# Rethinking the colour of precipitation

Bunde, A., U. Büntgen, J. Ludescher, J. Luterbacher, and **H. von Storch**

Precipitation variation can affect ecological systems, agricultural yields and human societies among various spatiotemporal scales[1]. Paleoclimatic insight on the persistence of wet and dry conditions is relevant to assess perspectives and drivers of ongoing climate change. Since systematic instrumental data are limited to the last century only, the main data sources of precipitation variability over the past millennium are proxy-based reconstructions and outputs from climate model simulations. Here we address, if these sources reflect a consistent picture of past precipitation variability. In fact, they do not.

We compare tree ring-based reconstructions from North America[2], Central Europe[3] and High Asia[4] with forced model simulations and instrumental measurements. To quantify the temporal rhythm of each precipitation record[5], we first consider the persistence lengths $l$ that are defined by the numbers of successive years in each record during which precipitation is either below or above the median (dry or wet period). It is known that in uncorrelated data (white noise), the persistent length is distributed exponentially, i.e. its frequency of occurrence decreases exponentially with increasing $l$. We show that the persistence lengths derived from model simulations and instrumental observations resemble white noise (Fig. 1c,d). In contrast, the length distribution of the reconstructions is quite broad and thus indicative for strong multi-annual and multi-decadal persistence (pink noise) (Fig.1a). Long-term persistent[7] data with Hurst exponents ~0.8-0.9 do indeed reveal similar behaviour (Fig. 1b).

We further quantify average precipitation patterns after wet or dry periods of certain lengths. Data without persistence mirror temporal insensitivity, whereas systems with memory exhibit more (less) precipitation after wet (dry) periods. The reconstructions indicate a strong dependence on previous conditions (Fig. 1 insets), again comparable to long-term persistent data with Hurst exponents ~0.8-0.9, while the simulations and observations again resemble white noise behaviour. These essential differences also derive from more advanced mathematical techniques like wavelet and detrended fluctuation analysis[5], and further appear robust in extreme year statistics (Supplementary Information). The reconstructed extremes cluster in time, while the model and observational extremes occur more randomly distributed.

Accordingly, there is no consistent picture of past precipitation variability emerging from the main two data sources. The course of millennium-long model simulations of regional precipitation variability is supported by instrumental measurements of the last century, suggesting that the appearance of dry and wet periods generally follows white noise behaviour. It is likely that tree-ring width chronologies overestimate the true precipitation memory, since tree growth is rather influenced by the (red) fluctuations in soil moisture availability than by (white) changes in rainfall. Nevertheless, at the same time reveal independent lines of palaeoclimatological and ecological evidence long-term changes in the Earth's hydrological cycle[6], which likely caused prolonged episodes of relative drought at regional to continental scales[7,8].

## References


1. IPCC, The Physical Science Basis (2007),
2. Salzer, M.W. & Kipfmueller, K.F., Clim. Change 3, 465-487 (2005).
3. Büntgen, U. et al. Science 331, 578-582 (2011).
4. Treydte, K. et al. Nature 440, 1179-1182 (2006).
5. Eichner, J.F. et al. Phys. Rev. 75, 011128 (2007).
6. Verschuren, D. et al. Nature 462, 637-641 (2009).
7. Cook, E.R. et al. Earth Sci. Rev. 81, 93-134 (2007).
8. Cook, E.R. et al. Science 328, 486-489 (2010).


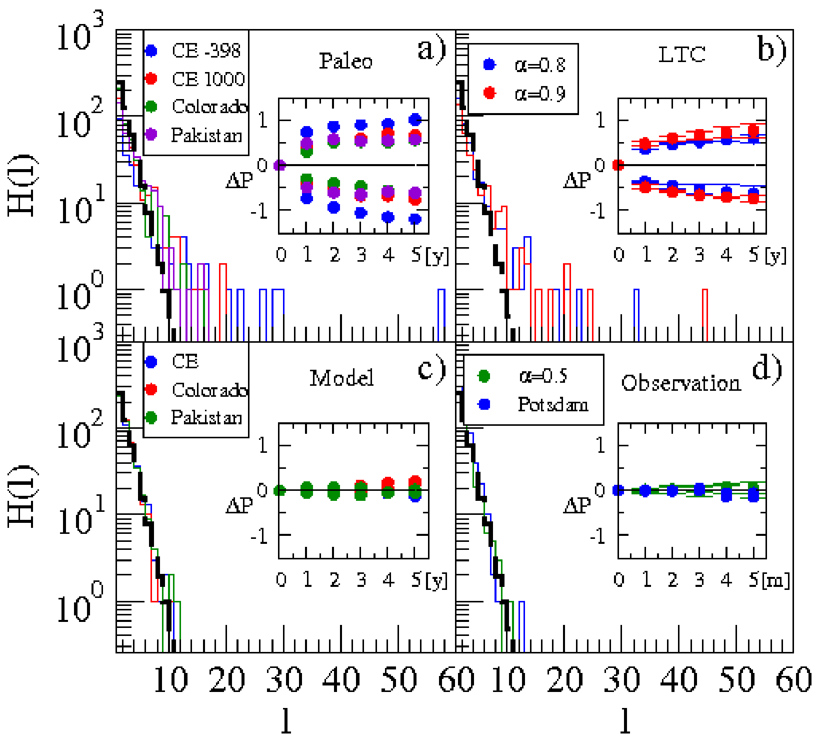


**Fig. 1. The colour of precipitation.** Histogram of persistence lengths of **(a)** tree ring-based precipitation reconstruction from Central Europe (396BC-604AC) and (985-1985), Colorado (1000-1988), and High Asia (1000-1998), as well as **(b)** synthetic long-term persistent data of comparable length (L=1000) with Hurst exponents of 0.8 and 0.9. **(c)** ECHAM6 precipitation output for the three proxy areas considered (885-1885), and **(d)** instrumental precipitation measurements (Potsdam, Germany, 1900-2000), together with generated white noise (green). Insets denote differences between the conditional mean precipitation (after 1-5 years where the precipitation is either below or above the median) and the mean precipitation, divided by the mean precipitation.