Homogenization of the water vapour time series using the penalized maximal *t* test modified to account for first-order autoregressive noise

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Motivation

- Realistic and reliable Integrated Water Vapour (IWV) trends can only be obtained from homogeneous IWV time series.
- The inconsistencies in the IWV time series obtained from the globally homogenously reprocessed GNSS data need to be investigated and corrected for climate applications.
- Contribution to the COST sub-working group "Data homogenization" to provide the community a homogenized version of long-term GNSS time series of tropospheric products.

Data sets

- IGS repro1 tropospheric solution and120 sites (see Fig. 1) were selected with the time series longer than 15 years (1995/01-2010/12).
- Screening of the IGS repro1 ZTD for a quality control. (O. Bock)
- The IWV difference time series were formed between IGS and ERA-Interim data. (O. Bock)
- Out of 120 sites, there are 14 sites with bad agreement (one example is shown in Fig. 2), with larger standard deviations, between GPS IWV and ERA-Interim IWV. Therefore, they were removed from the data sets for the PMTred test.

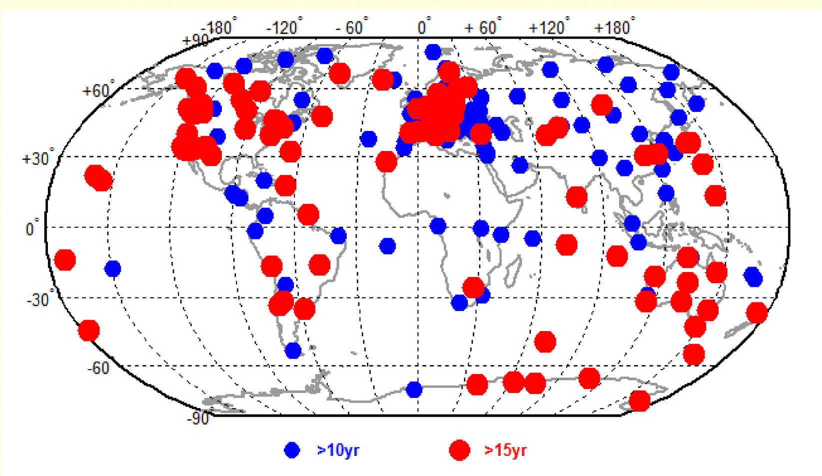

Fig 1: The geographical distribution of all GPS sites included in IGS repro1 where the red dots show all sites with a data length longer than 15 years. Courtesy of O. Bock

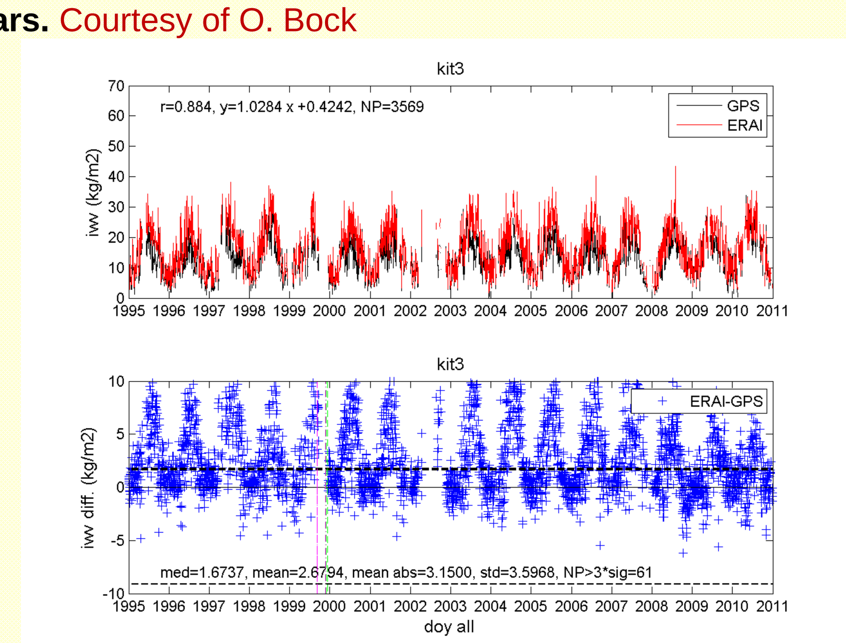

Fig 2: One example of the GPS sites with a bad agreement between GPS IWV and ERA-Interim IWV. A clear seasonal variation is seen in the time series of the IWV difference. Courtesy of O. Bock

