Noise characteristics in Zenith Total Delay from homogeneously reprocessed GPS time series

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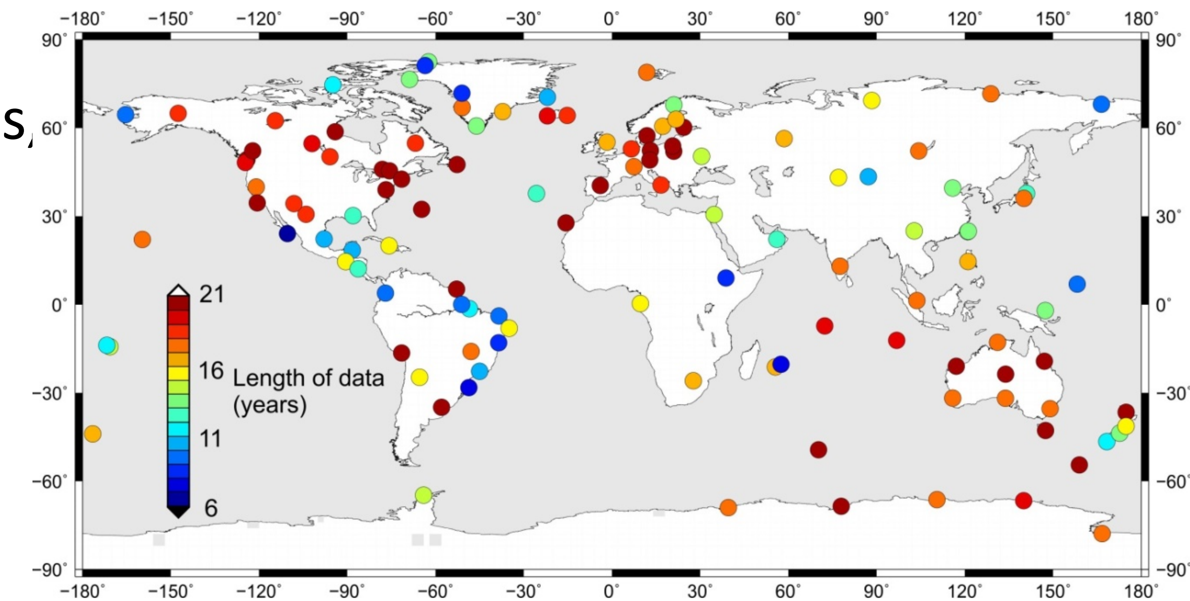
Motivation & workplan:

1. homogenisation of ZTD estimates,
2. division of TIGA stations into various climate zones,
3. modelling the ZTD series with mathematical model,
4. estimates of a proper noise model for ZTD series.

The aim: to show how much the uncertainty of the ZTD trends may be underestimated.

British Isles continuous GNSS Facility and University of Luxembourg Tide Gauge Benchmark Monitoring (TIGA) Analysis Center (BLT):

a) International GNSS Service (IGS) Tide Gauge Benchmark Monitoring (TIGA) analysis centre,
b) reprocessing of a global network of GPS stations from 1995 to 2015,
c) more than 700 stations,
d) hourly data.



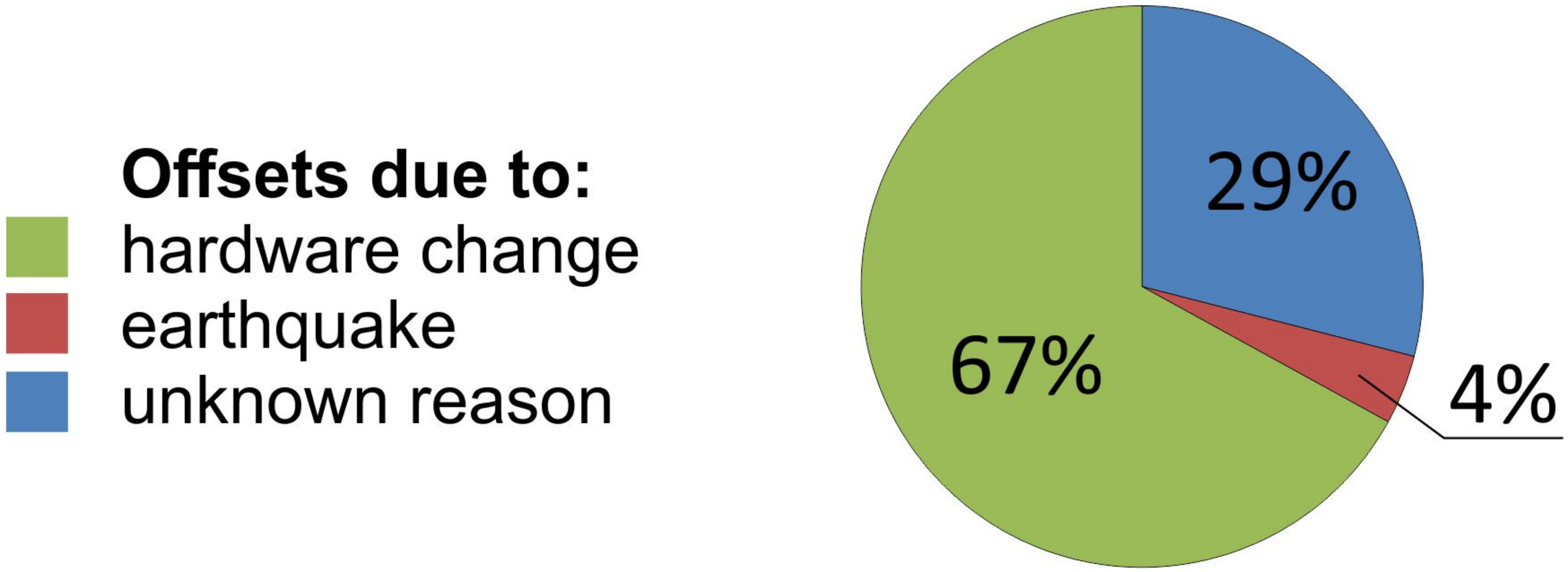
Reprocessing strategy and models applied for BLT repro2 solution:

