Atmos. Chem. Phys. Discuss., 15, C8867–C8869, 2015 www.atmos-chem-phys-discuss.net/15/C8867/2015/

Interactive comment on "Detecting moisture transport pathways to the subtropical North Atlantic free troposphere using paired H_2O-∂D in situ measurements" by Y. González et al.

Anonymous Referee #2
Received and published: 20 November 2015

This study uses multi-year measurements of the isotopic composition of atmospheric water vapour at two sites on Tenerife to build up climatological statistics on the composition and to infer distinct transport pathways. Nighttime data is used to factor out the influence of diurnal variation in local boundary layer height. Four pathways are identified: 1) from the extratropical upper troposphere over the Atlantic, 2) transport within the Saharan Air Layer, 3) from the subtropical lower troposphere and 4) descent from the upper troposphere into the local boundary where mixing of water vapour into the air-mass is experienced.

Observations of aerosol are used to distinguish the SAL air-mass. The data is of high quality and the deductions made from it were sound. A novel aspect was the use of scatter plots of the observations with water vapour mixing ratio and isotopologue ratio as the axes to distinguish different air-masses and mixing lines between them. The observations were found to be bound approximately by a mixing curve and a curve that represents the theoretical relation of isotopologue ratio to mixing ratio associated with Rayleigh distillation, where an air-mass experiences dehydration by condensation during adiabatic cooling. This approach enables the authors to identify "super-Rayleigh" points with evaporation – either from a warm ocean or from falling rain droplets – since such observations cannot be explained by condensation or mixing.
This paper will be of interest to readers interested in atmospheric transport processes in the subtropics and their influence on humidity and other constituent distributions. I recommend publication subject to minor revisions.

Thank you very much for your help for improving the manuscript. In the following we reply to your comments and hope that we are able to fully address them.

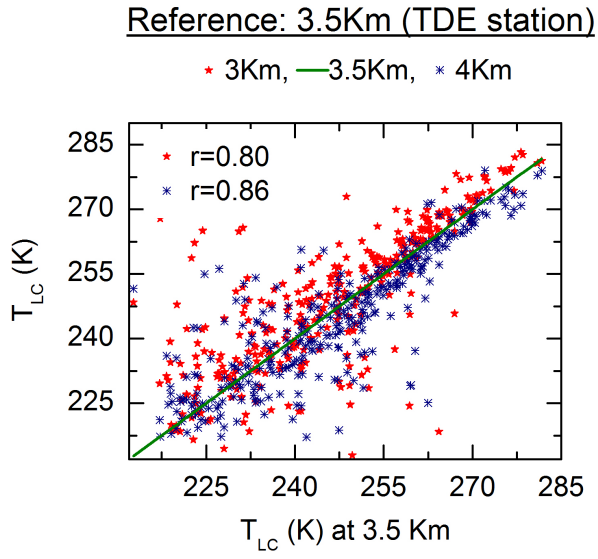
Specific comments

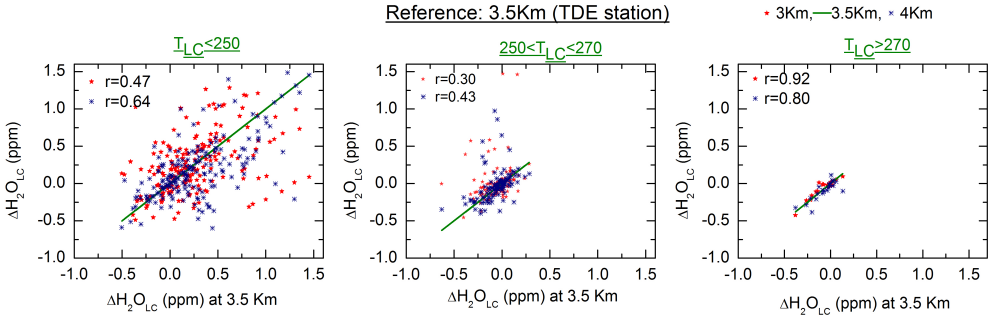
Comment 1: The abbreviation "TIL" has been used by several authors in the last decade to refer to the "tropopause inversion layer" and I am not aware of this abbreviation being used before for "temperature inversion layer". Since it is not used later, I recommend removing this abbreviation.

Answer to Comment 1: The abbreviation has been removed from the text.

Comment 2: trajectories were released from points “at the elevations of the IZO and TDE stations”. You need more detail here because the very tall volcano on Tenerife (where the stations are located) will not be well represented in the model used to produce the GDAS1 analyses. Are the trajectories released at the height above sea level of the actual stations? Or are they released at the pressure observed at the stations (time-dependent)? Since the mountain will be much lower and smoother in the analyses than reality, this makes a difference. If height ASL is used, the trajectories will in effect be far from the ground of the model which will have a strong influence on wind speed and direction. If observed pressure is used, the winds may be more consistent with the surrounding winds above the sea (at the same pressure level). However, again the trajectories will be far from the model orography. A 3rd alternative would be to release at 10m above the model orography at each station location, but I doubt this would work well since the mountain outcrops from the marine boundary layer as indicated in Fig.1.

