Evaluating Hydrologic Processes and Their Drivers for a Large Geographical Domain

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Motivation

- Hydrology lacks a coherent large-domain overview of the connections between hydrologic processes, and the drivers of these processes (e.g. climate, topography).
- Knowing which hydrologic processes are important in which places is important if one wants to run process-based models across large geographical domains.
- Doing so would provide a path to robust predictions under change, and for regionalization to ungauged basins.

Project Goals

- Evaluate a newly developed set of hydrologic landscapes for their ability to sort different flow regimes.
- Connect hydrologic behavior in each landscape to local drivers.
- Underlying hypothesis: Within similar regions of hydrologic behavior, the impact of drivers will be more pronounced.

Data and Methodology

- Preliminary Hydrologic Landscapes:

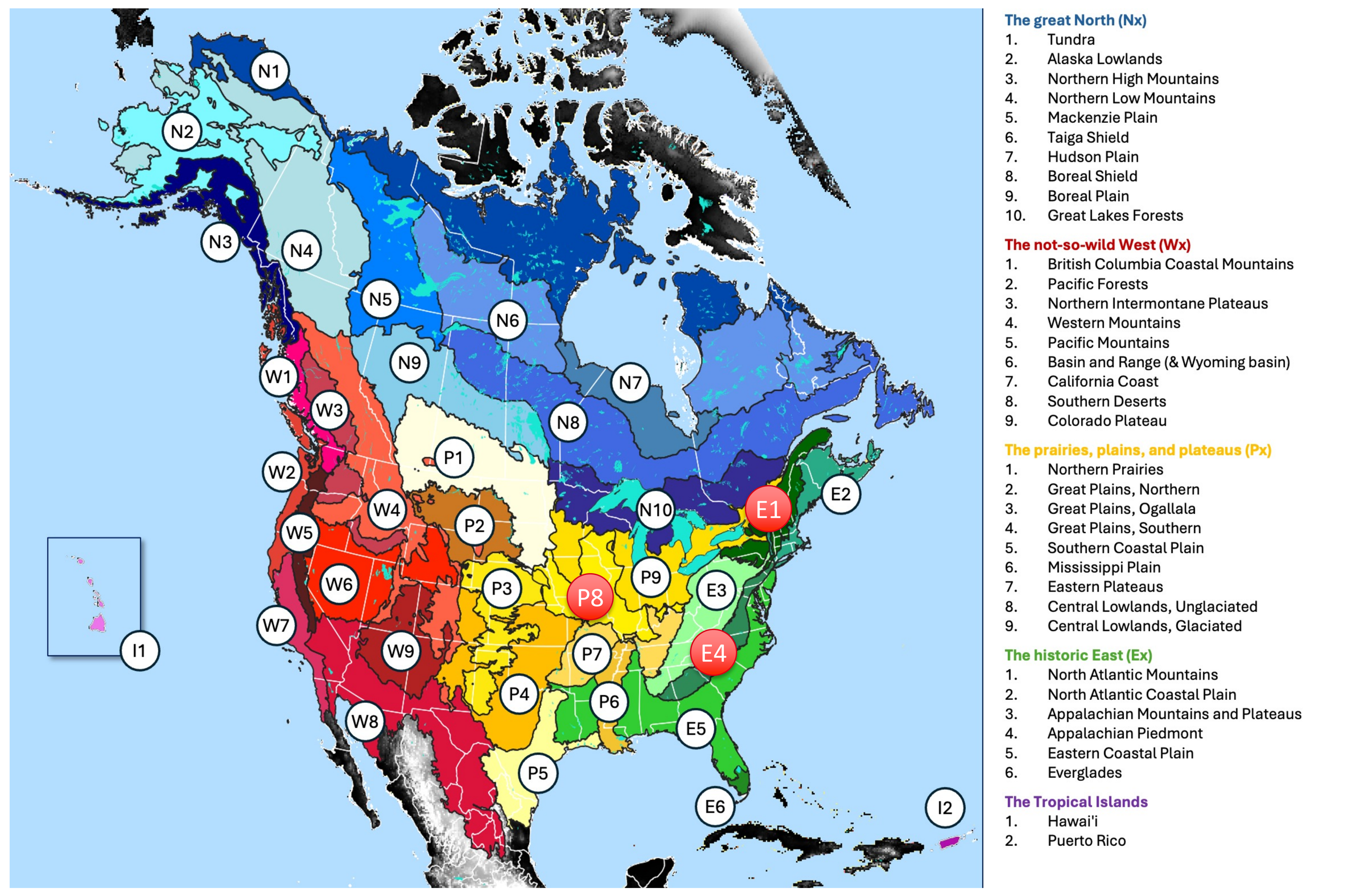

Figure 1: Hydrologic Landscapes for North America

- The basis for this analysis is the perceptual model landscapes presented in Figure 1 above. They were developed based on community workshops that occurred over the past months.

→ W. Knoben: "Towards a synthesis of perceptual models of dominant hydrologic processes across North America" (Thursday 1st May, 8:55 am in Room 3.16/17)

- The 1698 available CAMELS-Spat catchments are categorized into the hydrological landscapes.
- Hydrologic drivers are extracted from CAMELS-Spat (Knoben et al., 2025) that include climatic properties (precipitation, temperature, potential evapotranspiration, etc.) and catchment characteristics (land use, subsurface properties, topography).
- Additional attribute data were derived regarding their seasonal variation and representative hillslope methodology (Swenson, 2024).
- Signature selection was based on literature (e.g., McMillan, 2021), but must be refined as this paper presents preliminary findings.
- The presented analysis focuses on the analysis of signature variability and exemplified reflection of selected landscapes.

Results

Q1: How well do the hydrologic landscapes distinguish between different flow regimes?

We are using hydrologic signatures as a proxy for hydrologic behavior and flow regime.