a) Bernese GNSS Software BSW5.2 (double difference phase and code observations),
b) VMF1 and Hydrostatic a priori and Wet troposphere model from VMF,
c) tropospheric gradients: Chen and Herring tilt estimation for N-S and W-E directions,
d) estimates of Zenith Total Delay (ZTD) were computed every two hours using a piece-wise linear function and gradients were estimated at 12 hour intervals,
e) 3 degrees elevation cut-off and the cosine quartic dependent weighting.

Homogenisation of ZTD series:

The offsets reported in GPS position time series were validated manually in ZTD data.

The ones applied are the ones found/confirmed in ZTD series.



Division into climate zones:

Climate zones following the Köppen-Geiger classification (Peel et al., 2007). We focused on five climate zones for classifying the world's climate based on the annual and monthly averages of temperature and precipitation.

Number of stations:

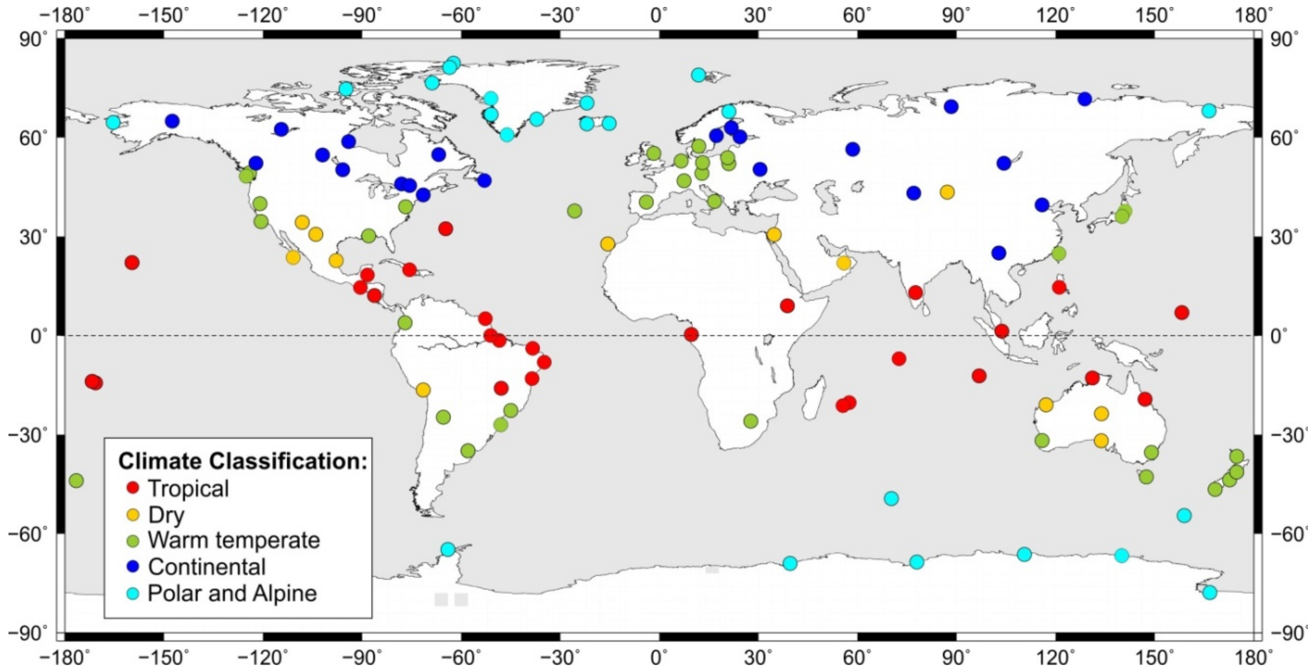
Tropical: 27

Dry: 13

Warm temperate: 35

Continental: 22

Polar and Alpine: 23

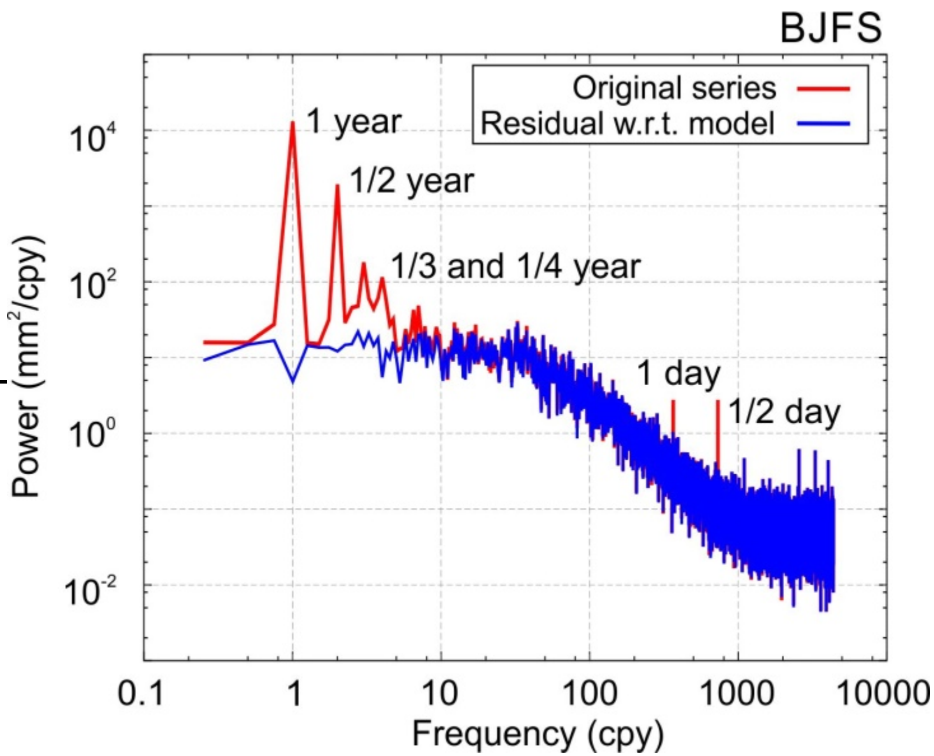


ZTD time series modelling:

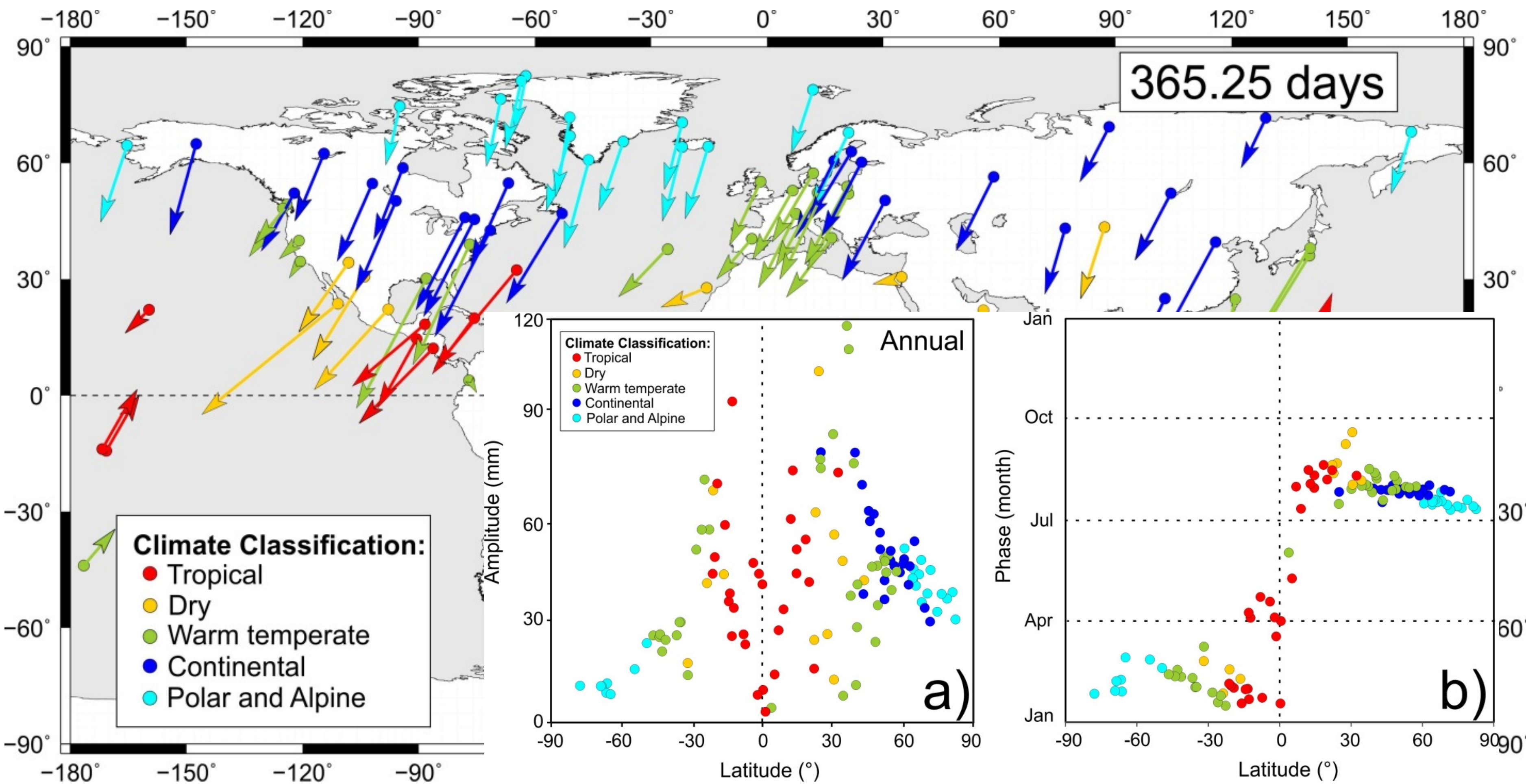
a) all significant periodics, trend + **their uncertainties**,

b) an optimal noise model delivered with Maximum Likelihood Estimation (MLE) in the Hector software (Bos et al., 2013).

