Atmos. Chem. Phys. Discuss.,
doi:10.5194/acp-2016-1029-RC1, 2017

Atmospheric Chemistry and Physics Discussions

Interactive comment on "A decadal time series of water vapor and D/H isotope ratios above Mt. Zugspitze: transport patterns to Central Europe" *by* Petra Hausmann et al.

Anonymous Referee #1

Received and published: 25 February 2017

General Comments

This manuscript presents a decade of water vapor and δD measurements above Mt. Zugspitze retrieved from mid-infrared FTIR solar absorption spectra. Several data products are retrieved: water vapor profiles with DOFS = 2.8, {H2O, δD} pairs with DOFS = 1.6 and maximum vertical sensitivity at $\sim$5 km, integrated water vapor (IWV), and integrated δD column. The weakly positive IWV trend is found to be statistically insignificant, although consistent with the 2005-2015 temperature increase observed at Mt. Zugspitze, assuming constant relative humidity. Strong seasonal cycles are observed in IWV and the δD column, with summer maxima and winter minima that are attributed to changes in the sea surface temperature of the Atlantic Ocean.

Large ensembles of HYSPLIT back-trajectories are used to identify atmospheric transport pathways to the Central European free troposphere. Low δD columns are found to be associated with the descent of dry air masses from higher latitudes, while high high δD columns are associated with the ascent of moist air masses from lower latitudes. The trajectory analysis is used to show that {H2O, δD} pairs have distinct signatures that can be related to (i) intercontinental transport from North America (TUS), (ii) intercontinental transport from North Africa (TNA), and (iii) stratospheric air intrusions (STI). For TUS events, {H2O, δD} values depend on surface temperature in the source region and the degree of dehydration during updraft in warm conveyor belts. TNA events involve dry convection of boundary layer air, resulting in relatively moist and weakly HDO-depleted air masses, while STI events bring predominantly dry and HDO-depleted air masses.

In situ measurements at Mt. Zugspitze and lidar profiles measured at Garmisch are used to verify TNA and STI transport events from 2013–2015. This work demonstrates that {H2O, δD} observations at Mt. Zugspitze can be used as a proxy for the transport of trace gases to the Central European free troposphere, e.g., pollution from North America, mineral dust from North Africa, and ozone from the stratosphere. This represents an interesting application of this relatively new dataset.

The manuscript is well written and provides a clear description of the work. I recommend publication in ACP after the minor comments below are addressed.

Specific Comments

Page 1, lines 11-12 and page 6, para 2 – Although the trend in IWV is described as statistically insignificant, it is still related to the positive trend in temperature. Is this valid? What is the correlation between IWV and temperature? Could add a third panel to Figure 2 showing the temperature time series.

Page 5, line 6 – Define LMDZ and give some information about the model a priori profiles used – which constituents? mean of profiles over some time period? specifically

for Mt. Zugspitze or mean over some region? etc.

Page 6, line 31 – It is not obvious from panel b of Figure 3a that the dD monthly frequency distributions are moderately left-skewed, which is used to conclude that there is episodic influence by strongly HDO-depleted air masses. Can this be better illustrated or justified?

Page 7, line 20 – Explain what “Based on positive experience” means.

Page 10, lines 20-22 – Why is a climatological tropopause altitude used to identify STI events? Justify this choice.

Page 11, lines 3-6 – This paragraph repeats much of the last paragraph of Section 4.1 (page 8, lines 32-35). Revise to reduce repetition, or move both to the Conclusions section.

Page 12, lines 10-15 – Some additional information could be provided to explain and justify the tracer thresholds used identify stratospheric intrusions.

Page 13, line 2 – R = -0.295 means R-squared = 0.09, although 99% is given as the confidence. Although statistical analysis allows a relationship to be weak but significant, R-squared = 0.09 indicates a very weak correlation between dD and Be-7. How useful is this?

In general – State clearly what the uncertainty bounds are. These seem to vary throughout the manuscript and are defined in some cases and not others, making it unclear what is meant in some cases. Consistency would be helpful. For example: - page 1, line 24 says “uncertainty of $\pm$ 2 standard errors” (can the standard error be asymmetric?), - page 4, line 8 says “uncertainty given as 95 % confidence interval”, - page 11, line 31 says “significance on 2-σ level", - page 12, line 4 says “mean $\pm$ 1 SE” - page 12, line 24 says “(mean $\pm$ 2 SE)”

Technical Corrections

Page 1, lines 24-25 – Give the altitude represented by the VMR values.

Page 2, line 1 – delete “above”

Page 2, line 2 – delete “potential” (if the H2O, dD observations are being used as a proxy, then the transport has occurred)

Page 2, line 2 – change to “database”

Page 2, line 12 – “regional climate AND air quality, as well as . . .”

Page 2, line 19 – “THE hydrological cycle”

Page 2, line 23 – “Along these major transport pathways, other trace gas signatures and pollution plumes also can travel over . . .”

