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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Tropospheric water vapour above Switzerland over the last 12 years" *by* J. Morland et al.

J. Morland et al.

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Dear Reviewers, Dear Editor, Dear ACPD Readers,
The Open Discussion has been closed for our article MS-NR: acpd-2008-0657

Tropospheric water vapour above Switzerland over the last 12 years
Author(s): J. Morland, M. Collaud Coen, K. Hocke, P. Jeannet, and C. Mätzler

Summary:

We thank the three reviewers for their constructive comments and their interest in our study. All reviewers agreed in principle with our study and provided numerous suggestions for optimization of the trend analysis and readability of the article which we try to include in the revised manuscript.

Point-to-point response *(reviewer comments are in cursive letters)*

Reviewer 1:

-Your technical and grammatical suggestions are welcome and will be incorporated in the revised version.

Technical comment 4: It would be good to give the coordinates of the nearest ECMWF grid

-ECMWF grid point nearest to Bern is: longitude=7.875 E and latitude=47.250 N

Technical comment 7: It would be good to give the equations used for the LSA analysis. Also, why are three sine and cosine harmonics used?

-we will provide complete equations for the least squares analysis. Equation 8 should also contain the error ϵ. The annual, semi-annual and ter-annual sine and cosine waves are sufficient for our purpose, since the main goal is the derivation of the linear

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trend. Using the addition theorem the sine wave $A \sin(\omega t + \varphi)$ can be expressed by $a \sin \omega t + b \cos \omega t$ with $\varphi = atan(b, a)$ and $A = \sqrt{a^2 + b^2}$.

The expression $a \sin \omega t + b \cos \omega t$ is better than $A \sin(\omega t + \varphi)$ for building a linear equation system. The procedure is already described elsewhere (e.g., W. Press et al., Numerical Recipes (textbook); or Weatherhead, E. C., et al. (2000), Detecting the recovery of total column ozone, J. Geophys. Res., 105(D17), 22,201Ð22,210). However our article will be certainly improved if we describe these fundamental steps in more detail and for readers who have not yet performed the decomposition of a time series.

For understanding and simple programming, it is most useful to use vectors and matrices:

$$IWV = \begin{pmatrix} IWV(t_1) \\ IWV(t_2) \\ IWV(t_3) \\ \vdots \\ IWV(t_n) \end{pmatrix}; \quad X = \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_8 \end{pmatrix}; \quad E = \begin{pmatrix} \epsilon(t_1) \\ \epsilon(t_2) \\ \epsilon(t_3) \\ \vdots \\ \epsilon(t_n) \end{pmatrix}$$

$$A = \begin{pmatrix} 1 & t_1 & \sin\omega_1 t_1 & \cos\omega_1 t_1 & \sin\omega_2 t_1 & \cos\omega_2 t_1 & \sin\omega_3 t_1 & \cos\omega_3 t_1 \\ 1 & t_2 & \sin\omega_1 t_2 & \cos\omega_1 t_2 & \sin\omega_2 t_2 & \cos\omega_2 t_2 & \sin\omega_3 t_2 & \cos\omega_3 t_2 \\ 1 & t_3 & \sin\omega_1 t_3 & \cos\omega_1 t_3 & \sin\omega_2 t_3 & \cos\omega_2 t_3 & \sin\omega_3 t_3 & \cos\omega_3 t_3 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & t_n & \sin\omega_1 t_n & \cos\omega_1 t_n & \sin\omega_2 t_n & \cos\omega_2 t_n & \sin\omega_3 t_n & \cos\omega_3 t_n \end{pmatrix}$$

$$IWV = A \cdot X + E \tag{1}$$

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The sum of the squares of the residual errors $\epsilon(t_i)$ is minimized when **X** is calculated as follows :

$$IWV \doteq A \cdot X \tag{2}$$

$$X \doteq (A'A)^{-1}A' \; IWV. \tag{3}$$

The solution vector **X** consists of the constant, the inclination of the straight line, and the amplitudes a_i, b_i of the sine and cosine waves of the annual, semi-annual and ter-annual variations.

