Conditional Approaches to Estimating Concurrent Wind and Precipitation Extremes

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Outline of the talk

- Concurrent extremes: **simultaneous** occurrence of extreme values for **multiple** climate variables
- Conditional approaches for estimating concurrent extremes:
  - **Quantile regression**
  - **Conditional extreme value models**
- Estimating concurrent extremes using a large ensemble
  - Estimating simultaneous extreme wind speed and precipitation
  - 35-member Regional Climate Model initial-condition ensemble

Some examples of concurrent extreme events

Credit: Shuttershock

Source: www.standardmedia.co.ke

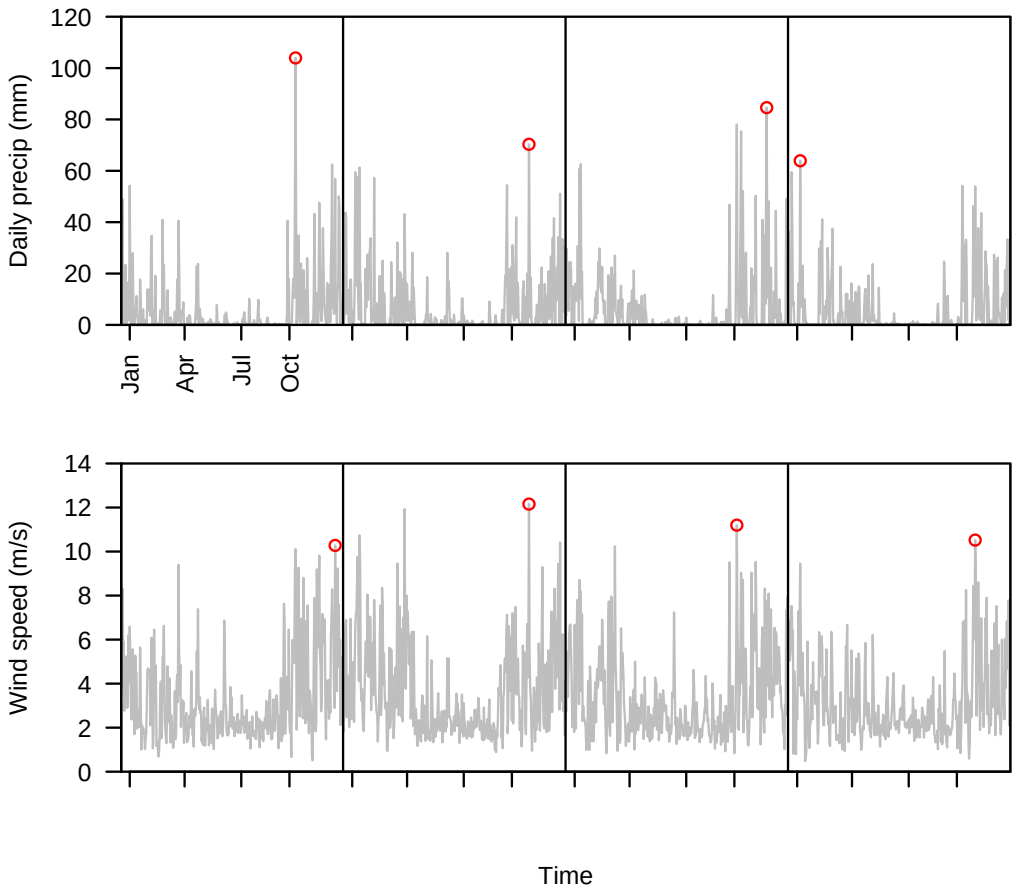
Estimating the magnitude of concurrent extremes

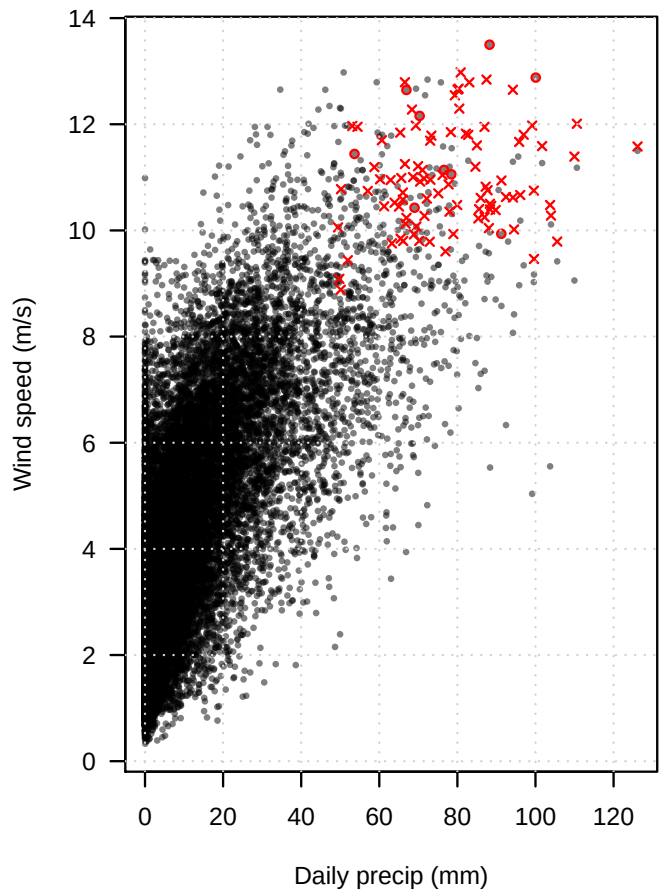
Consider the bivariate case, i.e., $\boldsymbol{X} = (X_1, X_2)^T$

