Limits of predictability: a global-scale investigation of distribution and stochastic structure of key hydrological-cycle processes

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Abstract

The limits of predictability of a natural process are defined by the strength of its variability, which is related to its intrinsic uncertainty. In this work, we measure the magnitude of the variability of key hydrological-cycle processes in the scale domain. Particularly, we analyze a collection of several billions of data values from thousands of worldwide stations for the near-surface hourly temperature, dew point, relative humidity, sea level pressure, atmospheric wind speed, streamflow and precipitation. Through the use of the second-order climacogram (i.e., variance of the averaged process vs. scale) and climacospectrum (i.e., climacogram-based power-spectrum), we estimate the Long-Range-Dependence (LRD) for each process, and we conclude whether the examined processes exhibit short-term roughness and long-term persistence, both of which are indicative of a process behaviour with high variability, and thus, limited predictability.

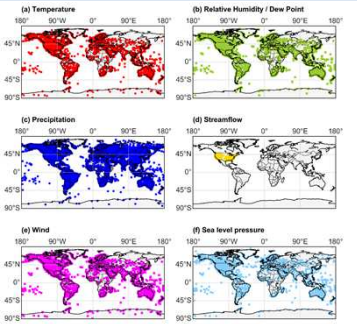
1 A global-scale massive stochastic analysis

In seeking a broad and comprehensive investigation of the stochastic similarities among key hydrological-cycle processes, a global-scale network of stations is analyzed (see more info in Dimitriadis et al., 2021).

- ISD database for hourly temperature, relative humidity, sea level pressure, and wind speed.
- USGS and CAMELS databases for hourly and daily streamflow.
- HPD and the GHCN databases for hourly and daily precipitation.

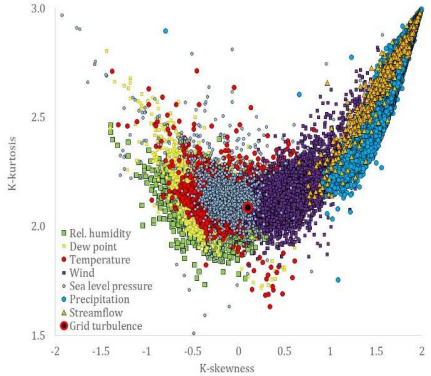
In total, approximately 50 × 10^{10} records from over 2 × 10^5 hydroclimatic global-scale stations on daily, hourly, and sub-hourly resolution are extracted and handled.

Data extraction



	Near-Surface Temperature	Dew Point	Humidity	Sea Level Pressure	Wind Speed	Precipitation	Streamflow
Temporal resolution	Hourly	hourly	hourly	hourly	hourly	hourly/daily	hourly/daily
Total number of stations/ time series	6613	5978	4025	4245	6503	93904	1815
Total number of records (× 10^9)	907.1	730.0	540.2	364.9	781.7	938.7	13.5
Time period	1938–today	1938–today	1940–today	1939–today	1939–today	1778–today	1900–today

