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G5.2 Atmospheric and Environmental Monitoring with Space-Geodetic Techniques

Karlsruhe Institute of Technology

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Statistical Significance of trend estimations for Integrated Water Vapor time series obtained from GPS: A case study in Europe

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1. Motivation

Motivation

Water vapor is one of the most abundant and dominant greenhouse gases in the atmosphere, which is crucial for global warming. With higher temperatures, the specific humidity will also increase as predicted by the nonlinear Clausius-Clapeyron relationship, indicating a positive feedback loop. Hence, estimation of the trends of Integrated Water Vapor (IWV) in the atmosphere is of great importance for global warming research

Since the 1990s, the Global Positioning System (GPS) has successfully been employed to retrieve IWV with a high temporal resolution and all-weather conditions. Thus, GPS is also a unique tool of monitoring the IWV trend

However, in order to obtain a realistic and accurate estimate of the IWV trend and its associated uncertainty, it is important to select a reasonable mathematical model for the homogenized time series from homogenously reprocessed GPS data sets

2 Data and Methods

GPS IWV Retrieval

- ZTD: hourly GPS provided by Hunegnaw et al. (2016)
- $e,\ T$: ERA5 profiles
- P: ERA5 profiles

$$\mathrm{IWV} = \frac{10^6}{\rho_W \cdot R_w \cdot [k_3/T_m + k_2']}\mathrm{ZWD}$$

$$\mathrm{ZWD} = \mathrm{ZTD} - \mathrm{ZHD}$$

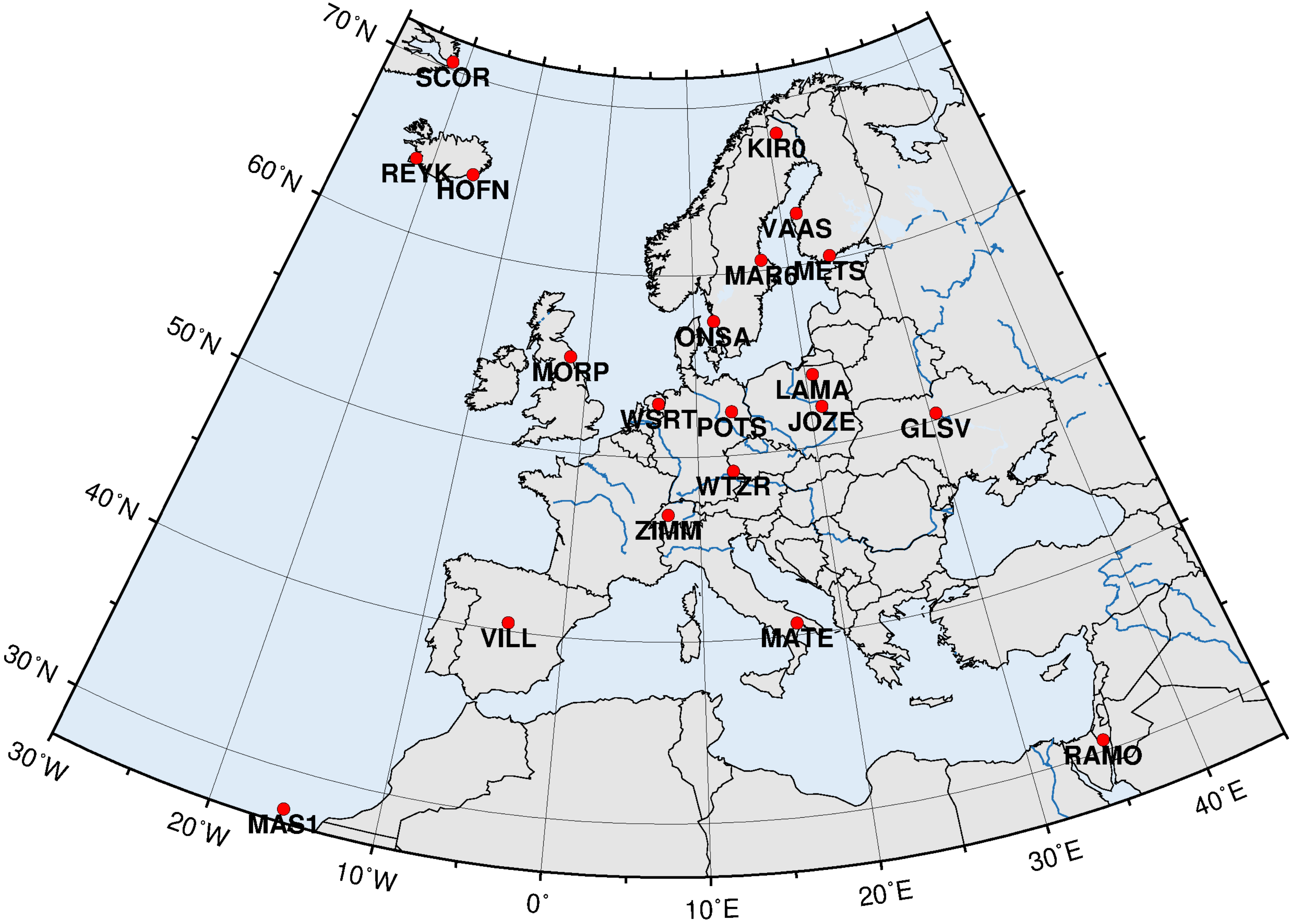
$$T_m = \frac{\int \frac{e}{T} dz}{\int \frac{e}{T^2} dz} \approx \frac{\sum \frac{e_i}{T_i} \Delta h_i}{\sum \frac{e_i}{T_i^2} \Delta h_i}$$