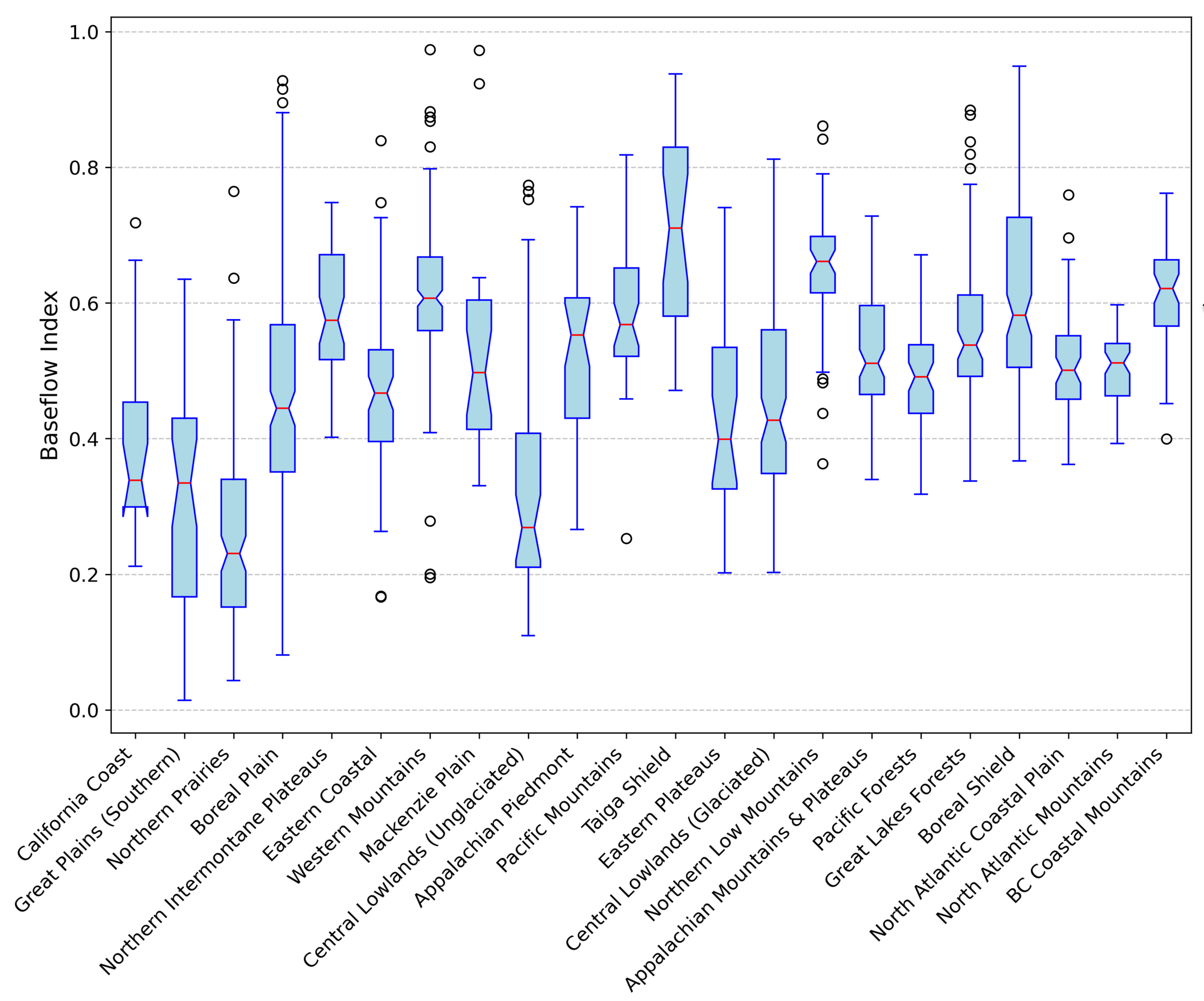

Figure 2: Spatial Variability of Baseflow Index within the Hydrologic Landscapes

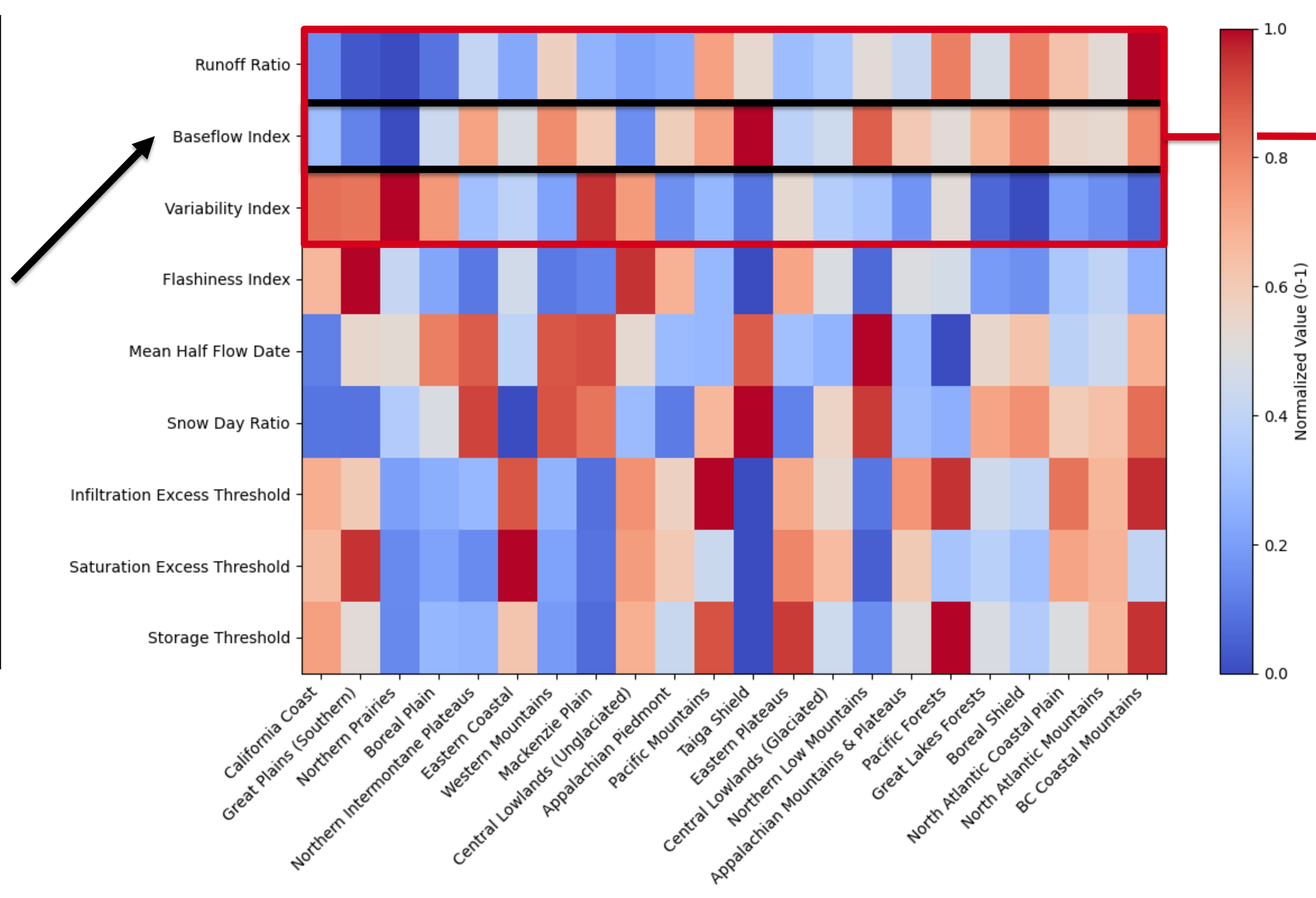

Figure 3: Mean Signature Values within the Hydrologic Landscapes

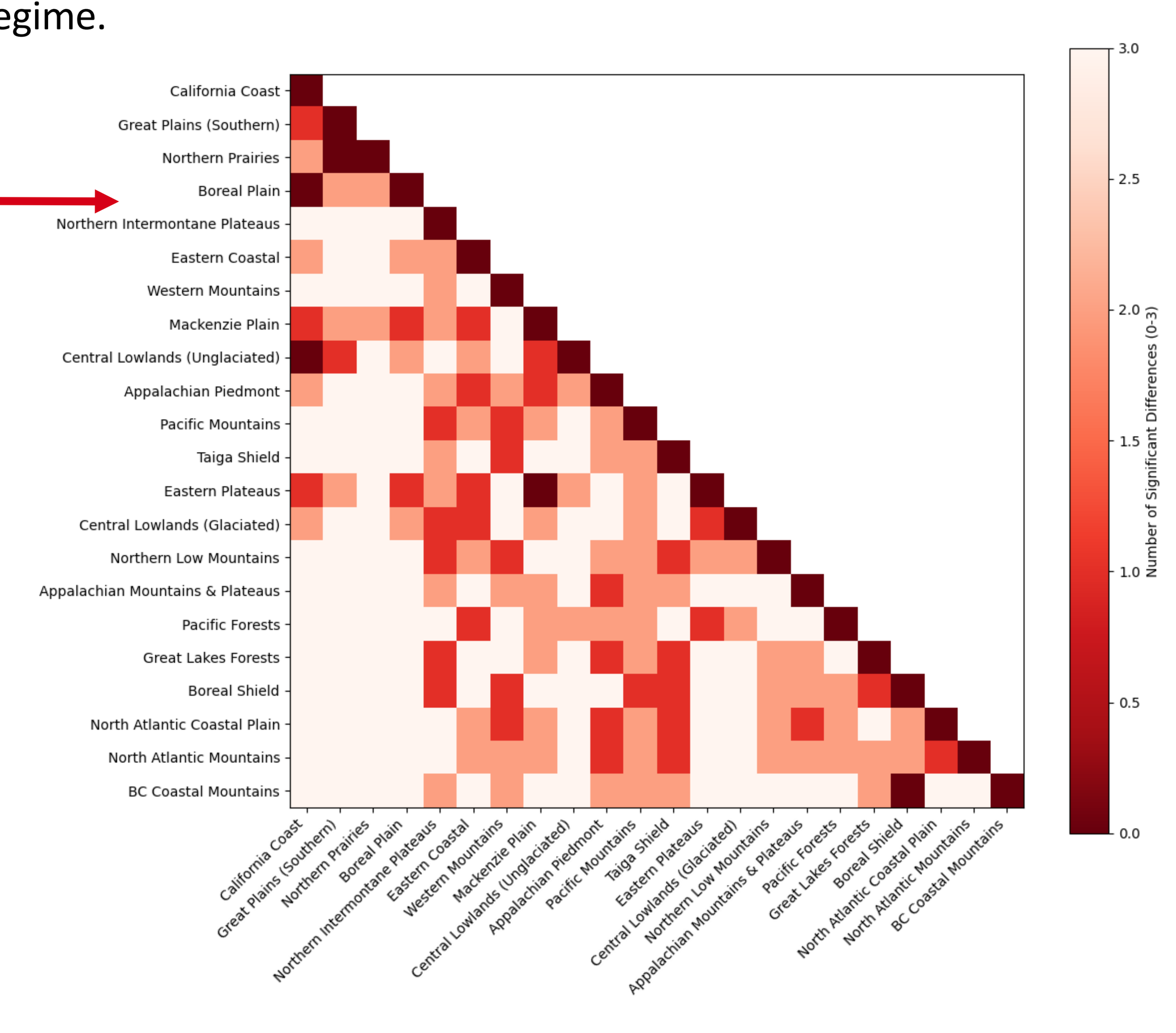

Figure 4: Number of significantly different signatures (RR, BFI, VI) between Hydrologic Landscapes

- The intra-landscape signature variability is high, for selected signatures (e.g. BFI) there is correlation with climatic indicators (e.g. humidity)
- The variance in signature values is strong, but the information added by each signature needs to be evaluated, since redundancy is visible for some of them.
- Most landscapes can be distinguished using a combination of t-tests for Total Runoff Ratio (Water Balance), Baseflow Index (Runoff Behavior), and Variability Index (Water Storage).

Q2: How do drivers affect signatures within hydrological landscapes?

