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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Impact of ozone observations on the structure of a tropical cyclone using coupled atmosphere–chemistry data assimilation" *by* S. Lim et al.

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We appreciate the positive comments by the Referee #1 along with many valuable suggestions, which helped us improve the manuscript significantly. In the following, we have provided an item-by-item reply to the referee's comments.

General comments:

1. The fact that only one assimilation cycle is used reduced the scientific impact of this

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study. The authors argue that OMI data are only available in the morning so only one DA cycle was done, on 3 September in the morning. The period of the Nabi cyclone is between 29 August and 8 September, 2005. The switch of OMI from normal to zoom mode occurred on September 2 where no OMI data were available over the TC region for that day. If I understand well, OMI data is then available for the other days during the Nabi cyclone but only in the morning (around 4 UTC).

To me, the entire period of the Nabi cyclone could be addressed. Cycles without OMI data (between 6 and 24 UTC) might be replaced by a forecast run. In this way, the performance of DA experiment could be evaluated by measuring the skill of the system to forecast OMI data of the next days. This is one question to which the current state of the study does not answer: is DA of OMI data improve the forecast of the cyclone. Also, increasing the number of cycle would reinforce the results of section 3.4.

⇒ *We greatly appreciate the suggestions by the Referee #1, and agree that performance of data assimilation (DA) cycling with several cycles could make the DA more powerful. Although one can potentially have 4 cycles with a 6-hour assimilation window in a day, the limited availability of OMI observations over the model domain allows only one DA cycle per day. This is an extremely unfavorable situation for DA. Therefore, we only conducted the first DA cycle, which has the strongest impact among the cycles. We believe that our current single cycle DA experiment is sufficient to illustrate the effect of coupled meteorology-chemistry DA and demonstrate its potential.*

A meaningful cycling of DA is inherently related to the ***prediction component*** *of DA, as every new cycle begins from the forecast guess from the previous cycle. However, the* ***analysis component*** *of DA is also important, as it provides the impact of observations on the analysis produced by DA.* ***In the current research, we focus on the analysis component of DA, as the first step towards the eventual DA system for OMI observations.*** *We believe that there are suffi-*

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cient new results in the context of the analysis component, which are relevant for coupled DA presented in this work. We plan to address some important issues related to the prediction component in the future studies.

Although including the forecast component (e.g., cycling) is desirable, it has, unfortunately, several difficult aspects that are not possible to resolve in the current setup. It is known that realistic DA, including ours, is not perfect in providing dynamically balanced initial conditions, typically resulting in a forecast spin-up period where some of the analysis adjustments are filtered out. A practical remedy is to produce an improved fit to observations and the related stronger impact on dynamical model variables such as wind, temperature, and pressure, which would eventually result in a longer, sustained impact into the forecast. However, given that the assimilation of OMI observations produces a stronger impact on chemical variables and some but insufficient impact on dynamical initial conditions, there is an unrealistic hope that this can impact the 24-hour forecast that we need for the next cycle with OMI observations. Thus we need to assimilate additional observations. Unfortunately, for typhoon this implies the need for assimilating satellite data, which are currently not available for the employed DA system, and thus would require additional development that is outside of the scope of this paper and is planned for the future step.

2. In the paper the terminologies "atmosphere chemistry model" or "atmospheric and chemical variables" is used. The chemical composition is part of the atmosphere state so I would change these terminologies by, e.g., "circulation chemistry model" and "physical (or dynamical) and chemical variables"

⇒ *We agree to the referee's suggestion and introduce adequate changes throughout the manuscript. Given that the chemical composition is part of the atmospheric states, we suggest to change "atmosphere-chemistry model" to "meteorology-chemistry model", and "atmospheric and chemical variables" to*

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"meteorological and chemical variables". Here "meteorological" variables include both "physical" and "dynamical" variables.

Technical corrections:

P11576-L7: I would not use the term "blending" to describe DA method because it is too subjective while DA methods are an objective way to use model, a priori and observation information, as well as their error covariances to produce an analysis. Please, update the sentence.