- There is no natural ordering to define an extreme value for multivariate data
- Traditional multivariate extreme value analysis mainly focus on modeling component-wise maximum $\Rightarrow$ may lead to "wrong" events ☹
- It is important to account for "event simultaneity" for modeling concurrent extremes $\Rightarrow$ we do this by conditioning on one variable being extremes

Classical multivariate extreme value analysis

Modeling componentwise maxima using multivariate extreme value distribution (extreme-value marginals + tail copula)





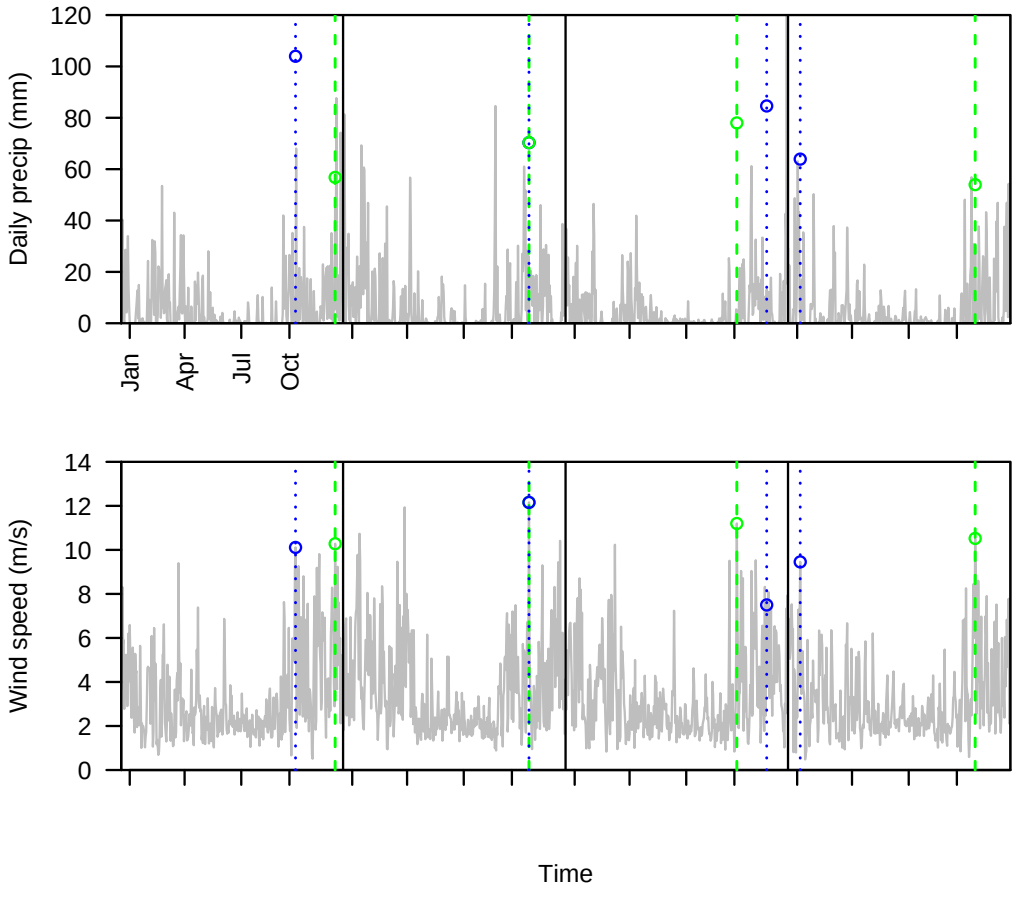
Issue: Ignore the event simultaneity

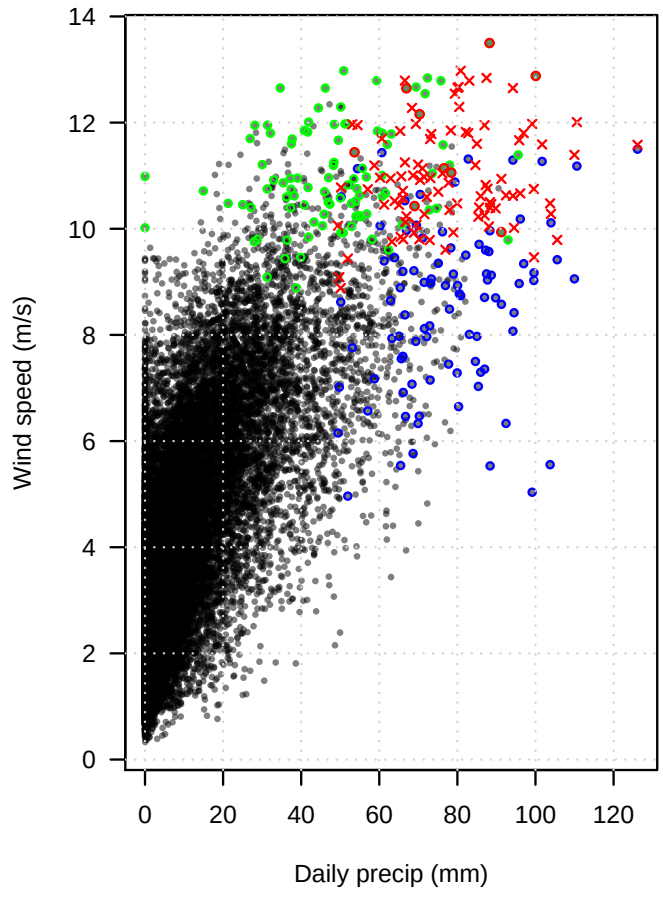
Componentwise maxima vs. concomitants of maxima

