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The recurrence of *unseasonable* and *rare* flood dynamics

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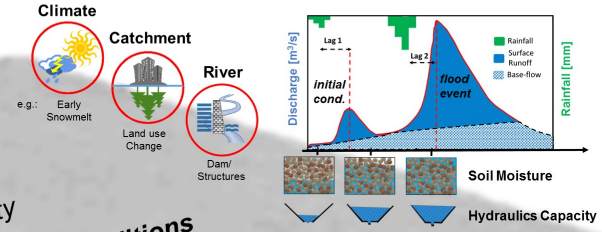
Backgrounds

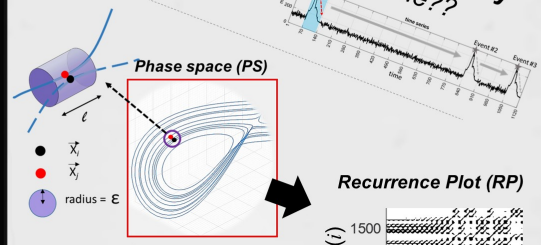
- **Complex** and **changing** boundary conditions
- **Unseasonable** and **rare** dynamics (or processes) increase susceptibility
- Influence of **antecedent/ initial conditions**
- Current method of delineating flood processes (**e.g. peak-volume**) is NOT satisfactory



Objectives

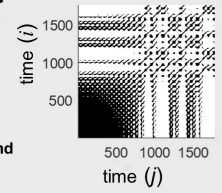
- **Quantification of Process Dynamics**
  That also considers time relation (continuity)
  i.e. phase space of a time-embedded discharge
  & develops flood hydrograph similarity index
- **Unseasonable and rare flood frequency**
  more or less recurrences over time??

Methodology



$$R_{i,j}^{m,\varepsilon} = \begin{cases} 0 \| \vec{x_i} - \vec{x_j} \| > \epsilon \\ 1 \| \vec{x_i} - \vec{x_j} \| \leq \epsilon \end{cases}$$

Recurrence (R) is defined when similar phase space vector is found within (Euclidian) distance (ε)

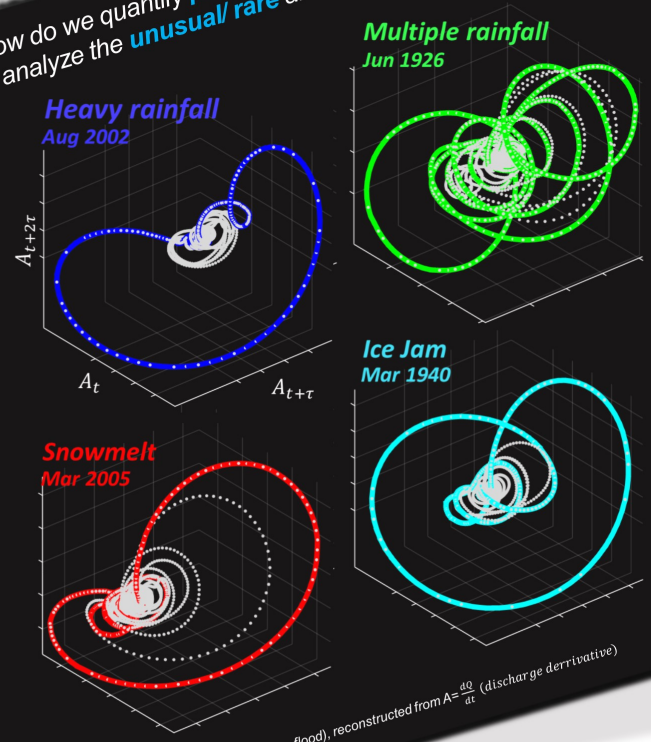


RP Quantification (RQA)

DET (diagonal measures) is used as **hydrograph similarity index** to imply flood process dynamics

$$DET = \frac{\sum_{d=d_{min}}^{N} d.P^{\epsilon}(d)}{\sum_{i,j}^{N} R_{i,j}^{m,\varepsilon}}$$