$$ZTD(t_i) = ZTD_R + v \cdot (t_i - t_R) + \sum_{k=1}^{6}\left[\begin{array}{l} S_k \cdot \sin(2\pi \cdot f_k \cdot (t_i - t_R)) + \\ + C_k \cdot \cos(2\pi \cdot f_k (t_i - t_R)) \end{array}\right] + \sum_{j=1}^{n}\left(d_j \cdot H(t_i, t_j)\right) + \varepsilon_{ZTD_i}$$



Temporal variations of ZTD



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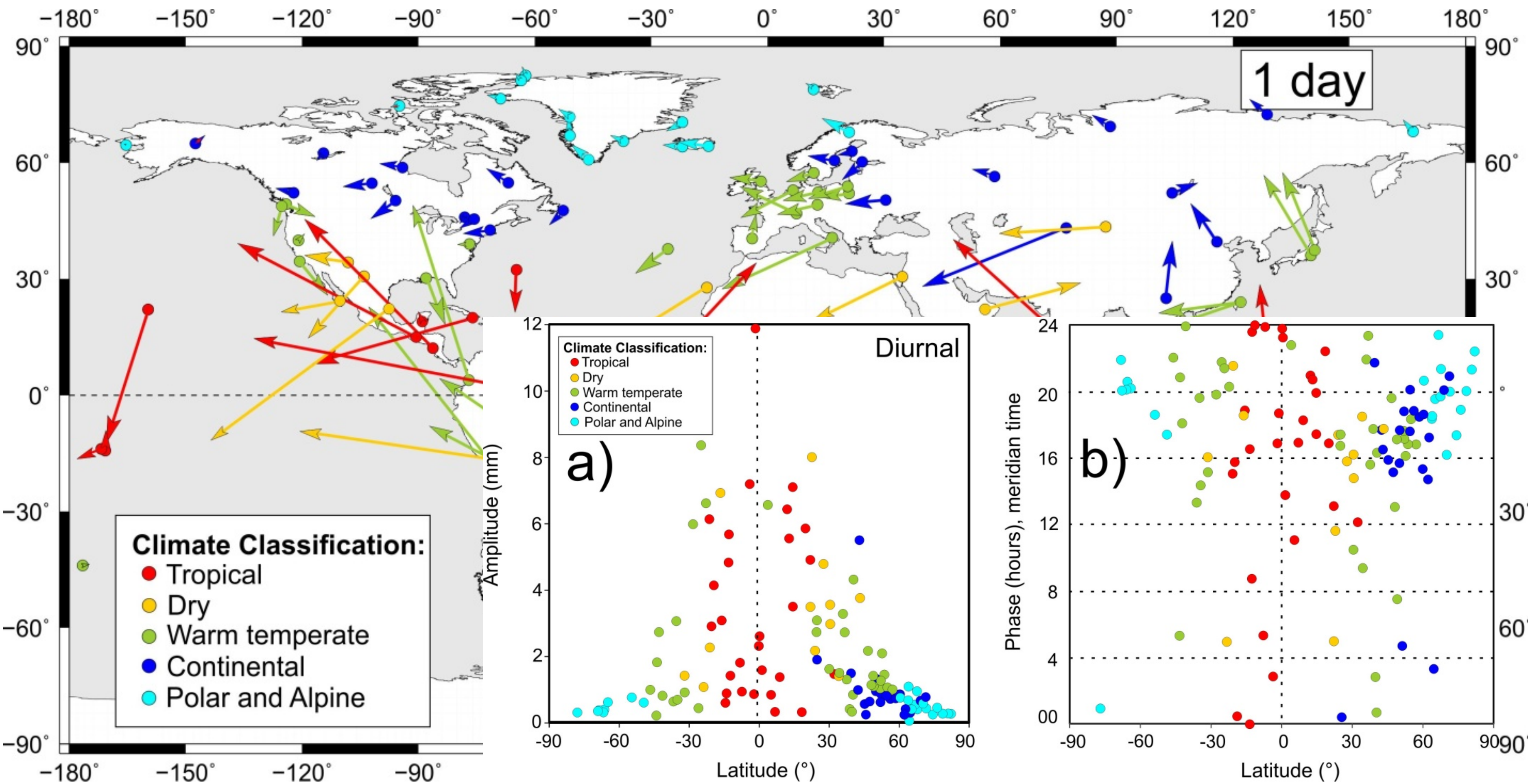
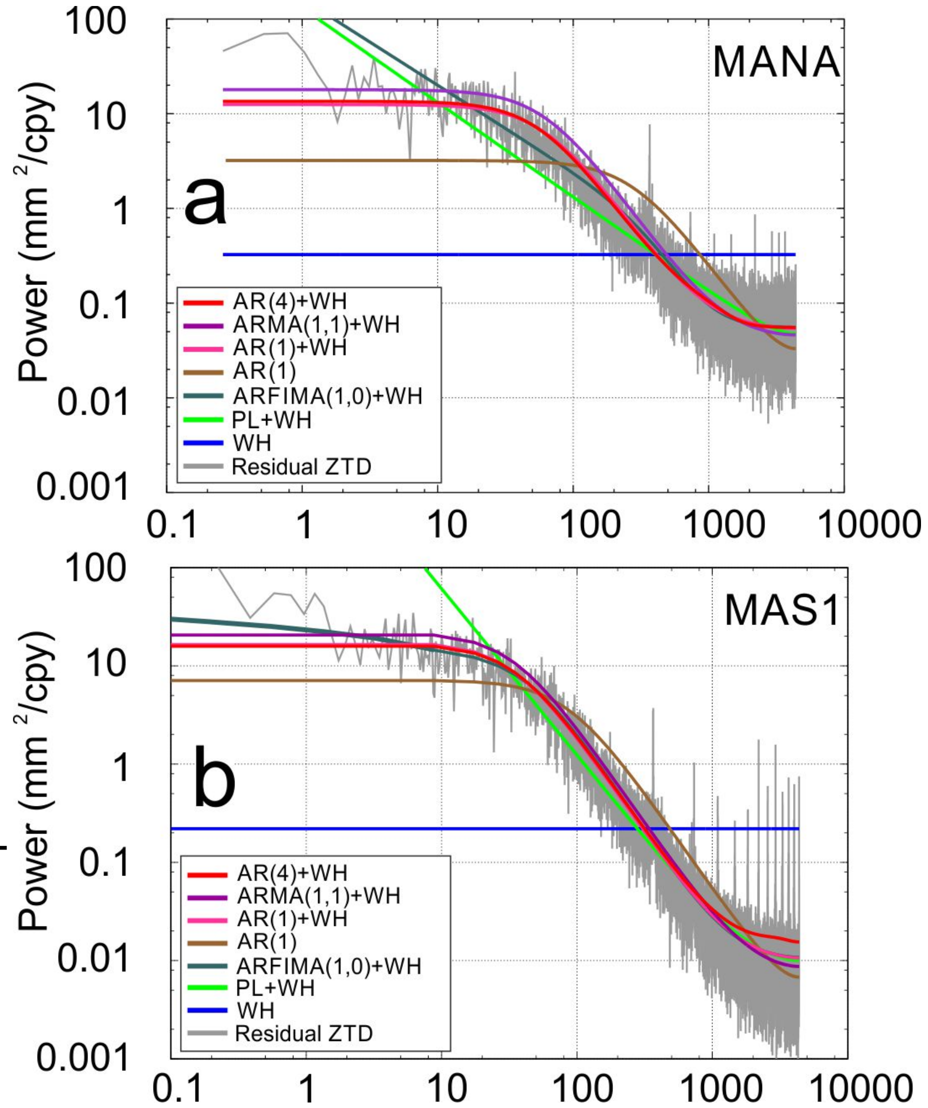


