The influence of stochastic processes on the significance of Zenith Wet Delay trends

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INTRODUCTION

A proper recognition of noise in the geophysical time series is crucial to obtain reliable estimates of parameters and their errors. Not only can these errors be underestimated, but also overestimated when assumptions about the stochastic characteristics of time series are improperly modelled. Nowadays, the Zenith Wet Delay (ZWD) estimates are being used to assess the amount of water vapour in the atmosphere through conversion into Integrated Water Vapour (IWV) and by forming time series of these parameters, scientists have started to investigate long-term changes and variations in these for climatological applications. In this study, we investigate the stochastic properties of such time series in order to provide an improved quantification of the errors in the trend estimates.

The ZWD time series employed in this research were estimated from the re-processing of Global Positioning System (GPS) observations of the IGS Tide Gauge Benchmark Monitoring (TIGA) Working Group archive and processed by the British Isles Continuous GNSS Facility and the University of Luxembourg Tide Gauge Benchmark Monitoring Analysis Center (BLT) in the Bernese GNSS Software Version 5.2 (BSW52). The reprocessing covered the period 1995 to 2017. In our analysis, we estimated the parameters of the deterministic part (trend plus seasonal components) and of the stochastic part (noise model) together to provide the best possible model representation of the ZWD time series. The model is resolved with Maximum Likelihood Estimation (MLE). We tested four different noise processes: pure white noise (WH), a combination of power-law plus white noise (PL+WH), pure autoregressive of order n (AR(n)) and a combination of autoregressive plus white noise (AR(n)+WH). The order n of AR noise was chosen from 1 to 4. On the basis of the Bayesian Information Criterion (BIC) and the logarithm of the MLE function, we show that AR(1)+WH is preferred to characterize the stochastic part of the ZWD time series. The amplitudes of AR(1)+WH noise processes ranged between 9 and 68 mm. Accounting for the stochastic properties of the ZWD time series resulted in 77 out of 120 trends to be statistically significant while disregarding the stochastic properties of the ZWD time series resulted in 115 out of 120 trends to be significant. This may lead to biased interpretations in terms of the aforementioned climatological applications. This may lead to biased interpretations in terms of the aforementioned climatological applications.

