A complex network approach for catchment classification based on co-occurrence of extreme floods

Wencong Yang[1], Hanbo YANG[1]

1. Department of Hydraulic Engineering, Tsinghua University, Beijing, 100084, China

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1. Introduction

■ **Background:**

1) Floods have regional characteristics. For different catchments, the similarity in floods reflects similarity in climatic or hydrological properties;
2) Co-occurrence of floods in different catchments indicates common flood drivers;
3) Complex network theory has been used to explore the spatial relationship of hydrological variables.

■ **The main objectives of this study are:**

1) To classify 319 catchments based on flood co-occurrence relationship using community detection method in complex network theory;
2) To find out the drivers of regional floods.

2. Data preparation

■ **Daily meteorology and streamflow series**

The data is from Model Parameter Estimation Experiment (MOPEX). We use 319 catchments that range in size from 80 km^2 to 10328 km^2, with daily streamflow, precipitation, potential evapotranspiration, temperature data in 1951-1990.

■ **Daily snowmelt and soil moisture series**

1) GR4J lumped hydrologic model is used for soil moisture simulation;
2) Cemaneige snow module is used for snowmelt simulation.

■ **Runoff depth with 2-year return period (Q_{50})**

We consider Q_{50} of 7-day runoff as the threshold to choose flood events. Generalized extreme value(GEV) distribution is used for annual maximum runoff depth fitting:

$$G(Q)=\exp\left\{-\left[1+\xi\left(\frac{Q-\mu}{\sigma}\right)\right]^{-1/\xi}\right\}$$

$$Q_{50}=\mu-\frac{\sigma}{\xi}\{1-[-\log(1-50\%)^{-\xi}]\}$$

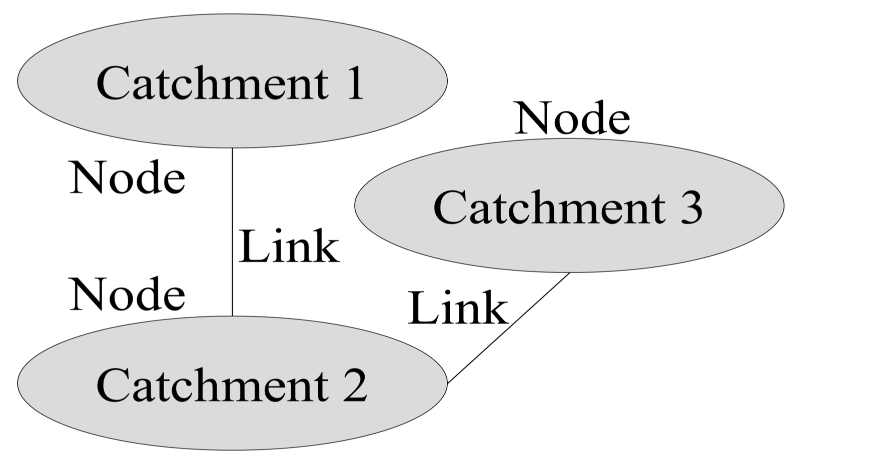
■ **Sea surface temperature (SST)**

COBE-SST2 $1^{\circ}\times1^{\circ}$ monthly data provided by the NOAA/OAR/ESRL PSD.

More information:
Please contact Wencong Yang (Tsinghua University)
E-mail:
ywc17@mails.tsinghua.edu.cn
Research Group Website:
www.hydroyang.com

3. Methods: complex network theory

■ **Network construction**



Linking criterion: at least 14 flood events (7-day runoff exceeding Q_{50}) overlap in time.

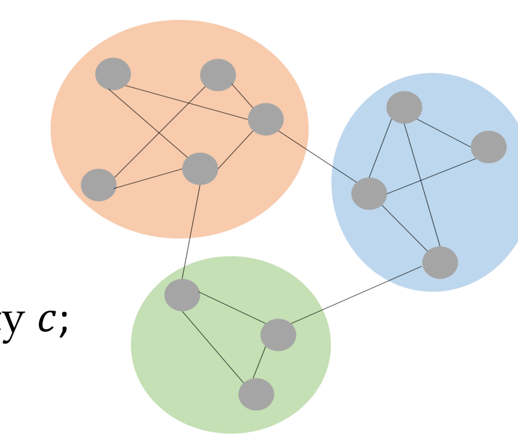
The threshold of 14 events makes:

$$Link\ density=\frac{actual\ links}{all\ possible\ links}\approx 0.02,$$

which helps to uncover the significant features of the network.