Answer to Comment 2: In our case, the trajectories are released at the height above sea level of the stations. We tested the uncertainty we could have in the representativeness of our backward trajectories by looking also in the backward trajectories released 500m above and 500m below. And we calculate for all trajectories the parameters T_{LC} and $\Delta H_2O=\log(H_2O_{t=0})-\log(H_2O_{LC})$.
For instance, for TDE we correlate the parameters as obtained at 3500 m (altitude of the site), with the parameters as obtained at 4000m (blue stars in the following figures), 3500m (green diagonal line) and 3000m (red stars). The uncertainty test was carried out with 3 years of back-trajectories (2012-2014). The tests for T_{LC} and ΔH_2O are shown in the two figures attached below. The Pearson’s coefficients obtained for T_{LC} and ΔH_2O (for each of the three T_{LC} categories) are shown in the figures.





The scatter in the plots documents the uncertainty in the representativeness of the T_{LC} and ΔH_2O as used in our study. There are two different reasons for a not perfect representativeness: First, there is an uncertainty in the trajectories, which is the larger the longer the trajectory. Second, the model does not well resolve the fine structured topography of Tenerife, which might affect the flow of airmasses and already the height attribution of the trajectories might be incorrect.

We agree with the referee that the representativeness of the T_{LC} and ΔH_2O parameters is not perfect. However, we think that our approach provides a reasonable first order insight into the airmass history. Furthermore, we again would like to point out that we work with nighttime data (midnight – one hour after sunrise). During that time the atmosphere above the island is rather stable and local effects (not resolved by the model) should by far be less important than during daytime. That is we think that the airmass recorded during nighttime at Teide corresponds to air traveling over the ocean around the island at very similar altitudes and the scatter as seen in the above figures obtained for altitude differences of as large as +/-500m might overestimate the actual uncertainty.

These Figures and the discussion will be inserted in the revised manuscript in form of an Appendix: “Discussion on the reliability of the used T_{LC} and ΔH_2O parameters”.

Comment 3: Sections 3.1 and 3.2. I would like to see more physical discussion on the Rayleigh distillation curve. Why does dD decrease so rapidly with water vapour mixing ratio? Also, how do you derive your mixing curves? A brief explanation is warranted for their shape. Usually if two distinct air masses are mixed then tracer-tracer scatter plots form a compact straight line. Would it be more straightforward to use [HDO] as one of the axes rather than dD=1000([HDO]/(RV*[H2O])-1)?

Answer to Comment·3:

a) Rayleigh distillation curve:
For a Rayleigh process the isotopologue ratio $R=HDO/H_2O$ and the water mixing ratio $[H_2O]$ are related by (Dansgaard et al., 1964):
$dR/R = (\alpha(T)-1)*d[H_2O]/[H_2O]$
This is equal to:
$\ln(R) = (\alpha(T)-1) * \ln[H_2O]$
Since furthermore $\ln[R] \approx \ln[VSMOW] + dD/1000$ it is:
$dD \sim (\alpha(T)-1) * \ln[H_2O]$

This means that dD is strongly decreasing for low mixing ratios.

b) Mixing curves:
For a 50/50 mixing of two water masses the H2O and HDO mixing ratios can be calculated as the average between the mixing ratios of the two water masses. However this is not the case for the ratio. The ratio is mainly determined by the ratio present in the humid airmass. The ratio has to be calculated as the weighted mean (weighted by the humidity levels of each mixing member). Formula see, for instance Noone et al., 2011.

c) Why are dD-versus-H_2O plots useful and HDO-versus-H_2O plots not really…:
HDO and H_2O have the same sources and sinks and their variations are strongly correlated. The differences in their variations are very difficult to observe in HDO-versus-H_2O plots. However, in HDO/H_2O these differences become clearly visible. And in the troposphere the HDO/H_2O ratio can be used to distinguish drying and moistening processes. Therefore we have to the HDO/H_2O ratio with respect to H_2O.

Comment 4: p.27230, l.23: In Fig.8 a dark grey colour marks data with large delta(H2O) (not orange as stated in the text). Need to change text, or perhaps make these points orange in Figs. 8 and 9.

Answer to Comment·4: This has been corrected in the text.

Comment 5: p.27231, l.10: This sentence does not make much sense as it is written. Please re- word.

Answer to Comment·5: The sentence has been corrected in the text.

Comment 6: Conclusions: Are air-masses 2 and 4 indistinguishable in an H2O-dD diagram (Fig.10)? Presumably this is why the aerosol obs. are required to partition them. You need to say something about this.

Answer to Comment·6: As the referee says, in the range of high humidity air masses 2 and 4 are difficult to distinguish. This is due to the fact that a strong mixing with a humid air mass with isotopic composition typical of low levels. The use of aerosol measurements allows distinguishing these two situations and also give new insights of the properties of the air masses accumulate over the Sahara desert and then travel towards the Atlantic Ocean. This is now included in the last second paragraph in the conclusions.

Comment 7: Figs. 2 and 3: The time series are too compressed. I recommend expanding them. Fig.5: needs to be expanded.

Answer to Comment·7: Figures have been expanded.