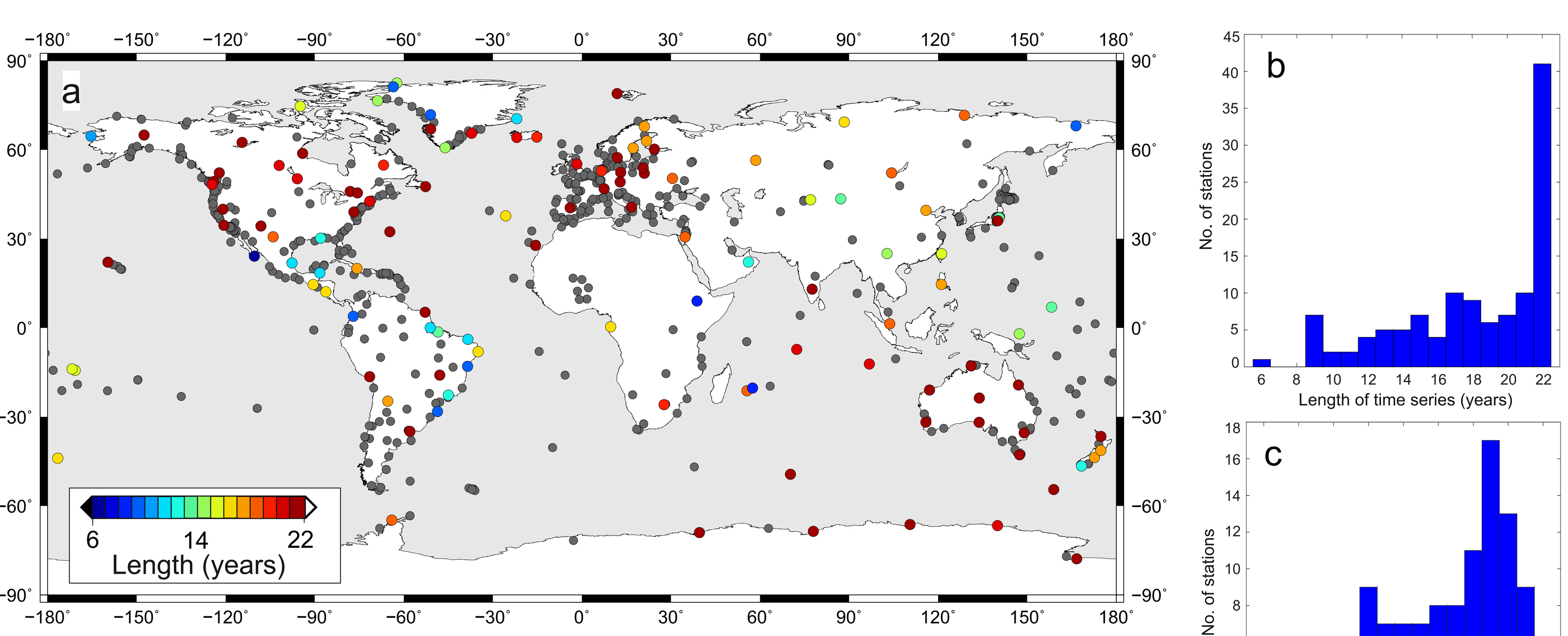

Figure 1. (a) Distribution of TIGA stations plotted in grey. The selected set of 120 stations we analysed in this research, was plotted in colours indicating the length of time series. (b) A histogram of length of employed data. (c) A histogram of latitudinal distribution of employed stations.

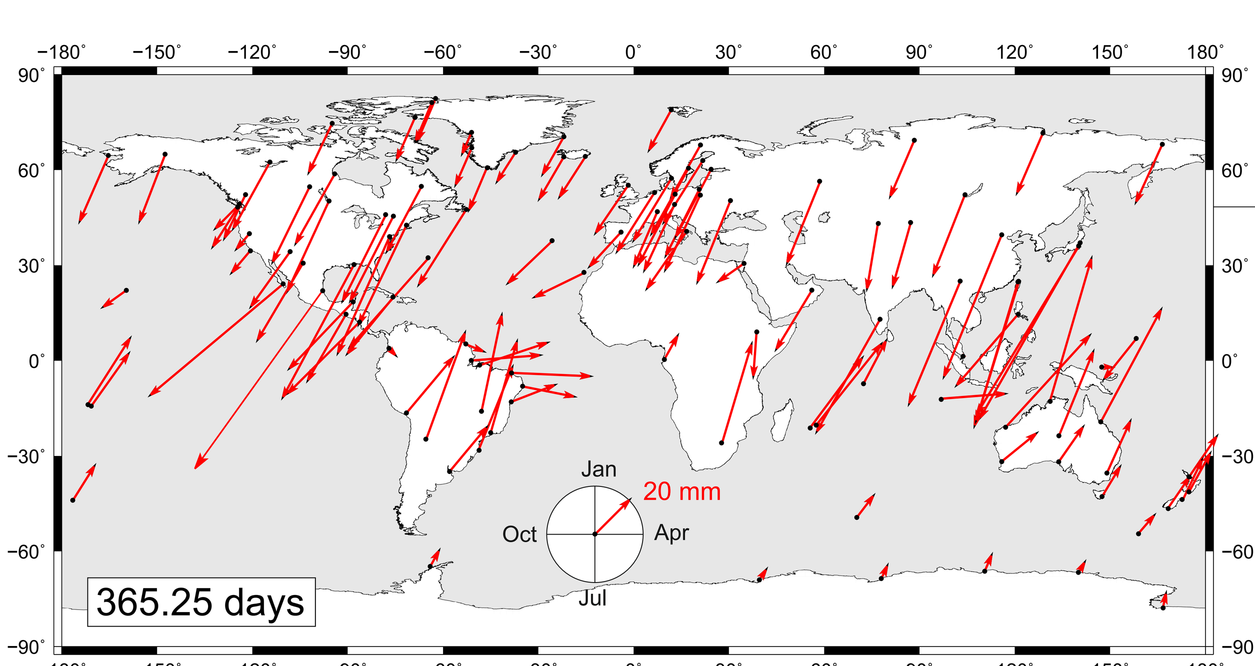

Figure 2. Annual amplitudes for 120 selected stations. The length of arrow depicts the amplitude of the annual sine curve with a reference to 20 mm. Phase shifts are counted as clockwise beginning from the North which means positive peak in January.