$$\mathrm{ZHD} = \frac{C \cdot P}{f(\varphi, H)}$$

$$C = 2.2767 \pm 0.0015$$

$$f(\varphi, H) = 1 - 0.00266 \cdot \cos(2\varphi) - 0.28 \cdot 10^{-6} H$$

Data



- 20 GPS stations
- Hourly ZTD time series
- 22 years (1995-2017)
- ERA5 pressure level products

ERA5 IWV Retrieval

ERA5 IWV were also obtained for comparison

- q: ERA5 profiles
- P: ERA5 profiles

$$IWV = \int \frac{q}{g} dP \approx \sum \frac{q_i}{g_i} \Delta P_i$$

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Pre-processing

- **Outlier Detection**

- **Range threshold**

  PWV<0 or PWV>83 mm were removed

  PS: 83 mm is from the Slide 6, PPT, O. Bock Post-processing of GNSS ZTD Summer School, 29-31 Aug. 2016

- **Robust outlier detection**

  1.5*IQR range

Function Model

According to previous studies, the IWV time series can be modelled by the following function model:

$$x(t) = x_R + v(t - t_R) + \sum_{j=1}^{n_j} b_j H(t - t_j) + \sum_{k=1}^{n_k} A_k \sin(\omega_k^A t + \varphi_k^A) + \sum_{l=1}^{n_l} D_l \sin(\omega_l^D t + \varphi_l^D) + \varepsilon$$

- b_j: offsets
- A_k: Amplitudes of the first n_k harmonics of annual signal
- D_l: Amplitudes of the first n_l harmonics of diurnal signal

Noise Model

According to previous studies, the IWV time series can be modelled by one of the following noise models or their combinations:

