

NCAR Initiative on Weather and Climate Impact Assessment Science

Extreme Events

Linda O. Mearns
NCAR/ICTP

MICE
Poznan, January 2004

Elements of the Assessment Initiative

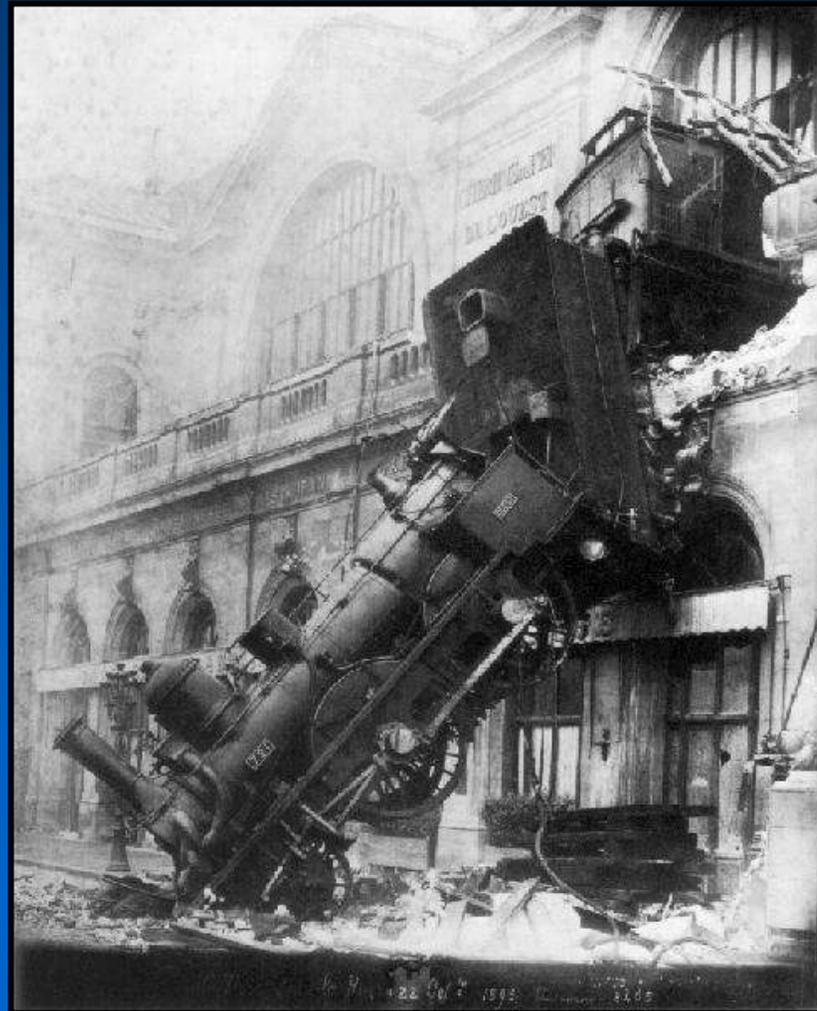
www.esig.ucar.edu/assessment

- Characterizing Uncertainty in Assessment Work
- Extreme Events
- Attribution in Climate Impacts:
Establishment of a Climate/Human Health Program

Extreme Events

“Man can believe
the impossible.
But man can
never believe the
improbable.”