■ **Community detection method**

$$Modularity=M=\sum_{c=1}^{n_c}\left[\frac{l_c}{m}-\left(\frac{d_c}{2m}\right)^2\right]$$



High M value: good classification.

- l_c: number of links in community c;
- d_c: total links of nodes in community c;
- n_c: number of communities;
- m: total links in the network.

■ **Assortativity**

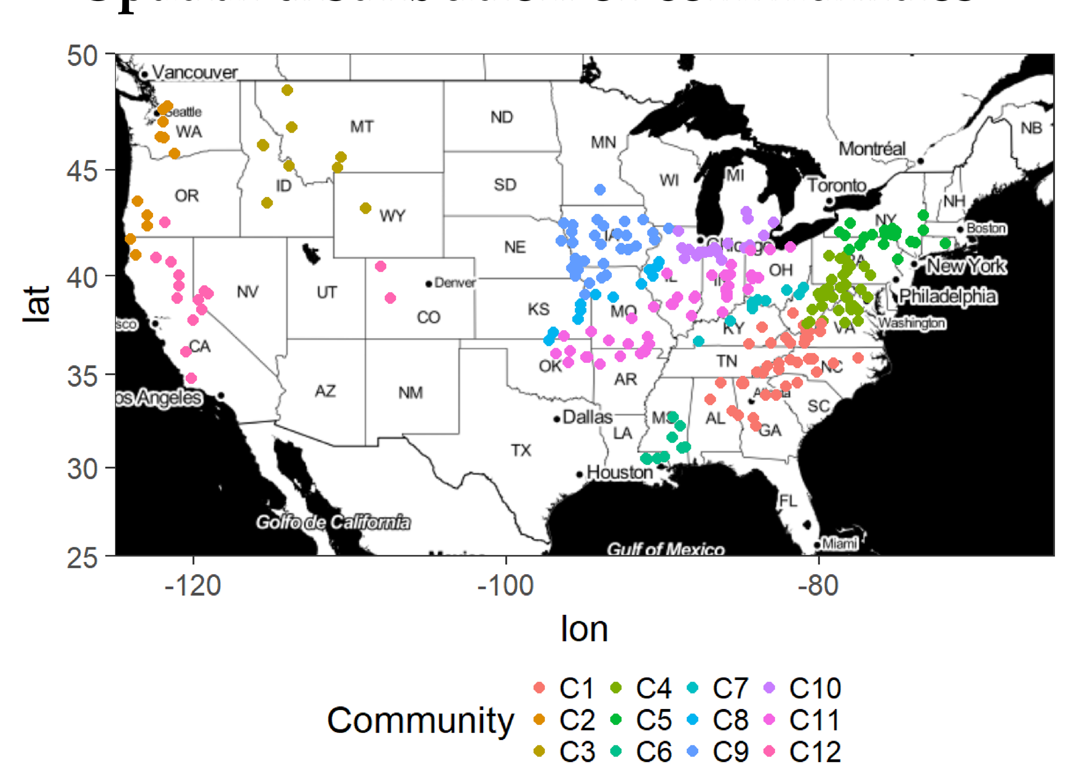
$$Pearson\ correlation=r=\frac{\sum_{x,y}xy(f_{xy}-f_{x+}f_{y+})}{\sigma_x\sigma_y}$$

High r value: vertices tend to be linked with similar values of a specific variable