Introduction of the homogenization tool

- A *t* test is normally used to determine if the mean values of two datasets are significantly different from each other. When μ_1 is significantly different from μ_2 , the point at the time *t=k* is defined as a changepoint:

$$M_a: \begin{cases} V_t \sim \mathcal{N}(\mu_1,\sigma^2), & t=1,2,3,\ldots,k \\ V_t \sim \mathcal{N}(\mu_2,\sigma^2), & t=k+1,k+2,k+3,\ldots,N \end{cases}$$

- To locate the changepoint, we need to find out the most probable point that is associated with the maximal value of the statistic (shown in right) and the test statistic for locating the changepoint is given as:

$$T(k)=\frac{1}{\hat{\sigma}_k}\left[\frac{k(N-k)}{N}\right]^{1/2}|\overline{V}_1-\overline{V}_2|, \quad (7)$$

where

$$\hat{\sigma}_k=\frac{1}{N-2}\left[\sum_{1\le t\le k}(V_t-\overline{V}_1)^2+\sum_{k+1\le t\le N}(V_t-\overline{V}_2)^2\right], \quad (8)$$

with

$$\overline{V}_1=\frac{1}{k}\sum_{1\le t\le k}V_t \quad (9)$$

and

$$\overline{V}_2=\frac{1}{N-k}\sum_{k+1\le t\le N}V_t. \quad (10)$$

$$T_{max} = \max T(k) > \text{Critical value (CV)}$$

- Wang et al. *(2007)* proposed a penalized maximal *t* test (PMT) to empirically construct a penalty function that evens out the U-shaped false-alarm distribution over the relative position in the time series being tested. They modified statistic to

$$PT_{max} = \max P(k)T(k)$$

where *P(k)* is the penalty function obtained empirically.

- In addition, if there is a positive autocorrelation existing in the time series being tested and its effects are ignored, it is highly possible that wrong changepoints will be detected. The autocorrelation of IWV difference time series were calculated for 101 global GPS sites (Ning et al. 2016). The result showed significant lag-1 values (from 0.33 to 0.95) for most sites. Therefore, the PMTred test which accounts for first-order autoregressive noise was used for the data homogenization.

- Fig. 3 depicts simulated CVs for different confidence levels and for different lag-1 autocorrelation as the function of the sample length using the monthly data. It is clear that CVs are larger for an increasing autocorrelation and for a higher level of confidence.

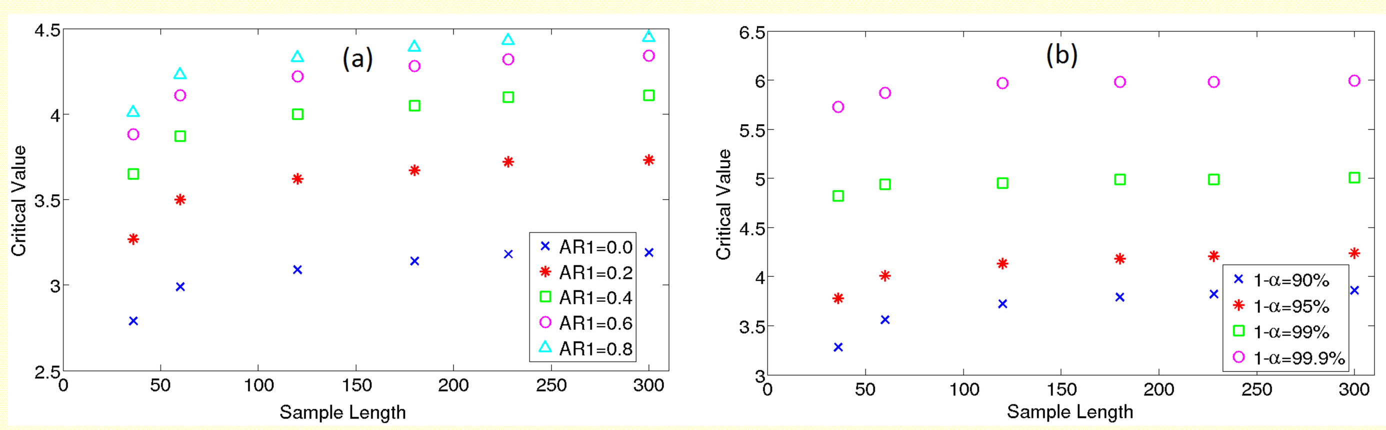

Fig 3: (a) Critical values (CVs) for five different lag-1 autocorrelation with a fixed confidence level of 95 % and (b) for four different confidence levels with a fixed lag-1 autocorrelation of 0.5, obtained from Monte Carlo simulations running for 1 000 000 times, as a function of the sample length (monthly data).

