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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Cirrus and water vapor transport in the tropical tropopause layer: a modeling study" *by* T. Dinh et al.

Anonymous Referee #2

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General comment:

The paper presents a model study investigating TTL cirrus formed by a large-scale equatorial Kelvin wave and concludes that the radiatively induced upward transport of water vapor dominates over the downward transport by microphysical processes.

The topic of the paper is of high interest, it is well structured and written and also fluently to read. Nevertheless, I recommend it for publication in ACP only after major revisions. I will explain this assessment in the following.

Though the principal concept of the study is sound, only one possible scenario of cirrus formation and evolution is simultated. The results are then compared with observations, concluding that the microphysical properties of the simulated cirrus agree reasonably well with the observations. I feel that this is a weak point of the study, since especially the initial high ice crystal numbers does not match the observations (see specific comments). The results of the paper would be much more convincing and robust if sensitiviy studies would be performed varying critical parameters as the vertical velocity and the deposition coefficient of water vapor on ice and thus producing a range of initial ice crystal numbers matching the observations. For more details see the specific comments.

Specific comments:

(in order of appearance in the text)

1. **Page 10730, lines 12-14 (Abstract):**
   'The net direction of transport is determined by the relative magnitudes of the upward advection of water vapor and the downward transport associated with microphysical processes.'

   Please insert already here a short statement on the result of the study.

2. **Page 10730, lines 21ff:**
   I miss the reference (and discussion) of Schiller et al., 2009, ACP.

3. **Page 10731, lines 18-21:**
   '... horizontal transport over this region leads to freeze-drying of the air to a very low water vapor mixing ratio. This hypothesis helps to explain why the stratosphere is drier than the saturation water vapor mixing ratio indicated by the mean tropopause temperature.'

Do you mean that the stratosphere is drier since the saturation water vapor mixing ratio is higher in the stratosphere (due to the higher temperature) than in the TTL? Please explain.

4. **Page 10735, lines 5-6:**
   'Ice nucleation J is based on the formula for homogeneous freezing derived experimentally by Koop et al. (2000).'

   In the last years, it is found that the ice crystal numbers in the TTL are much lower than expected from homogeneous ice nucleation theory (McFarquhar et al., 2000 Thomas et al., 2002, Lawson et al., 2008, Krämer et al., 2009, Jensen et al., 2010).

   See also comment 8.

5. **Page 10735, lines 7-11:**
   'The deposition coefficient of water vapor on ice is assumed to be 0.01, which is larger than the experimental value suggested by Magee et al. (2006) but smaller than those suggested by cloud modelers (e.g. Kay and Wood (2008)). Sensitivity of our model results to the deposition coefficient will be discussed in a subsequent paper.'

   The sensitivity of the ice crystal number on the deposition coefficient of water vapor on ice is quite large (see e.g. Gensch et al., ERL, 2008). I think it would be better to show the sensitivity of the model results to this already here.

6. **Page 10738, line 9:**
   'For this simulation, we set w_0 *=1.8 mm* s^{-1}*, ... '*

   How did you derive this value? It seems very slow to me.

7. **Page 10739, lines 10-12:**
   'The amplitude of the temperature perturbations near the tropopause is 2.0 to 2.5

   K in this simulation. Temperature perturbations in Kelvin waves were observed by Immler et al. (2008) to be up to 8 K, but typically 2 to 3 K.'

   What is with small scale temperature perturbations caused by gravity waves? As far as I know they are believed to be a major source of cirrus clouds in the TTL (see e.g. Jensen et al., 2010, ACP)?

8. **Page 10743, line 25-27:**
   'During the formation of the cloud, ice nucleation followed by ice growth quickly reduces the supersaturation ratio Si within the cloudy region from 0.6 (ice nucleation threshold) to close to zero (Fig. 5b).'

   The quick reduction of the supersaturation ratio Si (Fig. 5b) is linked to the high ice crystal number (Fig. 6a). Typically, in the TTL at low temperatures and low ice crystal numbers high supersaturation can persist over a quite long time (resulting in a broad RH_{ice} frequency distribution). In Krämer et al., ACP, 2009 the mean ice crystal number in this tempearture range is 5 L^{-1}, in your study the initial value is around 100 L^{-1}. I am wondering how realistic the study is, especially when the gas phase water remaining in the presence of cirrus is critical.

   Also here (as in comment 4) I miss sensitivity studies showing a range of possible scenarios, in particular those showing a lower ice crystal number and respective slow decrease of gas phase water.

9. **Page 10744, line 17:**
   '4.3 Consistency with observations'

   I suggest to change the title to **'4.3 Consistency with observations and other studies** since also model studies are discussed.

10. **Page 10745, line 18-19:**
    'Observed IWC ranges from just 10 mg m^{-3} *(Lawson et al., 2008) up to 10 mg* m^{-3} *(McFarquhar et al., 2000).'*

Please compare also with the IWC's from the climatology of Schiller et al., 2008, JGR.