Red: (annual max precip, annual max wind speed)

Blue: (annual max precip, concurrent wind speed)

Green: (annual max wind speed, concurrent precip)

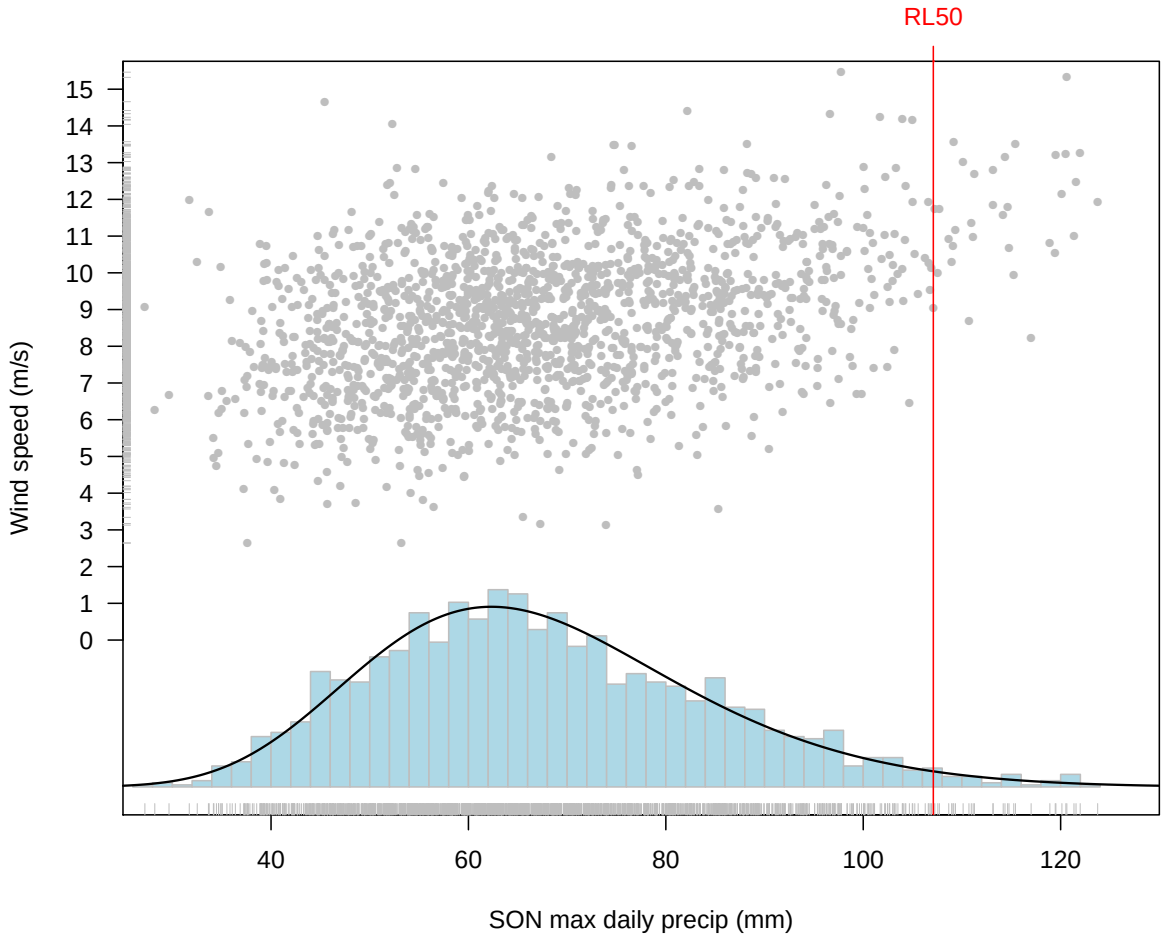




An illustration of conditional approach

Let X_1 and X_2 be daily precipitation and wind speed

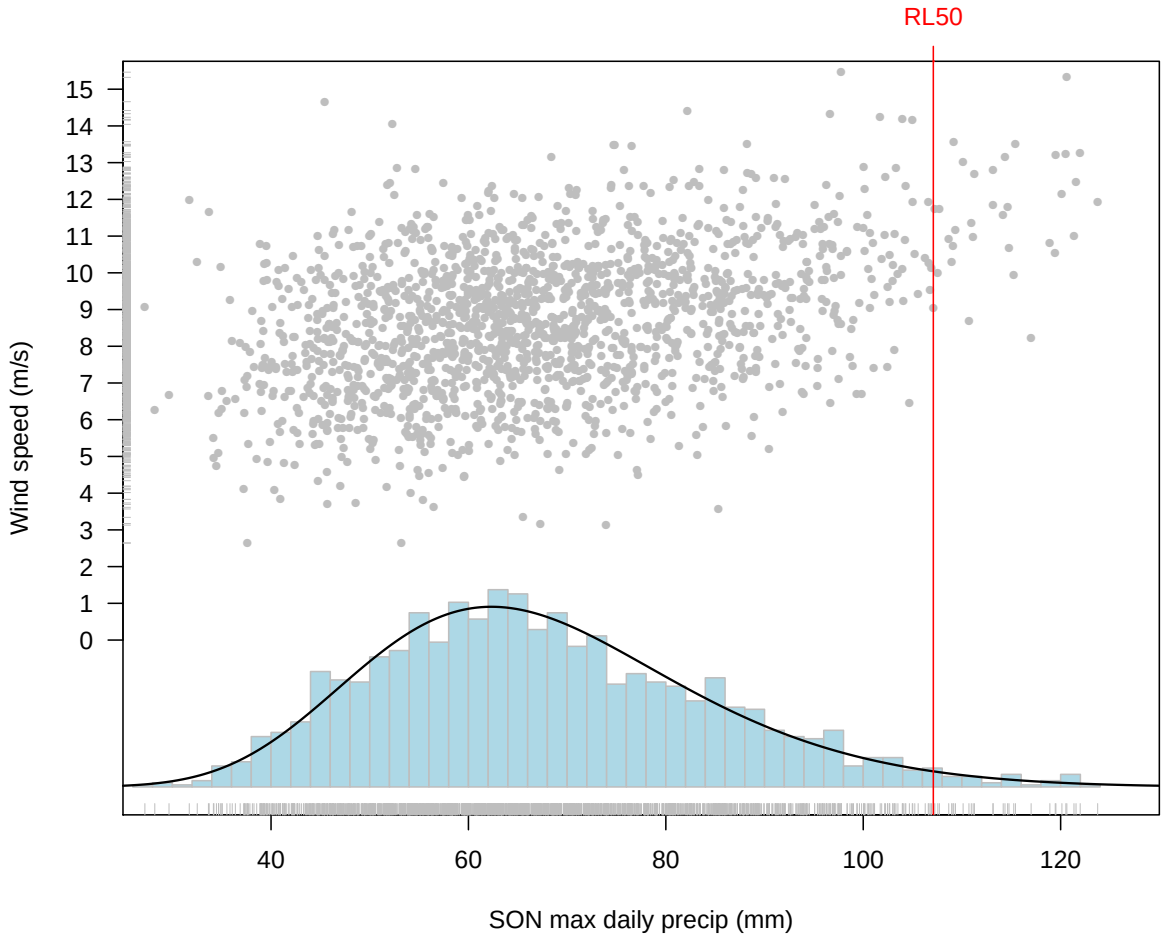
1. Condition on X_1 being "extreme" e.g., annual maximum



An illustration of conditional approach

Let X_1 and X_2 be daily precipitation and wind speed

1. Condition on X_1 being "extreme" e.g., annual maximum
2. Model the conditional distribution of X_2 given X_1 being "extreme"