Noise analysis of ZTD:

a) an innovative approach of autoregressive process plus white noise (**AR(4)+WH**),

b) choice based on the BIC and MLE and also, as a compromise between both mentioned and time of computations.

$$\varepsilon_{ZTD_i} = \phi_1 \cdot \varepsilon_{ZTD_{i-1}} + \phi_2 \cdot \varepsilon_{ZTD_{i-2}} + \phi_3 \cdot \varepsilon_{ZTD_{i-3}} + \phi_4 \cdot \varepsilon_{ZTD_{i-4}} + a_t$$



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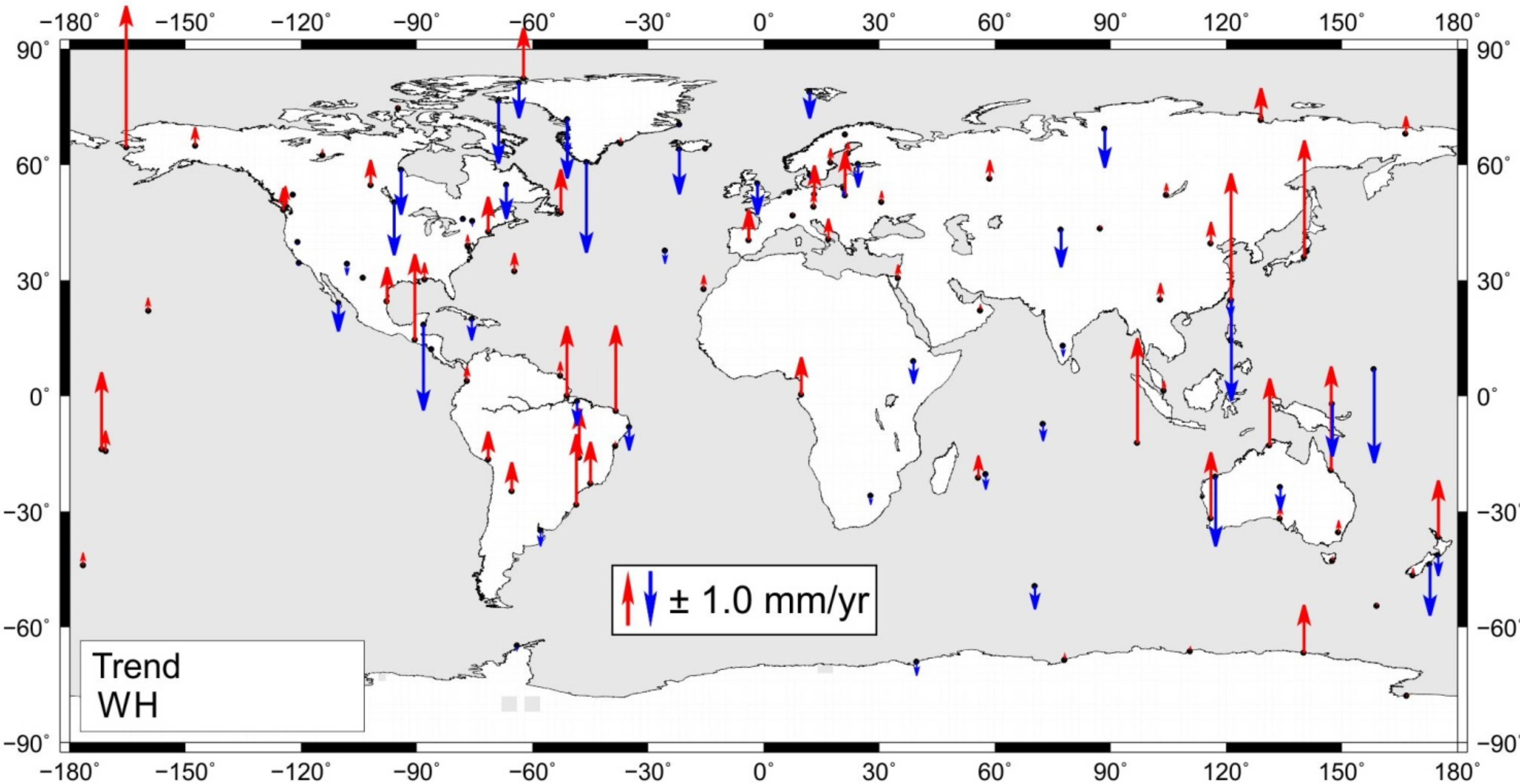
Median amplitudes of noise (mm)±1-IQR		
Climate zone	**WN**	**AR**
Tropical	13.00±5.67	9.59±8.12
Dry	9.23±6.18	6.80±5.72
Warm temperate	9.70±8.28	8.75±7.93
Continental	8.77±7.62	7.07±6.03
Polar and Alpine (NH)	7.17±6.45	4.85±4.06
Polar and Alpine (SH)	8.91±8.05	4.07±3.60