- **White Noise: WN**

  Observations are independent

- **Power Law Noise: PL**

  Covariance matrix for WN+PL

$$\mathbf{C} = a^2\mathbf{I} + b_k^2\mathbf{J}_{\boldsymbol{k}}$$

- **first-order autoregression: AR(1)**

$$y_t = \beta_0 + \beta_1 \, y_{t-1} + \varepsilon_t$$

3. Results

Power Spectrum

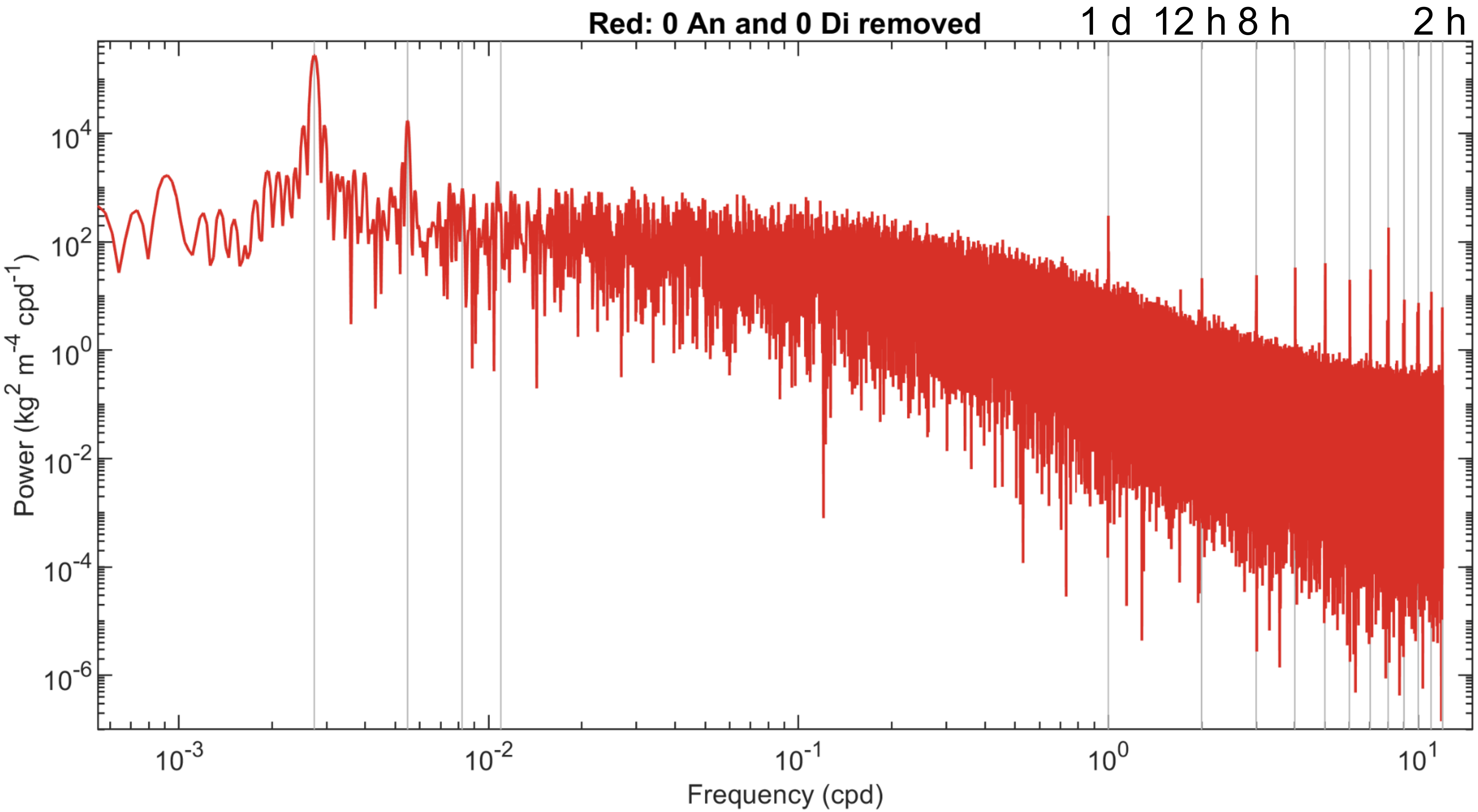

Figure. Power spectra of the hourly GPS IWV time series at the GLSV station

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Power Spectrum

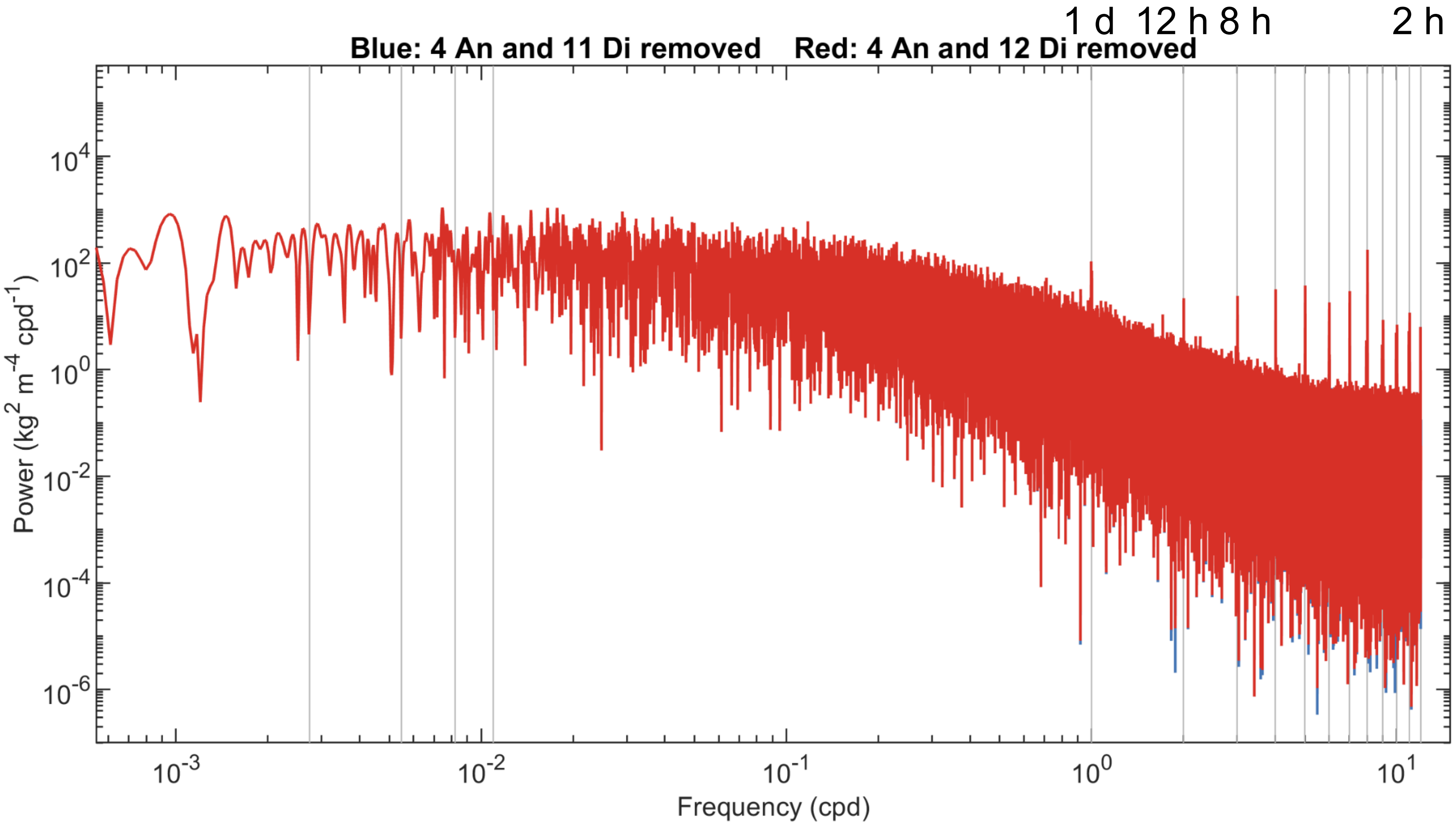


Figure. Power spectra of the hourly GPS IWV time series at the GLSV station with annual and diurnal harmonics removed

Function Model

As can be seen from the iterative power spectrum, peaks at high orders of diurnal harmonics cannot be removed with functional modelling

Hence, we modelled the IWV time series with the following function:

$$x(t) = x_R + v(t - t_R) + \sum_{j=1}^{n_j} b_j\, H(t - t_j) + \sum_{k=1}^{4} A_k\, sin(\omega_k^A t + \varphi_k^A) + \sum_{l=1}^{2} D_l\, sin(\omega_l^D t + \varphi_l^D) + \varepsilon$$

which is the same as the function model used by Klos et al. (2018)

