3A.3: Spatial Extreme Value Analysis for Large-Scale Severe Weather Indicators

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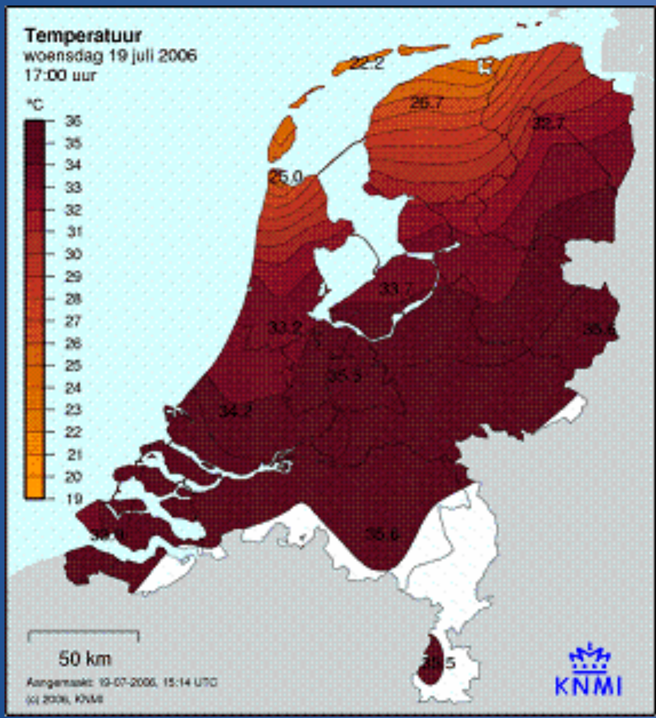
Scale of Extreme Weather Events



2006 European Heat Wave
(Fig. from KNMI)

F5 Tornado in Elie Manitoba on
22nd June 2007

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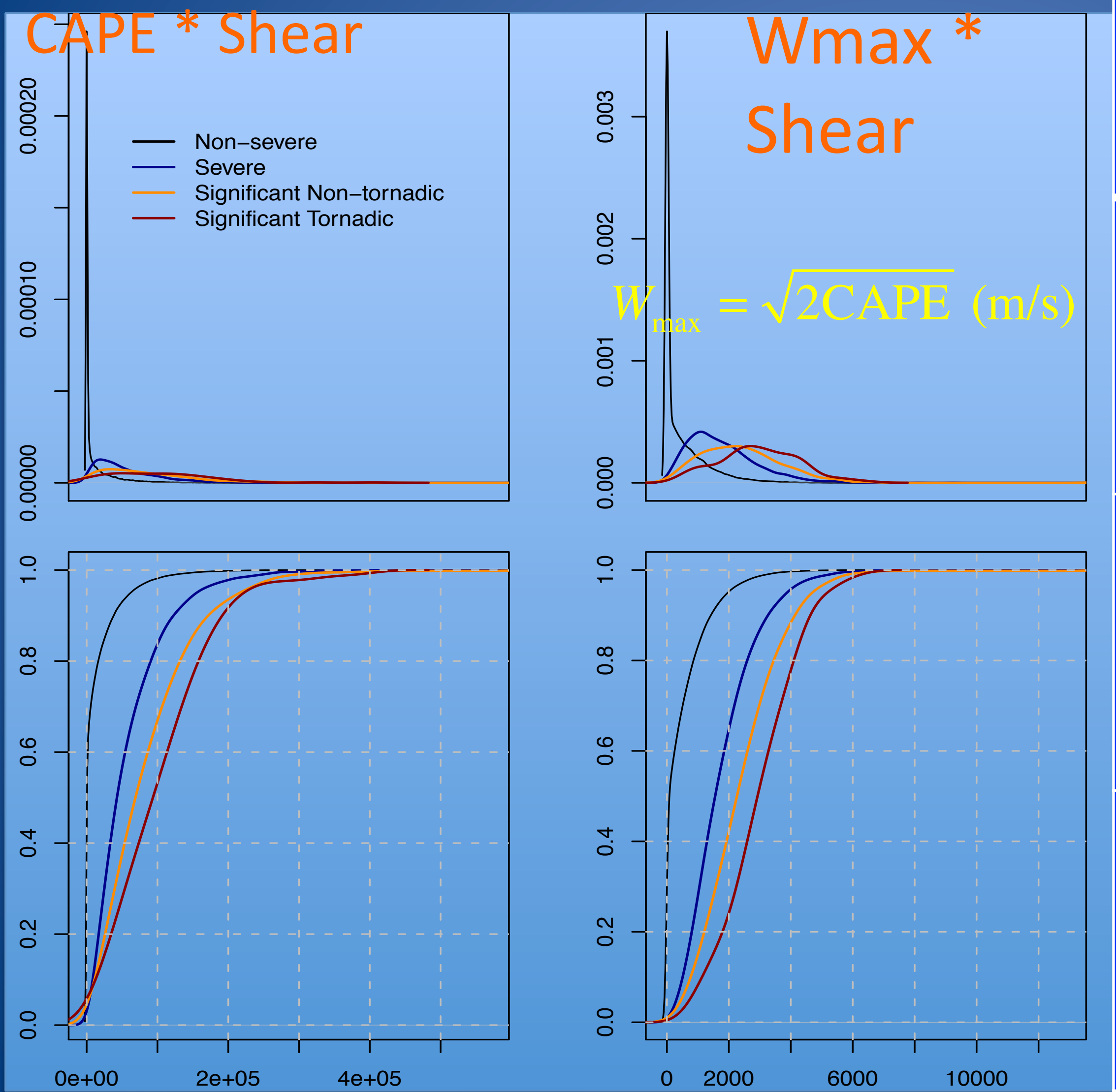
Large-scale indicators (CAPE and Shear)



