# An Investigation of the Pineapple Express Phenomenon via Bivariate EVT

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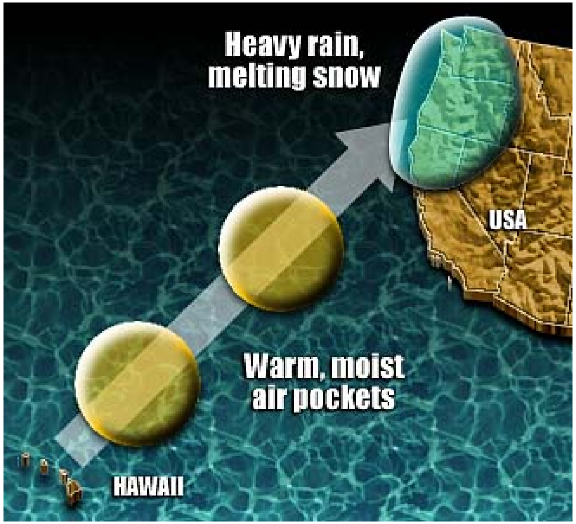
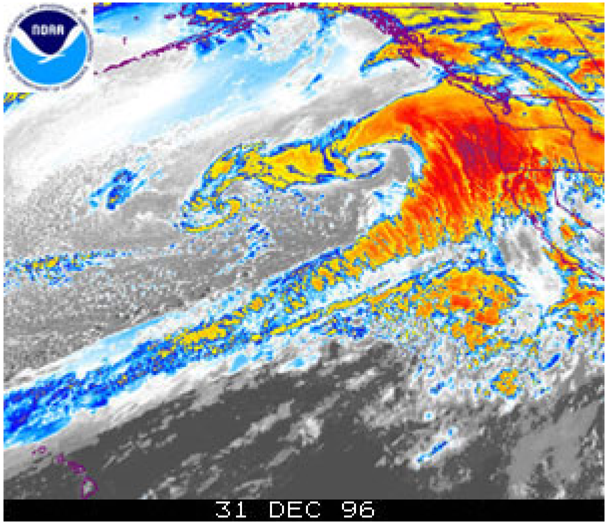
# Pineapple Express

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

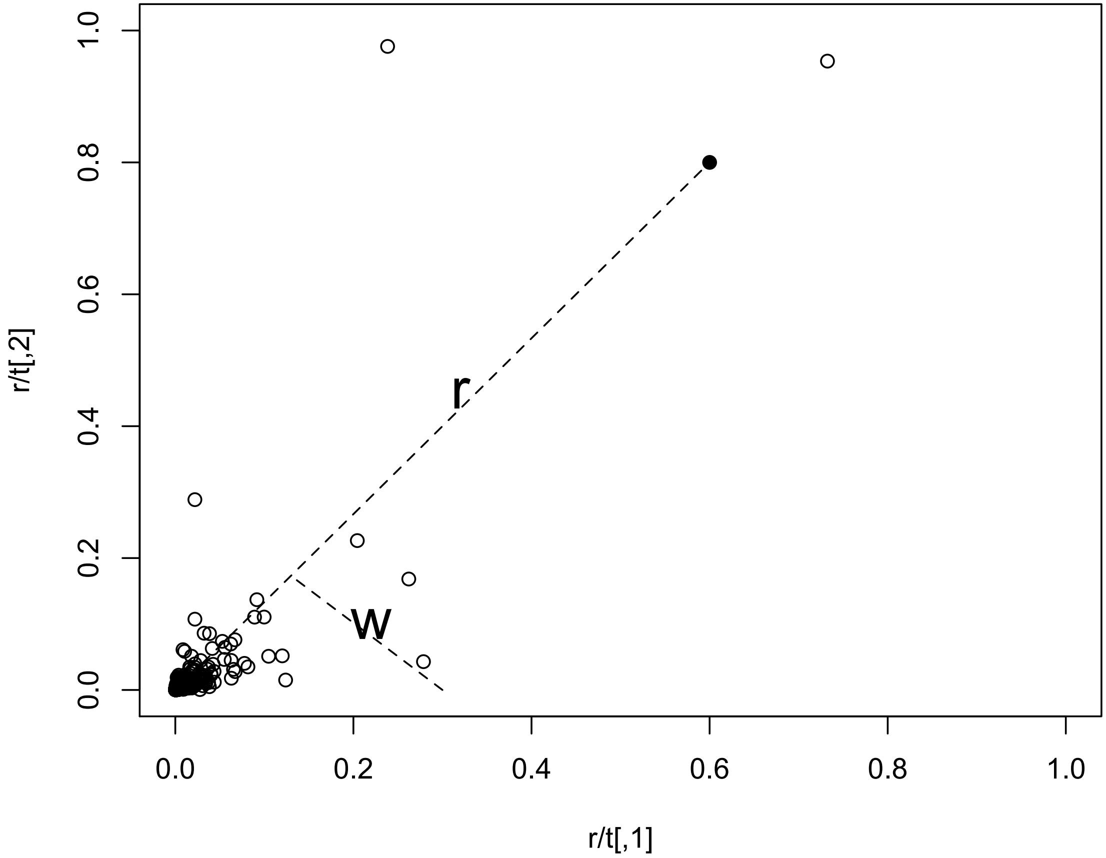
The aim of extreme value theory is to describe the (joint) upper tail of a (multivariate) distribution. *It is not necessary to know the data's entire distribution.*