⇒ *We have changed this part from "**by blending the model and observations** ···" to "··· **by combining the information from the model and observations in a mathematically consistent manner** ···"*

P11576-L10-13: This sentence is not very clear. They are many reasons to assimilate ozone which are reviewed in Lahoz et al. (2007) for the stratosphere. Please, clarify the sentence.

⇒ *We have rewritten this part as "**Ozone (O_3) has a relatively long photochemical lifetime and high concentrations in the stratosphere, except during ozone hole conditions, and at high latitude. It is a passive tracer at synoptic scale or smaller; thus variations of total ozone in space and time are a result of the atmospheric flow, and is highly correlated to many meteorological variables in the upper troposphere (Wu and Zou, 2008). Assimilation of O_3 has several motivations such as (Lahoz et al., 2007): 1) taking better account of stratospheric ozone when assimilating satellite radiance data; 2) leading to better radiative forcing when used by the model radiation scheme; 3)***

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providing useful dynamical information via the motion of ozone in the atmosphere; and 4) improving the accuracy of UV index forecasting. Moreover ...”

P11579-L11-17: Some readers will probably not know the locations of Saipan, Kyushu, South Korea and Hokkaido. Would it be possible to mark these locations in Figure 1?

⇒ *We have redrawn Fig. 1 by marking those locations in the revised manuscript.*

P11580-L17-19: “It contains ...” The description of the observation operator that transforms modelled Ozone volume mixing ratio to total column is very short. Can you add more information; in particular are the averaging kernels used in the observation operator?

⇒ *Following the referee's suggestion we described the observation operator in more detail in the revised manuscript. Please note that we are not using averaging kernels, following standard practice in DA, since we rely on the (multivariate) ensemble forecast error covariance for processing the information from the observation and the prior.*

P11582-L13: “(ii) 200 hPa (lower stratosphere)”. 200 hPa is usually in the upper troposphere lower stratosphere (UTLS) so I would replace “lower stratosphere” by “upper troposphere lower stratosphere”.

⇒ *It is rewritten as “**(ii) 200 hPa (upper troposphere/lower stratosphere; UTLS)**”.*

P11582-L18-19: “These are ...” This sentence is not clear in particular after “... and the control forecast ...” Please, clarify.

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⇒ *It is rewritten as "**These are estimated by taking the difference between the ensemble perturbation forecasts (total of 32) and the control forecast in the ensemble system (Zupanski, 2005; Zhang et al., 2013).**" For further clarification, we have also rewritten P11583-L1 as "**forecasts with corresponding initial conditions** x^0 **(i.e., control forecast) and ensemble initial conditions** x_n^0 **(i.e., ensemble forecasts)**".*

P11583-L25-26: "$\cdots$, provided total $\cdots$" This latter part of the sentence lack of clarity. Please, rephrase.

⇒ *It is rewritten as "$\cdots$**, provided that total** $\cdots$".*

P11584-L16: Do you mean Fig. 4b (instead of d)?

⇒ *Fig. 4d is right. Please note that Fig. 4d (i.e., analysis increment of O_3 at 200 hPa) is right beside Fig. 4a (i.e., analysis increment of O_3 at 850 hPa).*

P11584-L19: I would replace "$\cdots$ while the correlation is mixed $\cdots$" by "$\cdots$ while no clear correlation is found for $\cdots$"

⇒ *It is rewritten as "$\cdots$**, while no clear correlation is found in other regions.**"*

P11585-L10: The term "validation" is in general used when the analyses are "validated" w.r.t. independent observations. Here, it is more a verification. Please, update the title of Sect. 3.4.

⇒ *It is now changed to "**3.4 Verification of** O_3 **data assimilation**" in the revised manuscript. We have also corrected the **Abstract** (P11575-L18) accordingly as "**The analysis results are verified using** $\cdots$".*

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P11587-L2: "· · · at the time" The meaning of this sentence is not clear. Please, rephrase.

⇒ *It is rewritten as "**We include only a single data assimilation cycle since the OMI observations are covering the model domain only once per day (i.e., 06 UTC), and no other observations are available at that time.**"*

Interactive comment on Atmos. Chem. Phys. Discuss., 15, 11573, 2015.