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On the long-range dependence properties of annual precipitation using a global network of instrumental measurements

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ABSTRACT

The long-range dependence (LRD) is considered an inherent property of geophysical processes, whose presence increases uncertainty. Here we examine the spatial behaviour of LRD in precipitation by regressing the Hurst parameter estimate of mean annual precipitation instrumental data which span from 1916–2015 and cover a big area of the earth's surface on location characteristics of the instrumental data stations. Furthermore, we apply the Mann-Kendall test under the LRD assumption (MKt-LRD) to reassess the significance of observed trends. To summarize the results, the LRD is spatially clustered, it seems to depend mostly on the location of the stations, while the predictive value of the regression model is good. Thus when investigating for LRD properties we recommend that the local characteristics should be considered. The application of the MKt-LRD suggests that no significant monotonic trend appears in global precipitation, excluding the climate type D (snow) regions in which positive significant trends appear.

1. Introduction

The long-range dependence (LRD), also known in hydrological science as the Hurst phenomenon, is a behaviour observed in geophysical processes in which wet years or dry years are clustered to respective long time periods (Koutsoyiannis, 2002). A common practice for evaluating the presence of the LRD is to model the geophysical time series with the Hurst–Kolmogorov process (HKp) and estimate its Hurst parameter H (Koutsoyiannis, 2003; Tyralis and Koutsoyiannis, 2011) where high values of H indicate strong LRD.

The estimation of H is of great importance in engineering practice (Lins and Cohn, 2011). As indicated by Koutsoyiannis (2006), Koutsoyiannis and Montanari (2007) and Tyralis and Koutsoyiannis (2014) the uncertainty increases substantially when LRD is present. Furthermore, due to the increase in uncertainty, observed trends in data, even if they seem significant using classical statistical testing, can be insignificant under the LRD assumption as shown by Hamed (2008).

Most studies on the assessment of the magnitude of precipitation LRD using instrumental data are local (e.g. Liu et al., 2012; Munshi, 2015; Valle et al., 2013). However, some studies including Fatichi et al. (2012) and Iliopoulou et al. (2017) estimated the magnitude of the precipitation LRD from instrumental measurements in global spatial scale and argued for its weak existence although the evidence for its presence in annual precipitation records is inconclusive (O' Connell et al., 2015). Similar global studies based on dissimilar datasets include Kumar et al., (2013) who estimated the H parameter of Coupled Model Intercomparison Project (CMIP5) twentieth-century precipitation simulations, Sun et al. (2014) who used reanalysis datasets and Bunde et al. (2013) who used instrumental measurements, climate model simulations and precipitation reconstructions to infer the significance of LRD in precipitation.

The Mann–Kendall test is frequently used in hydrology to evaluate the significance of trends. However, the Mann-Kendall test under the LRD assumption (MKt-LRD) (Hamed, 2008), in which a possible presence of LRD is considered, has been less frequently adopted. A few local case studies, in which the authors applied the Mann-Kendall test considering the presence of LRD include the investigation of precipitation (Dinpashoh et al., 2014), stream flows (Ehsanzadeh and Adamowski, 2010; Khaliq et al., 2009; Kumar et al., 2009; Sagarika et al., 2014; Zamani et al., 2017) and both (Fathian et al., 2016).

The analysis of point precipitation at a global setting is an important topic in hydrology (for instance see de Lima et al., 2012). It can be supported by the analysis of precipitation instrumental data from stations that spatially cover the globe, which has become a common subject in the recent literature and is supported by the increasing

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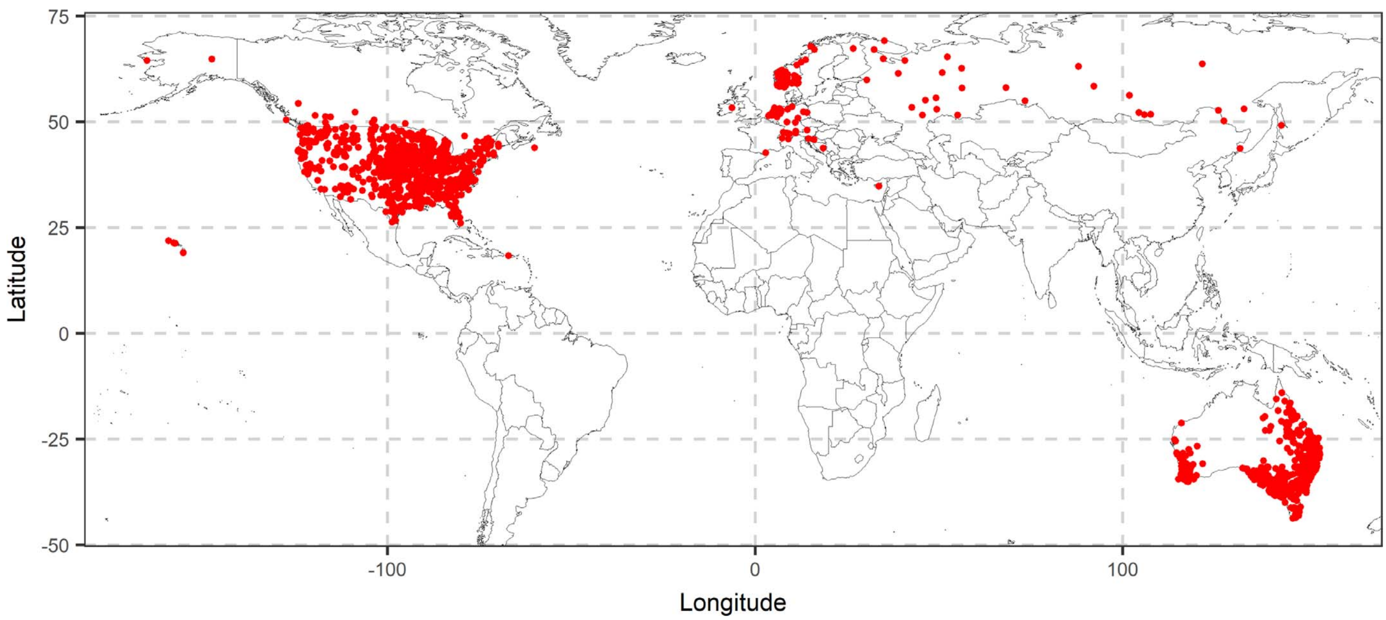

