

Response to E. Ray (Referee)

Dear Eric Ray,

Thanks for your constructive and inspiring comments. They helped us a lot to improve the paper. In the following, we address all the points raised by you (denoted by italic letters). Following your (and Gloria Manney's) recommendation, section 5 and related Figures were almost completely revised. To render this response easy to read, you will find your original comments in italic letters, our answers in roman letters and the references to the manuscript (and in the manuscript) are highlighted in red.

This paper describes the NH major sudden warming event of 2009 from a modeling and satellite observation perspective. The CLaMS model provides explicit information about the effects of sub-grid scale mixing and this is used to explain features in the trace gas correlations related to the MW seen in MLS measurements and CLaMS output. The description of the dynamical evolution of the NH stratosphere from the tropics to the pole before and after the MW is interesting and well done. The description of the evolution of the N₂O-O₃ correlations related to this dynamical evolution is important but unfortunately is not described or shown well enough.

I have used tracer correlations extensively and appreciate their value but it took me several readings to understand all of the features described in Section 5. This was due to a combination of not describing all of the features well, not showing the changes in the correlations clearly enough and not giving the reader enough motivation up front to make the effort to follow the description. Tracer correlations are not widely used and understood, even though they are powerful indicators of transport features. Extra help in guiding readers through this section is necessary if you want them to understand what you have done and how useful it is. Consistent translation between physical space and tracer correlation space is required throughout this section.

There are many grammatical errors and I have attempted to list the most obvious ones below. This made the paper difficult to understand in sections. I would suggest the authors perform a detailed grammar review before the paper is resubmitted.

Overall the paper describes interesting work and I suggest it is published after revision of Section 5 and grammatical improvements are made.

We totally agree with referee that the difficulty in reading section 5 arises from lack of translation between tracer space and physical space and a too high density of information without proper guidance in text. To improve this, we revised the paper in following two ways:

1) One schematic (new Fig. 1) was added into introduction. This figure and its corresponding discussion will give the readers the background of tracer- tracer correlations before further in depth analysis.

2)Section 5, as the main concern of the reviewer, is rewritten. Four subsections are included in section 5: N₂O-O₃ correlations: MLS versus CLaMS; tracer and physical space; isentropic mixing versus cross-isentropic transport; impact of chemistry. Following the recommendation of the reviewer, we combined the original Figure 7 and Figure 9 as the new Figure 9 to get an easier comparison between MLS and CLaMS. To achieve the consistent translation between physical space and tracer correlation space, the Figure 8 is extended: the physical space interpretations are

added to the corresponding tracer correlation. Accordingly, the text of Section 5 is re-organized and revised.

Specific comments

- Pg. 4384, line 8: *using tracer-tracer correlations is not really a “technique”. I would remove that word and just say “tracer-tracer correlations and by. . .”*

Changed, see Pg.1 Line 6.

- Pg. 4385, line 26: *insert “the” before “Pacific”*

Insert.

- Pg. 4386, line 2: *remove “the” before “recent” and “10” after “recent”*

Changed, see Pg. 2 Line 56.

- Pg. 4386, line 8: *change to “, which describes” after “advection”*

Changed, see Pg. 2 Lines 65-66.

- Pg. 4386, line 9: *“along a 3D”, insert commas after “trajectory” and after “mixing”. Add “which parameterizes”*

Changed, see Pg. 2 lines 65-67.

- Pg. 4386, line 10: *remove “the” before “air”*

Article is removed.

- Pg. 4386, line 21: *remove “the” before “models”*

Article is removed.

- Pg. 4388, line 9: *change “at” to “on”*

Changed.

- Pg. 4388, line 14: *add “the” before “generation”*

Added.

- Pg. 4388, line 16: *add “the” before “disturbance”*

Added.

- Pg. 4388, line 22: change “during” to “over”

Changed.

- Pg. 4388, line 25: change “at the end” to “in turn”

Changed, see Pg. 6 line 165.

- Pg. 4391, line 12: change “on” to “in”

Changed.

- Pg. 4393, line 22: change “altitudes” to “altitude”

Changed.

- Pg. 4393, line 23: add “mid-latitude” before “surf zone”

Changed.

- Pg. 4394, line 7: add comma after “easterlies”

Changed.

- Pg. 4394, line 27: Remove “Complementary,” and change “illustrate” to “illustrates”

Changed, see Pg. 10 line 331.

- Pg. 4395, line 1: change “vertex” to “vortex”

Changed.

- Pg. 4395, lines 2 and 3: change “days” to “day”

Changed.

- Pg. 4395, line 24: remove “and” before “after”

Removed.

- Pg. 4396, line 3: add “shown” before “although”

Added.

- Pg. 4396, line 24: add “of” before “picture”, remove “does” and change “respond” to “responds”

Changed, see Pg. 12 lines 380-381.