- Oscar Wilde



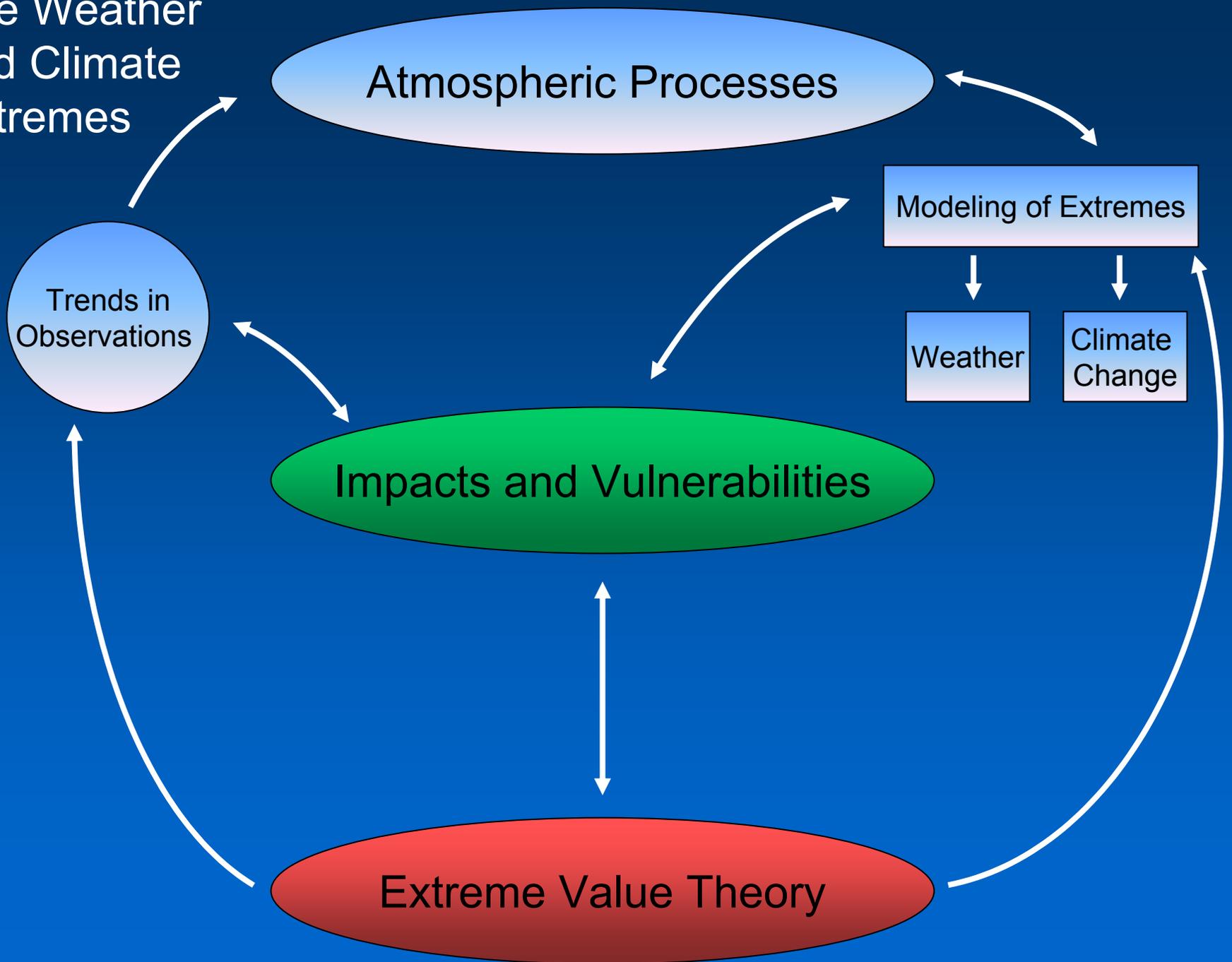
Extreme Events

Goal

Integrate different aspects of research in weather and climate extremes.

- Atmospheric science (processes and modeling)
- Statistical aspects of extremes
- Societal impacts and vulnerability

The Weather and Climate Extremes



Atmospheric Processes and Modeling of Extremes

- Research in the physical processes of extremes: (e.g., warm season heavy rainfall - see new hydrologic cycle initiative)
- Modeling of extremes -
 - Regional climate and mesoscale model validation - how well models produce extremes.
 - What improvements in parameterization of convection can be made specifically for improving extremes.
 - Spatial scaling of extremes - point support versus area support.
 - Projections of changes in extremes with climate change.
- Downscaling of extremes

Application of Extreme Value Theory

- Preliminary analysis of weather and climate variables (and their impacts) regarding suitability of using heavy-tailed distributions.
- Reexamination of trends in extremes (temperature and precipitation) - allowance for heavy tailed distributions.
- Application in climate change projections.
- Application to other types of extremes, (e.g., icing, turbulence, wind shear).

Extreme Value Theory for Climate and Climate Impacts

“It seems that the rivers know the [extreme value] theory. It only remains to convince the engineers of the validity of this analysis.”

–E. J. Gumbel

1. Distributions

- Heavy-tailed: “surprises” that should not be surprising.

2. Statistical Downscaling

- Can extremes be downscaled? (Unify downscaling and extreme value theory)

Societal Impacts of and Vulnerability to Extremes

- Identification of extremes significant to society
- Modeling of impacts of extreme events
- Reducing societal vulnerability to extremes

Understanding vulnerability requires knowledge of the behavior and interactions of all systems involved in an extreme event.

E.g., town ↔ storm ↔ flood
culture meteorology hydrology

Fort Collins Flood, July 1997

Heaviest rains ever documented over an urbanized area in Colorado (10 inches in 6 hours).

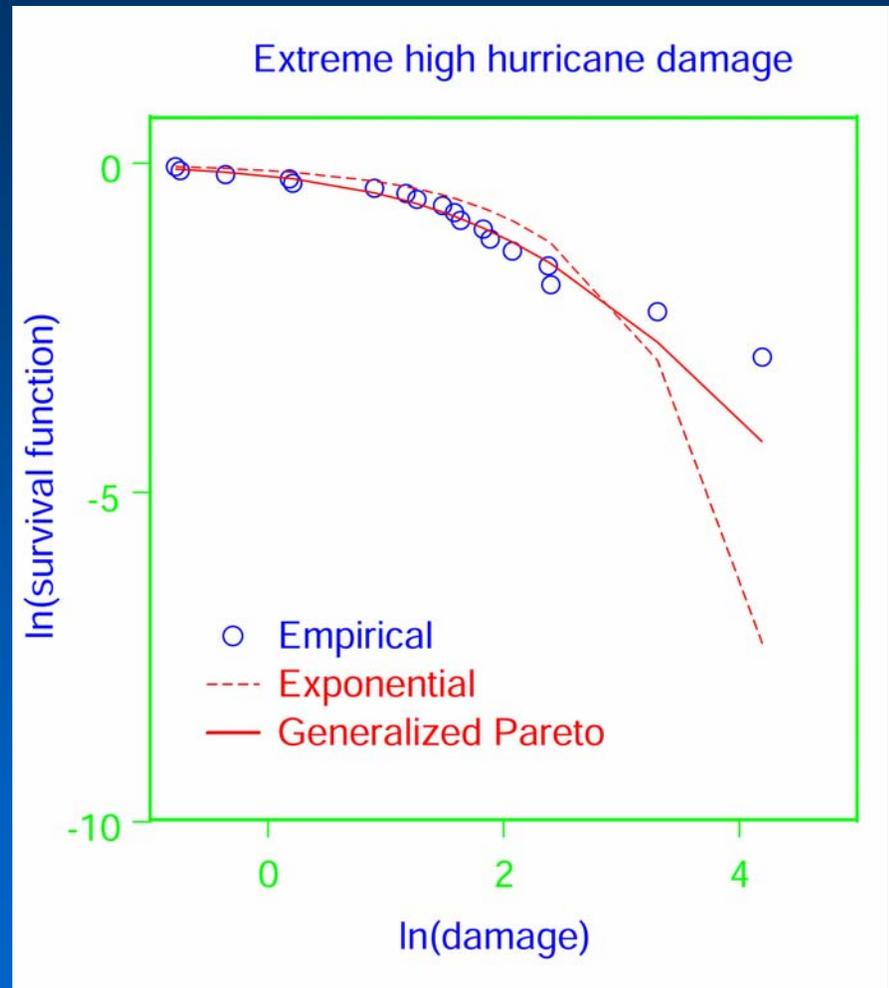
5 dead, 54 injured, 200 homes destroyed, 1,500 structures damaged.