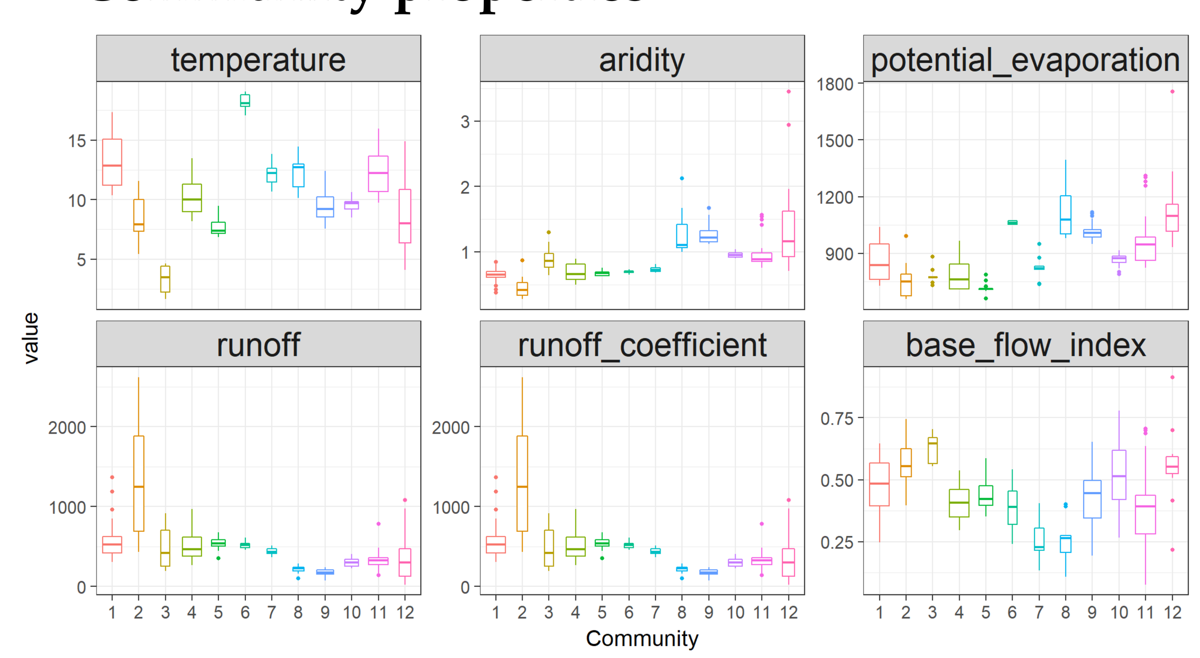
- f_{xy}: fraction of links that join vertices with values x and y for the variable
- $f_{x+}(f_{y+})$: fraction of links that starts at vertices with values x (or y) for the variable
- $\sigma_x(\sigma_y)$: standard deviation of the distributions of $f_{x+}(f_{y+})$.

