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Hydrological climate classification: can we improve on Köppen-Geiger?

Introducing CLASSY - CLimatic Aridity, Seasonality and Snowfall for hYdrology

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To transfer knowledge from basin to basin, hydrology needs its own structured way to think about climates

The Köppen-Geiger classification is widely used in earth sciences[1] but has limited applicability in hydrology[2,3]. It is **bioclimatic** in origin and uses **thresholds** to create **categorical, discrete** climate classes. To transfer knowledge from one basin to another, hydrology needs a climate classification that has a **hydrologic** basis, uses **deterministic, easy-to-use numbers**, and acknowledges the **gradual spatial change** in climatic conditions that occurs in reality.

Conclusions

- CLASSY uses aridity, seasonality and snowfall indices to define the global hydro-climate (fig 1,3)
- Spatial changes in flow regimes follow spatial changes in hydro-climate (fig 3,4)
- Basins should be compared on a continuous hydro-climatic spectrum and CLASSY provides a framework for this
- CLASSY outperforms the Köppen-Geiger classification, especially in colder regions (fig. 5,6)

Method

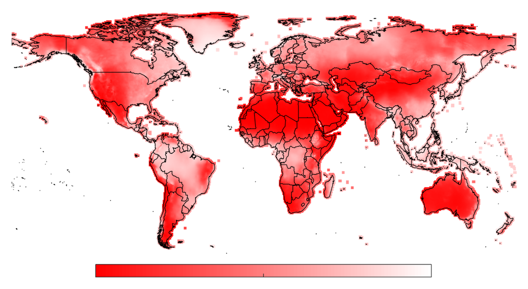
We use monthly rainfall, temperature and potential evapotranspiration data for 1984-2014[4] to define indices for annual average aridity[5], seasonal changes of aridity[5] and snowfall[6]:

$$I_m(t) = \begin{cases} 1-\dfrac{E_P(t)}{P(t)} & ,P(t) > E_p(t) \\ 0 & ,P(t) = E_p(t) \\ \dfrac{P(t)}{E_P(t)} - 1 & ,P(t) < E_p(t) \end{cases}$$

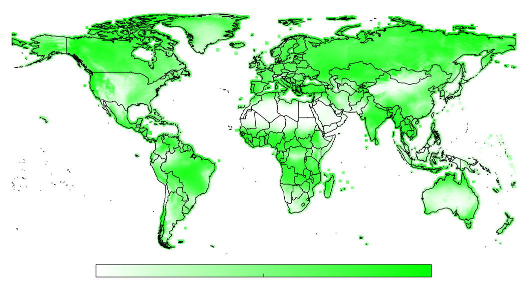
$$I_m = \frac{1}{12}\sum_{t=1}^{t=12} I_m(t) \qquad \text{(eq. 1)}$$

$$I_{m,r} = \max_{1\le t \le 12}(I_m(t)) - \min_{1\le t \le 12}(I_m(t)) \qquad \text{(eq. 2)}$$

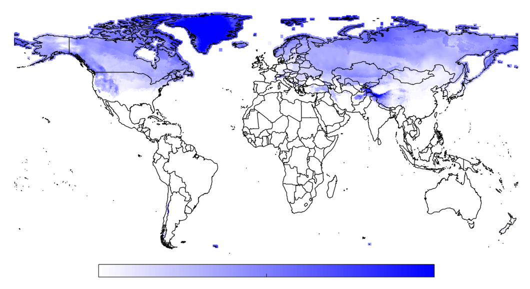
$$f_s = \frac{\sum P(T(t) \le 0)}{\sum_{t=1}^{t=12} P(t)} \qquad \text{(eq. 3)}$$