Estimating conditional distribution: Quantile regression (QR) [Koenker and Bassett, 1978]

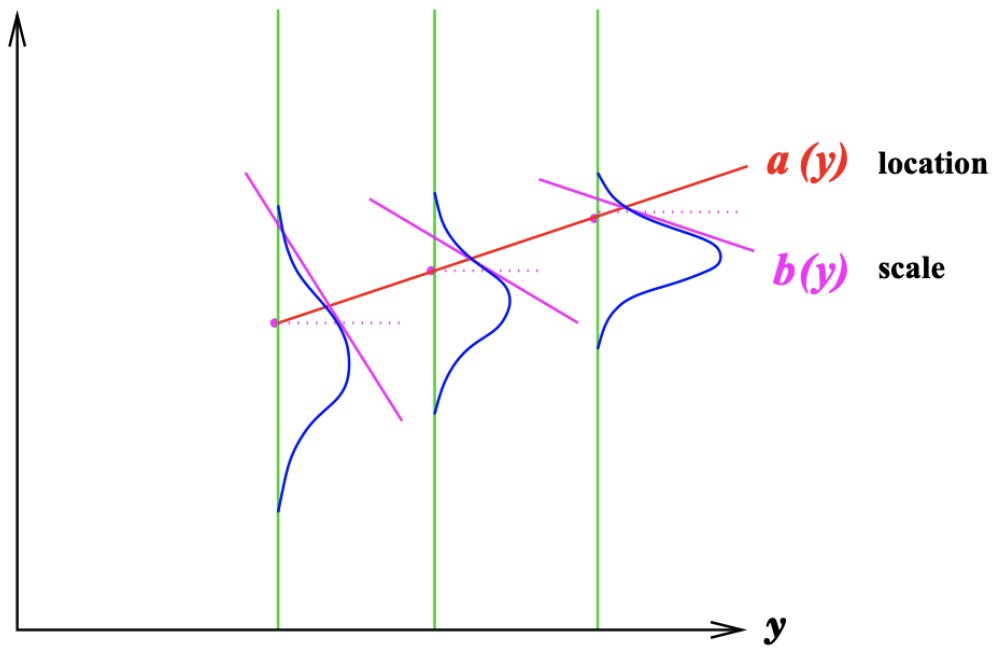
- Extending regression analysis by estimating conditional quantiles: $Q_{X_2}(\tau|X_1 = x_1) = \inf\{x_2 : F(x_2|x_1) \geq \tau\}$, $\tau \in (0, 1)$
- Estimate $Q_{X_2}(\tau|x_1)$ at a finite number of quantile levels $\tau_1, \tau_2, \cdots, \tau_J$
- Could suffer from the issue of quantile curves crossing $\Rightarrow$ We use Monotone Composite Quantile Regression Neural Network [MCQRNN, Cannon, 2018] to (non-parametrically) estimate quantile curves **simultaneously**