Typical GPS IWV time series

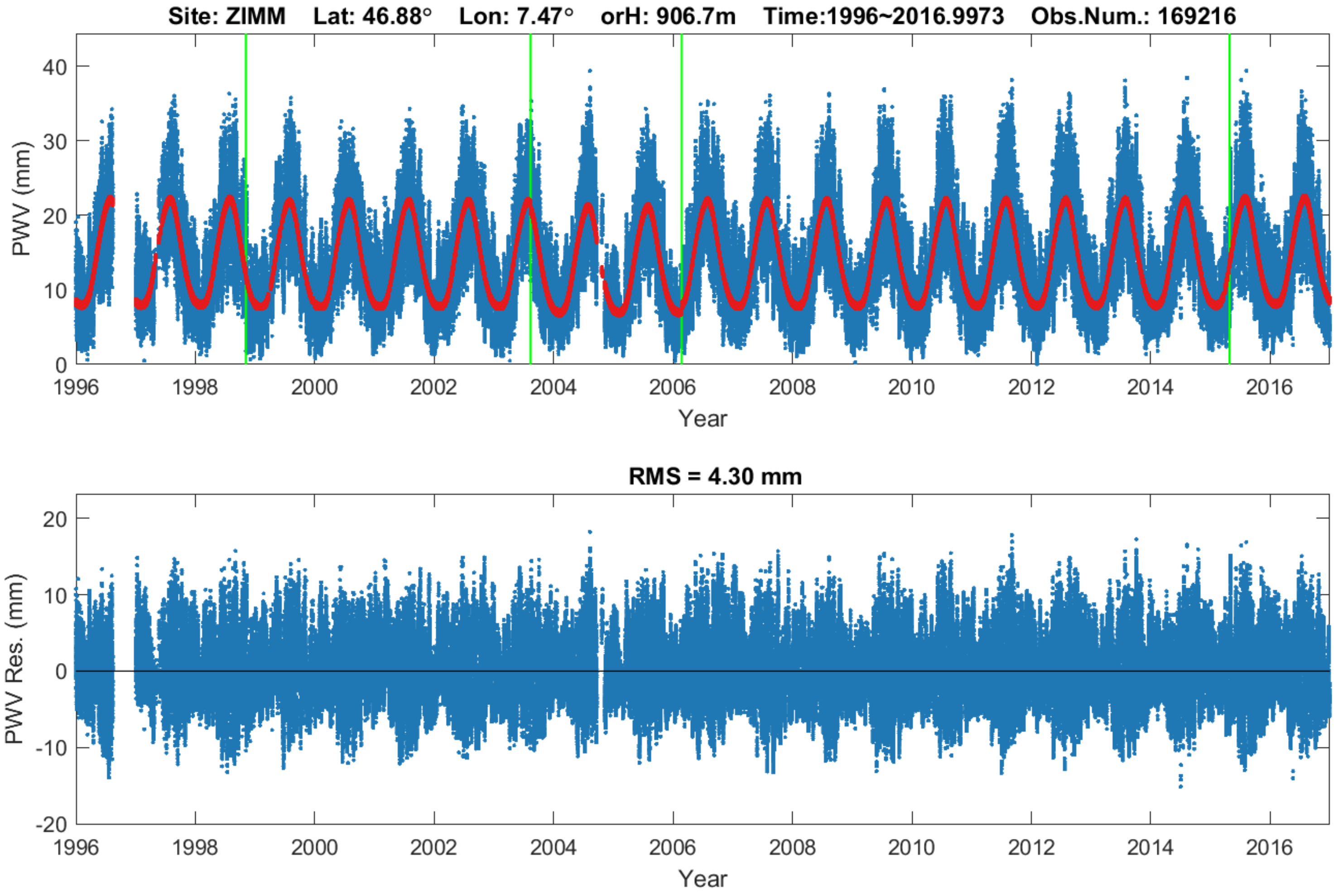
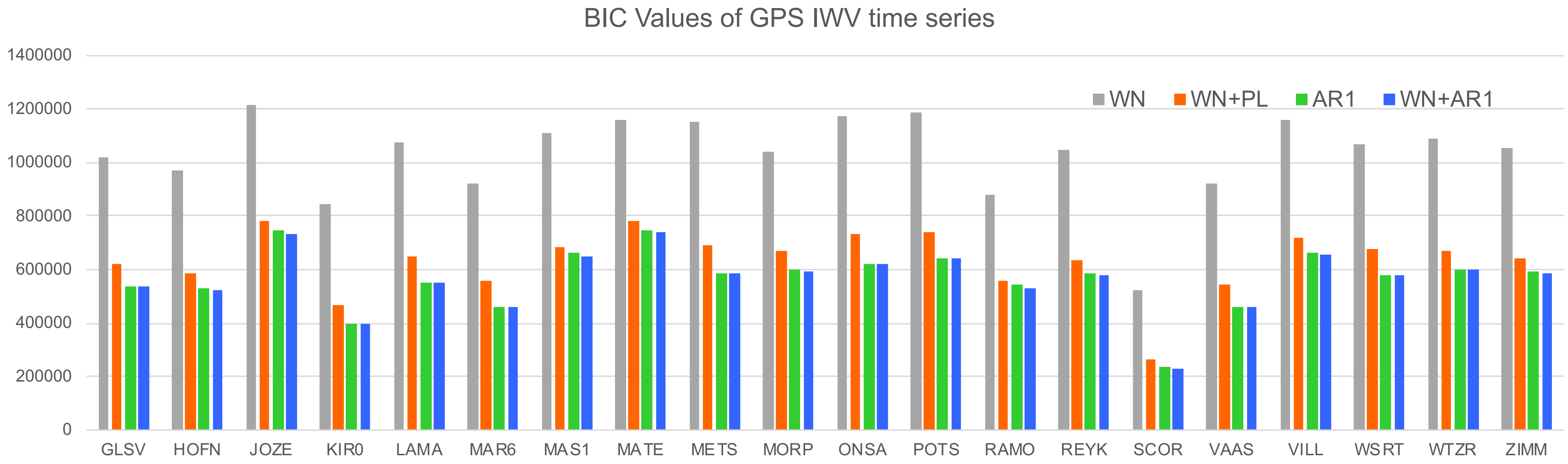