- Pg. 4396, line 29: change “Another important point is” to “This would help provide”

Changed, see Pg. 12 line 385

- Pg. 4397, line 1: add “of” before “how” and remove “itself”

Changed, see Pg. 12 line 385.

- Pg. 4397, line 5: change “much” to “even” and add “so” after “more”

Changed, see Pg. 12 line 389.

- Pg. 4397, line 9: I’d suggest removing “technique” and just saying “correlations”

Changed, see Pg. 12 lines 392.

- Pg. 4397, line 12: remove “the” after “shows”, change “correlation” to “correlations”, remove “the” before “MLS” and remove “a” before “probability”

Changed, see Pg. 12 lines 396-397.

- Pg. 4397, line 14: change to “data cover the NH eq. latitudes. . .”

Changed.

- Pg. 4397, lines 20-21: change to something like “two stronger branches and one weaker branch of N2O-O3 correlations. . .”

Changed, see Pg. 12 lines 403-404.

- Pg. 4397, lines 22-23: end sentence after “Fig. 7a“. New sentence starts “These branches describe. . .”, change to “. . .within the polar vortex, the surf zone and the tropics. . .”

Changed, see Pg. 12 line 405.

- Pg. 4397, line 25: remove “the” before “tracer-tracer”

Removed.

- Pg. 4398, line 1: remove “the” before “tracer-tracer”

Removed.

- Pg. 4398, line 2: change “Reversely” to “Conversely”

Changed.

- Pg. 4398, line 3: change “at the same time” to “following the MW”

Changed to “in the time period after the MW”.

- Pg. 4398, line 5: change “will be” to “is”

Changed.

- Pg. 4398, line 13: change “Reversely” to “Conversely”

Changed.

- Pg. 4398, lines 20-25: *This paragraph should be rewritten or at least another sentence or two added to make it more clear what you are describing. In line 20 I would change to “. . . range of potential temperatures are considered. . .”*

This paragraph was rewritten.

- Pg. 4399, lines 14 and 15: remove “Similar”, remove “same”, add comma after “before”

This paragraph was rewritten according to the new combined Figure 9.

- Pg. 4399, lines 16-22: *Need to more clearly explain why the tropical latitudes are excluded in the correlation plots. Also, should explain more clearly that the tropical correlation is seen in the non-mixing run because of the tropical air that has physically moved into the mid-latitudes and not been mixed. It helps to relate physical space to tracer correlation space as clearly as possible so readers can translate between the two more easily.*

The new Figure 9 is marked with the latitude range more clearly. And the Subsection 5.3.1 “transport 415 from the tropics” explain this point.

- Pg. 4400, lines 1-2: *This is really for the whole paragraph but you need to more clearly show in Figure 9 how the non-mixing correlations cannot be reconciled with observations. I have more suggestions on how to change the figures below.*

We follows the suggestions to improve the figure.

- Pg. 4400, line 3: change “trajectories” to “trajectories”

Changed.

- Pg. 4400, lines 8-10: *The isentropes move upward in tracer space but not in physical space. This is another place where you should be clear so that it is easier to translate between what is happening in physical vs. tracer correlation space.*

We agree this sentence is not clear. So we add “in tracer space” to address it is not physical vertical moving of isentropes. See Pg. 15 Lines 484-486. And the Figure 1 (b) added in introduction would also prepare the readers about the interpretation of upwelling and downwelling in tracer space.

- Pg. 4400, lines 16-28: *This discussion of Figure 10 and how descent affects the tracer correlations should be moved after the discussion of Figure 9a1-c1 on Pg. 4401. The best flow of the discussion would be to first compare Figure 7 to Figure 9a1-c1 since those correlations should be the most similar. I would also strongly suggest that you combine Figure 7 with Figure 9 so that it is easier to compare the MLS correlations with the CLaMS correlations.*

We totally agree. The Figure 7 and 9 were combined, and Section 5 is re-organized.

- Pg. 4401, line 1: *What does “very similar” refer to here? Similar to what?*

The original statement “very similar” refers to the similarity of MLS tracer- tracer correlation with CLaMS tracer- tracer correlation. Since the Figure 7 and 9 are combined and text is revised, please check the text of Section 5.1.

- Pg. 4401, lines 7-8: *Not sure what is meant by the mid-latitudes “do not undergo further descent”. There is descent in the mid-latitudes all winter is not there?*

The text here brought some misunderstanding. The “do not undergo further descent” we meant is: the APs spread from polar region to mid-latitudes still stay inside the considered vertical range even with persistent descent during winter. So we changed the sentence accordingly. See Pg. 15 Line 512.