Estimating conditional distribution: Conditional extreme value (CEV) models [Heffernan and Tawn, 04]

- **Marginal modeling**:
  1. Estimate marginal distributions of X_1 and X_2
  2. Transform $(X_1, X_2)^T$ to Laplace marginals $(Y_1, Y_2)^T$
- **Dependence modeling**:
  Assume for large u,
  $[(Y_2 - a(Y_1)) / (b(Y_1)) \leq z | Y_1 > u] \sim G(z)$, where $a(y) = \alpha y$ and $b(y) = y^{\beta}$, $\alpha \in [-1, 1]$, $\beta \in (-\infty, 1)$

A cartoon illustration of the CEV dependence modeling

Assume for large u, $[(Y_2 - a(Y_1))/(b(Y_1)) \le z | Y_1 > u] \sim G(z)$, where $a(y) = \alpha y$ and $b(y) = y^\beta$, $\alpha \in [-1, 1]$, $\beta \in (-\infty, 1)$



- $Y_2 = \alpha Y_1 + Y_1^\beta Z$, $Z = \frac{Y_2 - \alpha Y_1}{Y_1^\beta} \sim G$
- α and β are estimated by making a parametric assumption of Y_2
- G estimated nonparametrically

"Data"

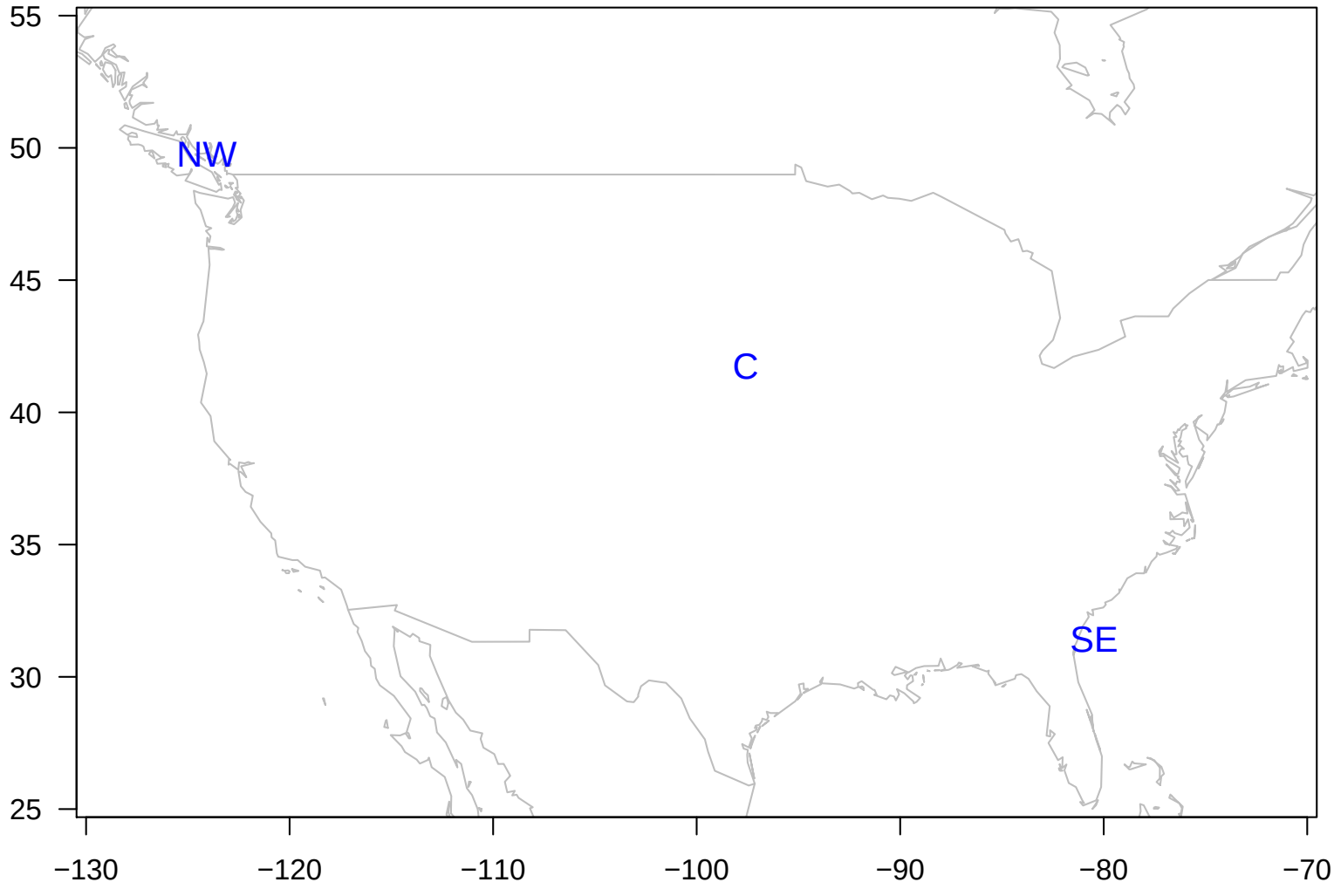
Output from CanRCM4, Canadian Regional Climate Model 4, 1950 – 2100

