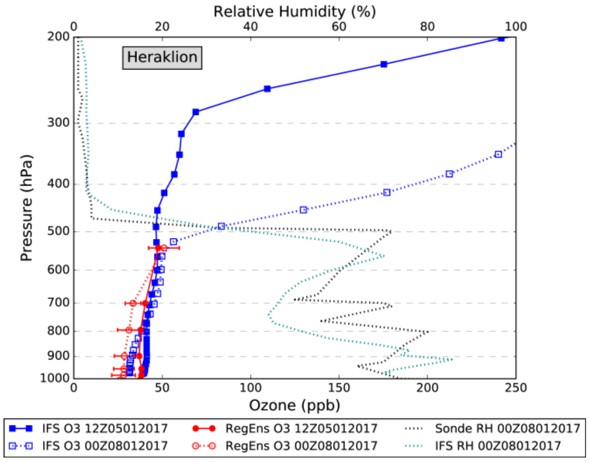


Figure 9

Please find the updated Figures 5, 6, 7, 9, 10 and captions in the revised manuscript: Figure 5: page 24; Figure 6: page 25; Figure 7: page 26; Figure 9: page 28; Figure 10; page 29.
Moreover, a small discussion on the relative humidity is included/modified in the revised manuscript:

Page 4, line 7: *"…specific humidity, relative humidity and PV…"*

Page 8, lines 6-8: *"The vertical profiles of the observed and IFS relative humidity (Fig. 5d) show a sharp decrease at 400 hPa, revealing that the intrusion of dry stratospheric air in the troposphere is well captured by the IFS.".*

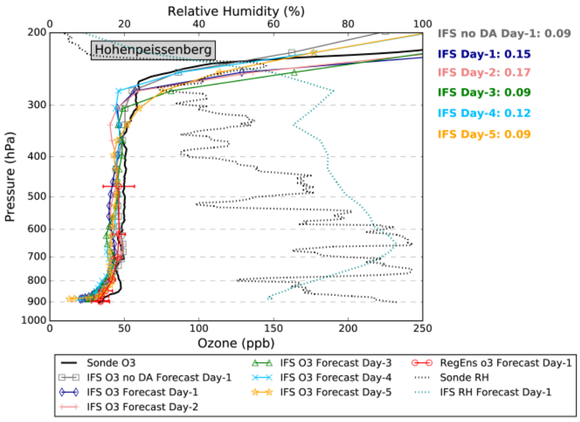
Page 8, lines 17-18: *"…which along with the sharp increase/decrease of IFS ozone/relative humidity above 550 hPa (Figure 6d), which is partially seen in RegEns ozone vertical profiles, indicates the downward transport of dry stratospheric air into the tropopshere".*

Page 8, lines 27-28: *"On top of that, the vertical profiles of the observed and IFS relative humidity (Fig. 7d) indicate that the sharp decrease of humidity is well reproduced by the CAMS global model.".*

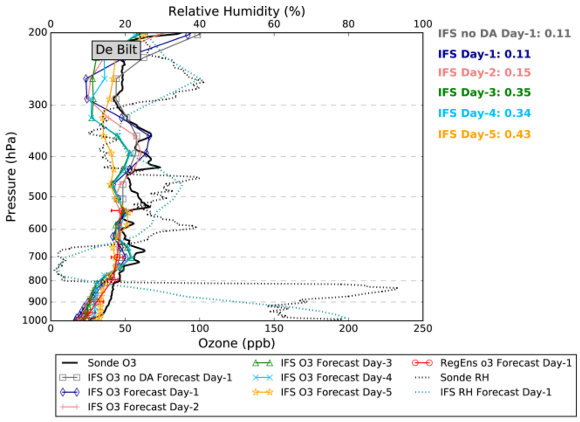
Page 9, lines 3-4: *"..and the respective vertical profiles of IFS ozone and relative humidity (Fig. 9d) reveal.."*

Page 9, lines 23-24: *"In support of the above findings, the respective vertical profiles of the observed and IFS relative humidity show both a distinct decrease at 500 hPa."*

