Atmos. Chem. Phys. Discuss.,
https://doi.org/10.5194/acp-2020-1010-AC2, 2021

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Processes influencing lower stratospheric water vapour in monsoon anticyclones: insights from Lagrangian modeling" *by* Nuria Pilar Plaza et al.

Nuria Pilar Plaza et al.

npplamar@upo.es

Received and published: 10 March 2021

1 General comments

We thank the Reviewer for the very thorough and detailed comments which will definitely help to substantially improve the paper. We see the critical, but also very constructive, tone in some of the comments, and we did some extensive work (including substantial extension of the methodology, several additional sensitivity simulations, significant text changes) and think we can finally address all of the comments very well. Below, the reviewer comments are in blue, our replies in black, indicating parts in the

Printer-friendly version

Discussion paper

manuscript with major changes. The major changes in the revised version are:

- Clearer description of the paper goals (effects of small-scale mixing transports on monsoon water vapour), and more appropriate relation of the used methodology to literature. In particular, we made it clearer that the focus is on comparing effects of different processes in sensitivity simulations (with all these based partly on simplifying assumptions) and not presenting a “best simulation case”.
- Added study of effects of supersaturation using sensitivity simulations with varied nucleation barrier (150% vs. 100% relative humidity) and added a new Fig. 3.
- We included effects of convection in the study, as suggested by the Reviewers, and added a discussion of related sensitivities (new Fig. 6).
- An analysis of the robustness of the calculation of the process effect as difference, from new sensitivity simulation VMIX without ice microphysics.
- Improved discussion of air parcel density in the monsoon, based on new sensitivity calculations.

2 Specific comments

#1: One big issue is the influence of individual factors is calculated as the difference between model simulations with and without this factor. For example, using the difference between the water vapor mixing ratio in CIRRUS and CHEM to represent ice effects. However, this value may yield different model designs. E.g., if compare the difference between the experiment VMIX, and the experiment with the same setting as VMIX but do not include the ice microphysics, will the value be the same as the difference between CIRRUS and CHEM experiments? Since the authors are trying to compare the contribution from different factors, more reasonable experiment settings or sensitivity tests would be the comparing STANDARD experiment and the experiments removing individual processes.

Reply: This is indeed a good comment, Thanks! First, we agree it would also be worth considering STANDARD as the reference and differencing from that case. However, as there is a number of existing studies based on pure trajectory approaches, we think that estimating the different effects as additions to such a set-up as reference (here TRAJ) is most useful for other groups.

Second, estimating the effect of ice microphysics is indeed somewhat tricky. In those experiments in which mixing is applied, here SSMIX and VMIX, we must consider the microphysics of ice after the mixing step. The reason behind is that mixing could lead to supersaturation of the air parcel. This situation is explained in Fig. 2b as response to comment #3 from Referee 1.

Considering two air parcels, "A" and "B", that are at the same pressure level and close enough to be mixed into C, the water vapour content of C would be the mean water vapour of A and B. However, the water vapour content of C could be larger (DH2O) than the corresponding 100% saturation conditions (see Fig. 2 in Reply to Reviewer 1. Therefore, mixing has produced a supersaturated air parcel C. With the second call of the microphysics scheme (after the mixing), the water vapour of C is set to saturation, and ice is formed from the water vapour in excess.

We understand the Reviewer's comment that this second application of the microphysics scheme could lead to a higher impact of ice on water vapour in "mixing" experiments. Following her/his suggestions, we have run a new experiment, here called "VMIXnocirrus", with the same setup as VMIX, but without the microphysics of ice. In this new experiment, whenever the water vapour content of the air parcel is above 100%relative humidity, all the water vapour in excess is removed (as in TRAJ). As in the case of "mixing experiments", SSMIX and VMIX, this process is applied twice, before and after small-scale mixing, in VMIXnocirrus.

Figure 1 shows the isolated effects of ice in water vapour at 100hPa between CIRRUS and CHEM (Fig. 1a) and between VMIX and VMIXnocirrus(Fig. 1b). In Fig. 1a the ice microphysics scheme has been applied only once, while in Fig. 1b the scheme has been applied twice, before and after mixing. Clearly, the estimated ice effect increases for the second case (in simulations including mixing), due to calling the scheme two times. However, this increase is spatially rather homogeneous. There are some regions with a slightly stronger water vapour signal, such as the western flank of the Asian Monsoon and the Northwestern Pacific. As these regions are characterized by strong mixing, we think that it is the regional pattern in mixing causing these weak regional structures. (in Fig. 2a as response to comment #3 from Referee 1, we show a schematic situation in which mixing could "help" air parcels to avoid cold minima of the temperature's vertical profile).