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

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

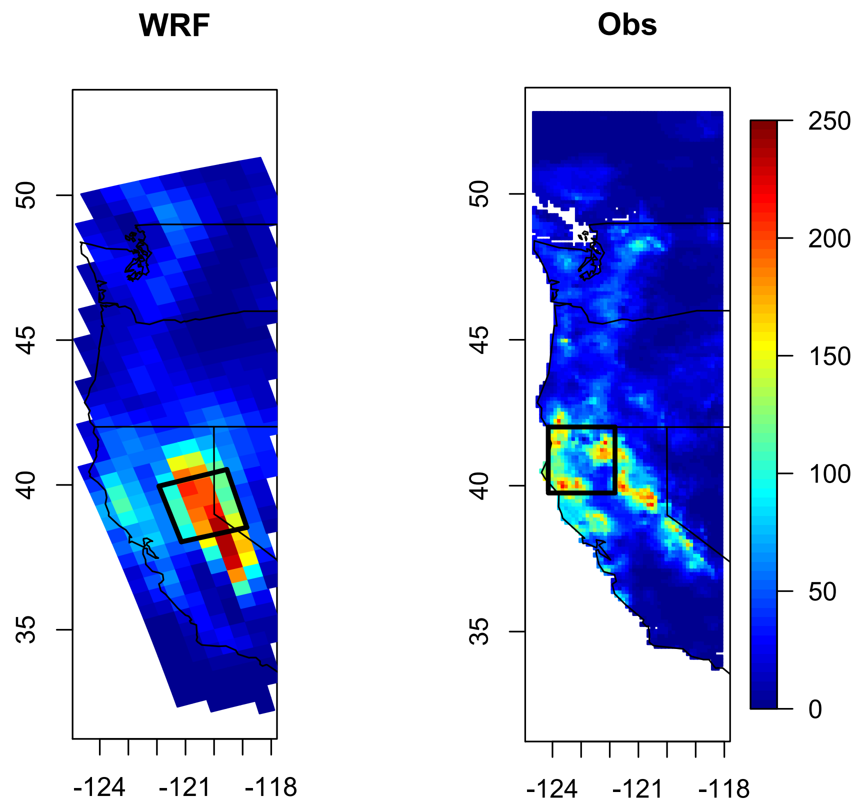
- $\xi$ determines tail behavior (bounded, light, heavy) and is difficult to estimate
- Bivariate extremes: estimate marginals first, then transform to unit Fréchet: $F_Z(z) = \exp\{-z^{-1}\}$
- Tail dependence is described by an *angular measure*