These locations were *not* in 500-yr floodplain.

Anticipating Hurricane Damages

This figure shows that the upper tail of the distribution of economic damage from hurricanes may be heavier than commonly assumed (i.e., storms with high damage are not as unusual as conventional analyses would indicate).



Extremes

Projects

Extreme Events in Climate Models and Spatial Scaling

...to analyze the frequency and intensity of various extreme events particularly relevant to climate impacts in regional and global climate models. Extreme value theory will be used in these analyses. In addition we will undertake a detailed robust examination of the spatial scaling characteristics of extremes in climate models

NCAR Team: R. Katz, J. Meehl, D. Nychka, R. Wagoner, J. Coen,
R. Rasmussen, M. Moncrief, C. Tebaldi

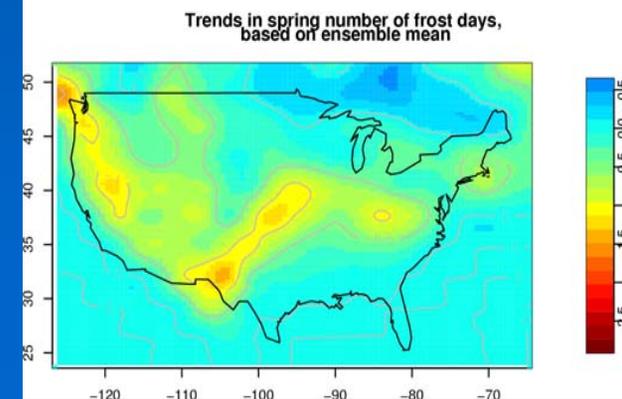
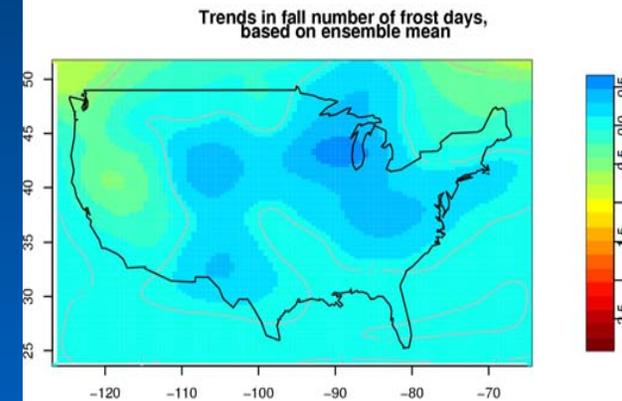
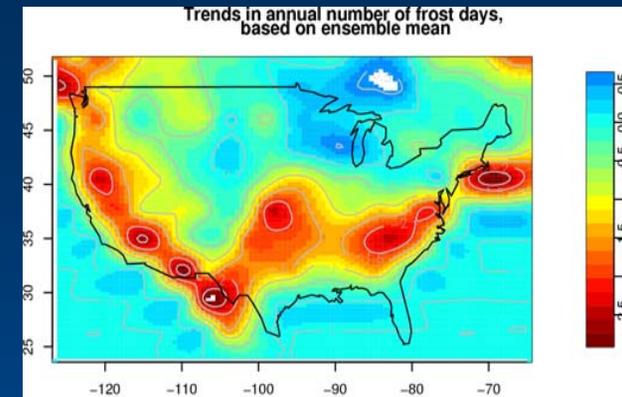
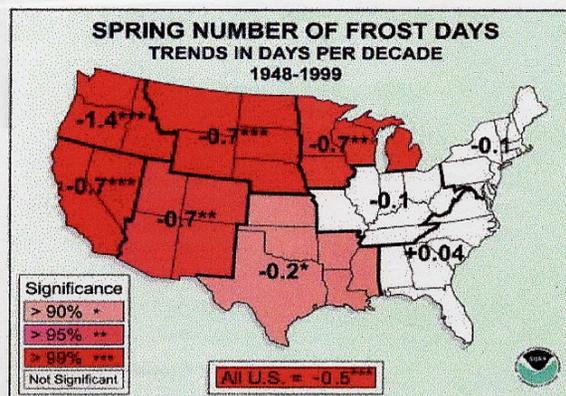
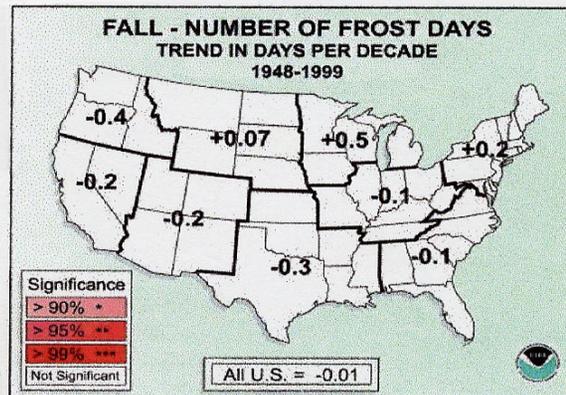
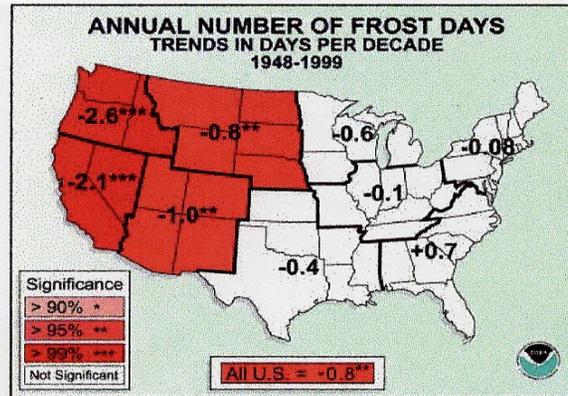
External Collaborators: R. Smith, U. of N. Carolina, P. Naveau, U. of Colorado