Non-severe	**Hail < 1.9 cm Winds < 55kts. No tornado**
Severe	**Hail ≥ 1.9 cm 55 ≤ Winds < 65 Or tornado**
Significant Non-tornadic	**Hail ≥5.07 cm Winds ≥ 65 kts.**
Significant tornadic	**Same as Significant non-tornadic, but with ≥ F2 tornado**

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Extreme Value Analysis

- Rare Events
- Only one Maximum in a Dataset
- Very few points above high threshold
- Theory suggests appropriate family of distributions for analyzing extremes
  - Generalized Extreme Value (GEV) df
  - Generalized Pareto (GP) df
  - Point Process characterization

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Extreme Value Analysis

- GEV (For large *n*)

$$\Pr\left\{\max\left(X_1,\ldots,X_n\right) \le x\right\} = F(x)$$

- GP (For large *u*)

$$\Pr\left\{X \le u + x \mid X > u\right\} = F(x)$$

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Spatial Extremes:

Different Choices for Different Goals

- Interpolate Extremes to Unobserved Locations
- Statistical Inference in the Face of Spatial Dependence
- Identify Sources of Variability in Space
- Analyze Extremes Jointly Over Space
- *Smooth Data Over Space*?

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Spatial Extremes: Methods

- Univariate Extremes with Spatial Covariates
- Multivariate Extremes
- Max-Stable Processes
- Copulas
- Bayesian Hierarchical Modeling (BHM)
- BHM + Max-Stable Processes
- Conditional Extremes

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Spatial Extremes: Methods

$$\Pr[T_A<1, T_B<1] = \phi_2(\phi^{-1}(F_A(1)), \phi^{-1}(F_B(1)), \gamma)$$

Recipe for Disaster: The formula that Killed Wall Street

Wired Magazine, 2/23/2009, by Feliz Salmon

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Conditional Extremes

$$X \mid Y = y, \text{ for } y \text{ large}$$

X, Y Follow marginal standard EVDs

X may or may not be extreme.

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Conditional Extremes

$$X \mid Y = y, \text{ for } y \text{ large}$$

X, Y Follow marginal standard EVDs.
If positively associated, then

$$\left[X \mid Y = y \right] = \alpha y + y^{\beta} Z$$

Heffernan and Tawn (2004, *JRSS* B, **66** (3), 497 – 546)