- 35-member initial-condition ensemble
- Using CMIP5 historical forcings (1950-2005) and then RCP 8.5 (2006-2100)
- North American region, 0.44° horizontal grid resolution ($\sim$ 50 km)

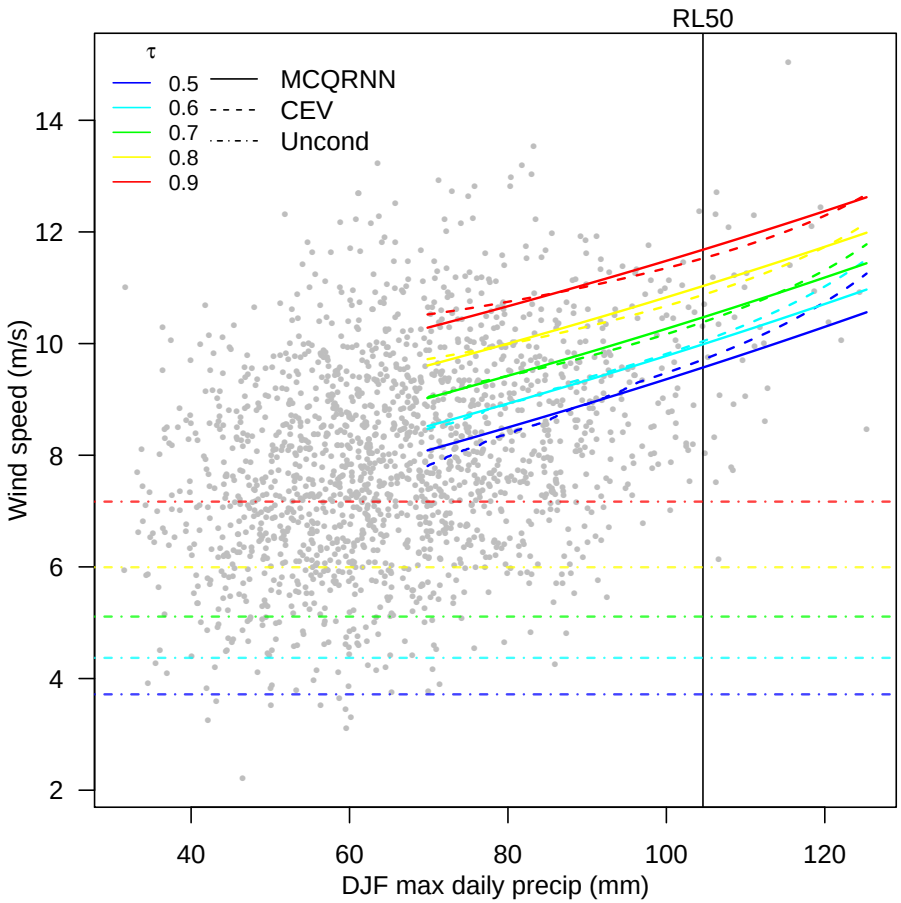
Each run in ensemble produces (nearly) statistically independent realizations of climate system, which allows us to:

- provide more accurate estimates and more realistic modeling in climate extremes
- assess how well statistical procedures work