Extremes from Climate Model Projections

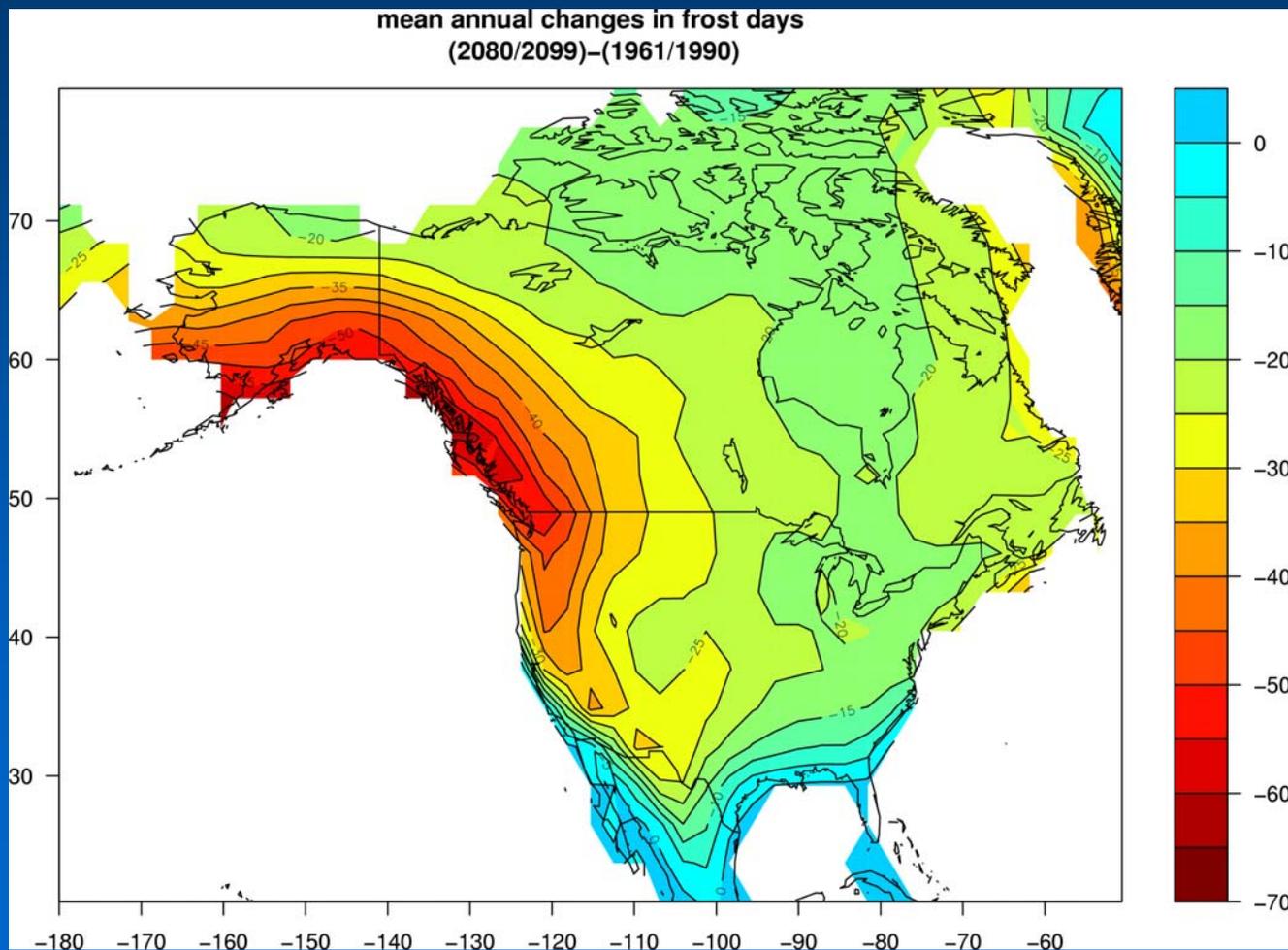
Number of frost days within a year is a useful indicator for determining agricultural impacts and also is a more extreme measure of climate variability