Median coefficients of AR(4)±1-σ				
Climate zone	**AR(1)**	**AR(2)**	**AR(3)**	**AR(4)**
Tropical	0.90±0.08	0.05±0.08	0.01±0.03	0.03±0.01
Dry	0.78±0.04	0.19±0.03	0.05±0.01	0.01±0.01
Warm temperate	0.72±0.03	0.17±0.02	0.08±0.01	-0.01±0.01
Continental	0.80±0.02	0.08±0.01	0.09±0.01	-0.03±0.01
Polar and Alpine (NH)	0.61±0.02	0.27±0.01	0.11±0.01	-0.02±0.01
Polar and Alpine (SH)	0.61±0.01	0.28±0.01	0.13±0.01	0.01±0.01

Median fraction of AR±1-IQR	
Climate zone	
Tropical	0.33±0.22
Dry	0.30±0.23
Warm temperate	0.44±0.37
Continental	0.40±0.31
Polar and Alpine (NH)	0.26±0.21
Polar and Alpine (SH)	0.21±0.18

Ratios of the trend uncertainties derived with AR(4)+WH ($\sigma_{AR(4)+WH}$) and WH-only (σ_{WH}):

$$ratio = \frac{\sigma_{AR(4)+WH}}{\sigma_{WH}}$$



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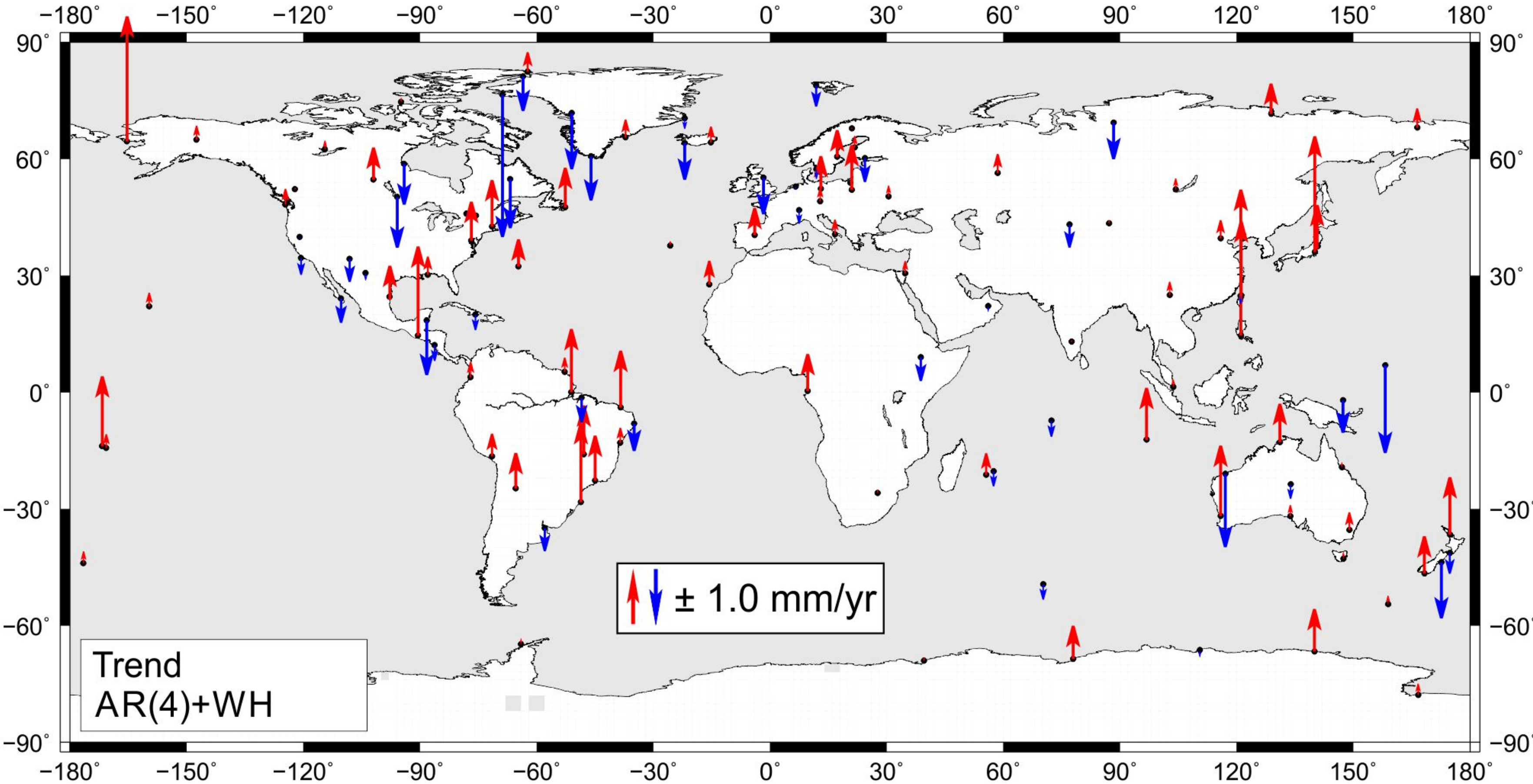

