An Investigation of the Pineapple Express Phenomenon via Bivariate EVT

Grant Weller
Department of Statistics
Colorado State University

Joint work with:
Dan Cooley, CSU
Steve Sain, NCAR

Acknowledgements:
Data provided by NARCCAP (NSF-ATM-0502977 and NSF-ATM-0534173)
GW supported by Weather & Climate Impact Assessment Program
GW & DC funded by NSF-DMS-0905315
Pineapple Express

PE storms: caused by atmospheric rivers hitting the west coast in winter

- Often bring heavy rain and warm temperatures
- Great impact on water resources of western US

This work aims to answer several questions related to this phenomenon:
Questions of Interest

1. Are regional climate models, driven by reanalysis, able to capture extreme precipitation events associated with PE, as seen in observational data? Some previous work: Leung and Qian (2009)

2. Can we draw a connection between PE extreme precipitation events and short-lived (daily) synoptic-scale processes?

3. Given a future-scenario climate model run, what might extreme precipitation events look like in observations, and what is the uncertainty in these estimates?

Method: bivariate extreme value analyses
A statistician’s view

Differing perspectives on climate, weather, and extreme events.

*Climate vs. weather:* Climate is the *distribution* of weather variables like temperature, precipitation, wind, etc.

*Extremes:* Think of extremes as the upper (or lower) tail of a distribution; e.g., the very largest values in a time series of precipitation measurements.

*Climate models:* Simulate from the distribution of weather variables over a long period of time (e.g. one year, 5 years, 20 years)
Data and Model Output

We utilize several sources of climate model output and an observational product:

- Daily RCM precipitation output from NARCCAP - focus on WRF model
- NCEP/NCAR global reanalysis
- Daily gridded observational precipitation from University of Washington (Maurer et al.)
- Future run: WRF forced by CCSM global model

We study NDJF days from 1981-1999 (‘current’) and 2041-2070 (‘future’).
Outline

1. (Very) brief overview of extreme value theory
2. Comparing RCM output extremes to observations
   • Modeling tail dependence
3. “Pineapple Express index”
   • North Pacific SLP fields
4. Examining future Pacific region precipitation extremes
   • Future PE events & uncertainty
5. Summary and Future Work
EVT Approach

The aim of extreme value theory is to describe the (joint) upper tail of a (multivariate) distribution. *It is not necessary to know the data’s entire distribution.*

- **Univariate case:** we employ a threshold exceedance approach using the Generalized Pareto Distribution:

  \[ P(X > x | X > u) \approx \left( 1 + \xi \frac{x - u}{\psi_u} \right)^{-1/\xi} \]

  - \( \xi \) determines tail behavior (bounded, light, heavy) and is difficult to estimate

- **Bivariate extremes:** estimate marginals first, then transform to unit Fréchet: \( F_Z(z) = \exp\{-z^{-1}\} \)

- **Tail dependence** is described by an *angular measure*
Radial and angular components
Comparing WRF model output to observations

We define a study region and quantity with the purpose of capturing PE events identified by Dettinger et al. (2011).

Precipitation from WRF-reanalysis output (left) and observational data product (right) on January 1, 1997.
Estimation of marginal tails

GPDs are fit to the largest 5% of data in each margin:

<table>
<thead>
<tr>
<th>Margin</th>
<th>(u).</th>
<th>(\hat{\psi}) (se)</th>
<th>(\hat{\xi}) (se)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(X_t^{NC}) (WRF)</td>
<td>1054</td>
<td>288.95(39.27)</td>
<td>0.0255(0.104)</td>
</tr>
<tr>
<td>(Y_t^C) (obs)</td>
<td>14240</td>
<td>3895.87(512.03)</td>
<td>0.0213(0.099)</td>
</tr>
</tbody>
</table>

Each margin is transformed to unit Fréchet:
Examining tail dependence

We find tail dependence and fit a parametric model to the angular density of points with large ‘radial’ components.

WRF reproduces extreme events relatively well

- Not all ‘extreme’ events associated with Pineapple Express: aim to connect to synoptic-scale processes
Pineapple Express Index

Mean sea-level pressure fields are extracted from the NCEP reanalysis product.