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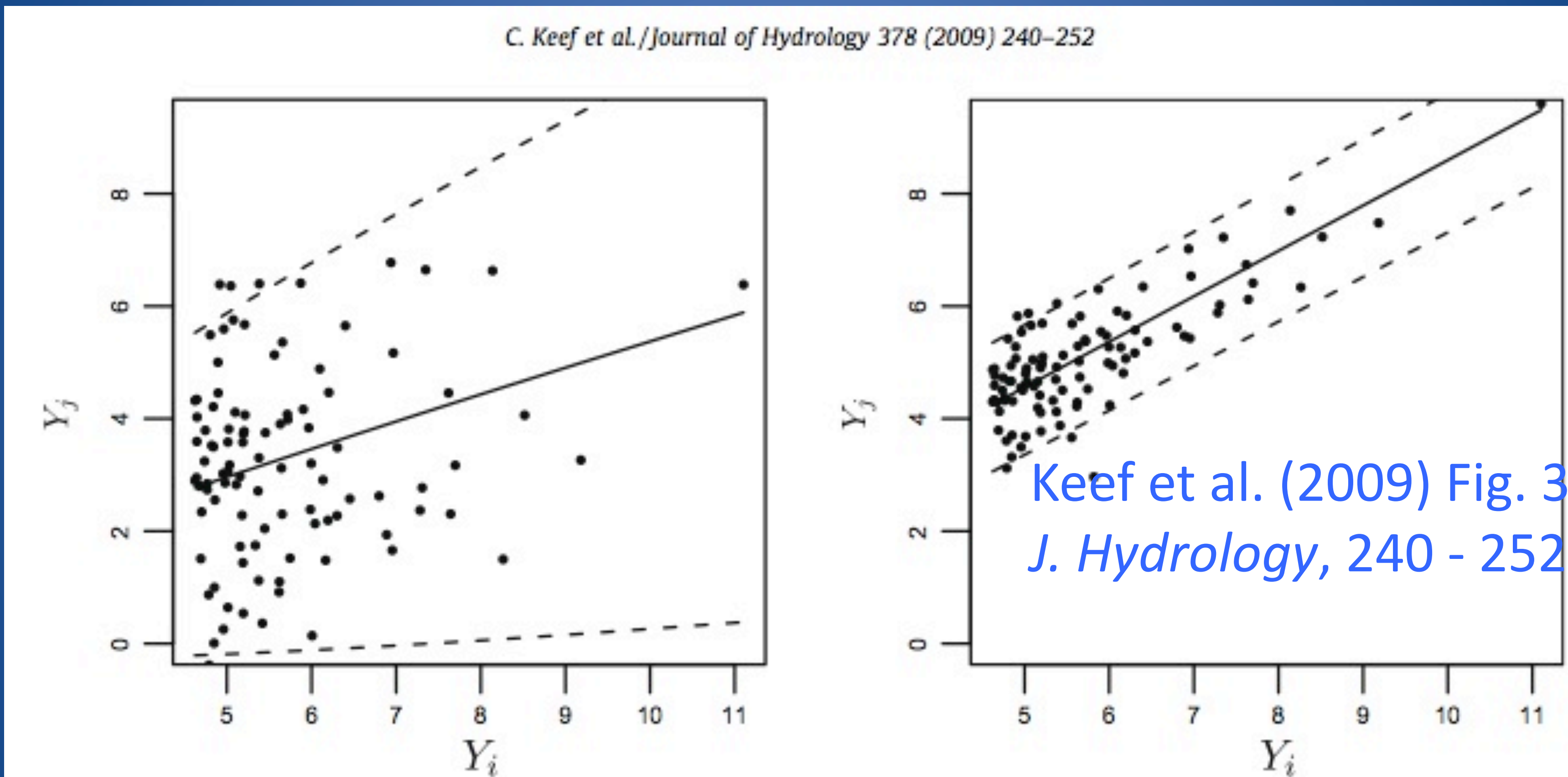
Conditional Extremes



α = 0.3, β = 0.7

α = 0.8, β = 0.1

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Conditional Extremes

$$\left[X_1,\ldots,X_n \mid Y = y\right] = \left(\alpha_1,\ldots,\alpha_n\right) y + y^{\left(\beta_1,\ldots,\beta_n\right)}\left(Z_1,\ldots,Z_n\right)$$

Dependence is determined by the parameters alpha and beta and the distribution function G(z).

α in [0, 1) describes the strength of dependence, with α = 1 perfect dependence.

β in (-∞, 1] describes the scale/dispersion of dependence.

Unknown what G is or should be.

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Choose Conditioning Variable

- Something to measure the energy in the field at a given time.
- q75 = Upper quartile of Wmax * Shear (WmSh) over space.
- Univariate quantity over time. Condition on its being large.