Result I

Different confidence levels:

We first carried out the data homogenization using four different confidence levels (90 %, 95 %, 99 %, and 99.9 %) on the monthly IWV. As shown in Fig. 4 the total number of the detected changepoints increases as the decrease of the confidence level. In total 64 changepoints, among 106 GPS sites, were detected when applying an confidence level of 90 %. Thereafter we calculated the amplitude of the offset given by the mean difference between the data from one year before and after the date of the changepoint being detected. The resulting amplitudes are mainly in a range from − 0.5 to 0.5 kg/m^2 while similar results are seen for four different confidence levels (see Fig. 5).

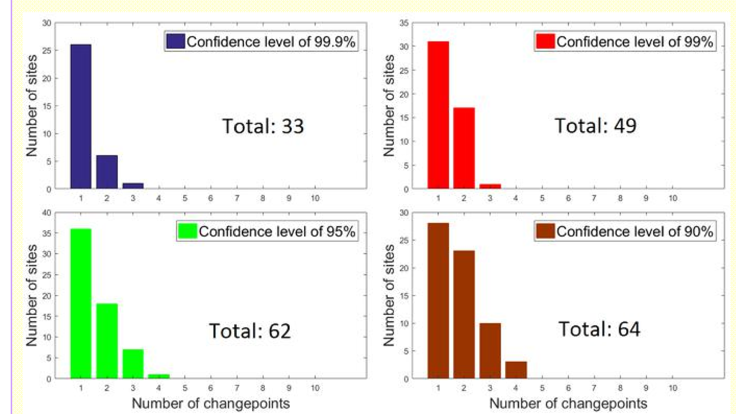

Fig 4: The total number of the changepoints detected using four different confidence levels.

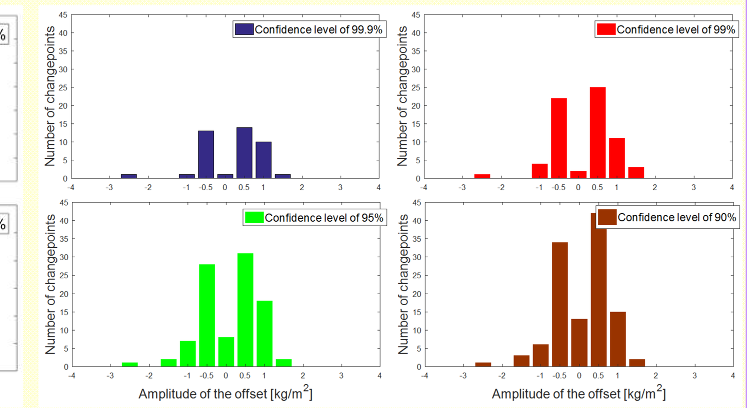

Fig 5: The amplitude of the offset calculated for four different confidence levels.

Monthly and Daily IWV:

In addition, we performed the data homogenization on both monthly and daily IWV using the confidence level of 95 %. More changepoints have been detected (91) when the daily IWV were used (see Fig. 6). The calculated amplitudes of the offsets, shown in Fig. 7, are mainly in a range from −0.5 to 0.5 kg/m^2 for both monthly and daily data.

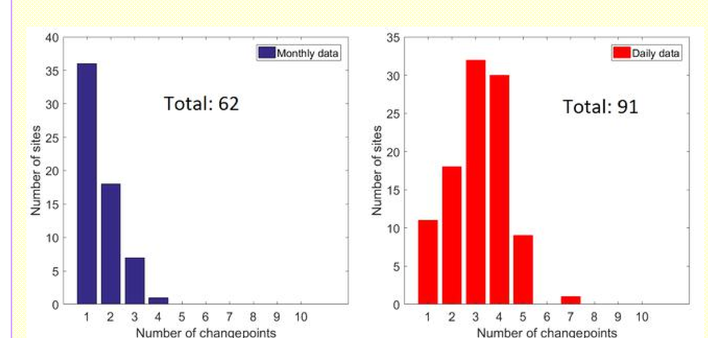

Fig 6: The total number of the changepoints detected for both monthly and daily IWV.

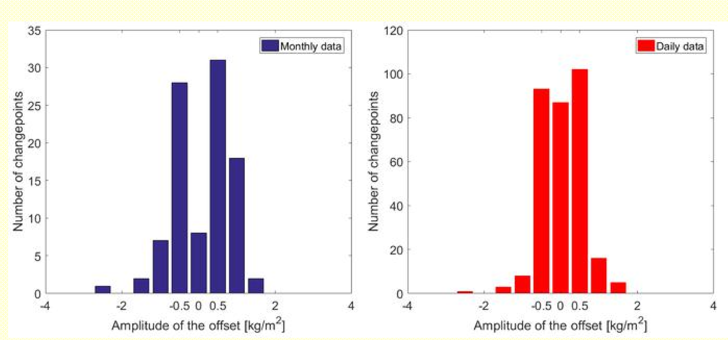

Fig 7: The amplitude of the offset calculated for both monthly and daily IWV.