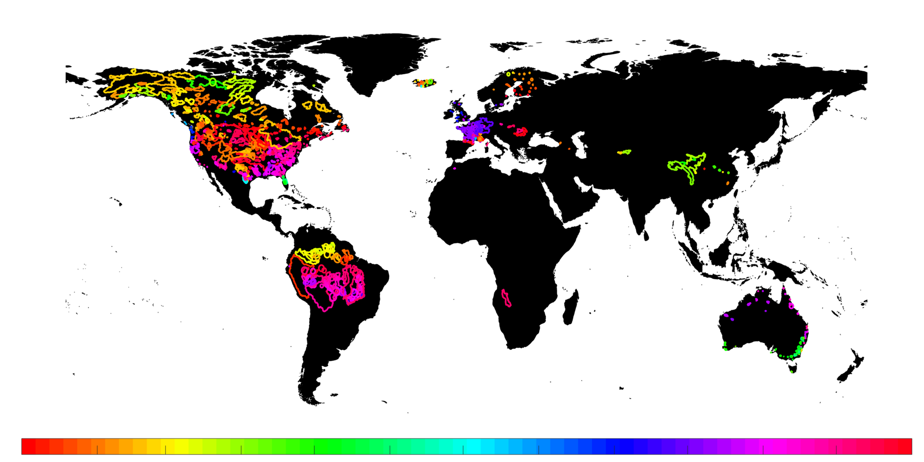
(fig. 1a): annual average aridity (eq. 1)



(fig. 1b): aridity seasonality (eq. 2)



(fig. 1c): annual precipitation as snow (eq. 3)



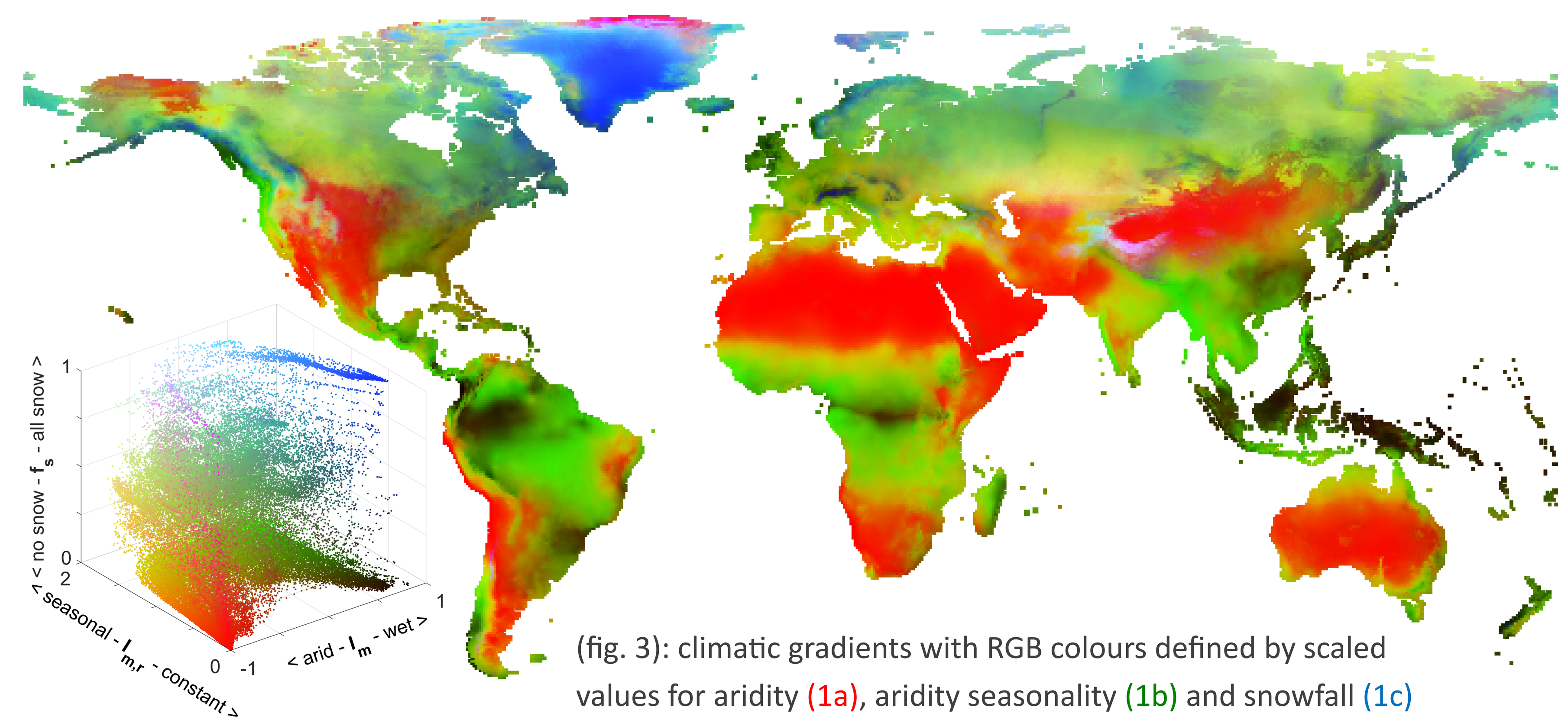
(fig. 2): location and start of water year for 1103 basins

