BIOGRAPHICAL SKETCH

Katherine (Katie) Hirschboeck's research involves the climatology and hydroclimatology of extreme events - especially floods, paleofloods, and droughts - which she analyzes from the perspective of their meteorological and climatological causes and their long-term variability. She also uses synoptic climatology and dendroclimatology to link tree-ring responses to anomalous atmospheric circulation patterns. She is a faculty member in the Laboratory of Tree-Ring Research and holds joint appointments in the departments of Hydrology & Water Resources, Atmospheric Sciences, and Geography & Regional Development. She also serves as the Chair of the Global Change Ph.D. Minor Graduate Interdisciplinary Program and participates in the Arid Lands Resource Sciences Interdisciplinary Program. She earned her B.S. and M.S. degrees in Geography, with a minor in Geology, from the University of Wisconsin - Madison and her Ph.D. degree in Geosciences from the University of Arizona in 1985. Her dissertation examined the hydroclimatic causes of mixed distributions in Arizona flood records, linking them to climatic variability. Prior to joining the UA faculty in 1991 she held positions at the University of Oklahoma and Louisiana State University.

ABSTRACT

FLOOD HYDROCLIMATOLOGY (Hirschboeck 1988) is the analysis of flood events within the context of their history of variation in magnitude, frequency, seasonality - over a relatively long period of time - and analyzed within the spatial framework of changing combinations of meteorological causative mechanisms. It was first proposed in the late 1980s as a conceptual framework within which to think about the underlying physical reasons for flood variations, how these might be linked to climate variability, and why the most extreme flood events and outliers in the upper tails of some flood distributions continue to confound practitioners of standard flood frequency analysis (FFA). Flood hydroclimatology challenges the underlying "iid" assumption that flood peaks are independently, identically distributed by re-examining flood time series to arrive at a mechanistic understanding of long-term flooding variability and its probabilistic representation based on hydroclimatically defined mixed populations. Strengths and weaknesses of the approach are illustrated with an example from Arizona gaging stations and the potential for use of the approach to address Central Valley FFA is addressed.

Flood hydroclimatology research to date has shown that: (1) in regions where floods are produced by several types of meteorological events, different storm types may exhibit unique probability distributions, (2) unusually large floods in drainage basins of all sizes are likely to be associated with well defined circulation anomalies - hence such features are good candidates for mixed distribution categories, (3) the interaction between storm properties and drainage basin properties may result in different combinations of mixed distributions, and (4) in the largest and most extreme floods studied, persistence was always a factor and served to bridge meteorological and climatological time scales. Some implications of the approach are: (1) the distributions of key subgroups may be better for estimating the probability and cause of extremely rare floods than the overall frequency distribution of the entire flood series, (2) to preserve spatial homogeneity, basins can be grouped according to how their floods respond to different types of mechanisms and circulation patterns, (3) the conceptual framework of climate-driven, time-shifting means, variances and/or mixed distributions provides a useful explanation for non-stationarity in flood times series which challenges the iid assumption, and (4) to address how flood frequencies might respond to a changing climate, such changes can be conceptualized as time-varying atmospheric circulation regimes that generate a mix of shifting streamflow probability distributions.
Flood Hydroclimatology:
Insights into Mixed Flood Populations

California Extreme Precipitation Symposium
April 13, 2007

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OUTLINE

• The Challenge of the “Upper Tails”
• The Standard iid Assumption for FFA
• “Flood Hydroclimatology” defined
• An example: Flood Hydroclimatology in Arizona with Mixed Populations
• Flood Hydroclimatology in the Central Valley?
• Concluding Remarks: Insights into Mixed Distributions & Their Implications
The Challenge of the “Upper Tails”

Gaged Flood Record -- Histogram
(Standardized Discharge Classes)

SKEWED DISTRIBUTION
Extreme events $\Rightarrow$ tails of distribution

The Challenge of the “Upper Tails”

Santa Cruz at Tucson Annual Peak
Flow Time Series

A fairly long record with lots of variability . . .

The long record made the gaging station a candidate for discontinuation in the early 1980s . . .
The Challenge of the “Upper Tails”
Santa Cruz River, Tucson Arizona Example

Typical dry river bed or minor low flow vs.

The record flood of October 1983!

The Challenge of the “Upper Tails”
Extrapolation from a “well-behaved” sample distribution . . .

Modified from National Water Summary: Floods & Droughts
Jarrett, 1991
The Challenge of the “Upper Tails”

... can fail when “outlier” floods occur!

Curves A & B indicate the range (uncertainty) of results obtained by using conventional analysis of outliers for 1954 & 1974 floods.

The Standard iid Assumption for FFA

The standard approach to Flood Frequency Analysis (FFA) assumes stationarity in the time series & “iid”

“iid” assumption: independently, identically distributed
The Standard iid Assumption for FFA ??