In summary, the particular way of differencing to calculate the ice microphysics effect changes the estimated global value (by about 0.2 ppmv, see Fig. 1c), but not much the regional patterns (e.g., moisture anomaly in the monsoon). We note this in the revised version on P10, L295.

#2: The second issue is that the Stratosphere-Troposphere filling experiment simulates closer results to the observation, so it is not clear why all of the previous experiments exploring the influence from chemical and physical processes are based on LTF strategy, instead of directly based on ST-Filling. At least the authors should provide an explanation of why most of the conclusions in this paper are drawn based on LTF stead of ST-filling

Reply: As mentioned already in the response to the previous comment, pure back trajectory (LTF) approaches are very frequently used to study UTLS water vapour. In fact, several studies have used the domain filling technique developed by Schoerbel et. al (2011), here called "LTF" scheme, to study water vapour in the Lower Stratosphere.

Some of the most recent papers are Wang et al. (2019), Schoeberl et al. (2018), Zhang et al. (2016). In those papers, some processes are considered to influence water vapour, apart from freeze-out at the Lagrangian Cold Point. We regard our results most useful if they can be directly applied to those studies, and hence we think it is advantageous to use the pure trajectory approach TRAJ as baseline. In particular, it has never been studied before, how the LTF setup could influence the water vapour results. The comparison between the LTF scheme experiments and the CLaMS full-CTM simulation (STANDARD) here allows addressing this issue. Following the suggestion from the reviewer, we have clarified this in the paper (e.g., P4, L97).

#3: Another recommendation is to add a sensitivity test based on the supersaturation level to the experiments if possible. It may influence the estimation of the influence of ice microphysics. And may also explain the low biased LTF simulation result.

Reply: We agree that this would be a very valuable addition. We have performed a second run of CIRRUS but setting the critical RH barrier for ice nucleation to 150% instead of 100%. Figure 2 shows that considering a higher RH value amplifies the pattern of water vapour at 100hPa, especially in those regions in which ice microphysics are expected to have a stronger impact (e.g., Asian monsoon). As less ice is formed, air parcels can transport more water vapour upward. Besides, a higher critical RH value leads to less water vapour in excess and smaller ice particles. Then, slower sedimentation of the ice particles prevents them from being removed from simulation (in the CIRRUS scheme a sedimentation length is calculated assuming mean spherical ice particles, as explained also in the reply to Reviewer 1 (specific comment L168), and in the revised manuscript (P11, L327). In other words, a larger reservoir of water vapour for future air parcel's excursions into subsaturated regions is available in RH=150% than in RH=100%. case We have included this sensitivity test and a new figure (Fig. 3) in a new section in the discussion in the revised manuscript.

#4: The convection information derived from the ERAi troposphere is not reliable. The grid in ERAi is too coarse to capture deep convections into the stratosphere. Lacking convection is another possible reason for the low biased LTF simulation result. It may also influence the estimation of the influence of ice microphysics.

Reply: As suggested by Reviewer 1 (see major comment #2 there), we have now included a simulation in which the effect of convection is estimated from observed convective cloud top information. We added these results to the revised manuscript to quantify the impact of convection on water vapor in the AMA. The effects of convection are mainly described in the revised manuscript as a new subsection in the Discussion, along with a Figure with our results (P14, L443-481, Fig.3). For further details see also our reply to Reviewer 1 (major comment #2).

#5: The last major issue is about the sensitivity test of water vapor in LTF in section 4.2. The authors conclude that there are many empty bins, or gaps, over the humid regions, and result in underestimation of the water vapor mixing ratio in LTF experiments. The question is if these gaps could be avoided, for example, by initiating air parcels on a denser grid. It seems that having empty bins is an indicator of not enough air parcels.

Reply: A similar comment was formulated by Reviewer 1. See our reply to Rev. 1 (major comment # 4).

3 Technical corrections

Ln 7 - . . .water vapor in that region and including it in the model simulation. . . -Is 'that' means AMA region?

Reply: Done. We have changed "that" to AMA to clarify it.

Ln 153 . . .the water vapor simulated by this experiment corresponds to the Lowest Mixing Ratio (LMR) encountered by each air parcels along its trajectory - Is it an initial h2o mixing ratio or an upper bound of mixing ratio along the path? E.g. the lowest mixing ratio of some parcels may be very high.