4. Climatic and hydrological properties of communities

■ **Spatial distribution of communities**



■ **Community properties**

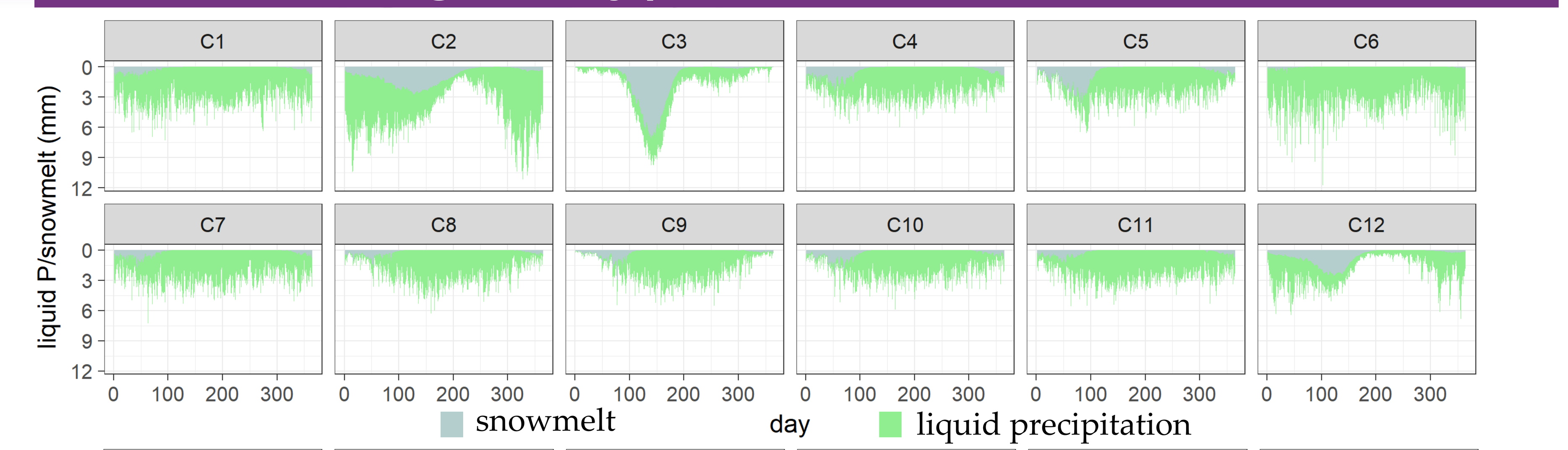


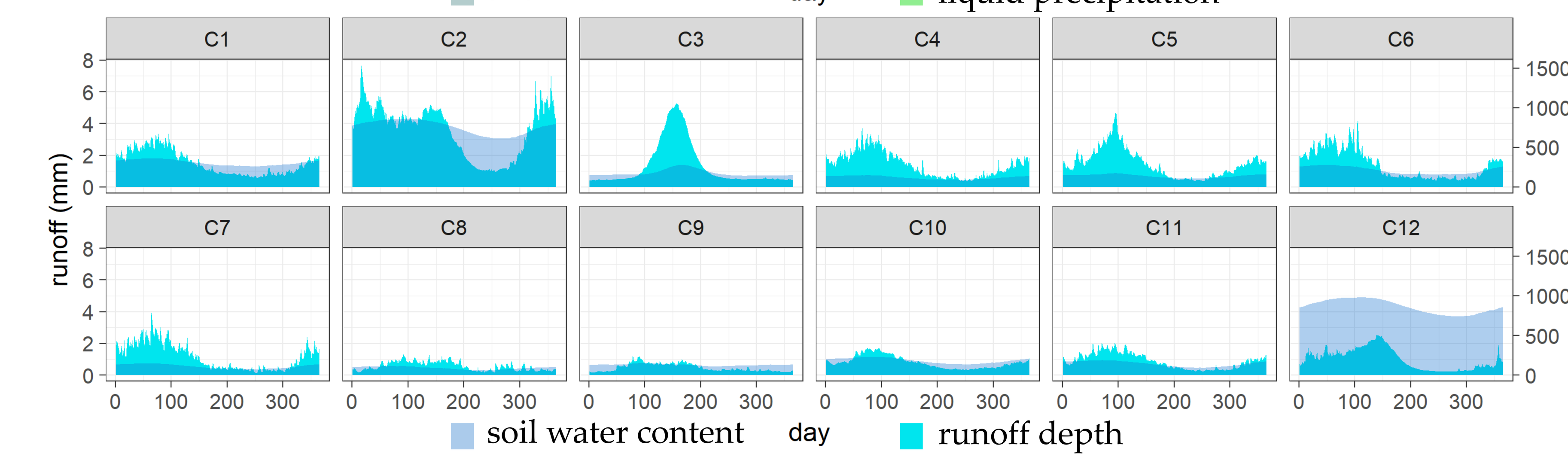
1) Catchments within the same community tend to cluster in space.
2) There are significant distinctions between different communities in climatic and hydrological properties.

7. Conclusions

1) The community detection method in complex network theory is an effective way to classify catchments based on flood co-occurrence;
2) Different communities of catchments show diverse properties on climate, hydrological characteristics and runoff regime types;
3) The co-occurrence of floods is highly related to the similar climate among the catchments. SST variation as the main force of climate variability, can be used to forecast the regional flood magnitudes.