11. **Page 10745, line 23ff:**
    'The average diameter of ice crystals is between 7 μm and 10 μm throughout most of our simulation (Fig. 7b). This is consistent with ice crystals of approximately 10 μm in diameter in TTL cirrus observed by Voigt et al. (2007) over Brazil, and Peter et al. (2003) over the western Indian ocean. On the other hand, Lawson et al. (2008) reported larger ice crystals with an effective diameter of approximately 18 μm for a TTL cirrus over the tropical Eastern Pacific.'

    In the study of Voigt et al. (2007), only measurements up to about 20μm are performed (see Figure 8) and it represents only one case. A much broader study of TTL and stratosphere cirrus is presented by DeReus et al., ACP, 2008. I suggest to show that instead.

    I also suggest to include the study of Krämer et al., ACP, 2009 in the discussion. They show frequency distributions of mean ice crystal sizes over the whole cirrus temperature range which agree well with your simulations for TTL temperatures.

12. **Page 10746, lines 4-9:**

    a) *However, the number of larger ice crystals in the simulated cloud is significantly smaller than observed.*

    This could be due to the initial high number of ice crystals and rapid reduction of RH$_{\text{ice}}$, hindering the ice crystals to grow to larger sizes.

    b) *'Nevertheless, because the observed number of crystals larger than 20 μm is small (note the logarithmic scale in Fig. 8a), they do not contribute significantly to the bulk properties, such as the average radiative heating rate, IWC and ice number concentration.'*

    The ice crystals larger than 20 μm can contribute significantly to the IWC, in fact in most cases the IWC is dominated by those crystals, even if their concentration is small.

    Please discuss both points in the paper.

13. **Page 10747, lines 24-28:**
    ' Another essential difference between Jensen et al. (2011)'s simulations and ours is the number of ice crystals nucleated when the cloud is formed. Jensen et al. (2011) tuned their heterogeneous nucleation scheme so that the number of ice crystals nucleated is 60 l^{-1}, following measurements by Lawson et al. (2008). On the other hand, homogeneous nucleation in our model produces an average number of 200 l^{-1} up to a maximum of 5000 l^{-1} (Fig. 6a).'

    Then I would say that the study of Jensen et al. (2011) is more realistic! Please discuss that.

14. **Page 10748, lines 1-4:**
    'In our simulation, more ice crystals are nucleated, hence sedimentation of smaller ice crystals occurs at a slower rate, which allows sufficient time for the radiatively induced dynamics to develop.

    Same comment as for the last point.

15. **Page 10748, lines 7-13:**
    'In our simulation, although many ice crystals (on the order of 10^2 l^{-1} to 10^4 l^{-1}) nucleate homogeneously, in less than a day the number is reduced to values comparable to or smaller than 100 l^{-1} (Fig. 6a).'

    The initial number of ice crystals strongly affects the gas phase water vapor evolution, particularly in TTL cirrus (see also comments 4 and 8). Thus, I do not see that the argument that the number of ice crystals reduces after one day enhances the reliability of the study.

... 'Hence we argue that homogeneous freezing cannot be ruled out as a viable nucleation mechanism in the TTL.

In case homogeneous freezing would produce a high number of ice crystals during cirrus formation, which would reduce after about a day to the observed numbers, than these high numbers would also appear in the observations. So I also do not see the argument for homogeneous freezing.

16. **Page 10752, lines 9-11:**
    'The ... microphysical properties (... ice number concentration) of the simulated cloud agree reasonably well with observations.'

    I have a problem with this statement, to my opinion the ice number concentrations are too high.

    That leads me to the question: if the cloud microphysical properties of the simulated cloud is not right, how solid are the results?

    I suggest to perform sensitivity studies (as I stated before) to estimate the magnitude of the effect of cloud microphysics to the stated results:

    Page 10753, lines 12-16: *'Under the conditions specific to our simulations, the radiatively induced upward transport of water vapor dominates over the downward transport by microphysical processes. The net result is upward transport of water vapor, which is equivalent to hydration of the lower stratosphere.'*

17. **Page 10753, lines 21-22:**
    ' The sensitivity of model results to the relative humidity of the surrounding air will be discussed in a subsequent paper.'

    Following my previous comment, I also suggest to include this sensitivity study into the paper.

References:

- DeReus et al. (2008): Evidence for ice particles in the tropical stratosphere from in-situ measurements, ACP.
- Gensch et al. (2008): Supersaturations, Microphysics and Nitric Acid Partitioning in a Cold Cirrus observed during CR-AVE 2006: An Observation-Modeling Intercomparison Study., Environ. Res. Lett. (ERL).
- Krämer et al. (2009): Ice supersaturations and cirrus cloud crystal numbers, ACP.
- Schiller et al. (2008): Ice water content of Arctic, midlatitude, and tropical cirrus, JGR.
- Schiller et al. (2009): Hydration and dehydration at the tropical tropopause, ACP.
- Thomas et al. (2002): In situ measurements of background aerosol and subvisible cirrus in the tropical tropopause region, JGR

Interactive comment on Atmos. Chem. Phys. Discuss., 12, 10729, 2012.