Technical comment (8) Conclusions. On the difference between GPS and TROWARA. It could be checked by examining the difference between GPS and TROWARA during non raining conditions. I think that the differences found, possibly due to limited sampling by TROWARA, are important.

-we will check the difference of GPS and TROWARA during non rain conditions

Technical comment (9): Fig. 9: what is the green line?

-we don't understand all of your comments because of some conversion errors in your pdf file on the ACPD website. So we are sorry that we don't know which green line you mean in Figure 9 (Figure 9 is not present in our manuscript).

-thank you, we will consider your grammatical suggestions too

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Reviewer 2:

The paper presents interesting results on the diurnal IWV cycle (and GPS problems in that), biases induced by instrument limitations and differences in IWV trends for night/day and winter/summer. There are many interesting details which can distract the reader from the "larger picture". In this respect I encourage the authors to add a last paragraph to the conclusions relating their significant trends (and uncertainty - both preferable in %/decade) to literature results.

-we will summarize the trend results in a separate paragraph of the conclusions

I am rather puzzled by the slightly negative August IWV trend between the two significantly positive trends of July and September. The suggestion that this is due to surface drying does not sound too plausible for Switzerland - especially as September has a strong positive trend. In order to better understand this it could be helpful to look at the precipitation climatology. GPS might be used to check if this is a sampling problem.

-a clear decrease of the IWV trend in August is also present in IWV from NCEP/NCAR reanalysis at the grid point 47.5 N and 7.5 E which is shown in Figure 1 below. It is a good idea to look for the precipitation trend in August since an increase of precipitation could reduce the average IWV. Martine Collaud Coen did a rapid search in MeteoSwiss climatology databases. The search proved that the mean precipitation during the month of August is the greatest one. The precipitation during August is really greater than during September, it is however not much higher than the precipitation during July. The 3 last years had more precipitation during August than the first years of the time series. We extend the revised manuscript by a discussion of IWV and precipitation in August.

- a clear decrease of the IWV trend in August is also present in IWV from NCEP/NCAR

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reanalysis at the grid point 47.5 N and 7.5 E which we analyzed for control.

I am a bit surprised that the authors use the standard ECMWF analysis output and not a reanalysis product which should show higher consistency.

-the ERA-40 data only reaches until 2002. We tried ERA- Interim data from 1989 to 2009. However we had problems with the ECMWF data portal on the web, and time resolution seems to be 1 day. So it appears to be better to stay with the highly resolved ECMWF operational data. Additionally we checked the ECMWF trends with the NCEP/NCAR reanalysis data of IWV which have a time resolution of 6 hours and which cover the whole atmospheric column (Fig.1 above).

The Introduction makes the point that microwave radiometer observations provide accurate water vapour observations. Therefore as a reader I would expect that section "2. Data Sources" provides error an assessment for each instrument. For example the cited GPS accuracy of 0.7 mm (page 7244, line 22) should be mentioned here. I know that such a one number error statement cannot be easily made for each instrument but for the reader it is always helpful to get more information on that. For example it might be worth to mention that noise is not the problem for the microwave method.

-we will include an error assessment of each missing measurement technique in section Ò2. Data SourcesÓ.

Did you take into account the 85 m height difference between Payerne and Bern which can lead to about 0.5 mm systematic difference? It is mentioned in the caption of Fig. 2 and 3 but has it been applied everywhere?

-Payerne is at 490 m above sea level while Bern is at 570 m. So the integration of the Payerne radiosonde profiles starts beyond 570 m. We will clarify this point in the revision.

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The introduction of the different periods (P1- P4) is a bit confusing since the periods are already named in the beginning (page 7245, 1st line) and the explanation about their definition comes much later.

-yes, we will provide a Table for a better description of P1–P4

Page 7245, Line 28: Give a motivation why the weather stations and not the radiosondes were used for the homogenisation: continuity, consistency?