Figure. Upper Panel: hourly GPS IWV time series (blue dots), offsets (green lines), and the fitting curve (red dots) for the ZIMM station

Comparison of Noise Models

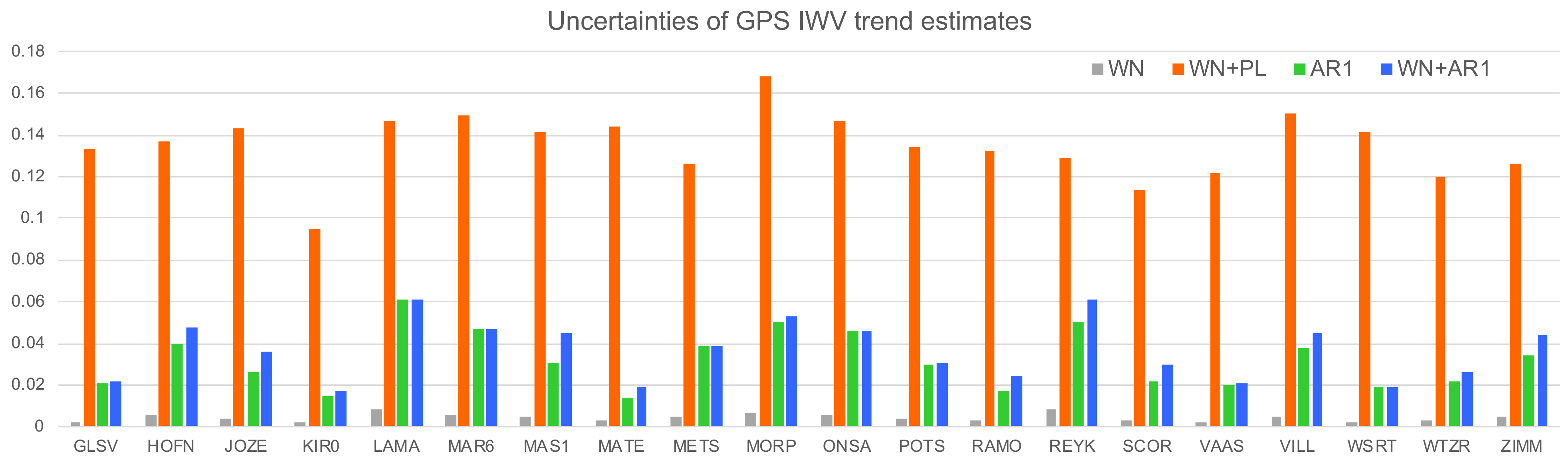


The **Bayesian information criterion (BIC)** provides a means for model selection