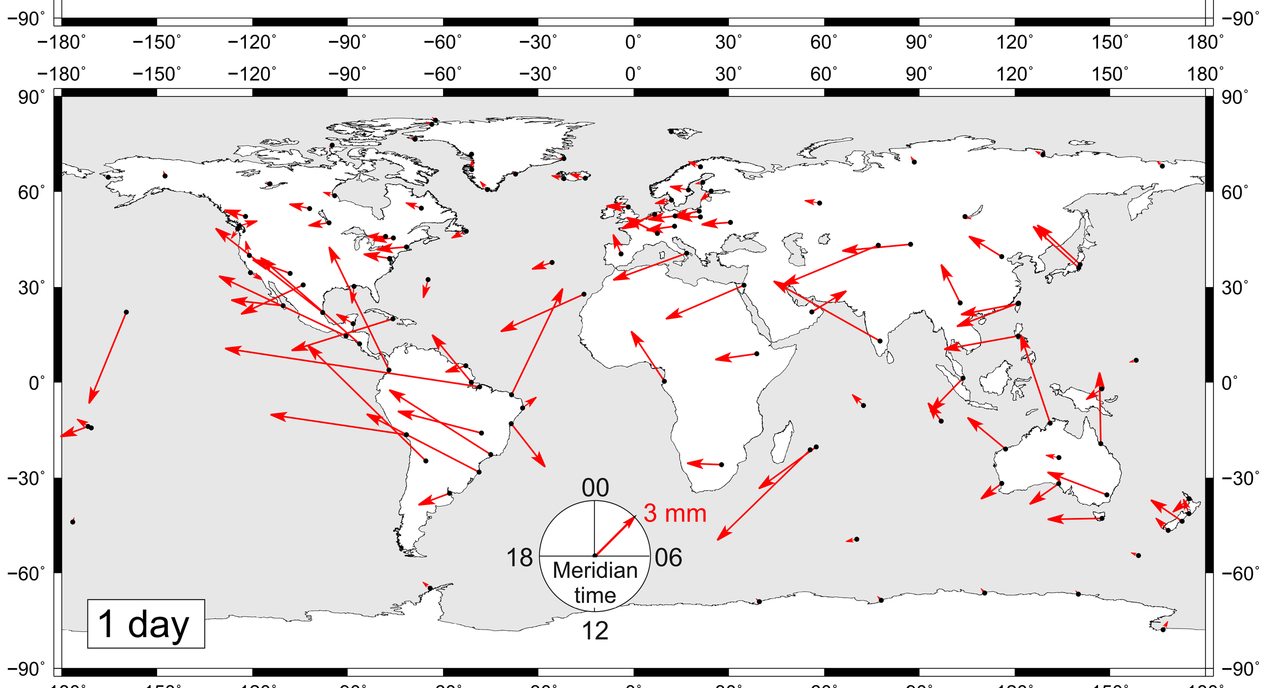

Figure 3. Diurnal amplitudes for 120 selected stations. The length of arrow depicts the amplitude of the diurnal curve with a reference to 3 mm. Phase shifts are counted as clockwise beginning from the North, which means a positive peak at 0 hours with respect to the local meridian.