# 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).



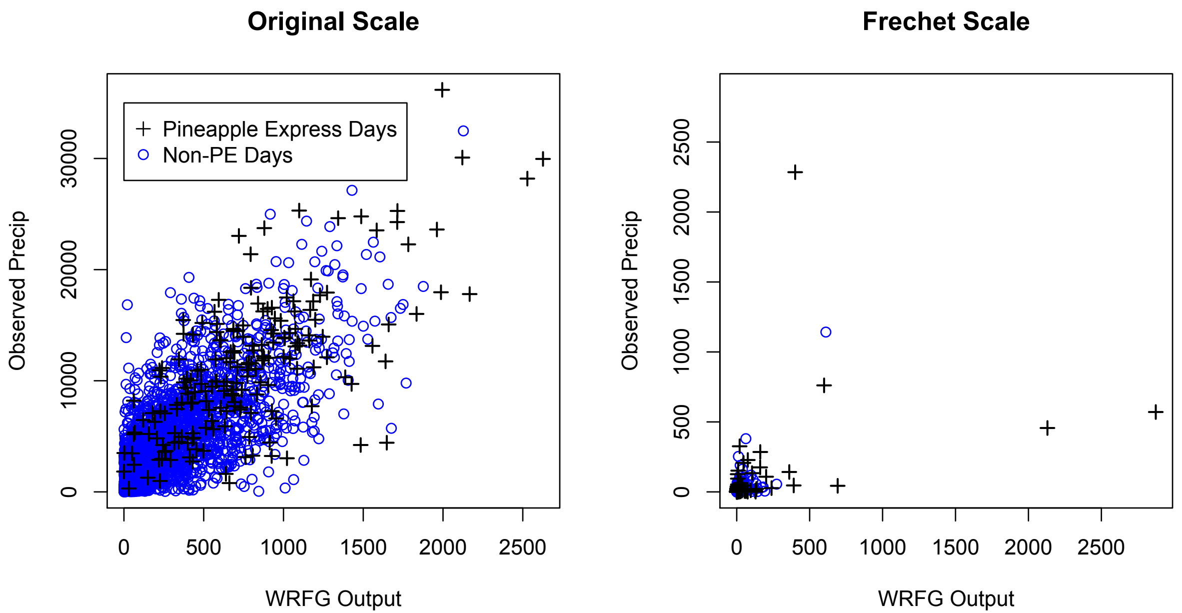

Precipitation from WRF-reanalysis output (left) and observational data product (right) on January 1, 1997.

# Estimation of marginal tails

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

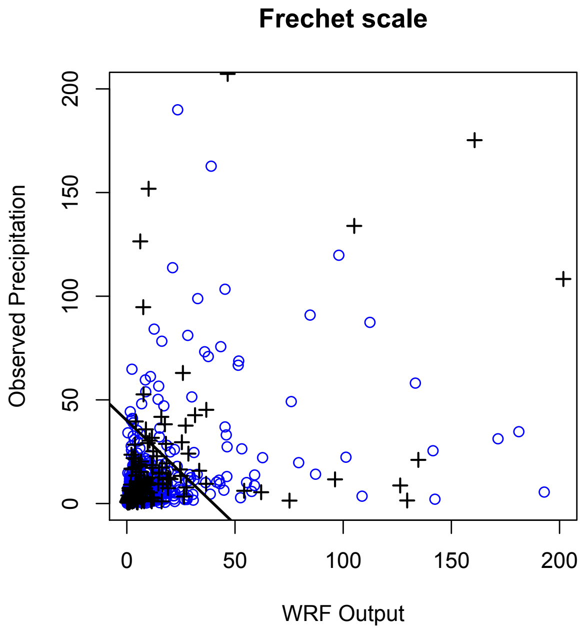
| Margin | $u_\cdot$ | $\hat{\psi}_\cdot$ (se) | $\hat{\xi}_\cdot$ (se) |
|---|---|---|---|
| $X_t^{NC}$ (WRF) | 1054 | 288.95(39.27) | 0.0255(0.104) |
| $Y_t^C$ (obs) | 14240 | 3895.87(512.03) | 0.0213(0.099) |