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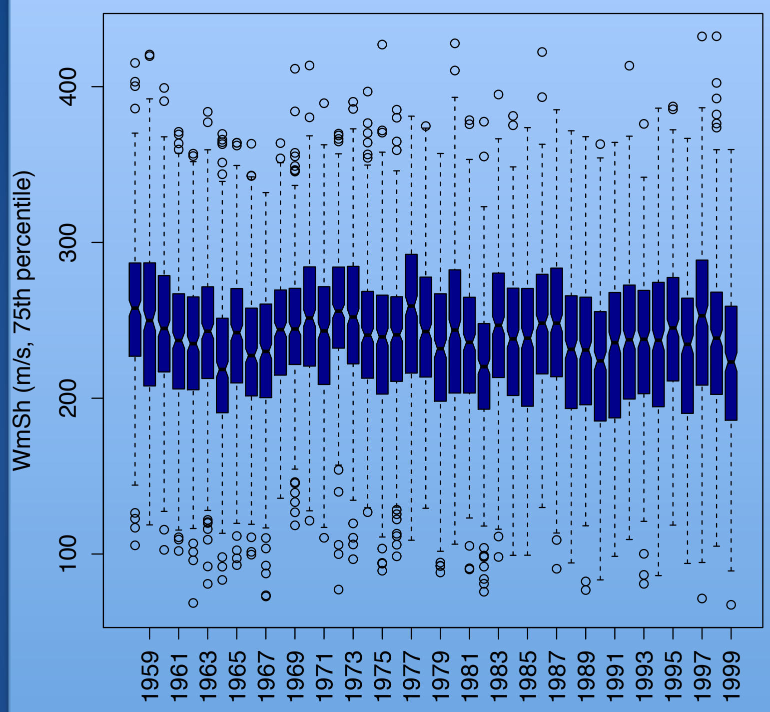
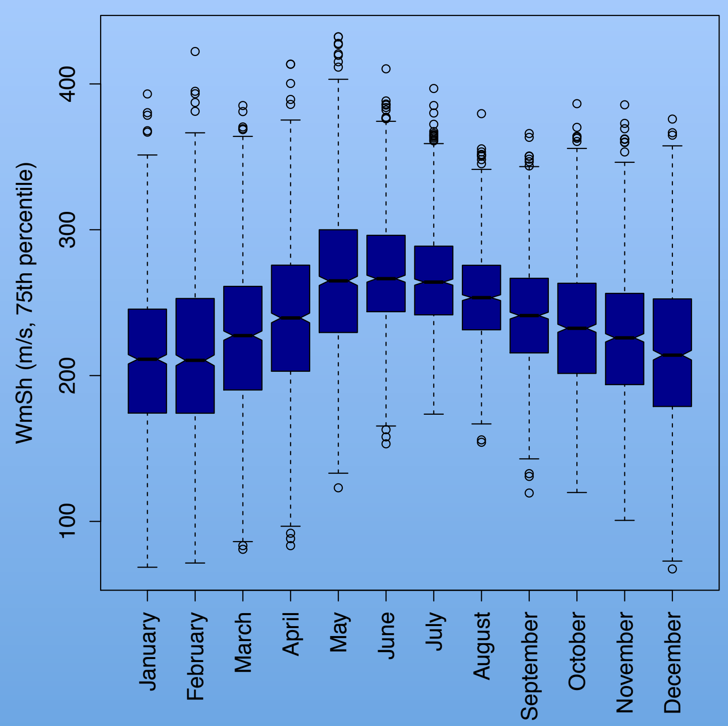
Choose Conditioning Variable





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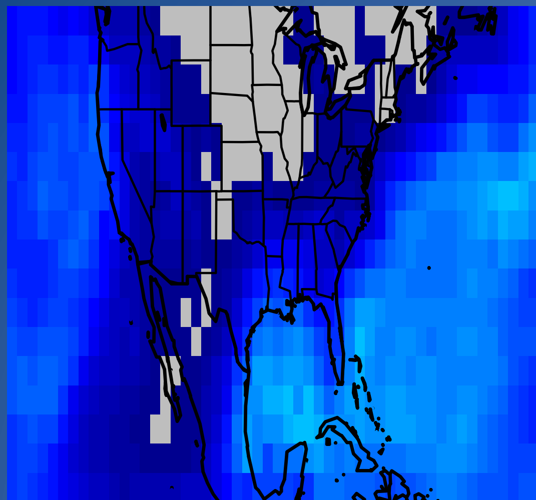
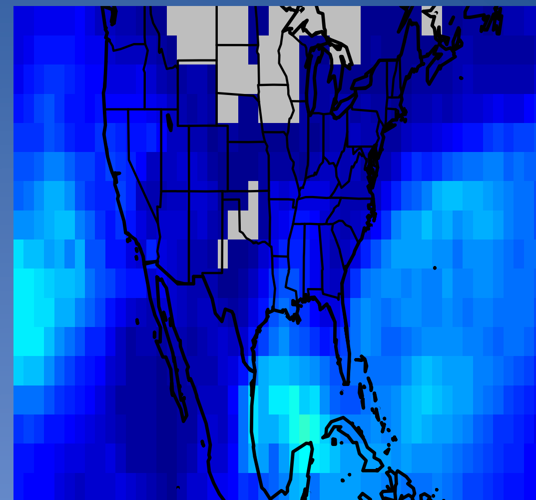
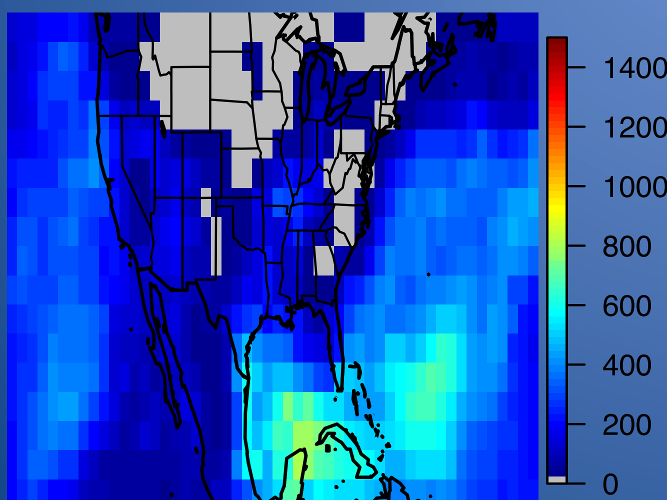
Winter WmSh (m/s)^2