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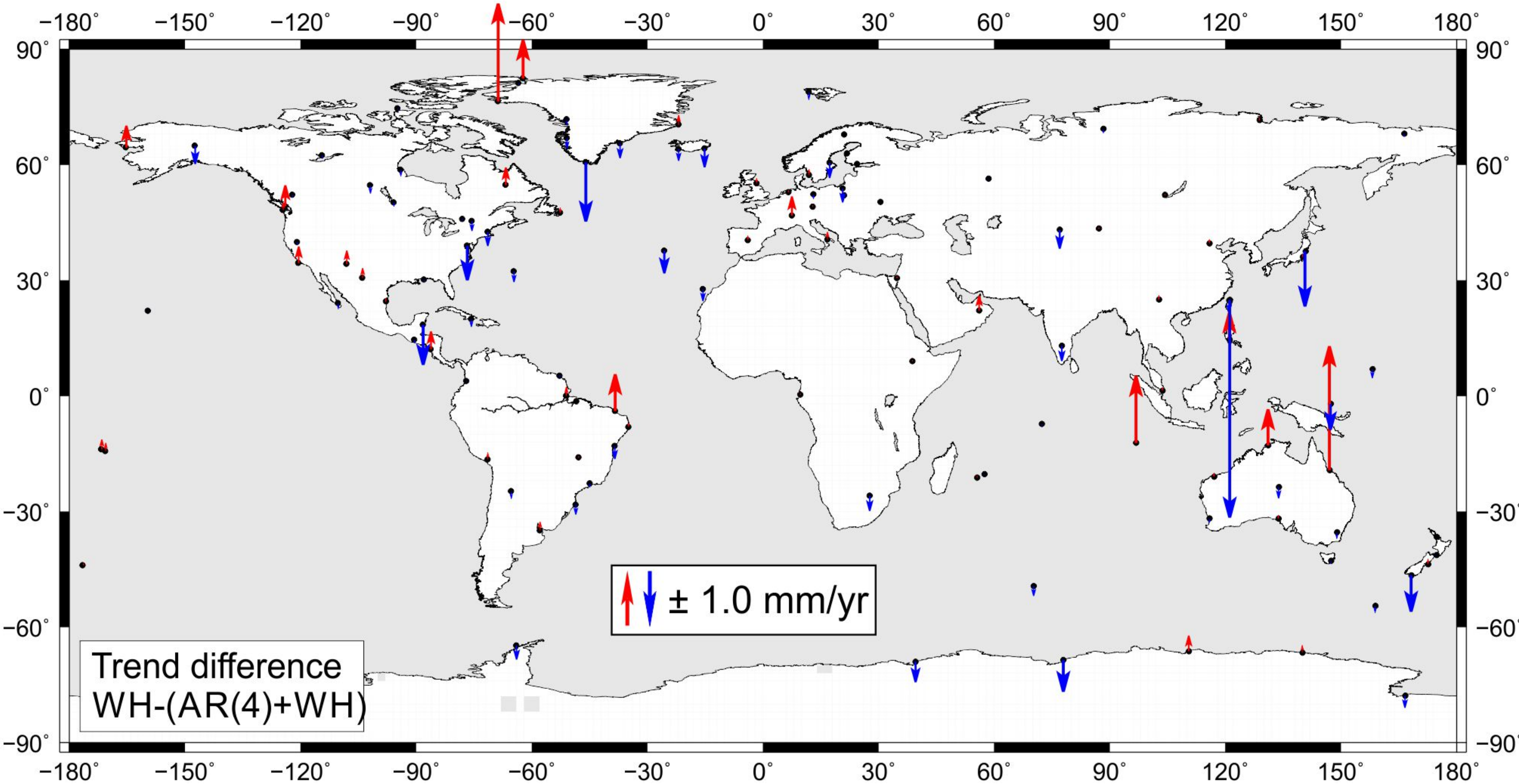