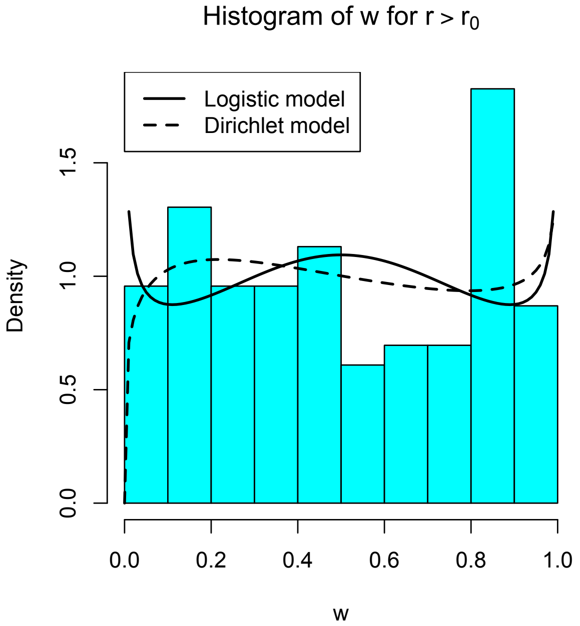
Each margin is transformed to unit Fréchet:



# Examining tail dependence

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



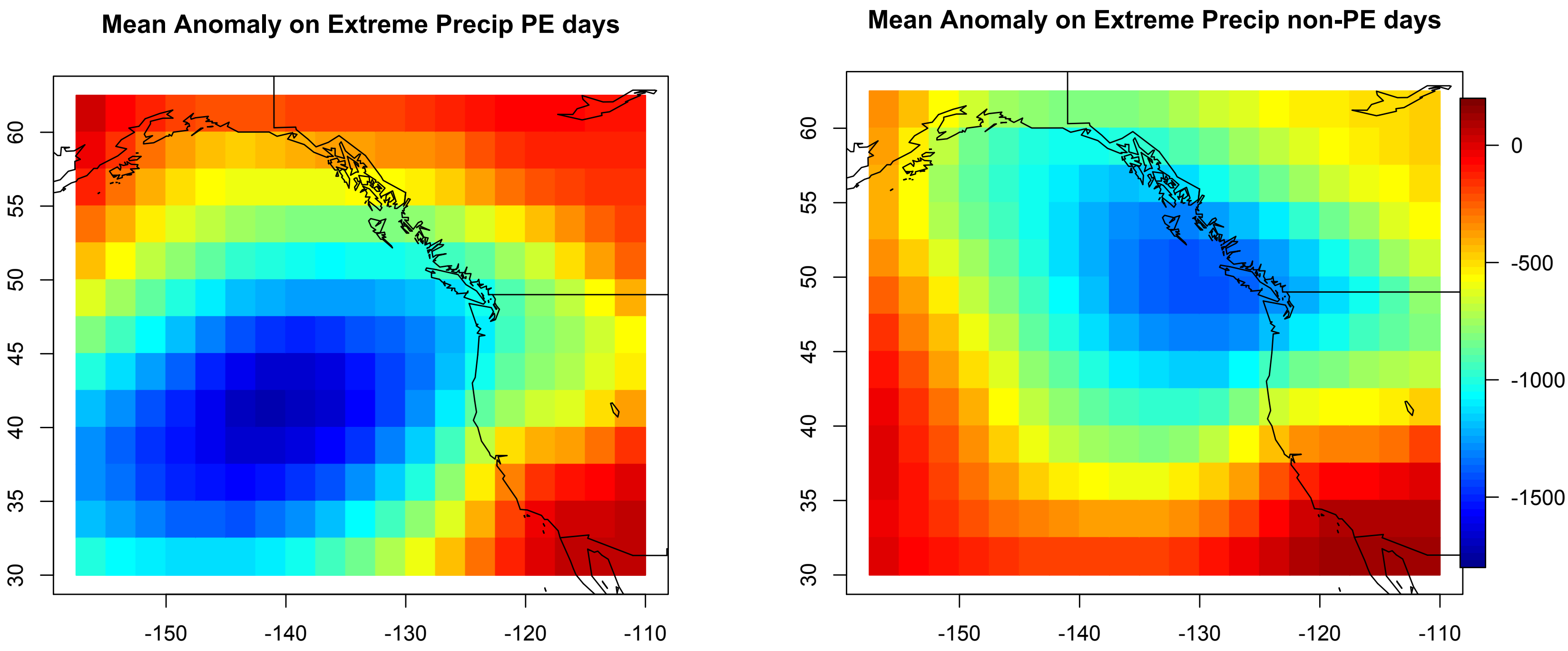




\+ WRF reproduces extreme events relatively well

– 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




Composite anomaly fields for largest 130 observed precipitation days, partitioned into PE and non-PE

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:

| | GCM | | | |
|---|---|---|---|---|