1958 - 1978



1979 - 1992



1993 - 1999

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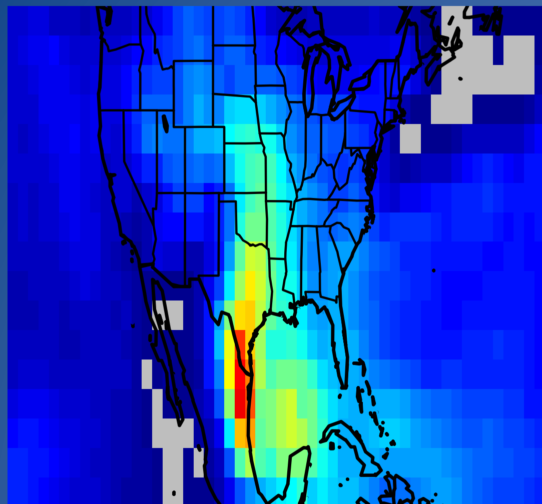
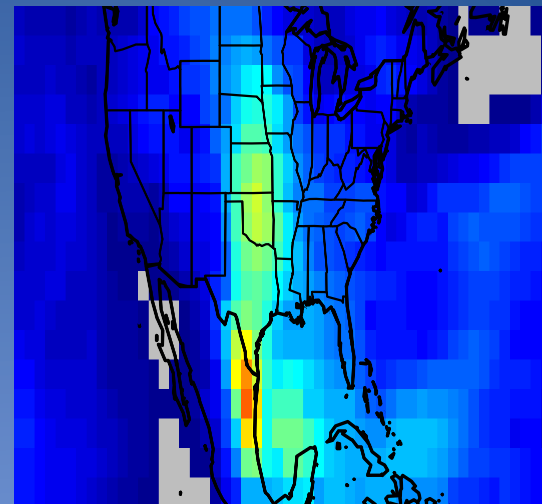
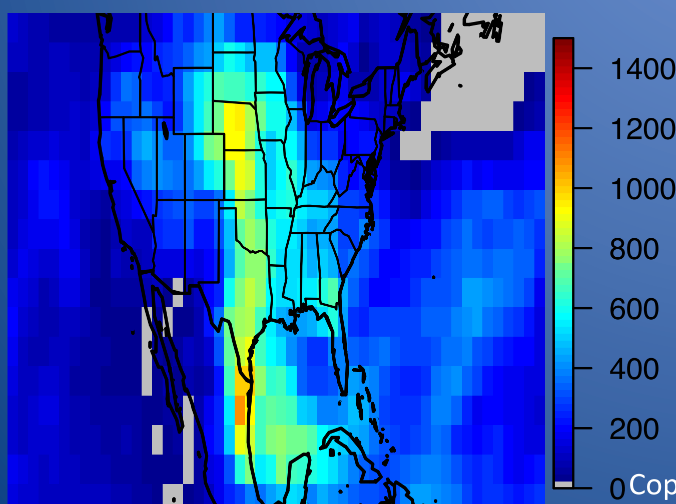