Time-varying mean

Time-varying variance

Time-varying mean & variance

Hirschboeck 1988

Meteorological & climatological flood-producing mechanisms operate at varying temporal and spatial scales

Hirschboeck 1988
The type of storm influences the shape of the hydrograph and the magnitude & persistence of the flood peak.

This can vary with basin size (e.g. convective events are more important flood producers in small drainage basins in AZ).

Hirschboeck 1987a

**HYDROMETEOROLOGY**

- Weather, short time scales
- Local / regional spatial scales
- Forecasts, real-time warnings

**HYDROCLIMATOLOGY**

- Seasonal / long-term perspective
- Site-specific and regional synthesis of flood-causing weather scenarios
- Regional linkages/differences identified
- Entire flood history context ➔ benchmarks for future events
FLOOD HYDROCLIMATOLOGY (def)

Flood hydroclimatolgy is the analysis of flood events within the context of their history of variation

- in magnitude, frequency, seasonality
- over a relatively long period of time
- analyzed within the spatial framework of changing combinations of meteorological causative mechanisms

Causative mechanisms:

precipitation type
storm characteristics
steering mechanisms
synoptic pattern
antecedent conditions

This framework of analysis allows a flood time series to be combined with climatic information

To arrive at a mechanistic understanding of long-term flooding variability and its probabilistic representation.
Non- "iid" Conceptual Framework for Flood Time Series:

Time-varying means

Time-varying variances

Both

Mixed frequency distributions may arise from:
- storm types
- synoptic patterns
- ENSO, etc. teleconnections
- multi-decadal circulation regimes

Flood Hydroclimatology Example: Arizona

- Peaks-above-base: 30+ gaging stations in Arizona
- Synoptic charts + precipitation data ➔ causal mechanisms
Flood Hydroclimatology Example

Sample Distributions of Gila Basin Gaged Peak Flows:

Are there climatically controlled mixed populations within?

<table>
<thead>
<tr>
<th>SANTA CRUZ RIVER AT TUCSON</th>
<th>SALT RIVER NEAR ROOSEVELT</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="chart1.png" alt="" /></td>
<td><img src="chart2.png" alt="" /></td>
</tr>
<tr>
<td>ANNUAL FLOOD</td>
<td>SAMPLE MEAN</td>
</tr>
</tbody>
</table>

DECISION TREE FOR CLASSIFYING GILA BASIN, AZ FLOODS

Systematic determination of causative mechanisms via synoptic charts, precipitation data, etc.

Hirschboeck 1987a
Hydroclimatically Defined Mixed Distributions for Two Gages
(detailed classification with 8 subgroups)

Mixed Distributions
(revised 3-subgroup classification)
Remember the Santa Cruz record? What does it look like when classified hydroclimatically? What kinds of storms produced the biggest floods?
Convective events are the most common, but the largest floods in the record were produced by other mechanisms.

Based on these results we can re-envision the underlying probability distribution function for Gila Basin floods to be not this . . . .

“iid” assumption: independently, identically distributed
... but this:

**Alternative Model to Explain How Flood Magnitudes Vary over Time**

Gila Basin, AZ example

Varying mean and standard deviations due to different causal mechanisms

In addition, extreme flood events can emerge from synergism in:

The way in which rainfall is delivered

- in both space (e.g., storm movement, direction)
- and time (e.g., rainfall rate, intensity)
- over drainage basins of different sizes & orographies

Therefore -- hydroclimatic subgroups may vary with drainage area in the same watershed
Flood Hydroclimatology “in practice?”

Subcommittee on Hydrology, Hydrologic Frequency Analysis Work Group, Bulletin 17-B Guidelines for Determining Flood Frequency Frequently Asked Questions

http://acwi.gov/hydrology/Frequency/B17bFAQ.html#mixed

MIXED POPULATION FAQ

Question: Floods in my study area are caused by hurricanes, by ice-affected flows, and by snowmelt, as well as by rainfall from thunderstorms and frontal storms. How do I determine whether mixed-population analysis is necessary or desirable?

Answer:

Flood magnitudes are determined by many factors, in unpredictable combinations.

It is conceptually useful to think of the various factors as "populations" and to think of each year's flood as being the result of random selection of a "population", followed by random drawing of a particular flood magnitude from the selected population.

The resulting distribution of flood magnitudes is called a mixture distribution.
In practice, one determines whether the distribution is well-approximated by the LPIII by:

-- comparing the fitted LPIII
--- with the sample frequency curve defined by plotting observed flood magnitudes versus their empirical probability plotting positions . . .

If the fit is good, and if the flood record includes an adequate sampling of all relevant sources of flooding (all "populations"),

then there is nothing to be gained by mixed-population analysis.

Only if the sample frequency curve has:
-- sharp curvature (kinks),
-- reverse curves, or
-- other characteristics that prevent its being approximated by the LPIII,
-- or if the available flood record omits important sources of flooding,
. . . . is there any reason to perform a mixed-population analysis.

