Review of “A mass-weighted atmospheric isentropic coordinate for mapping chemical tracers and computing inventories“ by Yuming Jin et al., submitted to ACP

This study introduces a new isentropic coordinate based on the dry air mass below a surface of equivalent potential temperature. The goal is to better constrain the seasonal cycle of long-lived chemical species and to compute inventories of such atmospheric constituents. The first part of the manuscript is about how to calculate the dry air mass below a surface of equivalent potential temperature $M_{\theta e}$ using reanalysis data. $M_{\theta e}$ is then used as a new coordinate, replacing latitude, first to analyze the seasonal cycle of ΔCO2 (detrended CO2 using the time series of CO2 from the Mauna Loa Observatory) and second to calculate mass weighted averages of ΔCO2 on hemispheric scales using observational data from two recent airborne missions (Atom and HIPPO).

Traditionally, tracer distributions are viewed in geographic coordinates. However, these coordinates do not necessarily reflect the dynamics and processes which determine the tracer distributions and as such potentially add a dynamically induced variability to the tracer distribution. Alternative coordinates taking into account dynamics and/or so called transport barriers (or better said which rely on a physical rather than on a geographical basis) are a useful tool to better describe the distribution of and constrain the variability of trace species. Such coordinate transformations have for instance been used to reduce dynamically induced variability in the stratosphere (equivalent latitude instead of latitude as horizontal coordinate, e.g., Butchart and Remsberg, 1986), at the tropopause (tropopause-based instead of surface-based vertical coordinate, e.g., Birner et al., 2002), or in the Arctic (Polar Dome relative horizontal coordinate, e.g., Bozem et al., 2019). It is also the major subject of a SPARC activity, OCTAV-UTLS to reduce tracer variability in the upper troposphere and lower stratosphere (https://www.octav-utls.net/). This study adds a novel coordinate to the suite of physically based coordinates to study tracer distributions in the atmosphere and is well suited for publication in ACP. The figures are clear, the line of thought is mostly clear to me, the language is very understandable. I generally recommend publication in ACP. I mainly have several minor comments which reflect my feeling that at some points the discussion in the manuscript could provide slightly more information and which the authors might consider for a final publication.

Comments

- I think the introduction could provide a bit more information on the benefit of using coordinates based rather on physical than on geographical means, slightly following what is mentioned in the paragraph above.
- One question which came to my mind is about the time scales for which this coordinate may be applicable. It is stated that $M_{\theta e}$ follows the synoptic distortions but is almost constant with respect to the seasonal cycle. So, would you then conclude that it is not applicable on the synoptic time scale? Or asked differently, is there a sort of a lower time scale limit?
- L74-77: From my point of view the mass integration which is currently in the supplement coulld be part of the main manuscript, since it is the central aspect of the first part of the manuscript. And about the mass integration, the upper boundary has only been introduced because you wanted to study the seasonal cycle of the tropospheric CO2, right?. So, let’s say, if I want to study a distribution of species in the upper troposphere and lower stratosphere, the upper boundary would not be needed anymore (also surfaces of Θ_e become “flat” at a certain altitude and as such are an upper boundary).
- Sec 4.1: Just out of curiosity, but have you looked at CO2 in a Θ_e - $M_{\theta e}$ coordinate system to study the seasonal cycle? Just similar to tracer distributions in an equivalent latitude-potential temperature coordinate system.
- L36ff: It is mentioned that M_θ has been used for Atom and HIPPO data. Is there any reference available? Or has it only be used for internal analysis?

- L41: A bit more details at this point between the Linz study and this study would be beneficial for the reader (since potentially, not everyone interested in this tropospheric study might be familiar with the Linz study).

- L42: $M_{\theta e}$ is mentioned here for the first time without being introduced before. This is only the case in the next paragraph.

- Sec 2.1: For each reanalysis, the number of levels is given but no more information. Could you provide at least the altitude/pressure of the top level and potentially, the level list (how much levels are roughly in the troposphere)?

- L72: It could also be mentioned here that the saturation mixing ratio of water vapor is a modified version of Wexler (1976).

- L79: Why did you not simply calculate the PV for NCEP2 data? I have no idea how well ERA-Interim and NCEP2 agree, but I wonder if it would not be better to calculate the PV for NCEP2 for consistency reasons.

- L81: Actually, what is meant with this? Do you refer to regions where pressure is not defined, such as the 850 hPa level over the Himalayan mountains?

- L90: Could you provide the range of Θ_e values for which $M_{\theta e}$ has been calculated?

- L94: For Figure 2, it would potentially be good to add two more panels showing the same as Fig 2a,b but not for the zonal average but for an arbitrary longitude? This would potentially help in the discussion centered around the two branches of the Hadley Circulation (L102ff). I also wonder if a Θ_e vs $M_{\theta e}$ plot for one or more time steps might be beneficial for the reader to get a more comprehensive idea on the relation between the two quantities and the evolution of these quantities with time.

- L96/97: This sentence confuses me. To which degree are they parallel? As stated the seasonal cycle is not similar between the two quantities. Do you mean that an $M_{\theta e}$ surface between two Θ_e surfaces is always parallel to these surfaces?

- L106-108: Is the displacement related to the monsoon circulations over the NH, in particular to the Asian monsoon?

- Discussion about Fig.4 : Are the fractions shown in Fig 4 constant with time?

- L122: Why do you focus on 2009? Has this year been randomly picked?

- L123: Is there a known reason why MERRA2 has this low bias? Did you check for differences in the temperature field (i.e., difference in potential temperature) and/or water content?

- Sec. 3.3: Just a note, ERA-Interim also has temperature tendencies, but I think they are only available for the forecast stream and on model levels.

- Fig. 6: Is the deviation between the blue and black curves around end of September/beginning of October a re-occurring event? Or is a random deviation for this year? How does this analysis look for other isentropes, maybe a second example could be given in the supplement? And how is the inter-annual variability?

- L177: What is meant with the term dynamic dissipation of energy?

- L191/192: Is there a reference for the NCAR UCATS and the Harvard QCL instruments?

- L193: What is meant with near-surface?

- L199: "." instead of "," after Figure 7b.
  Also the blue-red colorscale could be centered at 0.

- L228: Can you say something about why the airborne CO2 leads by about 10 days?

- L248: Can say something about how well CO2 is mixed on a surface of equivalent potential temperature?

- L256/260: Should the CO2 be ΔCO2?

- L257ff: Can say something about why the inventory is dominated by this $M_{\theta e}$ fraction?

- Figure 11: Please add a horizontal line at 0.

- L264: Which error are you referring to? The difference between the fit and the airborne data? Also would it make sense to add other CO2 data from the NH, eg. from Barrow to have further points for comparison.

- L338: over → below?

References

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