Model vs. Data:

Changes in frost days in the late 20th century show biggest decreases over the western and southwestern U.S. in observations and the model

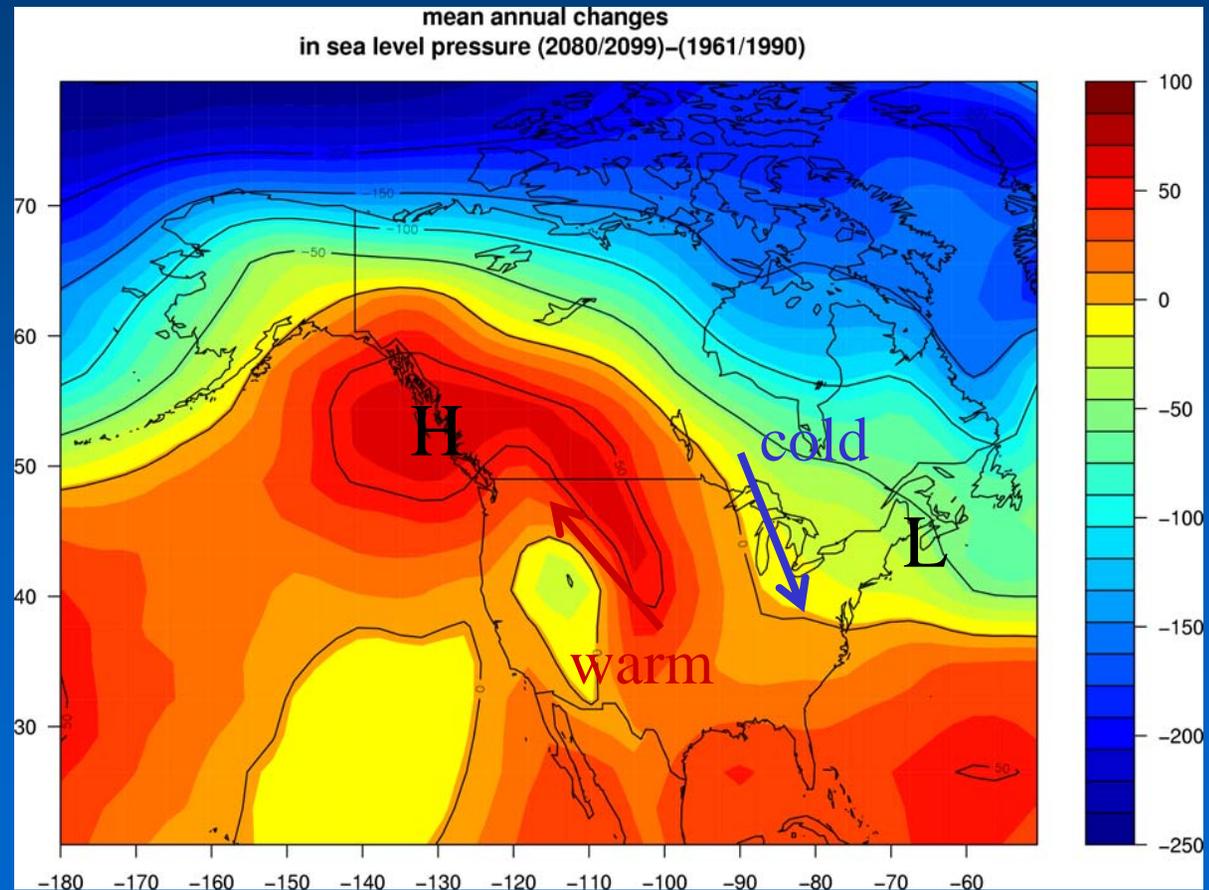


Future changes in frost days from the climate model show greatest decreases in the western and southwestern U.S., similar to late 20th century



Large-scale changes in atmospheric circulation affect regional pattern of changes in future frost days

Anomalous ridge of high pressure brings warmer air to northwestern U.S., causing relatively fewer frost days compared to the northeastern U.S., where an anomalous trough brings colder air from north