-the weather stations are in the surrounding of Bern while the locations of nearby radiosondes are further away and vary with the wind field

Actually I find equations 1 and 2 not necessary as they are just linear corrections. The resulting bias values are of course important (something for the table). I am a bit puzzled why period 1b is treated before 1a?

-equations 1 and 2 describe the details how the correction was calculated. Period 1B is treated before period 1A because of didactic reasons: Equation 1 is easier to understand than equation 2

Page 7250, Line 10: Does this mean that in contrast to Fig. 2 here TROWARA is only from 2000 on? Why didn't you filter the GPS data according to non-precipitating conditions?

-we will separate between precipitation and non- precipitation intervals

Page 7253, Line 21: The phrase "around 2 percent annual IWV" is not straightforward. The diurnal amplitude is around 0.6 mm corresponding to 4 percent of the mean IWV

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of 14.4 mm... Ok, now I understand it is +/- 2 percent... Please write it simpler.

-we will express the diurnal amplitude in absolute units [mm] . The diurnal amplitude is 0.3 mm corresponding with a day-night difference of about 0.6 mm.

Page 7255, line 9: Much simpler than dew measurements is the comparison it with water vapour flux observations from flux stations. However, evaporation/condensation is a rather local process with strong horizontal inhomogeneity while IWV is an integrated quantity. I suggest to eliminate this sentence and instead suggest to mention a possible separation of the diurnal cycle into seasons etc.

-we will study the seasonal change of the diurnal cycle in a future study. We still think that dew deposited on grass during night could be an efficient measurement

Why do you stop the integration of the radiosonde at 200 hPa while TROWARA measures the full column? If the reason is the poor quality of RS humidity estimates then it might be better to assume a climatological value (3-5 ppm) above the tropopause. Anyhow the reason needs to be mentioned.

-stratospheric IWV (beyond 200 hPa) is about 0.02 mm which is about 0.2 percent of total IWV. With respect to the small trends of IWV , 0.02 mm is a considerable amount. However the trend of stratospheric IWV at Bern over the past 12 years is unknown. It makes no sense to estimate stratospheric IWV from false radiosonde values near the tropopause or to add a constant from a satellite climatology. Adding a constant does not change our results.

The results of Fig. 6 might be better suited for presentation in a Table since in principal the different values shouldn't be connected by lines. Further it would be easier to compare the different values of the trend mentioned in the text - but this is more or less

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a question of taste.

-we will include a Table along with Fig. 6 and simplify the text accordingly

Page 7258, line 8. This is one of a few passages where the authors could make it easier for the reader to immediately get the message by saying: "The absolute values are larger than the LSA trends calculated for the full year because of compensating trends in winter and summer.

-will be changed accordingly

-Technical corrections will be incorporated in the revised manuscript

Thank you

Reviewer 3:

Both ECMWF and radiosondes are integrated up to the 200 hPa level. Whey not go higher? Both the radiometer, solar photometer and GPS measures through the whole atmosphere. At least mention the reason for not going higher (e.g. unreliable humidity data above).

-stratospheric IWV (beyond 200 hPa) is about 0.02 mm which is about 0.2% of total IWV. With respect to the small trends of IWV , 0.02 mm is a considerable amount. However the trend of stratospheric IWV at Bern over the past 12 years is unknown. It makes no sense to estimate stratospheric IWV from false radiosonde values or to add a constant from a satellite climatology. Adding a constant does not change the linear trend. At least, the trends of NCEP/NCAR (Figure above) are meant for the whole at-

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mosphere and are in a good agreement with the other trends of IWV ending at 200 hPa.

Page 7247-7248, equations 1 and 2: The corrections applied to that data is the mean of the correction estimated by four different methods. In doing this, it is assumed that the accuracy of the four methods is the same. This is not obvious, one method could be more accurate than the other. It could be interesting to see the effect on e.g. the trends if only one of the methods was used for the homogenisation. In general I think it would be interesting to have some kind of study on how possible errors in the homogenisation process could affect the results presented later in the paper.