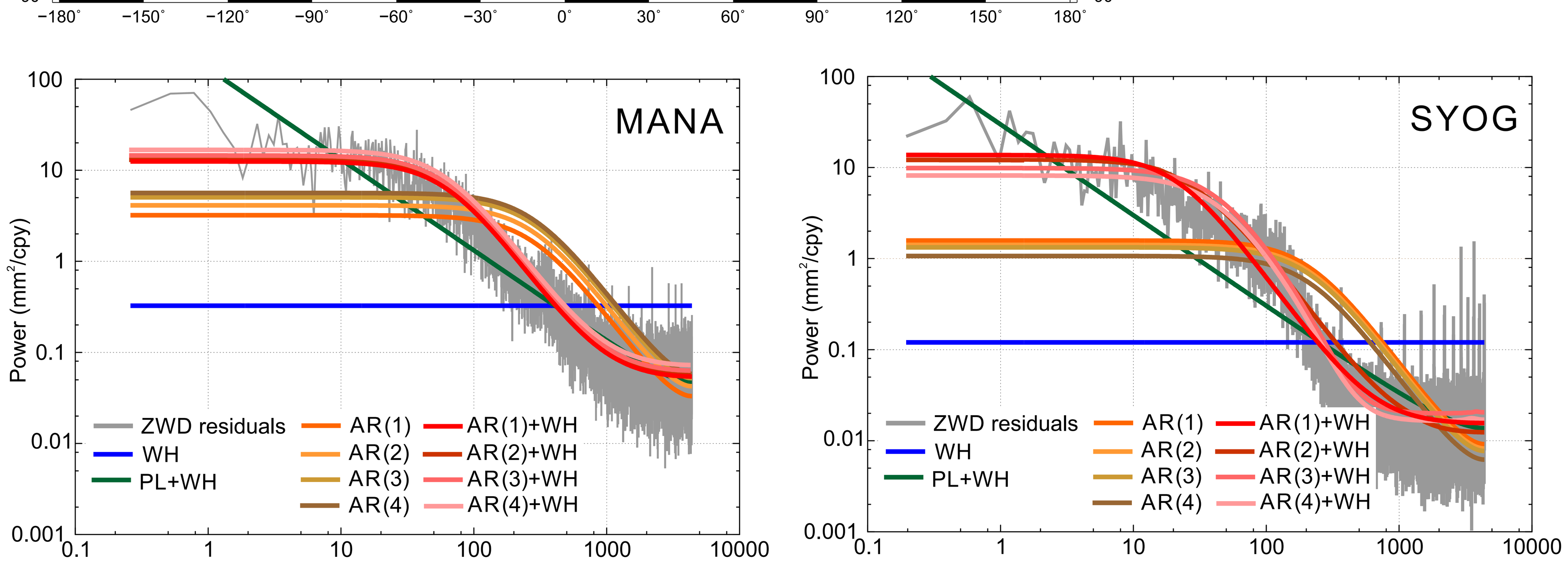

Figure 4. Examples of power spectra computed for MANA, Managua, Nicaragua and SYOG, Syowa, Antarctica. Different noise models: WH (blue), PL+WH (green), AR(n) (orange or brown), AR(n)+WH (red or pink) were fitted to the residuals (grey). There is little difference between the AR(n)+WH models. While the AR(4)+WH model is slightly superior than the AR(1)+WH, the latter outperforms the former in terms of computational efficiency.

REFERENCE

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.