- Pg. 4401, lines 11-12: *The effects mentioned here are not well discerned in Fig. 9. The changes in the correlations are subtle on plots of this size so lines need to be added to better compare between them. You could add the three main branches in Fig. 9a1-c1 onto 9a2-c2. You could add the main branches in MLS onto Fig. 9a1-c1. Something like this needs to be done to make the subtle shifts in the correlations more obvious.*

For better comparison between CLaMS run with and without mixing and to emphasize the effect of mixing, the dashed black curves were added to Fig. 9 (a2-c2) which show the estimated N₂O-O₃ correlation line from the case without mixing (i.e. from a3-c3). Reversely,

dashed lines in Fig. (a3-c3) are schematically transferred correlation branches from CLaMS with mixing (i.e. from a2-c2).

- Pg. 4401, line 14: change “(by far more)” to “mostly”, “mid-latitude” is misspelled, add “some” before “tropical”

Changed. See [Pg.16, L.519-520](#).

- Pg. 4401, lines 19-21: Again, this slight shift is too hard to see in the figure. Need to add some lines to help guide the reader.

The corresponding correlation lines are added in Figure 9. The dashed black curves in (a2-c2) show the estimated N2O-O3 correlation line from the case without mixing (i.e. from a3-c3). Reversely, dashed lines in (a3-c3) are schematically transferred correlation branches from CLaMS with mixing (i.e. from a2-c2).

- Pg. 4402, lines 2-5: This sentence is too long, needs to be broken up. Also, what are the “highest values” that are referred to here?

The long sentence has been re-organized. See [Pg. 16 Lines 530-533](#). The “highest values” are referred to **high (increased) values of NOx chemistry**.

- Pg. 4402, line 6: change to “warm winter in 2008/09, few PSCs. . .”, remove “subsequent,”

Changed.

- Pg. 4402, line 21: change “the” to “a”, change “latitude” to “location”

Changed. See [Pg. 16 L.546](#).

- Pg. 4402, line 25: change to “detail similar to Crutzen. . .”

Changed to “ as defined by Crutzen...”.

- Pg. 4403, line 1: remove “other”

Removed.

- Pg. 4403, line 3: change “Contrary” to “In contrast”

Changed. See [Pg. 17 L.556](#).

- Pg. 4403, line 4: change to “a most probable location of”

Changed. See [Pg. 17 L.557](#).

- Pg. 4403, line 8: change “here” to “in this part of the tropics”

Changed. See L. 560.

- Pg. 4403, line 9: change to “investigated whether the”, change “has” to “had”

Changed. See L. 561.

- Pg. 4403, line 23-24: change to “which resulted”, “upwelling through late March”

Changed. See L. 574.

- Pg. 4404, lines 8-9: change to “MW, triggered by”

Changed. See L. 585.

- Pg. 4404, line 10: add “been” after “have”

Changed. See L. 587.

- Pg. 4404, line 20: change “the order of” to “a”

Changed.

- Pg. 4404, line 24: add “us” after “allow”

Added.

- Pg. 4404, lines 26-27: remove “a” before “significant”, add comma after “loss”

Changed. See Pg. 18 Lines 602-603.

- Pg. 4405, line 12: remove “exemplary”

Removed.

- Pg. 4405, line 15: change to “correlation, which disappears. . .”

Changed. See Pg. 18 L. 618.

- Pg. 4405, lines 21-22: change to “is it the N₂O or the. . .”, “an impression of how. . .”

Changed. See Pg. 18 Line 623.

- Pg. 4406, lines 1-4: remove “Complementary,” end first sentence with “are also used.” Then start with “An ACE profile crossed the potential temperature surfaces. . .on this day (red circles are the profile. . .”. Remove “as well as the corresponding CLaMS profiles before and after applying the averaging kernel”

Changed. See [Pg. 19 Lines 630-632](#).

- Figures 7 and 9 should be combined so that the MLS correlations are on the top row and it is easy to compare among all the correlation plots. Clearly label on the left side of each row that it is MLS, CLaMS with mixing and CLaMS without mixing. Add correlation lines from similar plots such as was done in Fig. 11 for easier comparison.

Figures 7 and 9 have been combined as Figure 9 with side-labels. The correlation lines are added to middle and bottom panels derived from each other. Please see [Figure 9](#) and the corresponding text in [Section 5.1](#).

- Figure 12: Why is the bottom right plot so different from Fig. 9c1 or 9b1? Those plots are all from a similar time period and the plots in Fig. 9 do have a polar correlation.

It is because the Fig. 9 (last version) used all the APs of CLaMS in certain window while Figure 12 (last version) used the CLaMS APs interpolated to the corresponding MLS observations. The interpolation is done by collecting nearest neighbor APs to the corresponding observation. Thus, the number of the CLaMS APs in Figure 12 is much less than Figure 9. The detail of the interpolation is written in [Section 3.2](#).