5. Runoff regime types of communities





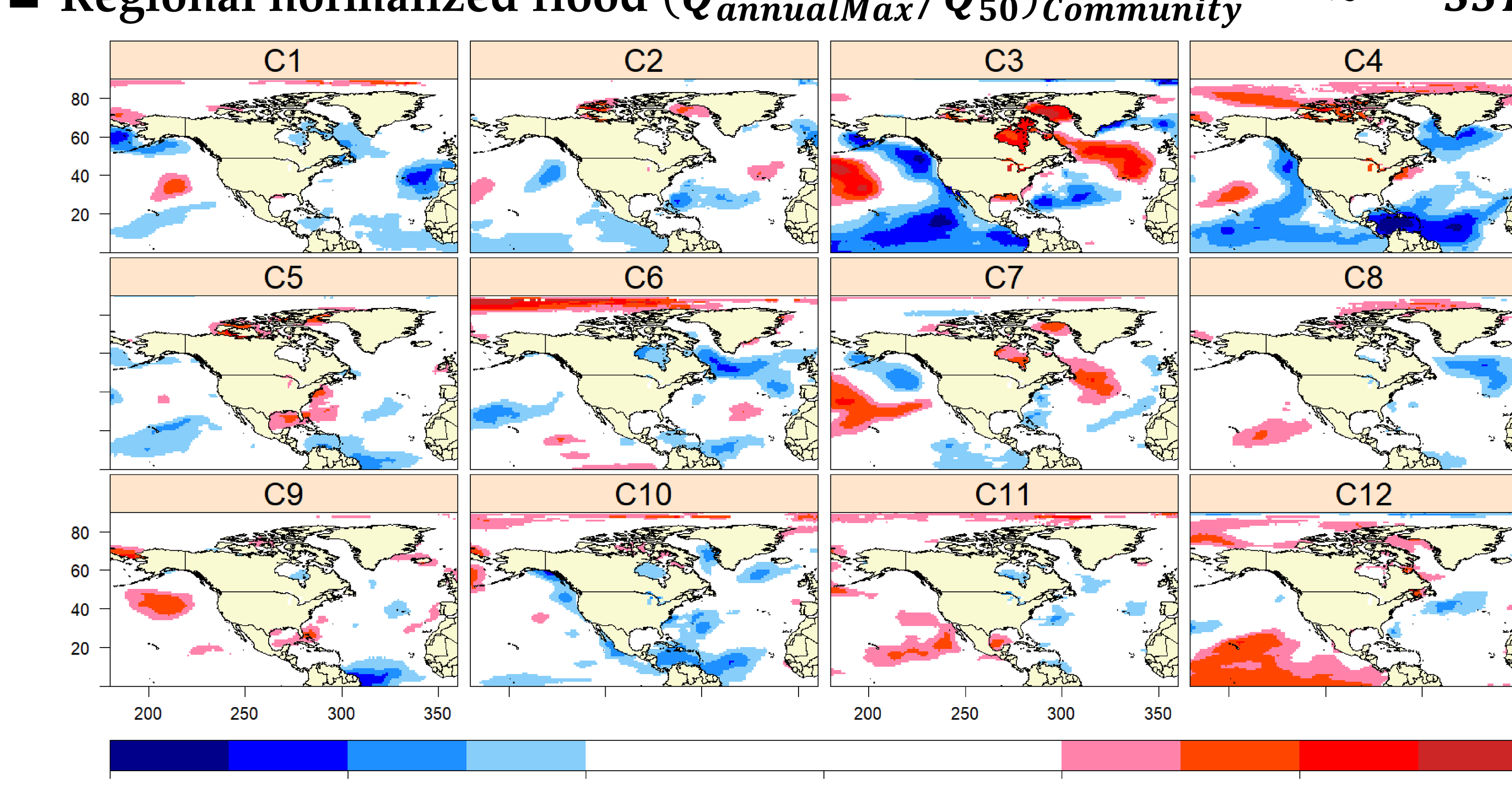
1) Flood seasons of C2 and C6 are driven by ample rainfall;
2) Flood seasons of C3, C4, C5, and C12 are driven by snowmelt coupled with rainfall;
3) C8, C9, C10 and C11 are dry catchments without significant flood seasons. The soil water content levels are low during the whole year.

6. Climatic drivers of flood co-occurrence

■ **Assotativity coefficients of climatic and hydrological properties**

temperature	aridity	PE	runoff	runoff coef	BFI
0.93	0.85	0.90	0.87	0.68	0.54

■ **Regional normalized flood $\overline{(Q_{annualMax}/Q_{50})}_{Community}\overset{correlation}{\sim}SST_{DJM}$**



1) Climatic similarity is the main cause of flood co-occurrence since the assortativity coefficients of temperature and potential evaporation are high;
2) Regional flood magnitudes of different communities response to different SST patterns, which reveals the atmospheric driving forces of regional floods.