Result II

Fig. 8 depicts the IWV trends estimated from the GPS data before and after the offset correction, together with the trends obtained from the ERA-Interim data (no offset correction implemented). The GPS data were homogenized using the confidence level of 90 %. The correlation between the trends is significantly improved from 0.58 to 0.92 after using the corrected GPS data. Similar results were seen when using other confidence levels. The correlations were increased to 0.92, 0.89, and 0.85 when an confidence level of 95 %, 99 %, and 99.9 % was used respectively.

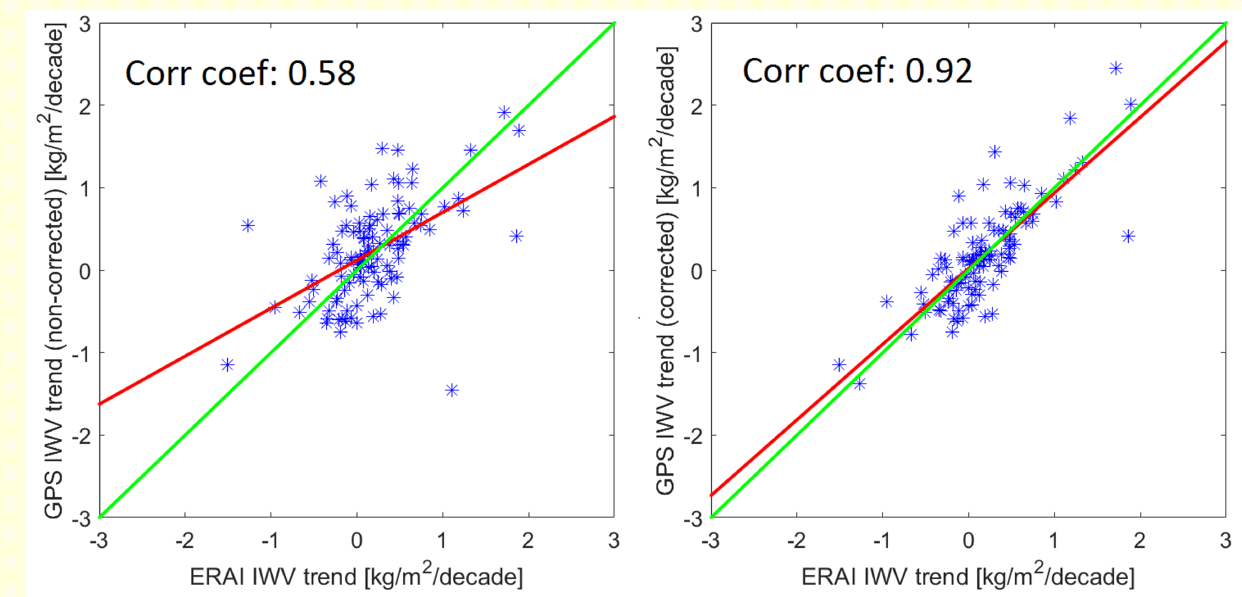

Fig 8: Correlations between the IWV trends, estimated for 106 sites from the ERA-Interim and the GPS data before and after the corrections for the GPS sites containing changepoints. The red lines are the linear fits of the plotted data, while the green line indicates the perfect correlation.

Conclusions

- Similar results were seen when using four different confidence levels (90 %, 95 %, 99 %., and 99.9 %) for the PMTred test.
- The amplitude of the offsets are mainly in a range of − 0.5 kg/m^2 to 0.5 kg/m^2.
- The correlation coefficient of the trends increases significantly from 0.58 to ~0.90 after using the homogenized GPS data.

Future work

- The detected changpoints need to be further validated due to the fact that the reference data (ERA-Interim) is not completely homogeneous. Other independent reference data should be used: nearby GPS, VLBI, Radiosonde, and/or DORIS).
- The results given by the PMTred test will be cross checked by the changepoints detected by different homogenization methods (contribution to the COST sub-working group "data homogenization").

Reference

Ning, T., Wickert, J., Deng, Z., Heise, S., Dick, G., Vey, S., Schöne, T. (2016), Homogenized time series of the atmospheric water vapor content obtained from the GNSS reprocessed data. *J. Clim.* 29, 2443–2456, doi:10.1175/JCLI-D-15-0158.1

Wang, X., Wen, Q. H., Wu, Y. (2007), Penalized maximal t test for detecting undocumented mean change in climate data series. *J. Appl. Meteor.*, 46, 916–931, *doi:10.1175/JAM2504.1.*

For further information

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