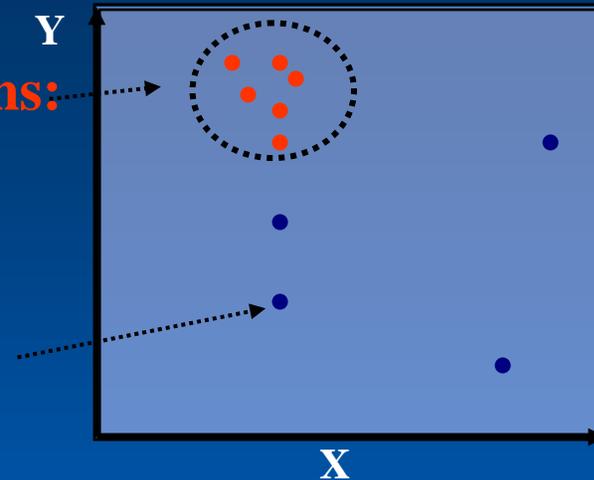
Spatio-temporal Aspects of extremes

P. Naveau and R. Smith

Weather Stations

**Proximity between weather stations:
=> similar extremes**

**Isolated weather station:
=> inference more difficult**



Extremes = Rare events



Necessity of a spatial approach



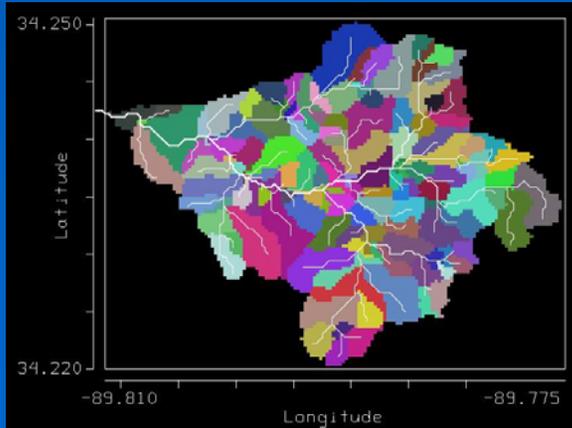
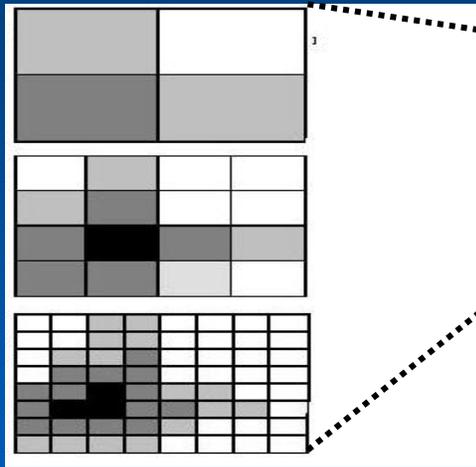
Better estimation of scale parameter of the GPD



Better return levels

Climate Modeling of Extremes

**CLIMATE
VARIABILITY**



Climate models

*Random cascade
(spatial structure)*

+

*Point Processes
(spatial structure)*

Precipitation

*Network runoff
model*

FLOODS

GP = Generalized Pareto

?

GP

?

GP

?

GP

?

?

GP

?

Extremes in Aviation-Related Weather

....apply extreme value theory to four forecasting problems of particular relevance to aviation

- In-flight Icing
- Turbulence
- Convection
- Public Weather Forecasting
- First three occur very infrequently – less than 5% at a time over continental US

NCAR Team: Barb Brown, Marcia Politovich, R. Katz, E. Gilleland, G. Young

Icing Severity as an Extreme Value Problem

Apply extreme value method for icing severity in an experimental version of the Integrated Icing Diagnosis/Forecast Algorithm.

Marcia K. Politovich
and Barbara G. Brown
NCAR RAP

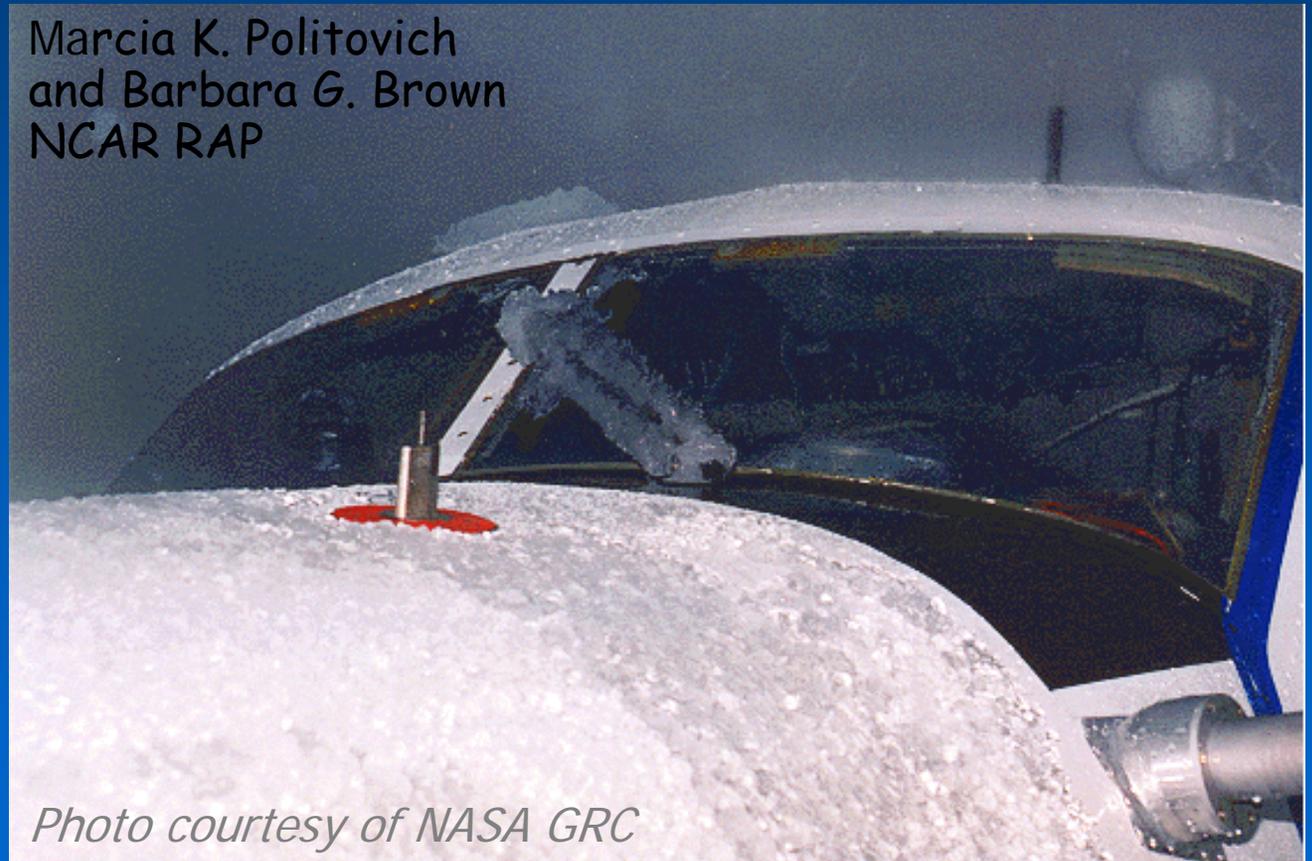


Photo courtesy of NASA GRC

Basics

- Icing is a high-impact phenomenon that is very difficult to diagnose or forecast
- Forecasting icing severity is even *more* critical – and difficult
- Extreme value theory provides one avenue...