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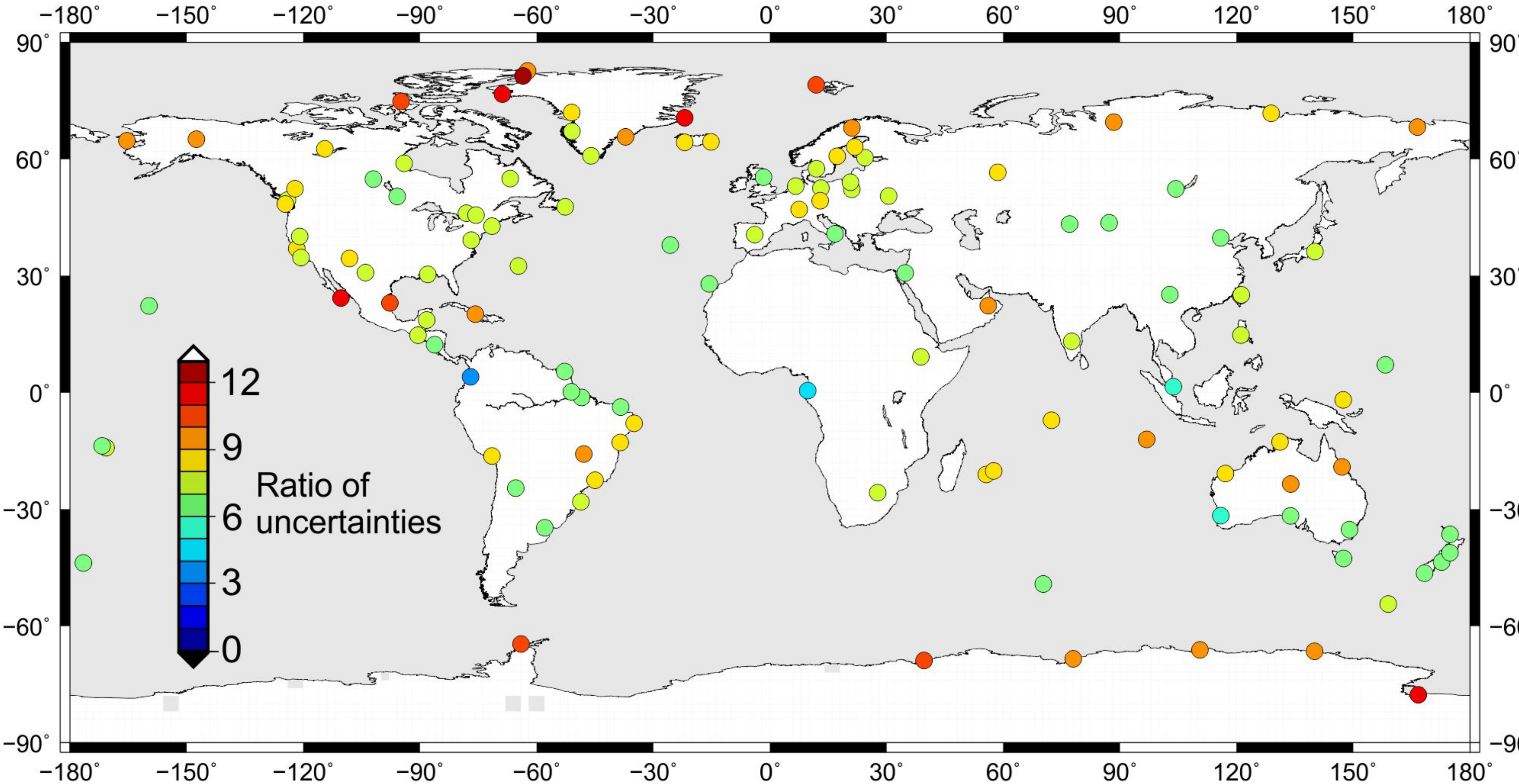

Summing up:

1. The **maxima of annual curve** fall between July and August for the Northern Hemisphere, while between January and February for the Southern Hemisphere. The **largest amplitudes of daily oscillations** are found for stations in the tropical zone, while those in both polar and Alpine zones are almost flat.
2. The **AR(4)+WH** noise model is found to be **optimal for ZTD time series** based on the BIC and MLE values. **White noise**, which is widely assumed for ZTD time series, **does not fit ZTD residuals** at all.
3. **53 of 120 examined** trends **became insignificant**, when the optimum noise model was employed, compared to 11 insignificant trends for pure white noise.
4. The uncertainty of the ZTD trends may be **underestimated by a factor of 3 to 12 compared** to the white noise only assumption.

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See: Klos, A., Hunegnaw, A., Teferle, F. N., Abraha, K. E., Ahmed, F., and Bogusz, J.: Noise characteristics in Zenith Total Delay from homogeneously reprocessed GPS time series, Atmos. Meas. Tech. Discuss., doi: 10.5194/amt-2016-385, in review, 2016.

Thank you!