Independent validation

We use streamflow data from 1103 basins[7] (fig. 2) to assess the effectiveness of the classification. For each basin, we define the 'typical regime' using the median flow for each Julian day (e.g. the typical 1-Jan is the median of all 1-Jan's available for that basin).

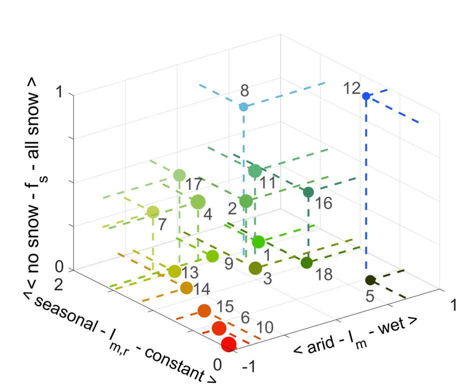
CLASSY shows that global flow regimes evolve along climatic gradients - similar climate → similar flow regime

Fig.3 shows the combination of the 3 climate indices (fig. 1) into a single map. We superimpose 18 cluster centroids on the 3D-climate index space and calculate the degree of similarity between the average climates of the 1103 river basins (fig. 2) and these 18 clusters. We find that flows evolve along climatic gradients (fig. 4). Statistical tests on 16 streamflow signatures (not shown) confirm that CLASSY is well-suited to group hydrologically similar regimes.

