Detect Gradual and Abrupt Changes in Climate

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Outline

• Introduction
• Change-point detection methodology
• Application
  – USHCN temperature and precipitation
  – USGS streamflow in IL
• Conclusion
Introduction

• Hydrological time series often exhibit non-stationarity, due to natural and anthropogenic environmental changes.
  – Non-stationarity: inconstancy in mean or variance
• “Systems for management of water throughout the developed world have been designed and operated under the assumption of stationarity.” (Milly et al., 2008)
• To understand non-stationarity process:
  – Detecting change points
  – Understanding internal dynamics or external influences
• Detection of change points
  – assessing risks in adaption strategies to climate change
  – exploring substantial implication in designing future water resources projects.
Detection Methodology

Structure of a time series

Four components:
- Trend
- Fluctuations about the trend
- Seasonal movement
- Irregular or random movement

Bayesian inference

Posterior distribution of model parameters including change point time $\theta$

Same point

Trend slope changes
Noise level changes

Posterior density function $p(\theta | y)$

Piecewise linear model with Gaussian distributed noise (varied variance)

Figure 1: Realization of a synthetic time series of $n_{0e}$ = 100 data points generated by Eq.(6) whereas the mean is parametrized by $F_{0e} = 5 + 0.22 \cdot C^2 + 0.08 \cdot C^3$ and the deviation is modeled as $\sigma^2_{\Omega_{e,2}} = [1.6(1 + 0.2 \cdot C^2 + 0.1 \cdot C^3)]^2$.


Detection Method

------Multiple change points

- **Window based local posterior method**
- **Data window** $n_{\text{sub}}$
- The global posterior distribution of change point timing is based on the local posterior probability with a weight produced by Pettitt method.

$$\sum_{\text{windows}} p(\theta | \text{cp in window}) p(\text{cp exists in window})$$
Change in Seasonal Climate and Streamflow

• Climatic variables, **temperature and precipitation** in particular, play critical roles in water resources management.

• It is essential to investigate **historic and current climate changes** and predict potential future climate changes
  – to assess the **impacts** of climate change on human and natural environment
  – to understand the **causes** of climate change

• **Data source:**
  – seasonal mean precipitation and maximum, average and minimum temperatures from 1910 to 2009 across the continental United States, 1217 stations of the United States Historical Climate Network (USHCN)
  – USGS stations with continuous seasonal mean streamflow from 1950 to 2010.
Spatial distribution of major change patterns in winter precipitation

Increasing in 1940s and 1950s abruptly; increasing gradually from 1950s
Spatial distribution of major change patterns in spring precipitation

Abrupt decrease, in 1940s in the middle IL; no change in the south.
Spatial distribution of major change patterns for summer precipitation

summer total precipitation, station 118740

- Simulated linear part
- 95% quantile upper
- 95% quantile lower
- Observation
Spatial distribution of major change patterns for precipitation

In North, abrupt decrease in 1990s; in South, decreasing trend by 1980s or abrupt increase in 1980s.
Spatial distribution of major change patterns for winter maximum Temperature

North: Gradual increase stopped during 1930s or abrupt decrease in 1930s.

South: Gradual increasing trend after 1970s (east); gradual increasing stopped during 1950s (west).
Spatial distribution of major change patterns for spring maximum temperature

North of IL: abrupt in 1980s
South: abrupt in 1960s or gradual increasing in 100 years

Spring mean maximum temperature, station 112193

- Simulated linear part
- 95% quantile upper
- 95% quantile lower
- Observation
Spatial distribution of major change patterns for summer maximum Temperature

North: gradual decreasing from 1950s /1920s
South: abrupt decrease in 1950s

summer mean maximum temperature,
station 110072
Spatial distribution of major change pattern maximum Temperature

In south: no change is dominant.
Spatial distribution of major changes for winter streamflow in IL

Winter maximum temperature:
North: Gradually increasing trend stopped during 1930s or abruptly decrease in 1930s.
South: Gradually increasing trend after 1970s (east); gradually increasing stopped during 1950s (west).

Winter precipitation:
Increased in 1940s and 1950s abruptly increasing in IL from 1950s.

Streamflow (ft³/s)

winter mean streamflow, station 5554500

-500
0
500
1000
1500
2000

year

- simulated linear part
- 95% quantile upper
- 95% quantile lower
- observation

15
Abrupt increase during 1980s

Winter mean streamflow, station 5554500
Spatial distribution of major changes for spring streamflow in IL

spring mean streamflow, station 5582000

- Simulated linear part
- 95% quantile upper
- 95% quantile lower
- Observation
Spatial distribution of major changes for summer streamflow in IL

Spatial distribution of major change patterns for summer streamflow in IL

- No change
- Increasing trend
- Abrupt upward change
- Abrupt downward change
- Increasing trend in later years
- Decreasing trend in later years
- Increasing trend in former years
- Decreasing trend in former years
- Two abrupt changes
- Others

Legend:
- 1950-1959
- 1960-1969
- 1970-1979
- 1980-1989
- 1990-1999
- >=2000
Spatial distribution of major changes for fall streamflow in IL

fall mean streamflow, station 5567500

Skewed, Not Gaussian distribution, error

Streamflow (ft³/s)

Year


Simulated linear part

Observation

Special distribution of major changes for fall streamflow in IL.
Conclusion

• Bayesian inference based change-point detection method is able to identify change patterns of a hydroclimatic time series.
• Assumed Gaussian distribution causes errors in fall streamflow with skewed distribution.
• Across the Continental U.S, spatial distributions of change patterns are distinct for winter, spring and summer temperatures, but not much different for changes in precipitation and temperature in fall.
• Streamflow in Illinois increased abruptly during 1980s in winter.
• No obvious synchronization of change point time between mean change of streamflow and climate variables.
• In spring, in the south areas, precipitation without change concurred with streamflow without change.
Thanks for your attention!

Questions & Comments?