The Reviewer suggests using additional ozonesonde stations in our analysis. We agree that there are available ozonesonde data from other European stations. Nevertheless, as our study is strictly focused on stratosphere-to-troposphere transport (STT), we are only interested in stations that during the examined period were clearly affected from the STT event exhibiting a distinct increase of ozone in the upper-middle troposphere. To our knowledge (visual inspection of ozonesonde data from European stations of the WOUDC network), from the available ozonesonde stations only the station at Prague exhibited a clear ozone enhancement in the middle-upper troposphere. Still, we present below the ozonesonde data from other European stations (same as Figure 10) during the examined period in support of the models general performance.



Hohenpeissenberg (DE) 06Z 04JAN2017



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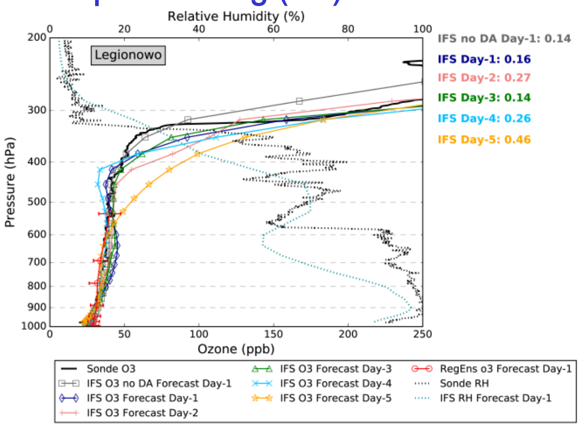

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3. More description is required on the data assimilation. What kinds of observation data were used in the assimilation? Were the ozonesonde data at Prague or aircraft data at Frankfurt used? If so, this should be pointed out when discussing Figures 10 and 11.

The ozonesonde and aircraft data at Prague and Frankfurt respectively were not used in the assimilation process and are therefore completely independent validation data. We have included the following sentences in the revised manuscript:

Page 3, lines 25-28: *"For ozone the CAMS near real time system only assimilates satellite retrievals. These include total column ozone retrievals from the Ozone Monitoring Instrument (OMI) and the Global Ozone Monitoring Experiment-2 (GOME-2) on Metop-A and Metop-B, profile data from the Microwave Limb Sounder (MLS) and partial columns from Solar Backscatter Ultra-Violet (SBUV/2) and from the Ozone Mapping and Profiler Suite (OMPS)."*

Page 5, lines 27-28: *"It is noteworthy to mention that both ozonesondes and IAGOS profiles are not assimilated and hence they constitute completely independent validation data."*

Specific

1. Please indicate the locations of radiosond, ozonesonde stations, and Frankfun in Figures 1-4.

We understand the rationale behind the comment and we thank the Reviewer for the constructive suggestion. We have included the names of the observational sites at their locations in Figures 1-4 (pages 20, 21, 22 and 23 in the revised manuscript) and modified the respective captions accordingly.

2. Figure 10, humidity data usually are available together with the ozonesonde data. Humidity can be validated at the same time.

Please refer to our response in a previous comment. Relative humidity is now included in Figures 5, 6, 7, 9 and 10 in the revised manuscript.

3. References:
P12, L3, CO 2 and CH 4?

Corrected (page 13, lines 3-4 in the revised manuscript).

P12, L13, more information is required.

Done (page 13, line 13 in the revised manuscript).

P12,34, CATHALA?

Corrected (page 13, lines 34-35 in the revised manuscript).

P15, L22, Spell out the full name of the journal.

Done (page 16, line 27 in the revised manuscript).

*** Page 17, line 8 in the revised manuscript, *"LOTOS?EUROS*" is replaced with *"LOTOS-EUROS"*.

*** In the revised manuscript for the RegEns ozone vertical profiles the altitude of the sites was considered (if needed) for choosing Standard Atmosphere pressure and temperature.

*** In the revised manuscript in Figures 11a and c the RegEns ozone is plotted for time 12Z (in order to be consistent with IFS) instead of 13Z that was by mistake in the initial manuscript.