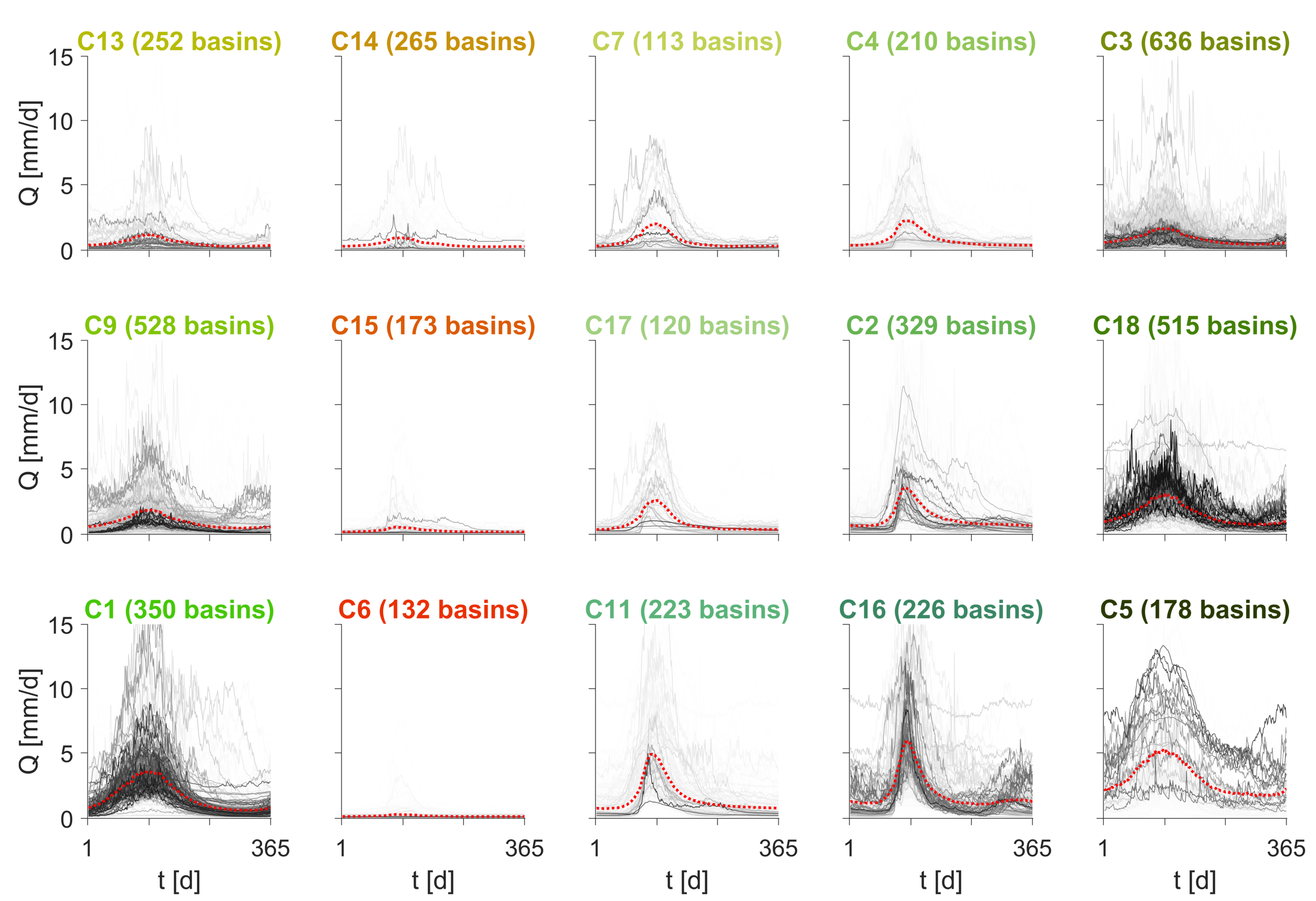


(fig. 3): climatic gradients with RGB colours defined by scaled values for aridity (1a), aridity seasonality (1b) and snowfall (1c)