Fig. 1. Map of locations for the 1535 stations used in the analysis.

Table 1
Köppen–Geiger climate classes (Adapted from Fig. 1 in Kottek et al., 2006).

Main climate		Precipitation		Temperature	
A	equatorial	W	desert	h	hot arid
B	arid	S	steppe	k	cold arid
C	warm temperate	f	fully humid	a	hot summer
D	snow	s	summer dry	b	warm summer
E	polar	w	winter dry	c	cool summer
		m	monsoonal	d	extremely continental
				F	polar frost
				T	polar tundra

Table 2
Köppen–Geiger climate types of stations in Figure 1 and their regroupings.

Climate class	Number of stations	Grouping 1	Grouping 2	Grouping 3
Am	5	A	A	Am
As	4	A	A	As
Aw	9	A	A	Aw
BSh	65	BS	B	steppe
BSk	223	BS	B	steppe
BWh	21	BW	B	BWh
BWk	6	BW	B	without dry season
Cfa	419	Cfa	C	without dry season
Cfb	206	Cfb	C	without dry season
Csa	41	Ca	C	summer dry
Csb	125	Csb	C	summer dry
Cwa	5	Ca	C	winter dry
Dfa	181	Dfa	D	without dry season
Dfb	148	Dfb	D	without dry season
Dfc	52	Dfc	D	without dry season
Dsb	8	Dsw	D	summer dry
Dsc	1	Dsw	D	summer dry
Dwb	3	Dsw	D	winter dry
Dwc	4	Dsw	D	winter dry
ET	9	E	E	polar tundra

availability and accessibility of global data sets (Bierkens, 2015) while it is an important constituent of global-scale hydrology whose emergence was highlighted by Eagleson (1986; 1994). Such studies include the analysis of extremes (Alexander et al., 2006; Asadieh and Krakauer, 2015; Koutsoyiannis, 2004; Papalexiou and Koutsoyiannis, 2013), droughts (Nasrollahi et al., 2015), analysis of trends (van Wijngaarden and Syed, 2015), the temporal concentration of precipitation (Monjo and Martin-Vide, 2016) and reconstruction of past precipitation (Smith et al., 2012). Although the instrumental data need some processing to be used, they could be considered more reliable compared to climate simulations or reconstructions. However, the coverage of the earth's surface by rain gauges is not high, while it decreases considerably when the analysis demands a sufficient long time period to obtain more reliable results (New et al., 2001). In such cases, several alternative methods have been proposed including the use of satellite data (Kidd and Huffman, 2011).

The spatial analysis of precipitation based on instrumental measurements can be applied in local case studies, because the areas of interest are uniformly covered by the stations. This is the case, e.g. in Blanchet et al. (2009) who study the extreme statistics of snowfall, Villarini and Smith (2010) who investigate flood peak distributions, Li et al. (2011) who study precipitation trends and Dyrrdal et al. (2016) who analyse the extreme precipitation.

In this study, we estimate the H parameter of the mean annual precipitation from instrumental data from a large part of the earth. The database used in this study (Menne et al., 2012a, 2012b) includes stations that cover the largest part of the inhabited earth surface. However, for statistical reasons we examine stations with data, which span the hundred-year period 1916–2015 and thus the coverage decreases considerably. However, we prefer to use this reduced dataset instead of reanalysis datasets, because the artificial nature of the latter can alter considerably the results, particularly when using reanalysis data from uncovered areas at early time periods.

The primary aim of our study is to investigate the relationship between H and locations features, which has been suggested for further research in Iliopoulou et al. (2017), while Fatichi et al. (2012) did not identify the presence of a particular geographical pattern. The results of Sun et al. (2014) and Markonis and Koutsoyiannis (2016, Figure S3) indicate that H varies considerably with the location of the stations; however they were obtained by reconstructions of past precipitation. Classical spatial statistical analysis cannot be applied, because the coverage of the earth's surface by the examined stations is low and