1958 - 1978



1979 - 1992

Spring WmSh (m/s)^2



1993 - 1999

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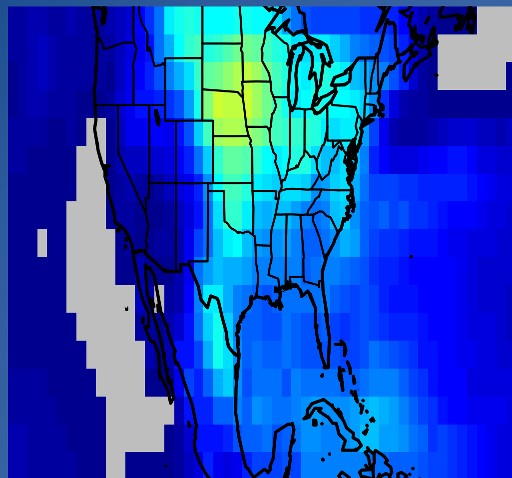
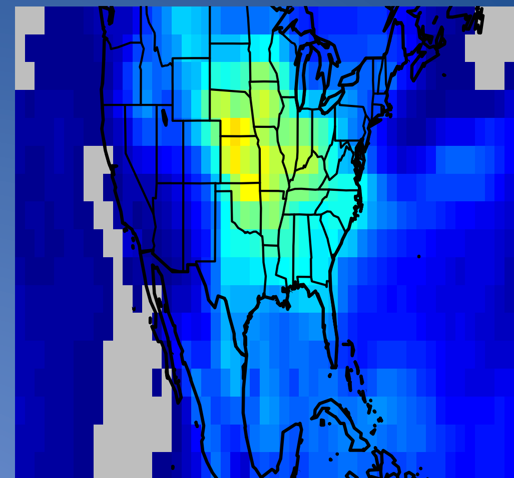
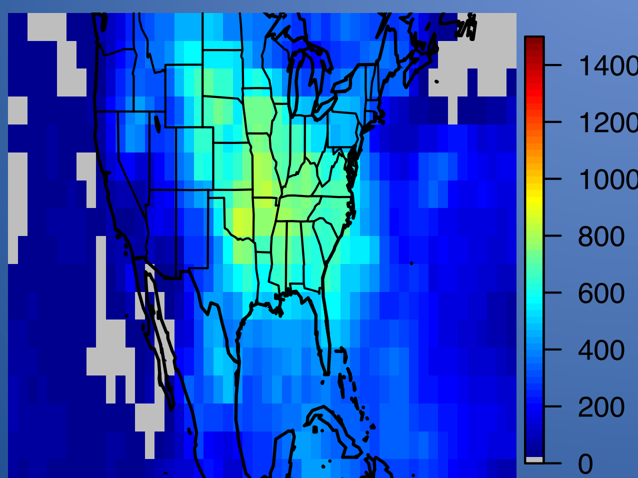


1958 - 1978



1979 - 1992



Summer WmSh (m/s)^2

1993 - 1999

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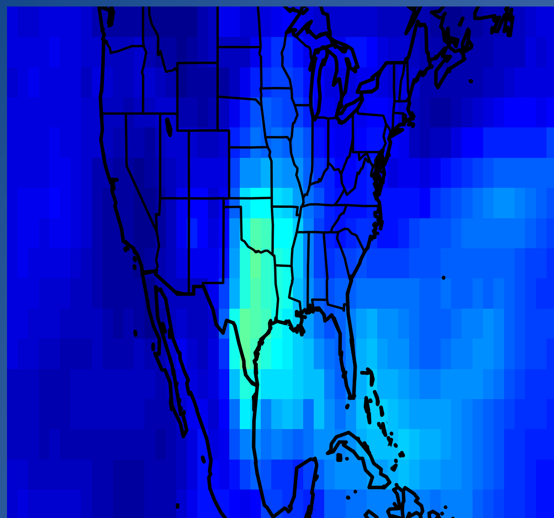
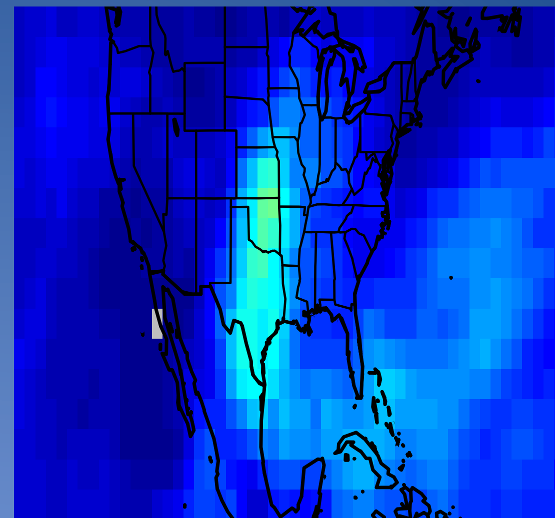
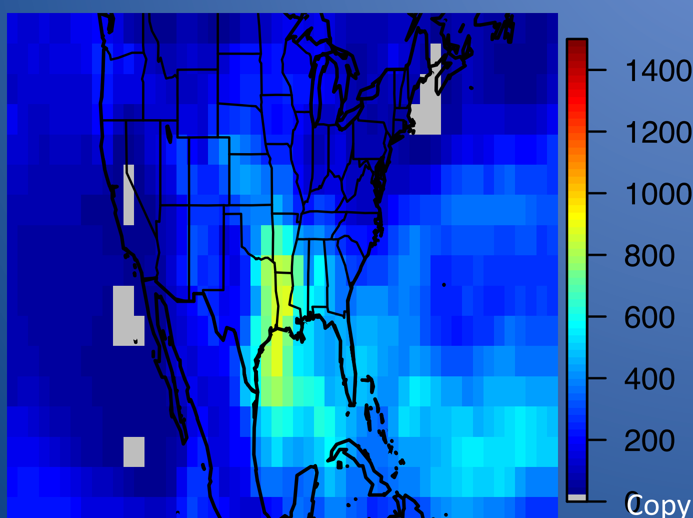