| RCM | CCSM | CGCM3 | GFDL | NCEP |
| WRFG | X | X | | X |
| ECP2 | | | X | X |
| CRCM | X | X | | X |
| MM5I | X | | | X |
| RCM3 | | X | X | X |

- 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:

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

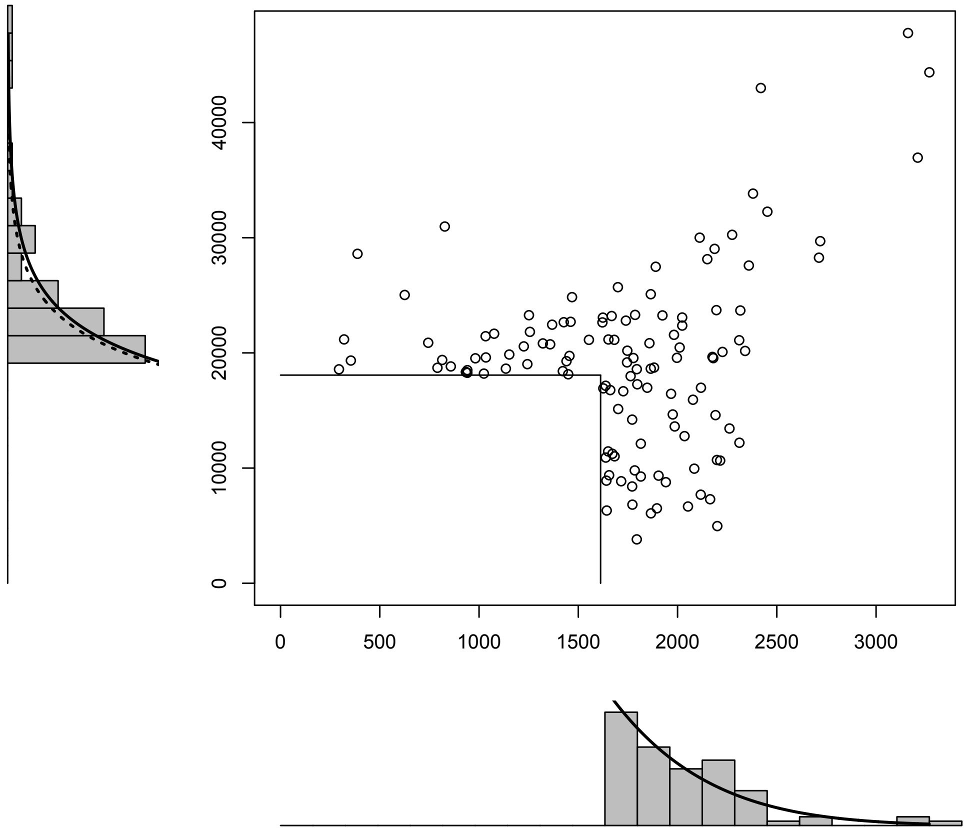
- $\alpha_i$ = effect of RCM $i$, $i = 1, ..., 5$
- $\beta_j$ = effect of GCM $j$, $j = 1, ..., 4$ (4 = reanalysis)
- $\gamma$ = difference between current and future
- $\epsilon_{ijr}$ incorporates numerically estimated covariances