The three grid cells considered in this talk

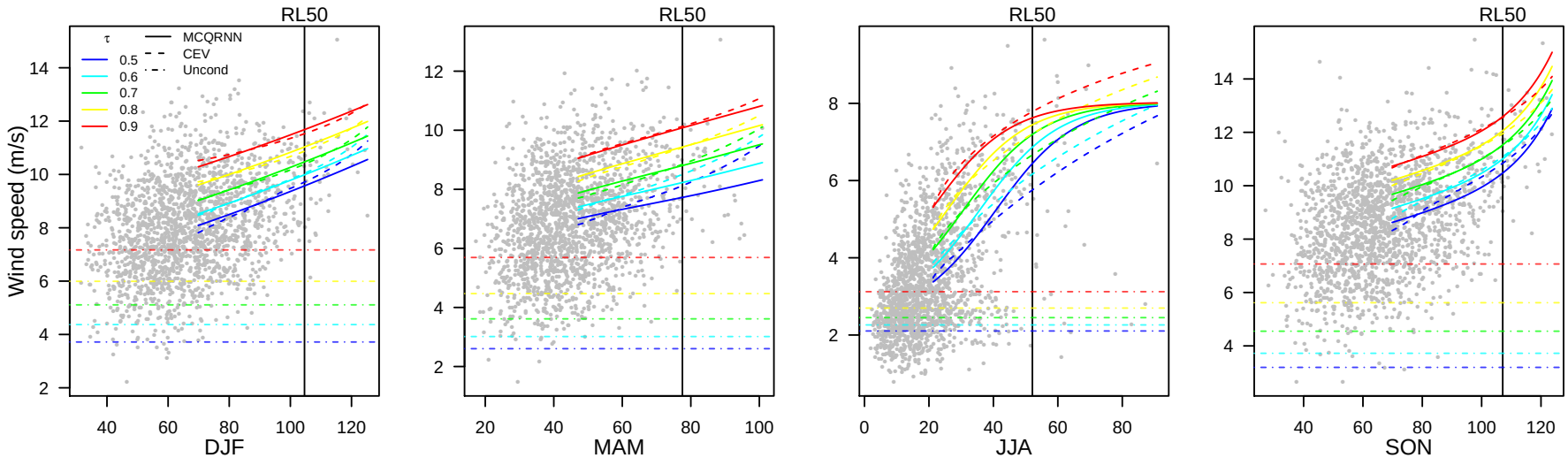


Estimating conditional quantiles using MCQRNN and CEV



- DJF max precipitation ↑ concurrent wind speed ↑
- QR and CEV yield reasonably close wind speed high quantile estimates
- Conditional quantiles are substantially larger than their unconditional counterparts

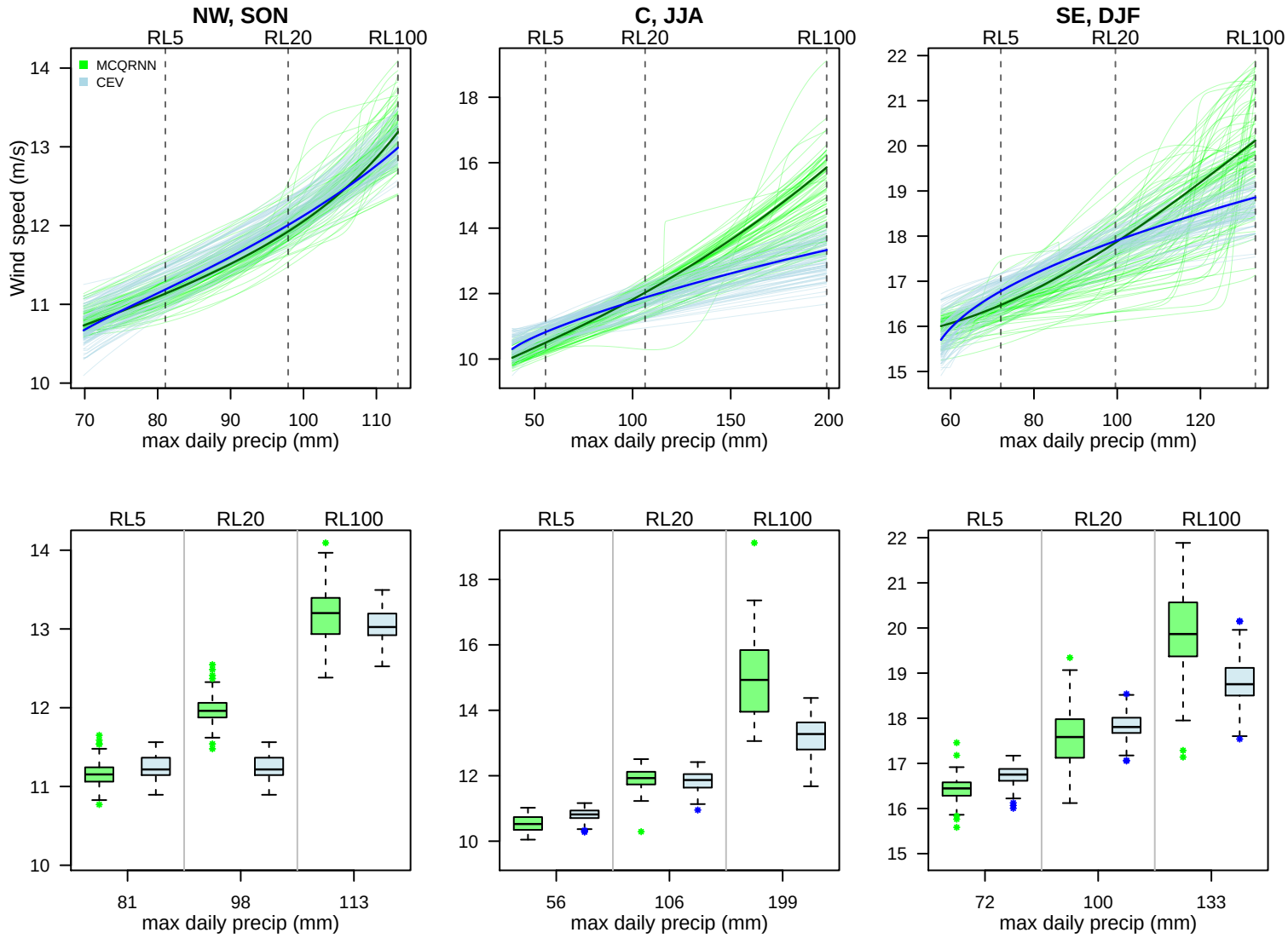
Seasonal conditional upper quantiles



- Wind speeds and precipitation are larger during SON and DJF
- Both methods produce close high quantile estimates up to the 50-year return level but can diverge beyond that
- Conditional quantiles are substantially larger than their unconditional counterparts