Reply: In this experiment, the saturation mixing ratio of each air parcel is computed using Murphy and Koop (2005)'s formula. If during a calculation timestep the air parcel experiences a saturation mixing ratio lower than the actual water vapour mixing ratio, then its actual water vapour value is set to the saturation value (same as in many previous trajectory approaches, e.g., Fueglistaler et al., 2005: Schoeberl et al., 2011). Otherwise, if an air parcel shows mixing ratios higher than the LMR already experienced before, then its mixing ratio is not updated and the LMR remains the same. Therefore, the initial LMR of the air parcels released in TRAJ is the Mixing Ratio computed following Murphy and Koop (2005) which only depends on the temperature experienced by the air parcel, which is interpolated from the reanalysis field, and its pressure. However, we carried out an additional sensitivity test (changing the initial water vapour mixing ratio) to show that final water vapour value is largely independent from the initial value (P16, L488).

Ln 164 the third experiment, CIRRUS. . . - Is the supersaturation level still 100% when considering the ice micro-physics? 100% may not be a realistic level. **Reply:** Schoeberl et al. (2018) performed several experiments to study the impact of tropical convection on stratospheric water vapour, concluding that convection has little effect. However, their results are focused on the analysis of changes in global stratospheric water vapour, with special attention to the winter season, without studying the effect on monsoon regions during boreal summer. More recently, Schoeberl et al. (2019) found that convection in the Asian Monsoon is tied to the highest RHi region consistent with Ueyama et al. (2018), which has been already mentioned in our paper (P3, L70). However, they do not focus in explaining this process but in the TTL boreal winter. Nevertheless, we have changed our sentence to "has not been fully assessed yet." (P3,L77).

Figure A1 how do you calculate the water vapor mixing ratio on 80 hPa in MLS? By interpolation?

Reply: No, the level of MLS used is 82hPa which is very close to 80hPa. We have specified this issue in the Methodology.

Interactive comment on Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2020-1010, 2020.

Printer-friendly version

Discussion paper

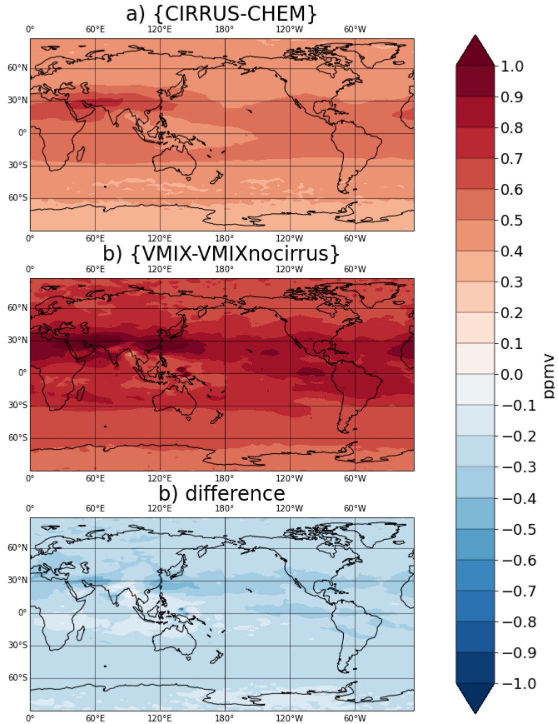

Fig. 1. Isolated ice effects computed as the difference in water vapour between (a) CIRRUS and CHEM, (b) VMIX and VMIXnocirrus and (c) the differences between both distributions at 100hPa during 2005-2007

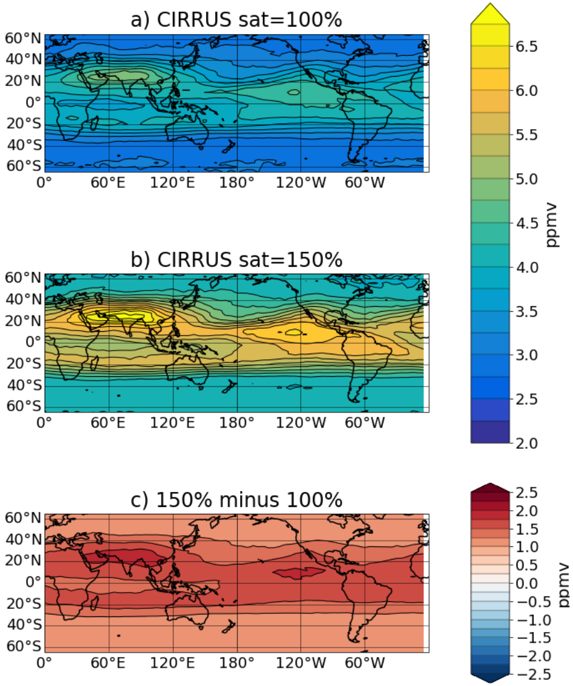

Fig. 2. Boreal summer distribution of water vapour of CIRRUS experiment using (a) RH=100% and (b) RH=150% during 2005-2008 and (c) their differences.

Printer-friendly version

Discussion paper