Estimates:

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

# Simulation of observations

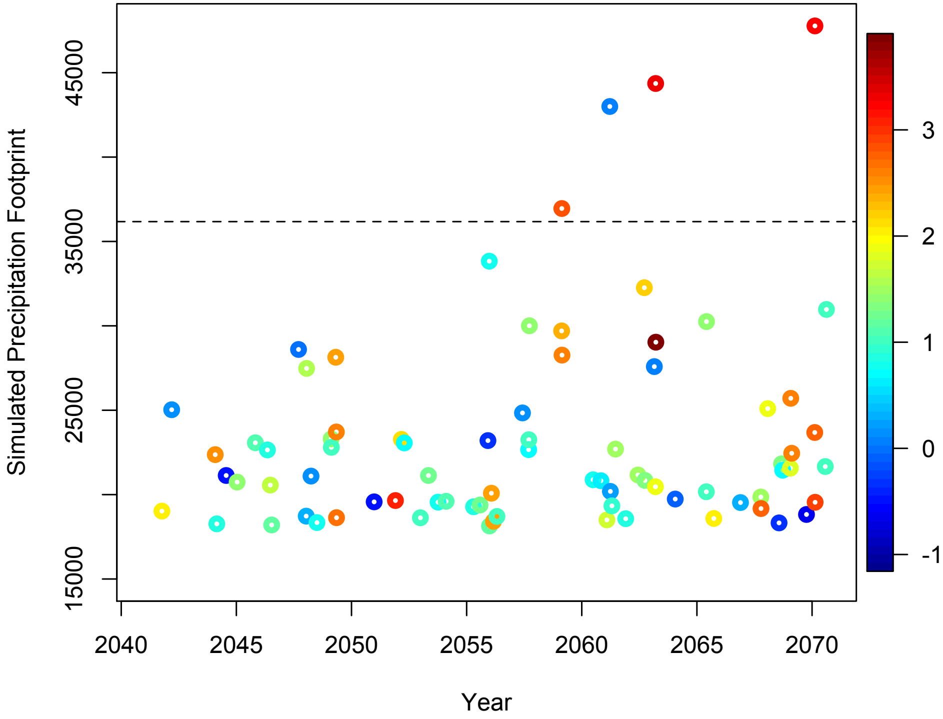
Repeated simulation gives uncertainty estimates based on how RCM represents extreme events.




$x$-axis: WRF-CCSM output. $y$-axis: simulated observations

# PE Index of simulated future events

## Color shows PE index expressed as a $z$-score




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)

| Quantity | Estimate[1] | 95% Interval[1] |
|---|---|---|
| $q_1$ | 0.203* | (0.144, 0.257) |
| $q_2$ | 0.571 | (0.477, 0.656) |

[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

# Reference

Manuscript and figures available at
http://www.stat.colostate.edu/~weller.

**References**


Dettinger, M., Ralph, F., Das, T., Neiman, P., and Cayan, D. (2011). Atmospheric rivers, floods and the water resources of California. *Water*, 3(2):445–478.

Leung, L. and Qian, Y. (2009). Atmospheric rivers induced heavy precipitation and flooding in the western US simulated by the WRF regional climate model. *Geophysical Research Letters*, 36(3):L03820.

Weller, G., Cooley, D., and Sain, S. (2012). An investigation of the Pineapple Express phenomenon via bivariate extreme value theory. *Environmetrics*.