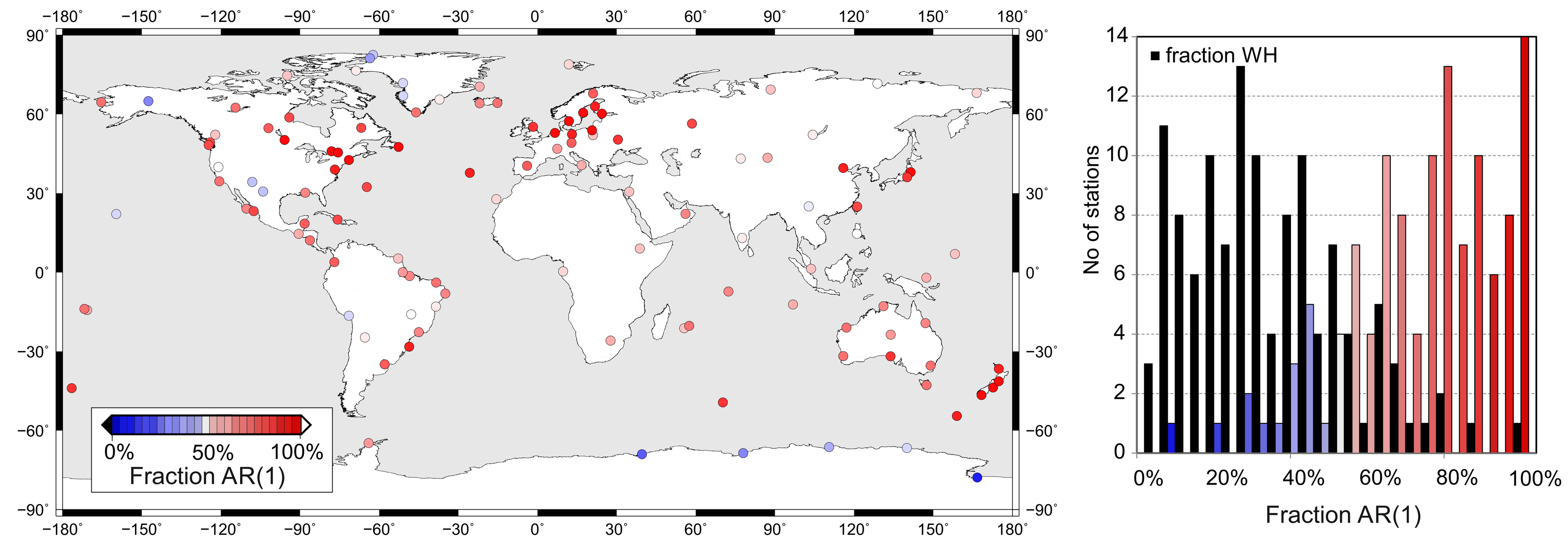

Figure 5. Fraction of AR(1) noise in the combination of AR(1)+WH, depicting the contribution of the AR(1) process in the stochastic part of the ZWD series. Right, a histogram of the fraction is given. Also, a fraction of WH noise was plotted in black. Note that the fraction of WH plus fraction of AR(1) always gives 100%.
We estimated the fraction of AR(1) noise in the employed combination. We found that for a number of 103 out of 120 stations, the AR(1) noise model contributes into AR(1)+WH in more than 50%. This means that it overbalances the white noise which is added to the combination. Also, for 14 stations the percentage of the AR(1) contribution is higher than 95%, which means that the ZWD residuals resemble a nearly pure autoregressive behaviour.