Define a daily index as a projection onto PE anomaly field - exhibits tail dependence with precipitation.
Future PE Extremes

We analyze precipitation output from WRF driven by CCSM global model (2041-2070).

- Previous studies suggest increases in frequency and intensity of PE under A2.

Here: use fitted dependence model and PE index to simulate future observed precipitation extremes, given climate model output

Challenges: we need to estimate

1. Marginal distribution of future reanalysis-driven precipitation
2. Marginal distribution of future observations
Extremes from the NARCCAP ensemble

Use other NARCCAP model combinations to infer the upper tail of future reanalysis-driven WRF precipitation:

<table>
<thead>
<tr>
<th>RCM</th>
<th>CCSM</th>
<th>CGCM3</th>
<th>GFDL</th>
<th>NCEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>WRFG</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>ECP2</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>CRCM</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>MM5I</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>RCM3</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

- GCM-driven runs for current and future; reanalysis for current only
- For each RCM-GCM-time combination, obtain ML estimates and standard errors of GPD parameters
Estimating future reanalysis-driven WRF

An ‘ANOVA-like’ model on the parameters of the GPD:

\[
\begin{pmatrix}
\psi_{ijr} \\
\xi_{ijr}
\end{pmatrix} =
\begin{pmatrix}
\mu_\psi \\
\mu_\xi
\end{pmatrix} +
\begin{pmatrix}
\alpha_{i\psi} \\
\alpha_{i\xi}
\end{pmatrix} +
\begin{pmatrix}
\beta_{j\psi} \\
\beta_{j\xi}
\end{pmatrix} +
\begin{pmatrix}
\gamma_\psi \\
\gamma_\xi
\end{pmatrix} 1_{\{r=2\}}(r) + \epsilon_{ijr}
\]

- \(\alpha_i\) = effect of RCM \(i\), \(i = 1, \ldots, 5\)
- \(\beta_j\) = effect of GCM \(j\), \(j = 1, \ldots, 4\) (4 = reanalysis)
- \(\gamma\) = difference between current and future
- \(\epsilon_{ijr}\) incorporates numerically estimated covariances

Estimates:

- \(\hat{\beta}_{4\xi} = 0.150 \Rightarrow\) NCEP-driven RCM runs produce heavier tail of precipitation than GCM-driven runs
- \(\hat{\gamma}_\xi = 0.057\): evidence for heavier-tailed precipitation in A2 scenario (WRF 100-year event becomes 36.3-year event)
Simulation of observations

Repeated simulation gives uncertainty estimates based on how RCM represents extreme events.

$x$-axis: WRF-CCSM output. $y$-axis: simulated observations
Plot shows only observations simulated to be extreme, dashed line corresponds to largest event in current period (1981-1999)
Uncertainty through Simulation

We examine two quantities of interest through simulation:

- $q_1$: Proportion of simulated exceedances of $p$ quantile which correspond to exceedances of $p$ quantile of PE index values ($p \approx 0.96$).
- $q_2$: Proportion of ‘extreme’ observations occurring in years 2055-2070 (measure of nonstationarity)

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Estimate$^1$</th>
<th>95% Interval$^1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q_1$</td>
<td>0.203*</td>
<td>(0.144, 0.257)</td>
</tr>
<tr>
<td>$q_2$</td>
<td>0.571</td>
<td>(0.477, 0.656)</td>
</tr>
</tbody>
</table>

$^1$ Based on 500 conditional simulations

*Value from current period: 0.143

Evidence for increased correspondence of PE events and extreme precipitation - more intense PE events
Summary

This work is a novel application of bivariate EVT in a climate study.

- Tail dependence between RCM output and observations - modeled this parametrically
- PE Index - derived from SLP fields; tail dependent to observed precipitation
- Conditional simulation from parametric model given future RCM output - uncertainty estimates
Future work

Important to remember that we have studied one RCM, driven by one GCM, and compared it to one observational product.

- Improvement of the PE index - storms evolve over several days
- PE events from other climate models
- Examining other regions/phenomena
Manuscript and figures available at
http://www.stat.colostate.edu/~weller.

References