1958 - 1978



1979 - 1992



Fall WmSh (m/s)^2

1993 - 1999

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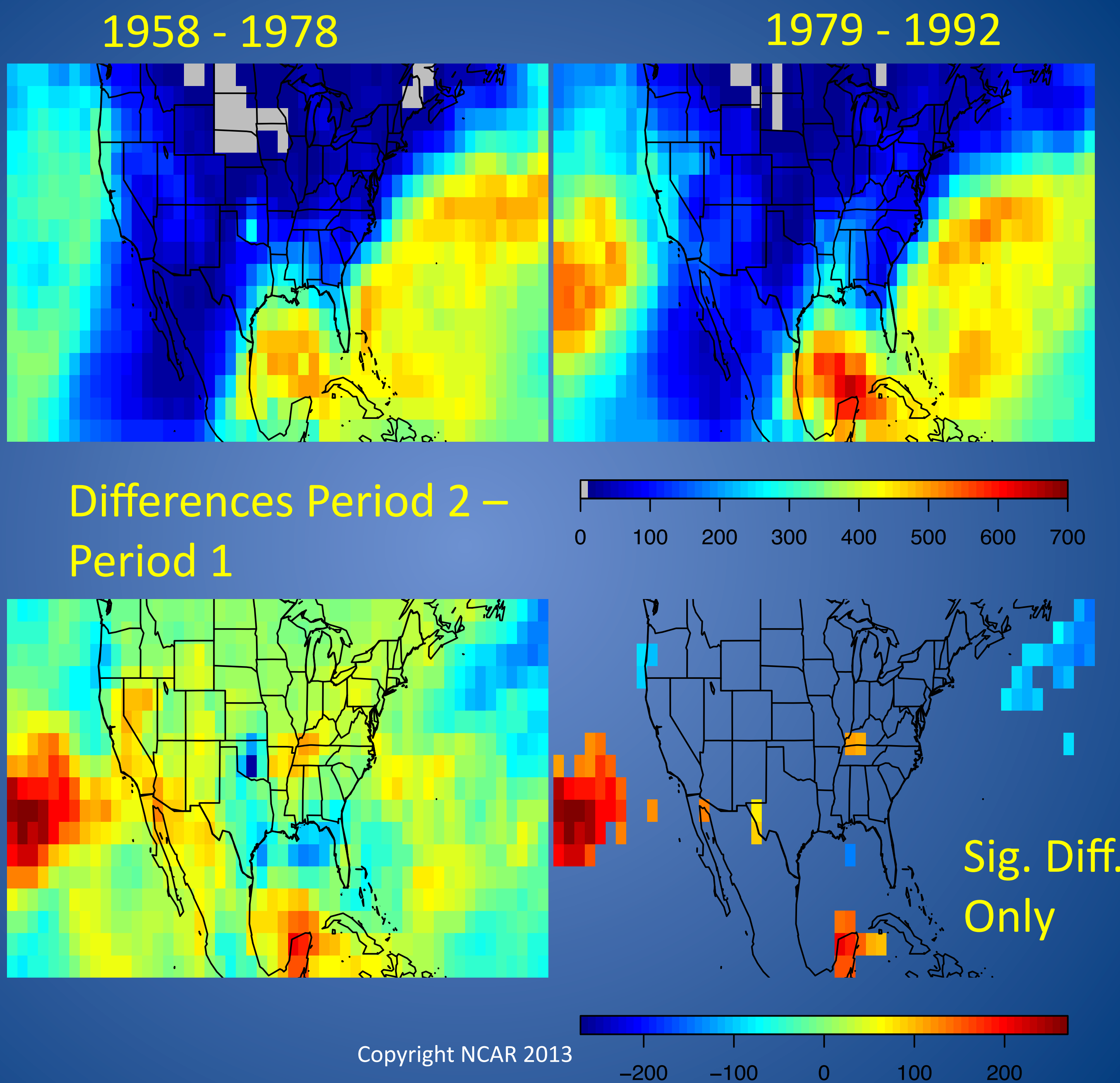
Winter WmSh (m/s)^2