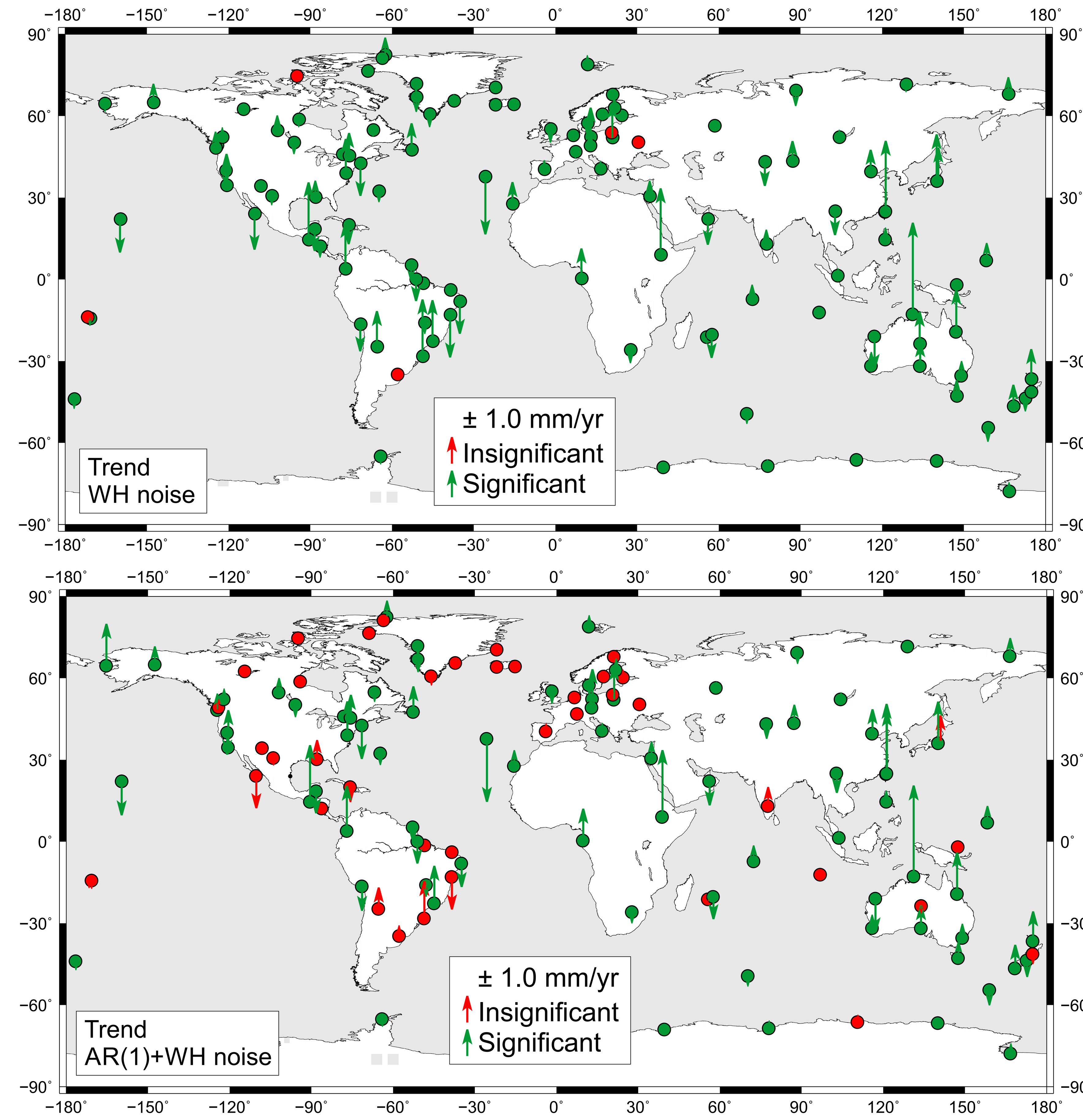

Figure 6. Values of trends (mm/yr) and their significance when pure white noise (WH) (top panel) and the combination of autoregressive and white noise (AR(1)+WH) processes (bottom panel) were assumed. The figure presents an investigation into the significance of trends when those two noise models were employed. By a significant trend we mean that the value of trend is higher than its 1-σ error. For a pure WH noise assumption, the trends estimated for a number of 115 out of 120 (96%) stations were significant. For AR(1)+WH noise processes, trends were significant only for a set of 77 out of 120 stations (64%).

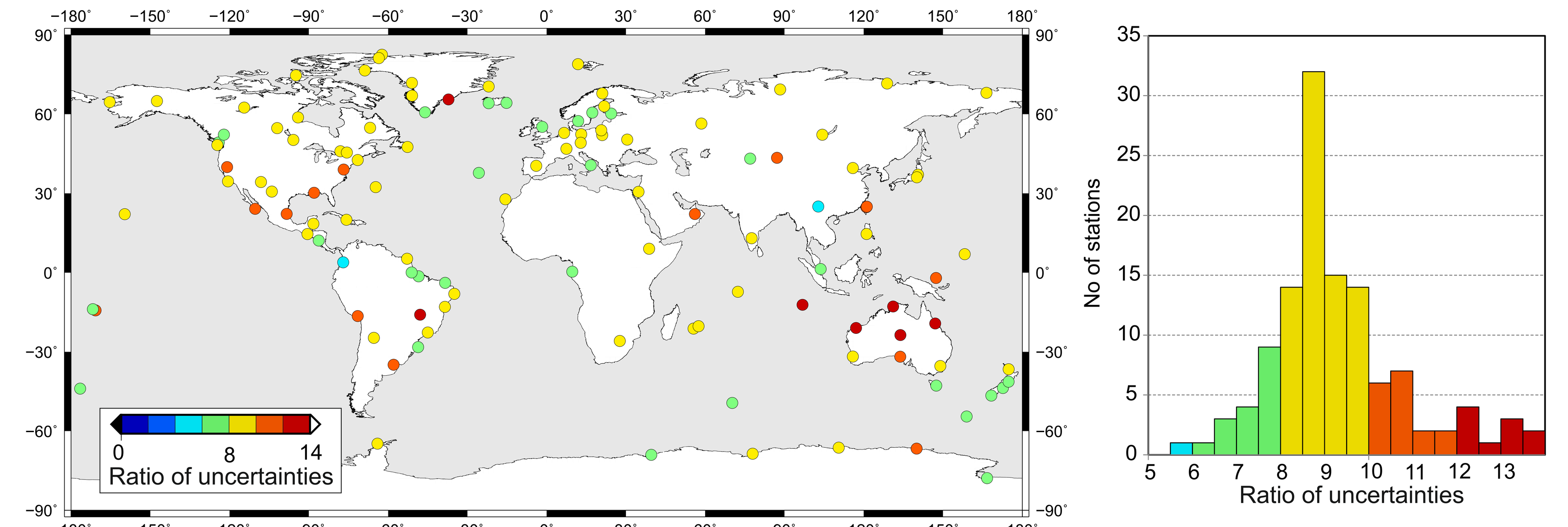

Figure 7. Ratio of trend uncertainties estimated with the AR(1)+WH and WH-only noise models.
The ratio between AR(1)+WH and WH trend uncertainties ranges between 5 and 14 for the set of analysed stations with the average of 8. No dependence on climatic region is apparent here. The trend itself may become insignificant when the noise model was changed from WH into AR(1)+WH as e.g. for ALIC (Australia), HOFN (Iceland), METS (Finland), ZIMM (Switzerland), etc. A set of 91 out of 120 (76%) employed stations has a ratio greater than 8, while 22 (18%) stations are characterized by a ratio of uncertainties greater than 10.

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