Some attempts to use flood hydroclimatology as the basis for FFA have been pursued ➔

Implications of heterogeneous flood-frequency distributions on traditional stream-discharge prediction techniques

Younes Ahla² and Ahmed Mirzaoni
Department of Forest Resources Management, Faculty of Forestry, University of British Columbia, 2030-2524 Main Mall, Vancouver, BC, Canada V6T 1C4

(Based in part on Hirschboeck’s Gila Basin stations & subgroups)
Sample frequency curve defined by plotting observed flood magnitudes vs their empirical probability plotting positions

- Conventional Flood Frequency Analyses

Mixed population analysis using a heterogeneous distribution:

Alila & M'traoui 2002
Other useful aspects of Flood Hydroclimatology:

Applying Mixed Distributions to another conceptual framework:
Circulation Regime Changes

When the dominance of different types of flood-producing mechanisms or circulation patterns changes over time, the probability distributions of potential flooding at any given time (t) may be altered.

Conceptual Framework for low-frequency variations and/or regime shifts:

a) A shift in circulation regime (or anomalous persistence of a given regime) will lead to different theoretical frequency / probability distributions over time.

b) modified from Knox, 1983

Hirschboeck 1988
What insights can Flood Hydroclimatology bring to Central Valley flooding?

Several excellent hydroclimatic analyses already exist . . .

Winter Orographic Precipitation Ratios in the Sierra Nevada—Large-Scale Atmospheric Circulations and Hydrologic Consequences

MICHAIL DETTINGER
U.S. Geological Survey, Scripps Institution of Oceanography, La Jolla, California

KELLY REYNOSO
Resource Region Climate Center, Desert Research Institute, Reno, Nevada

DANIEL CHILAN
U.S. Geological Survey, Scripps Institution of Oceanography, La Jolla, California

Journal of Hydrometeorology 2004

A LONG TERM (-50 YR) HISTORICAL PERSPECTIVE ON FLOOD-GENERATING WINTER STORMS IN THE AMERICAN RIVER BASIN

Michael D. Dettinger, US Geological Survey
Scripps Institution of Oceanography, La Jolla, CA

Proceedings, California Extreme Precipitation Symposium April 22, 2005
Some potential synoptic classification modes for CA Flood Hydroclimatology:

Based on: Maddox et al. 1980

Western Type III Pattern linked to flash flooding in CA

Blocking and “Pineapple-express” synoptic patterns leading to severe CA flooding in Feb 1986

Hirschboeck 1987b

“Atmospheric river” linked to flooding in Russian R

Schematic showing 3 modes of westerly flow associated with flooding in Central CA

Four Insights into Mixed Distributions
1. The identification of hydroclimatically defined mixed distributions in flood records suggests that in regions where floods are produced by several types of meteorological events, different storm types may exhibit unique probability distributions.

2. Unusually large floods in drainage basins of all sizes are likely to be associated with circulation anomalies involving quasi-stationary patterns such as blocking ridges and cutoff lows in the middle-level flow – hence such features are good candidates for mixed distribution categories.
3. The interaction between storm properties and drainage basin properties (e.g. area, aspect, slope) plays an important role in the occurrence and magnitude of large floods both regionally and seasonally – and may result in different combinations of mixed distributions.

4. In the largest and most extreme floods studied, **PERSISTENCE** was always a factor

- Persistence of INGREDIENTS (e.g., deep moist convection environment) most important at small scales (flash floods)
- Persistence of PATTERN most important at larger scales (basin-wide / regional floods)
- Persistence bridges meteorological and climatological time scales
Four Implications for Flood Analyses based on Flood Hydroclimatology

Mixed Distributions
1. Implications for predicting the tails of a distribution

The distributions of key subgroups may be better for estimating the probability and cause of extremely rare floods than the overall frequency distribution of the entire flood series.

Separate out causes & linkages by stratifying by subgroup.
Hydroclimatic Regions
2. Implications for spatial homogeneity

-- Basins can be grouped according to how their floods respond to different types of mechanisms and circulation patterns

-- This grouping can change from season to season

-- This grouping is also basin-size dependent

Non-Stationarity & iid
3. Implications for time series homogeneity, stationarity & the iid assumption

The conceptual framework of climate-driven time-shifting means, variances and/or mixed distributions provides a useful explanation for non-stationarity in flood times series and challenges the iid assumption.
Climatic Variability

4. Implications for evaluating how flood time series may vary under a changing climate

For floods, climatic changes can be conceptualized as time-varying atmospheric circulation regimes that generate a mix of shifting streamflow probability distributions.

This conceptual framework provides an opportunity to evaluate streamflow-based hydrologic extremes under climatic scenarios defined in terms of shifting modes or frequencies of known flood-producing synoptic patterns, ENSO, etc.

References