Superimpose 18 cluster centroids on 3D climate-index space



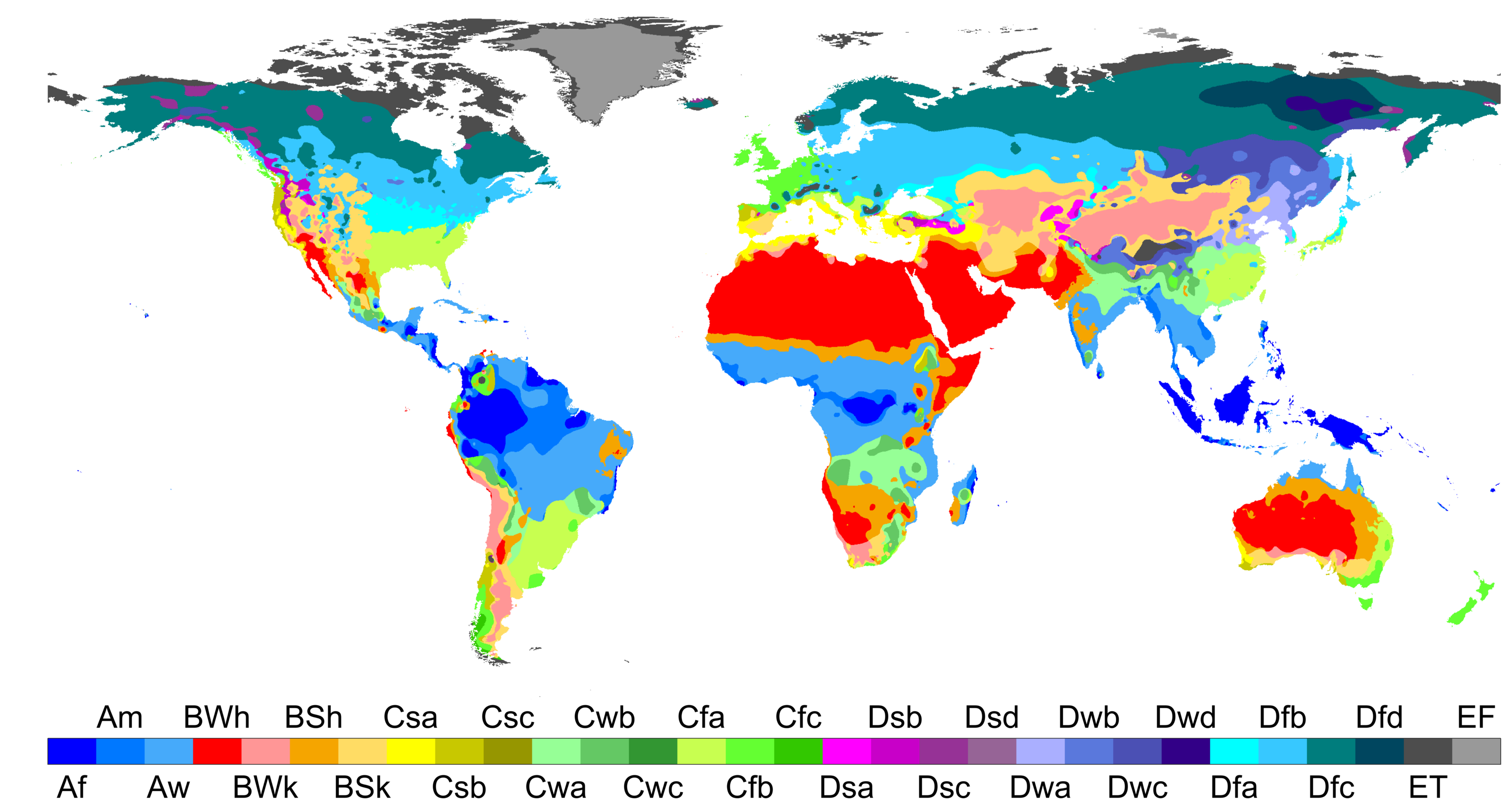
column	clusters	climatic gradient
1	[13, 9 ,1]	decreasing aridity
2	[14, 15, 6]	decreasing seasonality
3	[7, 17, 11]	decreasing aridity
4	[4, 2, 16]	decreasing aridity & seasonality
5	[3, 18, 5]	decreasing aridity & seasonality