The preferred model should have a lower BIC value

- **WN model is the worst**
- **The WN+AR1 is generally slightly superior to the models of pure AR1 and WN+PL**

Comparison of Noise Models



- **The uncertainties of IWV trends are underestimated with an assumption of pure WN but overestimated with the WN+PL model**

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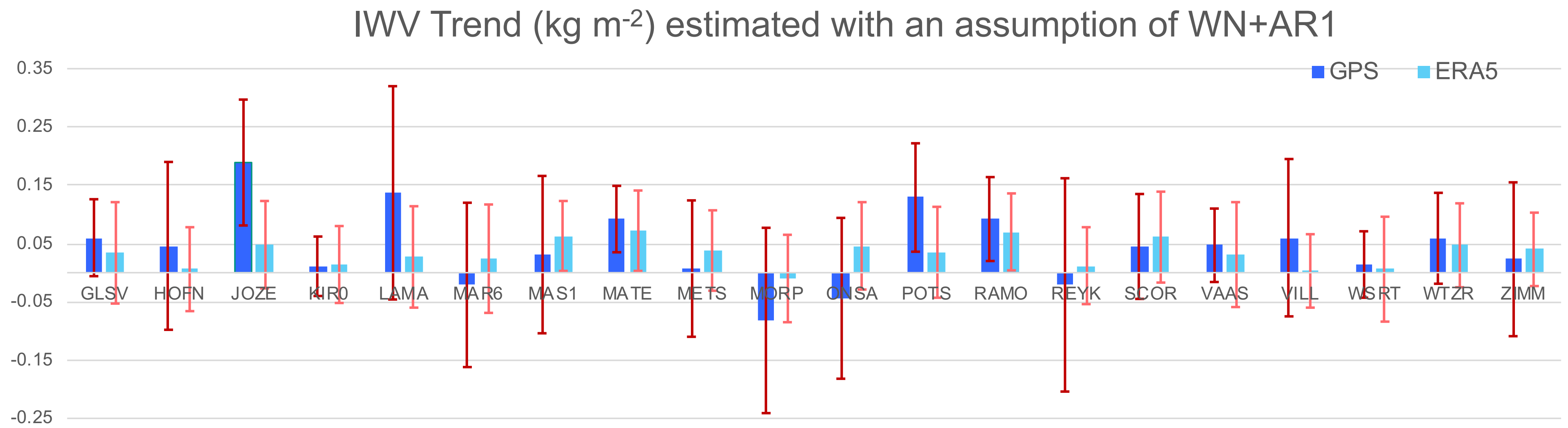
Comparison of Noise Models



Note that the error bars represent three standard deviations

- **The GPS- and ERA5-derived IWV trends are positive at 16 and 19 stations, respectively**
- **However, they are significant (greater than three standard deviations) only at 4 and 3 stations, respectively**
- **All of the negative IWV trend estimates are insignificant**

4. Summary

Based on the long-term hourly GPS and ERA5 time series up to 22 years for 20 European GPS stations, we investigated the influence of noise model assumptions within the mathematical model on the uncertainties of IWV trend estimates, and we find that

- The assumption of a white noise only model tends to underestimate the IWV trend uncertainty, whereas the combination of white noise and power-law noise overestimates it
- The combination of white noise and first-order autoregression is preferred
- The GPS- and ERA5-derived IWV trends are positive at the majority (16 and 19) of the 20 GPS stations
- However, only several (4 and 3) of the IWV them are significant
- All of the negative IWV trend estimates are insignificant

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Thanks for your attention

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