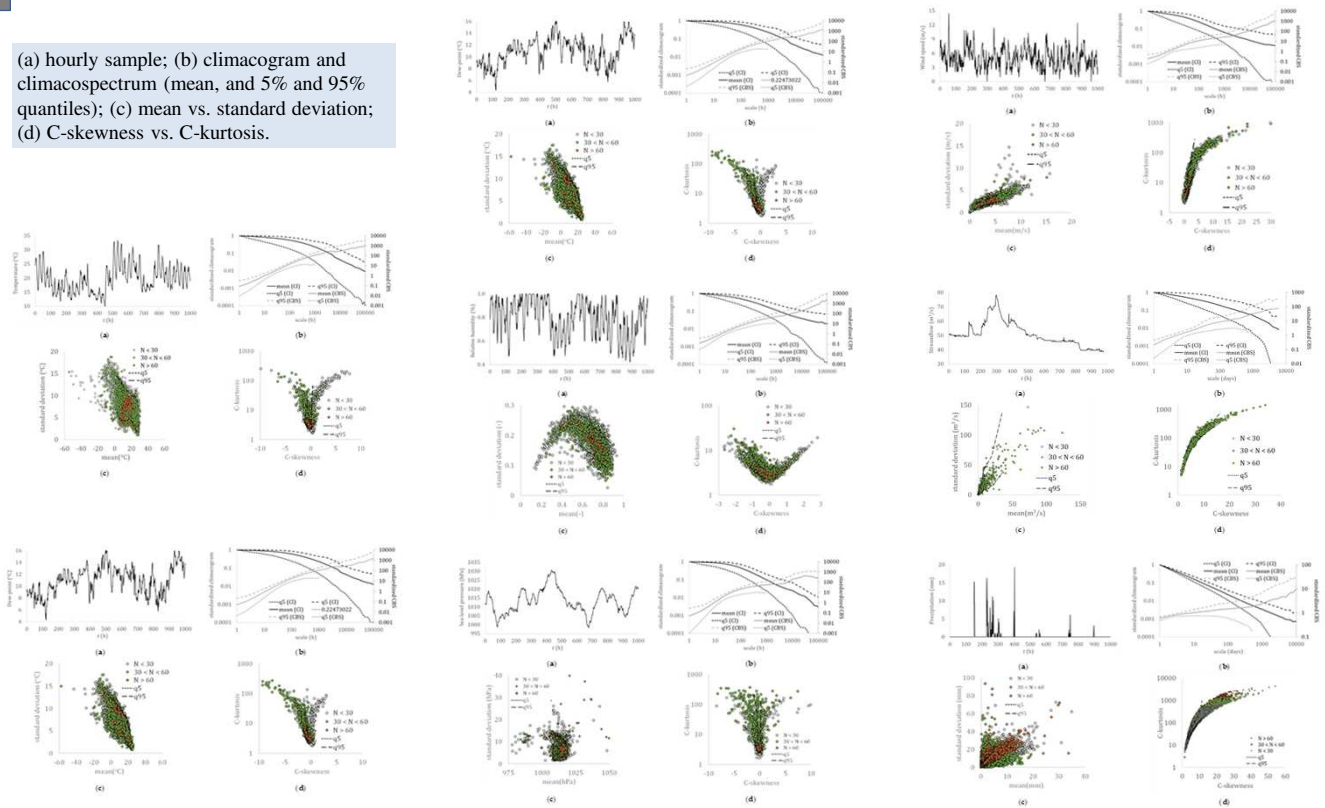
2 Hydrological-cycle path: Marginal structure



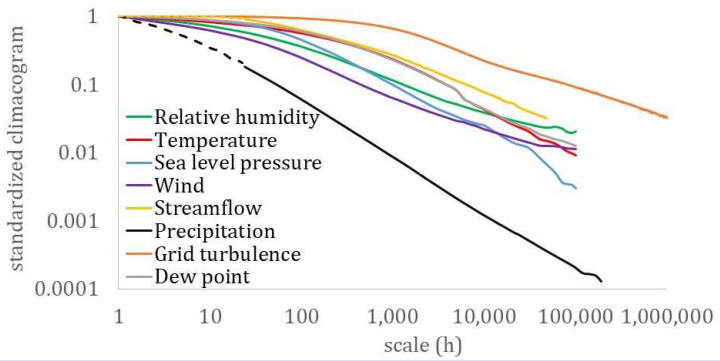
K-skewness vs. K-kurtosis (Koutsoyiannis, 2021) for the key hydrological-cycle processes driven by turbulence

3 Hydrological-cycle path: Patterns due to climatic conditions

(a) hourly sample; (b) climacogram and climacospectrum (mean, and 5% and 95% quantiles); (c) mean vs. standard deviation; (d) C-skewness vs. C-kurtosis.



4 Hydrological-cycle path: Dependence structure



Similarities among the 2nd order dependence structure of the key hydrological-cycle processes and turbulence

Conclusions

- Hierarchy in hydrological-cycle key processes in terms of the marginal structure (robustly estimated by the K-moments) extending from (truncated) Gaussian to Pareto-type tails.
- Strong long-range dependence (LRD) behaviour in the dependence structure (robustly estimated in scale rather than in lag or frequency and by adjusting for statistical bias).
- All examined hydrological-cycle processes exhibit similar dependence structure that extends from the fractal behavior with roughness located at the small-intermittent scales to the LRD behaviour at large scales, while both indicate large uncertainty and high climatic variability, and thus, limited predictability.

References

Dimitriadis, P., D. Koutsoyiannis, T. Iliopoulou, and P. Papanicolaou, A global-scale investigation of stochastic similarities in marginal distribution and dependence structure of key hydrological-cycle processes, *Hydrology*, 8 (2), 59, doi:10.3390/hydrology8020059, 2021.

Koutsoyiannis, D., *Stochastics of Hydroclimatic Extremes - A Cool Look at Risk*, ISBN: 978-618-85370-0-2, 333 pages, Kallipos, Athens, 2021.

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