-a change of the homogenisation procedure of the TROWARA data is not possible yet since the complex procedure was performed by Dr. June Morland and she left the Institute of Applied Physics. However we thank you for the valuable suggestions and we will consider the variation of the homogenisation procedure in a future work on the TROWARA series. We have some more ideas how we can avoid data gaps in the beginning of the TROWARA series but this will be a completely new study. The influence of the various correction terms can be roughly estimated from Figure 1 of the manuscript, it is of the order of 1 mm per decade (smaller than TROWARA's error bars in Figure 7).

When investigating e.g. the monthly climatologies, there are biases resulting from the fact that some instruments cannot measure for all weather conditions. It might be more interesting to limit the investigations to the times when there are data available from all instruments, or at least to the times when there are data from TROWARA (since that paper mainly evaluates the data from this instrument).

-we agree that it is a good idea to calculate the trends only for coincident measurements. However the rain flags of TROWARA are usually over short time intervals 0.5-1 hour while the sampling time of the radiosondes is about 12 hours.

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Section 4.2: As the authors discuss, estimating the mean temperature Tm from surface temperature measurements may give errors in the diurnal cycle since Tm has a lower diurnal variability than the surface temperature. Thus the authors use a damped surface temperature. A more accurate method probably is to estimate Tm from ECMWF data. Of course, this only gives a resolution of 6 hours, but it could be interesting to investigate is this way of estimating Tm will give a diurnal signature closer to that of TROWARA.

-we think that the damped surface temperature measurement is the best approach. ECMWF temperature is questionable on small scales and at the surface.

It could be interesting to investigate the diurnal cycle for different seasons, since it can be very different in summer compared to winter.

-The diurnal cycle of IWV is indeed interesting since it has a strong variability: short time intervals of strong diurnal amplitude followed by time intervals of disappearance of the diurnal cycle.

No radiometer data during rain is used since these are unreliable.. How is theses periods detected? Is data from a rain gauge used, or are all data where the estimated liquid water content is high (e.g. > X mm) removed? This should be stated in the paper.

-treshold for rain data is ILW $>$ 0.5 mm (integrated liquid water is measured by TROWARA) or rain gauge at Bern shows precipitation greater than 0. If precipitation is detected according to this criterion, the data within a time interval of ± 15 min are not used.

Page 7249, equation 5: This equation seems to be the equation for retrieving the IWV

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Interactive Discussion

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from the paper by Ingold and Mętzler (2000) , although the constant term is given as -0.5059 in the this equation while it is -2.0059 in Ingold and Mętzler (2000). Which value is the correct one?

-Constant in equation 5 is -0.5059. Because of your question we checked the retrieval program and this value is in the TROWARA analysis program since the beginning. Rohrbach (1999, diploma thesis, Univ. Bern) mentioned that an empirical correction of 1.5 mm is necessary for an adjustment of TROWARA with respect to coincident GPS measurements of IWV. Adding 1.5 mm explains the change from -2.0059 to -0.5059 which was the point of debate.

Page 7557, line 9-19: It seems like the movement of TROWARA indoors (which stabilised the temperature) is a likely reason for the different differences in midday/ midnight trends between TROWARA and radiosondes. Would it be possible to in the homogenisation process to estimate an offset which was not constant but had a diurnal variation?

-an offset of the TROWARA series due to diurnal variation might be possible because of the change of TROWARA from outdoor to indoor

Page 7257, line 15: Would it not be more appropriate to compare the TROWARA trend for 2003-2008 with the radiosonde trend for the same period, not 1996-2007?

- we are going to calculate the trend for 2003-2008 and will include the comparison in the revised manscript

Page 7248, 16: I think it would be good if the typical temperatures of the hot and cold load were given here. Below the cold load is given as 24 K, but the hot load temperature is not given.

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-temperature of the hot load is 312 K (June Morland: TROWARA - rain flag development and stability of instrument and calibration, IAP Research Report, No. 2007-14-MW, Institut f¿r angewandte Physik, Universitęt Bern, 2007)

-yes, T is equal to the length of a year, we will add this information.

Thank you for your help to improve the article!

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 7239, 2009.

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