A statistical/dynamical framework for seasonal streamflow forecasting in an agricultural watershed

Gabriele Villarini
IIHR-Hydroscience & Engineering, The University of Iowa
Analyses focus on a broad range of discharge quantiles, from minimum to maximum flow.

- **Analysis period:** 1927-2012
- **Quantity of interest:** all the discharge quantiles from $Q_{0.00}$ (daily annual minimum) to $Q_{1.00}$ (daily annual maximum)
Rainfall and agriculture are used as predictors.

- Basin-averaged yearly rainfall ($x_r$)
- Basin-averaged harvested corn and soybean acreage ($x_a$)

Predictors are standardized with respect to the 1927-2005 period.
The parameters of the gamma distribution are related to the predictors via simple relations.

**Gamma distribution**

\[ E[Q_{\downarrow i}] = \mu_{\downarrow i} \]
\[ Var[Q_{\downarrow i}] = \mu_{\downarrow i} \sigma_{\downarrow i}^2 \]

\( i \in [0, 1] \) is for the discharge quantile:
\( i = 0 \rightarrow Q_{\text{min}} \)
\( \ldots \)
\( i = 1 \rightarrow Q_{\text{max}} \)

**Relationship between parameters and covariates**

\[ \mu_{\downarrow i} = \exp(\alpha_{\downarrow 0,i} + \alpha_{\downarrow 1,i} x_{\downarrow r} + \alpha_{\downarrow 2,i} x_{\downarrow r} \cdot x_{\downarrow a}) \]
\[ \sigma_{\downarrow i} = \exp(\beta_{\downarrow 0,i} + \beta_{\downarrow 1,i} x_{\downarrow r} + \beta_{\downarrow 2,i} x_{\downarrow r} \cdot x_{\downarrow a}) \]

- \( x_r \) - basin-averaged rainfall
- \( x_a \) - basin-averaged harvested corn and soybean acreage

Agricultural land does not, by itself, impact discharge but may interact with precipitation to change the distribution of discharge.
These simple models reproduce the observed records very well
We can now use this modeling framework to examine what future discharge may look like.

We consider different formulations to relate discharge to rainfall and agriculture

\[ \mu = \exp(\alpha_0 + \alpha_1 xlr + \alpha_2 xlr \cdot xa) \]
\[ \sigma = \exp(\beta_0 + \beta_1 xlr + \beta_2 xlr \cdot xa) \]  
**Model 1**

\[ \mu = \exp(\alpha_0 + \alpha_1 xlr + \alpha_2 xlr \cdot xa) \]
\[ \sigma = \exp(\beta_0) \]  
**Model 2**

\[ \mu = \exp(\alpha_0 + \alpha_1 xlr + \alpha_2 xlr \cdot xa + \alpha_3 xlr,0) \]
\[ \sigma = \exp(\beta_0) \]  
**Model 3**

\( x_{r,0} \) : monthly rainfall during the month prior to the season to forecast (proxy for antecedent soil moisture conditions)
By “optimally” merging these models, we reproduce the historical records very well.
The GCMs have some skill in forecasting extremes for floods and droughts.
The relation between observed and forecast rainfall deteriorates for increasing lead time.
The forecasts are based on models that are updated as new information becomes available.

Spring forecast for $Q_{max}$ initialized in March.
Forecasting of spring discharge

Spring

Initialization in March

Initialization in October (-1)

Initialization in June (-1)

Discharge (ft$^3$/s)

Short lead

Long lead

Low flow

High flow

$Q_{0.05}$

$Q_{0.5}$

$Q_1$

Fit Forecast
95th-99th percentiles
50th percentile (median)
25th-75th percentiles
Forecasting of summer discharge

Summer

Initialization in June

Initialization in January

Initialization in September (-1)

Discharge ($\text{ft}^3/\text{s}$)

$Q_{0.05}$

$Q_{0.5}$

$Q_1$

Short lead

Long lead

Fit Forecast

5th-95th percentiles

50th percentile (median)

25th-75th percentiles
Generally, it is possible to skillfully forecast seasonal discharge (from low to high flows)
The forecasts for 2016 point to conditions similar or below the 2001-2015 averages.
• Development of statistical models to describe annual changes in discharge (from low to high flow) for the Raccoon River at Van Meter.

• These models accurately characterize the year-to-year variations in discharge.

• It is possible to skillfully forecast seasonal discharge months before the season starts. The summer season is the one that is better forecasted.

Questions?
gabriele-villarini@uiowa.edu