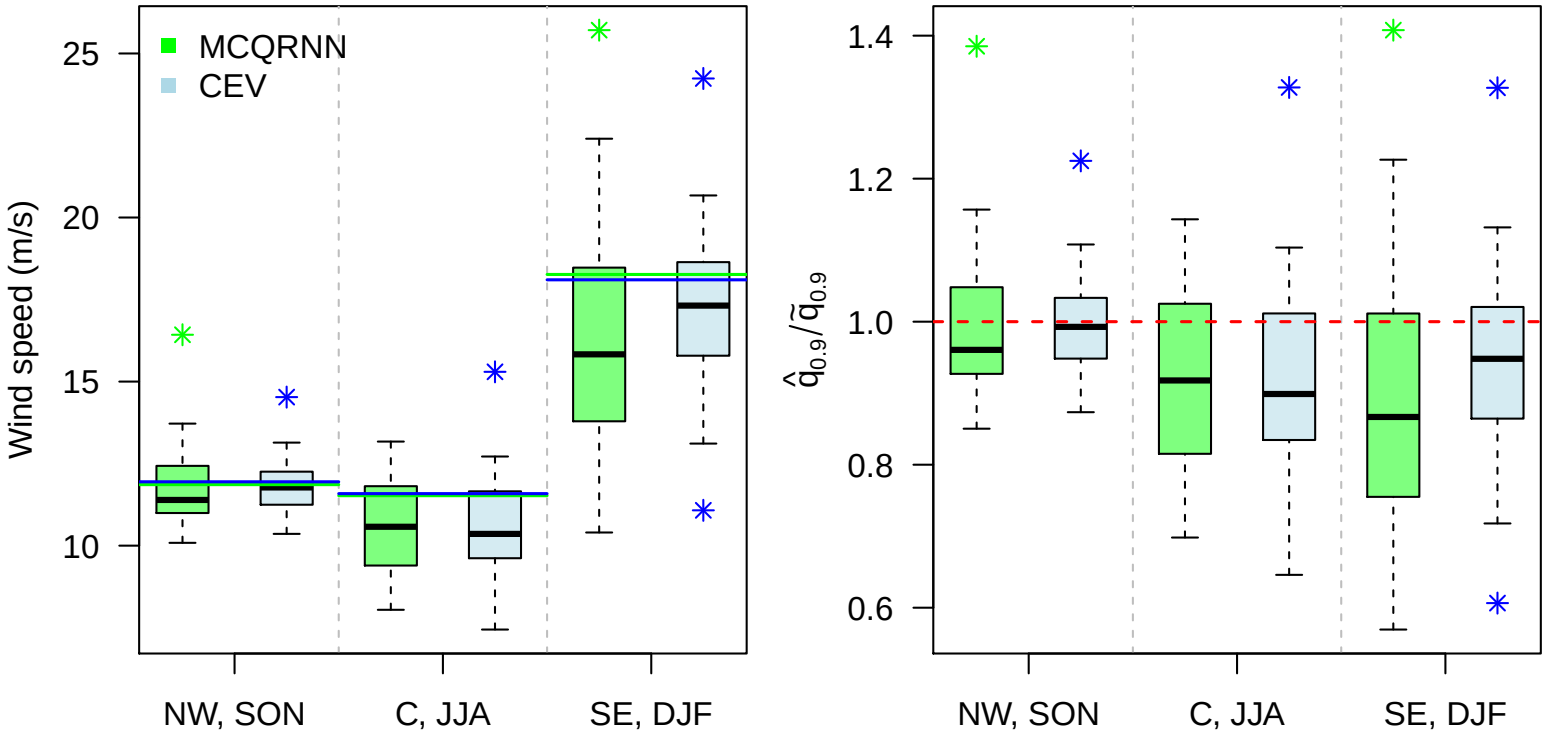
Resample ensemble runs to obtain uncertainty estimates

Here we show quantile function estimates with $\tau = 0.9$



A quick assessment of statistical model performance

- We treat the fitted conditional quantile function at $\tau = 0.9$ using all 35 ensemble members as the "truth"
- We assess the model performance by fitting CEV and MCQRNN for each ensemble member



Summary & Discussion

- We explore conditional approaches to estimate the concurrent wind and precipitation extremes
- Large climate model ensemble is a power tool for studying climate extremes
- **Ongoing work**
  - Nonstationary extension account for both seasonality and long term trend for marginal and dependence structures
  - Spatial extension to borrow strength across space to improve estimation of concurrent extremes
  - Estimating conditional upper tail of precipitation conditioning on extreme wind speed

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Thank you for your attention!
ArXiv: https://arxiv.org/pdf/2006.08720.pdf.