Page 2, line 24 – why “– possibly even to other continents” when this is known to occur? delete this phrase

Page 3, line 1 – “such as [Mt.?] Zugspitze AND Jungfraujoch”

Page 3, line 3 – “. . . modeling HAVE PREVIOUSLY identified”

Page 3, line 8 – “typically after descending”

Page 3, line 21 – “. . . sets have become available”

Page 3, line 30 – “. . . sensing, a promising new”

Page 3, line 31 – delete “vast”

Page 3, line 32 – “associated WITH the”

Page 4, line 4 – “representative OF”

Page 4, line 6 – add comma after “dataset”

Page 4, line 7 – “and TO combine”

Page 4, line 19 – add comma after “NDACC”

Page 5, line 13 – “as THE sum”

Page 5, line 13 – Is “exemplary” the correct word here? Exemplary means perfect or the best. Perhaps “typical” is more appropriate?

Page 5, line 18 – “sensitivity AT 5 km”

Page 5, line 22 – “root-mean-square (RMS) residuals of the spectral fit, which”

Page 5, line 28 – Are these “quality-selected spectra” the result of applying the RMS residual threshold described in the previous paragraph? If so, for clarity, could say “10184 FTIR spectra selected after filtering by the RMS residual as described above, with . . .”

Page 6, line 1 – “site).” delete extra period

Page 6, line 3 – “at THE nearby”

Page 6, line 30 – add comma after “measurements”

Page 7, line 15 – “than THE 95th”

Page 7, line 18 – “measurements, 120-hour”

Page 7, line 21 – define NCEP

Page 7, line 21 – “estimated to BE 10-20 %”

Page 7, line 23 – Clarify whether the initial point is in time (i.e., the end point of the back-trajectory) or in space (the first point of the back-trajectory). Also, explain why the point of last condensation is chosen as the initial point.

Page 7, line 24 – “defined as THE region”

Page 7, line 25 – “120-hour”

Page 7, line 26 – “in THE absence”

Page 7, line 30 – “at THE nearby”

Page 8, line 2 – add comma after “observations”

Page 8, line 6 – “only if AN LC point”

Page 8, line 32 – “The dD-outlier analysis reveals the potential of . . .”

Page 8, line 34 – “as A useful”

Page 9, lines 2-3 – “observations also provide information on long-range”

Page 9, line 17 – “reach THE Northern”

Page 9, lines 20 and 25– suggest breaking up this paragraph, starting new paragraphs at “The second category” and at “The third transport class”

Page 9, line 22 – add comma after “Each year”

Page 9, line 23 – add comma after “Europe”

Page 9, line 30 – here and elsewhere, Zugspitze or Mt. Zugspitze?

Page 9, line 31 – define ECMWF

Page 10, line 3 – change “above” to “at higher altitudes”

Page 10, line 32 – “In THE case”

Page 11, line 11 – “In THE case”

Page 11, line 4 – delete “valuable” – not necessary

Page 11, line 16 – “at THE Garmisch site”

Page 11, line 25 – “4-day” “315-h”

Page 11, line 31 – add comma after “transport”

Page 12, line 11 – add comma after “unambiguous”

Page 13, line 31 – “implies that weakly depleted air masses are also found”

Page 13, line 12 – “Both IWV and dDcol exhibit”

Page 13, line 16 – delete “vast”

Page 13, line 22 – don’t need to redefine STI, TUS, and TNA

Page 13, line 27 – change “from” to “using”

Page 13, line 28 – “nearby”

Page 13, line 29 – “on the 2-sigma”

Page 13, line 30 – change “of” to “using”

Page 14, line 1 – “confirm the importance”

Page 14, line 8 – delete “valuable”

Page 14, line 25 – change “on the coupling” to “of the coupling”

Page 14, line 31 – “We thank the D. . . and . . . for support.”

Page 22, Table 1 caption – “and THE range”

Page 22, Table 1, last row – give the altitude (range) for the H2O VMR

Page 25, Figure 1 caption – Is “typical” really meant, rather than “exemplary” (i.e., best)?

Page 26, Figure 2 – could add a third panel with the temperature time series

Page 27, Figure 3 caption – “data at 5 km a.s.l.”

Page 28, Figure 4 caption – “at 5 km a.s.l.”

Page 29, Figure 5 caption – More information is needed to describe the three curves

each shown for the Rayleigh and mixing processes.

Figures 6-9 – No need to redefine STI, TUS, and TNA in all four captions. Already defined in the main text.

Page 33, Figure 9 caption – add comma after “For comparison”

Page 34, Figure 10 – This figure could be improved for clarity. The labelling and grouping of the legends could be improved, e.g., better contrast between blue and green lines in the legend, group RH terms together and dD terms together. What are the red bars going across the plot between RH at the top and dD at the bottom?

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