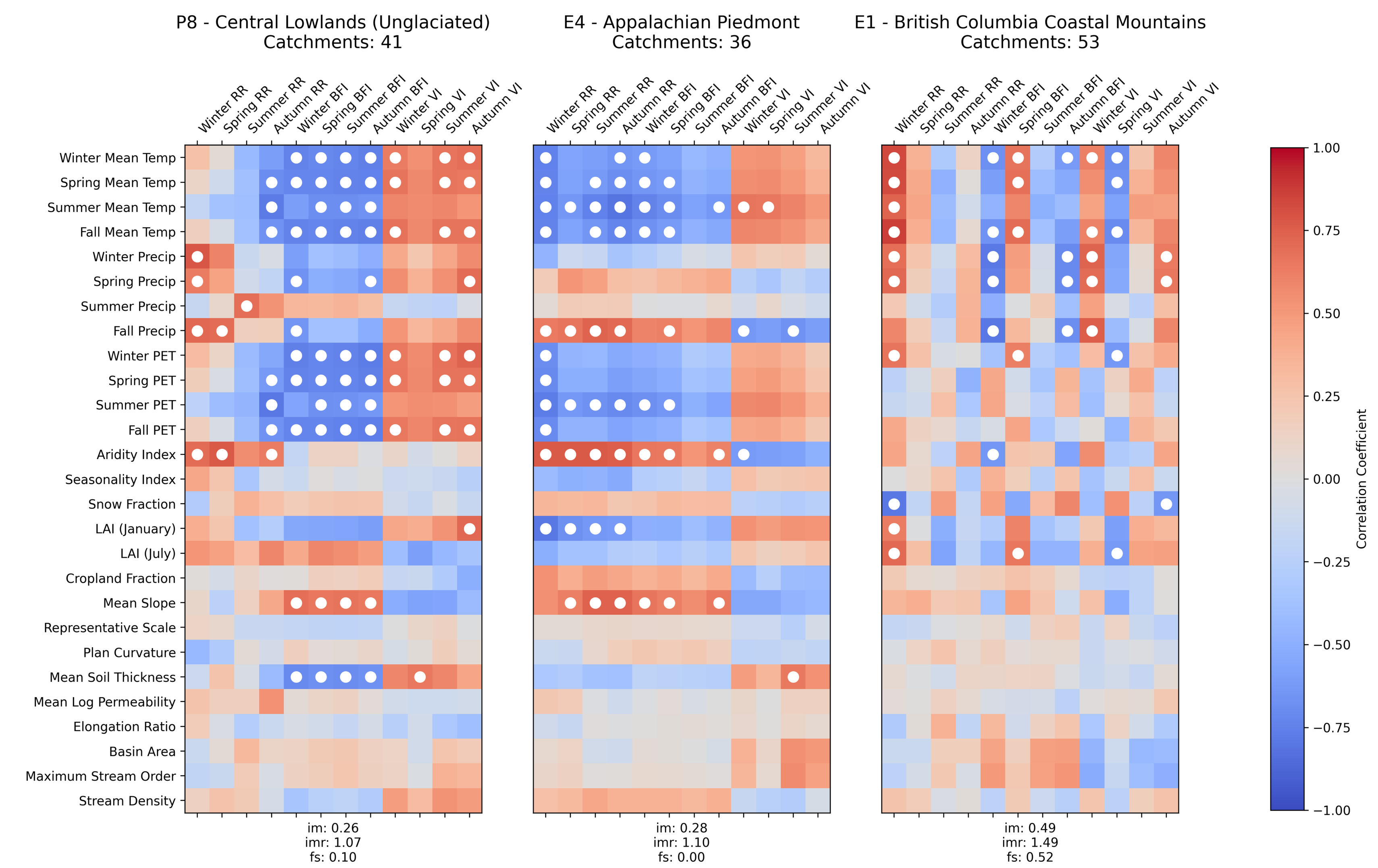

Figure 5: Correlation Analysis of Drivers and Signatures for three selected Hydrologic Landscapes (A circle indicates a correlation >0.6 or <-0.6)

What are key differences in hydrologic variability across North America?

The correlation analysis (Figure 5) suggests that relevant drivers vary strongly in space and time:

- Central Lowlands: precipitation only drives water balance, climatic impacts affect both BFI and VI; land use, slope, and soil thickness affect baseflow behavior
- Appalachian Piedmont: Fall precipitation is crucial for water balance, but temperature and PET are important as well, LAI and slope have impact on water balance, partitioning and storage
- North Atlantic Mountains: snow tendency leads to strong seasonality for climatic drivers, P and PET seem to have a strong seasonal correlation

- Climatic drivers dominant hydrologic variability, catchment characteristics are secondary as was expected.
- Seasonal analysis of drivers give more insight into the intra-annual variation of processes.
- Positive correlation between slope and BFI is not intuitive.

Discussion

- The derived regions are typically quite different from each other in their signature representation, indicating that the approach of landscape synthesis has led to sensible results. Further investigation will be necessary to confirm details and investigate regions with insufficient data availability.
- The evaluation of the underlying drivers and signatures using correlation analysis can highlight some important impacts on the hydrologic regime. To gain more detailed insight, it is necessary to account for non-linearities in their relationship, incorporate local knowledge about the systems, and investigate the relationship between drivers.

Open Questions:

- What processes are crucial or what signatures could be better proxies?
- How does the process scale affect the outcomes of this analysis and how should it be accounted for?
- What is the relationship between drivers and how does it vary in space and time?
- How can we transfer the gained knowledge effectively into models?

Future Work

- Extract further forcing and streamflow data from USGS and WSC
- Include more catchment characteristics based on literature review and local expertise
- Further statistical analysis on the relationship between signatures and drivers:
  → Random Forest
  → Causal Analysis
- Evaluation procedure

References

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