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# *Interactive comment on* "Impact of major volcanic eruptions on stratospheric water vapour" *by* M. Löffler et al.

**M. Löffler et al.**

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We thank referee #1 for the quick report. Here are our replies to the comments:

- *This paper focuses on a question of interest (at least to me) and the results look reasonable.*

  Reply: Yes, indeed the results are reasonable. And as we discuss, they are consistent with earlier results.

- *That said, the experimental set-up does not seem robust and I cannot recommend publication until that is fixed. Let me expand on this main criticism. The authors have two runs of their model – one version has the volcanic cloud in*



*it, while the other does not. The difference between these models is then interpreted as the impact of the eruption. Both models, however, are nudged to ECMWF-interim reanalysis, which has the impacts of the eruption in it. Because both versions of the model or being nudged towards a reanalysis that is perturbed by the volcano, it is not clear to me how to interpret the actual difference between these model runs.*

  Reply: It is a common misunderstanding that a nudged chemistry-climate model (CCM) is equivalent to a chemistry transport model (CTM). This is not the case, since – depending on the nudging procedure – the nudged CCM develops its own physical state on sub-synoptic scale. Therefore, our model setup is very well suited for the analysis. As we state on p. 34411 line 24 ff.:
  "The Newtonian relaxation (nudging) of the prognostic variables, divergence, vorticity, temperature and the (logarithm of the) surface pressure is applied in **spectral space** with a corresponding relaxation time of 48, 6, 24 and 24 h, respectively. The sea surface temperatures (SSTs) and the sea ice concentrations (SICs) are prescribed every 12 h. **A nudging of the "wave zero" (i.e., the global mean) temperature (T) is, however, excluded. This allows a temperature response of the model.**"

  This means: The nudging is applied such that the large(r than synoptic) scale **patterns** correspond to those of ERA-Interim, but not the absolute temperature. Otherwise, the shown water vapour response on altered temperature would not be visible. Excluding the (level-dependent) global mean of the temperature (i.e., wave zero in spectral space) allows the absolute temperature to react (and propagate) as effect of the additional heating caused by the volcanic aerosol. In other words: the additional volcanic aerosols changes the absolute temperature, which then affects the hydrological cycle (cold-point temperature, convection, evaporation, etc.).

  The interpretation of the results is as follows: We have two nudged simulations, both incorporate effects of the volcanoes as they are represented in the nudging data: effect on the SSTs (but not on the land surface), effect on the wind systems, effect on the temperature patterns (the local effect of temperature increase due to the aerosols is not visible in the nudged data!). These effects cancel out after subtracting the results of one simulations from the results of the other.

The concept is a sensitivity study, where we perturbed one simulation with the aerosol clouds of volcanic eruptions. The effect in the perturbed simulation is a strong local heating in the stratosphere and subsequent increase in stratospheric water vapour. This aspect (impact) is studied in detail by a comparison with the unperturbed simulation. The analysis of the difference between the 2 simulations gives us information on how the vertical temperature profile is modified by the heating and how the distribution of water vapour changes compared to a unperturbed simulation. Nudging keeps the model meteorology towards what is really observed, but does not prescribe the mean temperature.

The results do not give us new information about the impact of the eruptions in terms of cooling of SSTs, because this information is already in the prescribed SST.

We will add a clarifying paragraph to the description of our methodology in the revised manuscript.

- *To their credit, the authors recognize this limitation, but this seems much more severe than they seem to recognize. For example, around line 25 of p. 34412, they state that the hydrological cycle is "free running". That is very misleading. Stratospheric water vapor is determined by the cold point in the TTL – and temperature is nudged towards the reanalysis. So the key parameter they are investigating, stratospheric water vapor, is indeed impacted by the nudging. In the end, I do not believe this paper should be published until the authors can better characterize the difference between the runs.*



Reply: The referee is right in stating that the cold point temperature determines (to the largest extend) the amount of water vapour entering the stratosphere. However, in our case, the absolute temperature (including that at the cold point) is NOT influenced by Newtonian relaxation, because we exclude "wave-0" in spectral space (see above). Thus, the cold point temperature is affected by the volcanic aerosol and this in turn affects the water vapour. Moreover, non of the hydrological cycle variables is nudged. The setup is such that the large scale dynamics between both simulations is similar, but the hydrological cycle reacts on the altered temperature induced by the volcanic aerosol in the stratosphere. Furthermore, the free running (of freely responding) hydrological cycle is mass conserving.

- *Other comments: 1) I found the paper difficult to read. The grammar was fine – I'm referring more to the overall style of writing and sentence structure. I don't have any specific suggestions other than that the authors should spend some time crafting the text.*

  Reply: This is unfortunately a very vague statement. Although, none of us is a native English speaker, neither our institutional internal referee, nor the editor doing the quick-access review complained about the language. Maybe it is simply a matter of taste. Nevertheless, we appreciate specific suggestions for improvement.

- *2) One recent paper on this subject not cited is Dessler et al., (2014), Variations in stratospheric water vapor over the past three decades, J. Geophys. Res., 119, 12,588 – 12,598, doi: 10.1002/2014JD021712.*

  Reply: Thank you very much for pointing this out. We will check the reference and add the citation, where appropriate.

- *3) Section 3.3 argues that tropospheric water vapor increased after the eruption. That neither makes any physical sense nor does it agree with previous research.*

*Given that the eruption cools the troposphere, you would expect tropospheric humidity to decline, which has been seen in observations, e.g., by Soden et al. (2002), Global cooling after the eruption of Mount Pinatubo: A test of climate feedback by water vapor, Science, 296, 727–730.*

Reply: We agree that we have to explain some points more clearly. Volcanic aerosol has two effects on temperature: Warming of the stratosphere due to long wave radiation effects and cooling of the surface and thus the troposphere due to shadowing of the surface in the short-wave radiation. The latter leads to a global cooling. Both effects are in part due to the nudging and the prescribed SSTs already incorporated in both simulations. Both simulations show a cooling of the lower troposphere and subsequent lower water vapour concentrations after the eruption of Mt. Pinatubo. This is in accordance with observations, e.g. Soden et al. (2002) as stated by the referee.

However, the warming of the stratosphere partly offsets the water vapour decrease by stabilising the vertical temperature profile with subsequent lower convective activity and precipitation. Our experiment design isolates the effect of the aerosol heating in the stratosphere on the atmosphere.

We will clarify this in our discussion of the revised manuscript.

- *4) In Section 3.2, the authors turn to the "stratospheric fountain" hypothesis to explain the volcanic impacts on the monsoon regions. That is a weird argument because (to the best of my knowledge) nobody views the stratospheric fountain as a legitimate way to think about troposphere–stratosphere exchange.*

  Reply: Yes, this is indeed wrong as it stands. It was simply used to refer to the role of the specific region. We will remove this statement, since it is not needed for our analysis.

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