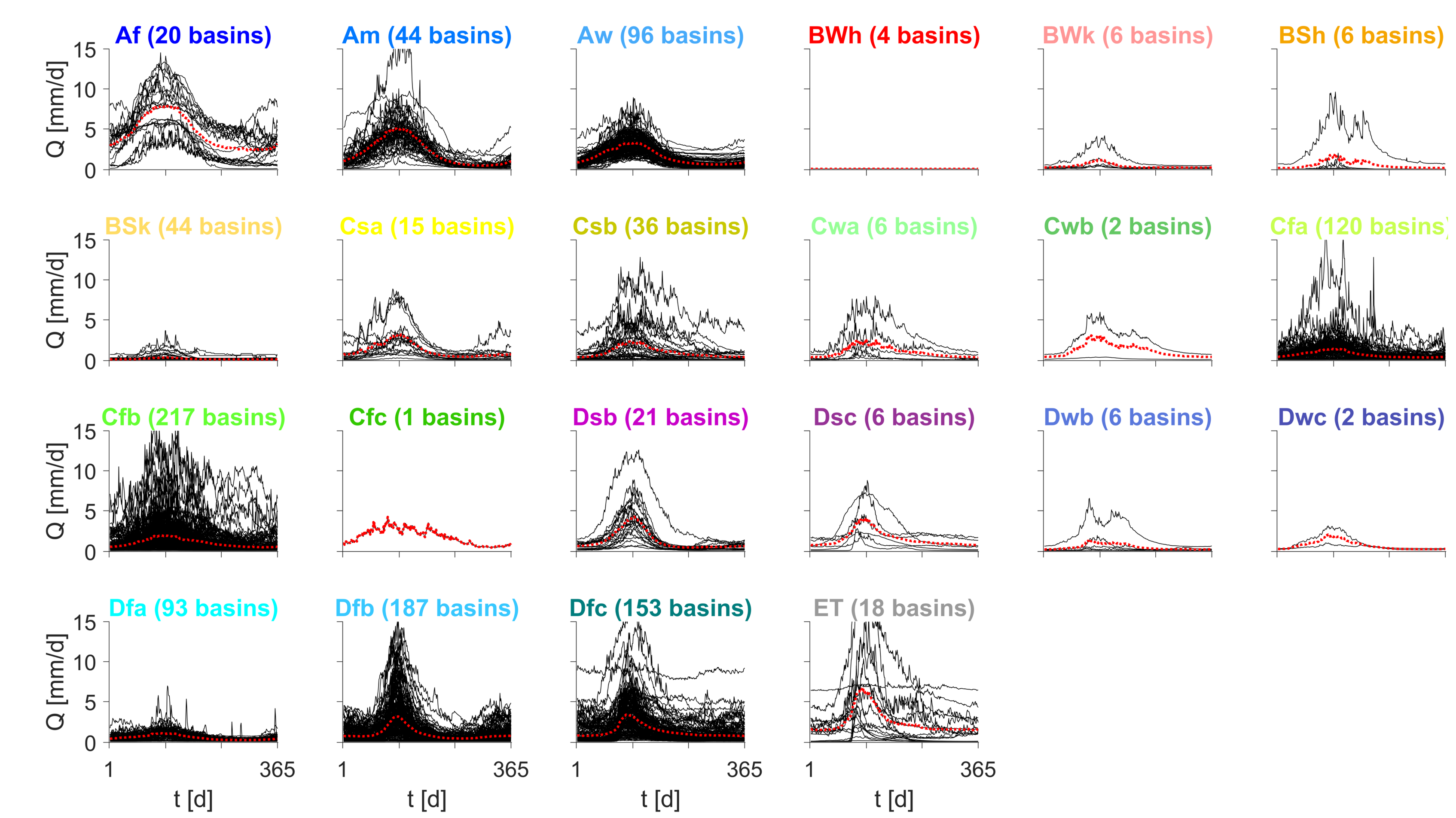
(fig. 4): flows grouped and shaded by climatic similarity between each basin and each climate cluster. Per cluster, only flows with similarity > 0.1 are shown, along with the weighted cluster mean (...). Columns show how various gradients in climate space affect seasonal flow regimes in basins associated with these climates.

Köppen-Geiger groups show large within-class variability of streamflow regimes, even though it has many classes

We repeat the analysis and now use the Köppen-Geiger classification (fig. 5) to group flow regimes (fig. 6). Qualitatively, we find that Köppen-Geiger main classes A (tropical) and B (arid) sort flows into groups similar to some of our index-based clusters. The colder C (temperate), D (continental) and E (polar) Köppen-Geiger classes are less able to group hydrologically similar river basins. Quantitative analysis of the values of 16 streamflow signatures confirms this (not shown).



(fig. 5): Köppen-Geiger classification[1]



(fig. 6): flows grouped by Köppen-Geiger class, and the class mean (...). Flows in main classes A are comparable to our "non-arid, varying-seasonal, no-snow" clusters (i.e. cluster 5, 18 & 1). Flows in main class B are comparable to our "arid, non-seasonal, no-snow" clusters (i.e. 10, 6, 15, 14). Classes C, D and E do not sort regimes well.

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