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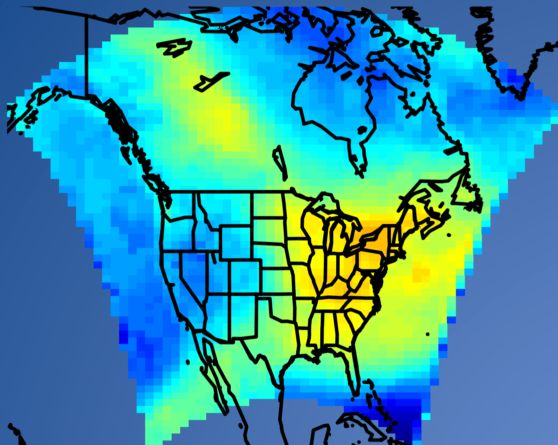
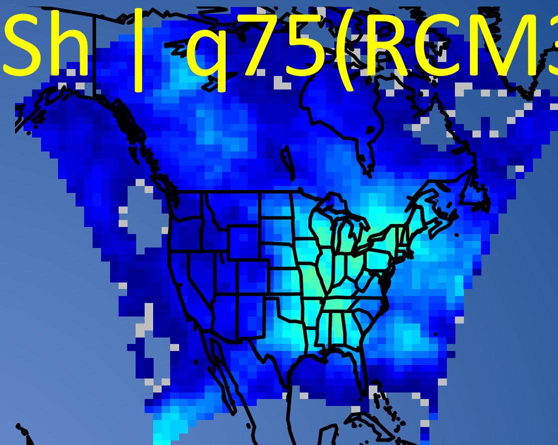
Current (1979 – 2004) RCM3

WmSh | q75(RCM3) large



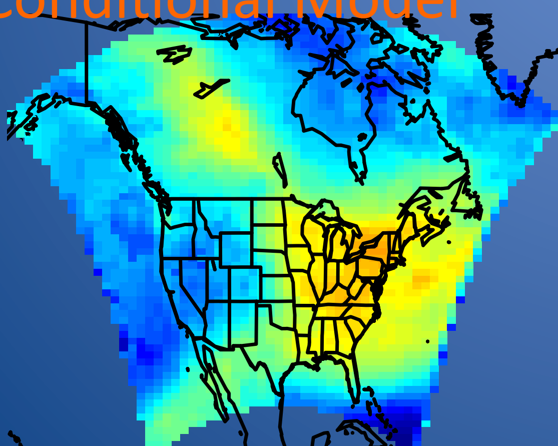


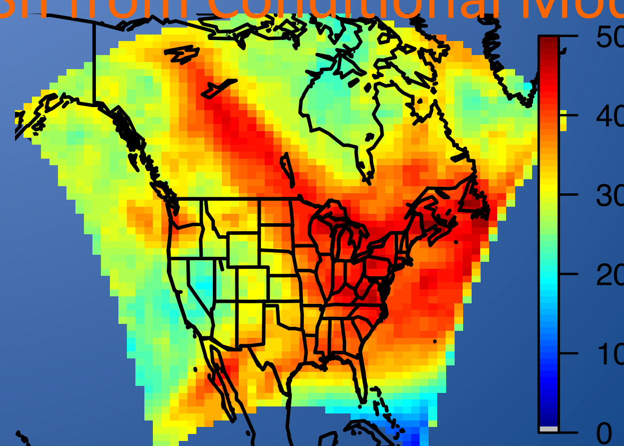
Mean Simulated WmSh from Conditional Model

5th percentile of Simulated WmSh from Conditional Model

Mean Simulated WmSh from Conditional Model

95th percentile of Simulated WmSh from Conditional Model





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Summary

- Univariate EVA well studied
- Spatial Extremes is an active area of research
- Current spatial extremes methods require strong assumptions
- Conditional approach alleviates problems with assumptions
- Estimation for conditional approach is tricky, and is an active area of research
- Conditional approach shows a lot of promise for making statistical inferences in the face of spatial dependence
- Challenge in determining how to incorporate future climate model output

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