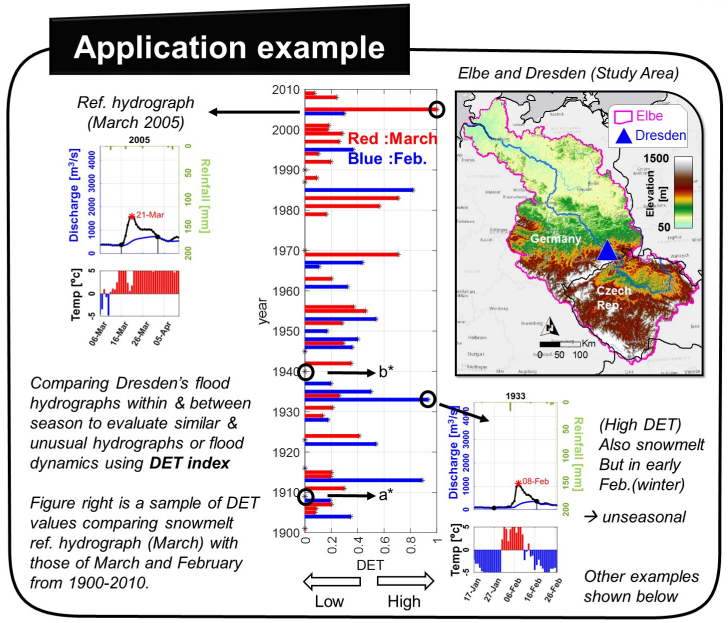
How do we quantify **phase space similarity** as an index (i.e. DET) to analyze the **unusual/ rare** and **unseasonable** processes?



Unique 3D Phase Space of Flood in Dresden - Germany

Example here (Grey = annual time series, Colored = flood), reconstructed from $A = \frac{dQ}{dt}$ (*discharge derrivative*)

Application example



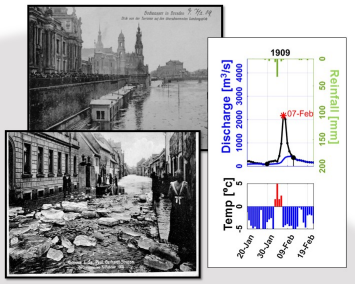
*Comparing Dresden's flood hydrographs within & between season to evaluate similar & unusual hydrographs or flood dynamics using **DET index***

Figure right is a sample of DET values comparing snowmelt ref. hydrograph (March) with those of March and February from 1900-2010.

(High DET) Also snowmelt But in early Feb.(winter)

→ unseasonal

Other examples shown below



Photos: collection of Dr. M. Deutsch (Erfurt/ Göttingen).

Unseasonable Flood (a)*

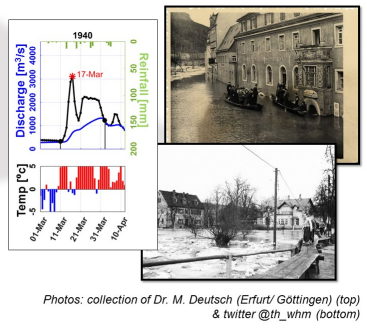
February 1909 Rain-on-ice

Unusually high rainfall in cold winter where icy ground impede the infiltration rate & hence triggers fast response and high flow (see hydrograph: relative low base flow)

Rare Flood (b)*

March 1940 Ice Jam

Ice debris upstream were brought down during the first peak of the flood & accumulated. This created an 'ice dam' and jam the 2nd flow (see hydrograph: attenuation of 2nd peak)



Photos: collection of Dr. M. Deutsch (Erfurt/ Göttingen) (top) & twitter @th_whm (bottom)

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Selected Reference

Wendi, D., Marwan, N., & Merz, B. (2018). In Search of Determinism-Sensitive Region to Avoid Artefacts in Recurrence Plots. *International Journal of Bifurcation and Chaos*, *28*(1), 1850007. https://doi.org/10.1142/S0218127418500074

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