How is severity defined?

Trace: Ice becomes noticeable. Rate of accumulation is slightly greater than the rate of sublimation.

Light: The rate of ice accumulation may require occasional use of ice protection systems to remove/prevent accumulation.

Moderate: The rate of ice accumulation is such that frequent use of ice protection systems necessary.

Severe: The rate of ice accumulation is such that ice protection systems fail to remove the accumulation of ice.

Real-Life Examples



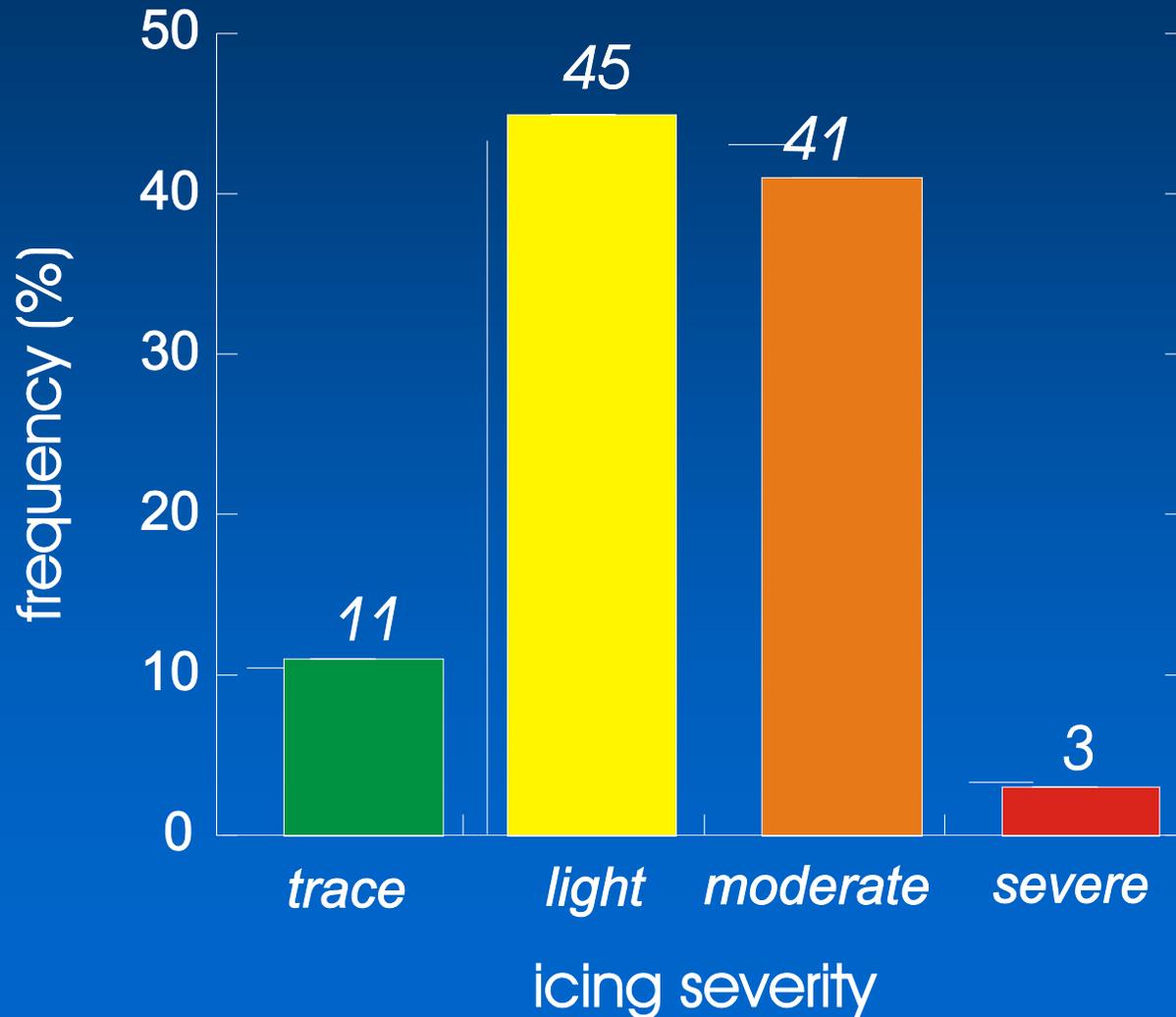
Trace/Light



Moderate/Severe

Photos courtesy of: NASA-Lewis Research Center

From Pilot Reports over the CONUS

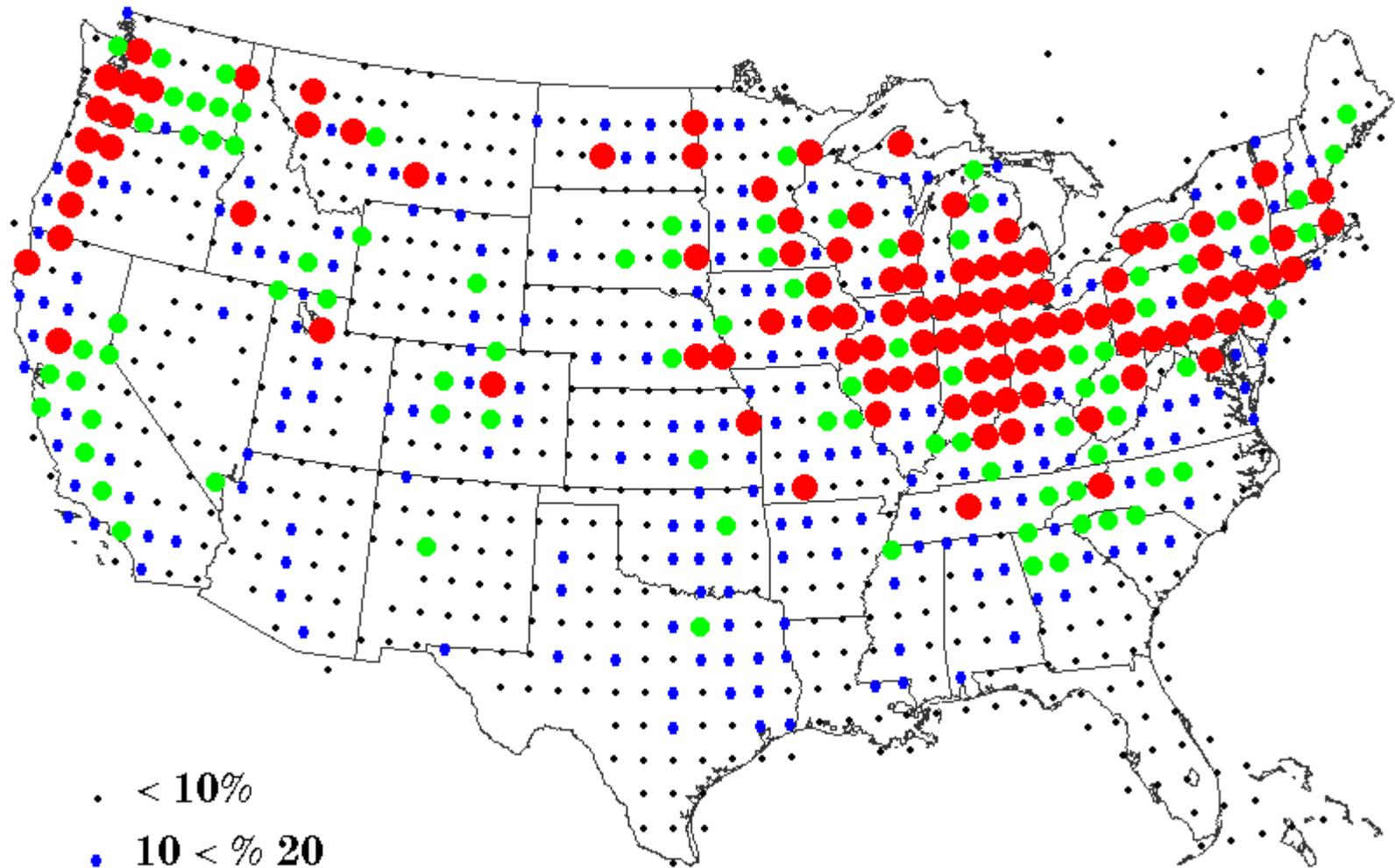


What are characteristics of PIREPs?

- Subjective (pilot and aircraft dependent)
- Non-systematic
- Relatively few negative reports
- They occur where airplanes are
 - Most common in regions around airports
- Process is not automated

How rare (or extreme) an
event is icing, according to
PIREPs?

Percent of Days with a Positive Icing Pirep Nov thru Mar 1992 - 1997 & Jan 1998, missing Jan 1992



- $< 10\%$
- $10 < \% < 20$
- $20 < \% \leq 30$
- $> 30\%$

What is our approach?

- Identify clues to icing severity
 - Factors and *combinations of factors* that have a physical and statistical relationship with observed severity
 - Connect to PIREP observations
 - Connect to research aircraft observations
- Use clues to develop extreme value model of icing severity

What are some of the clues?

- Model output: temperature, humidity, cloud parameters, winds, ...
- Surface observations: precipitation type, temperature, dew point, and trends
- Radar
- Satellite (vis and IR)
- IIDA, IIFA

Extremes Toolkit

....designed to facilitate the use of extreme value theory in applications in weather and climate problems – oriented toward the nonexpert

- Tutorial document including examples
- GUI based - programming not required
- Fits data to extreme value distributions
- Estimates return values with uncertainty measures
- Allows for trends, annual cycles, etc.
- www.esig.ucar.edu/extremevalues/extreme.html

NCAR Team: R. Katz, E. Gilleland, G. Young, D. Nychka

Acknowledgments: S. Coles

Influence of Climate Variability and Uncertainty on Flood Hazard Planning in Colorado

...to enhance the understanding and use of flood-related climate information in floodplain management in the Colorado Front Range.

Project Components:

- Policy and decision making
- Weather and climate extremes diagnostics
- Hydrological modeling
- Impacts of flood hazard planning

NCAR Team: M. Downton, R. Morss, O. Wilhelmi

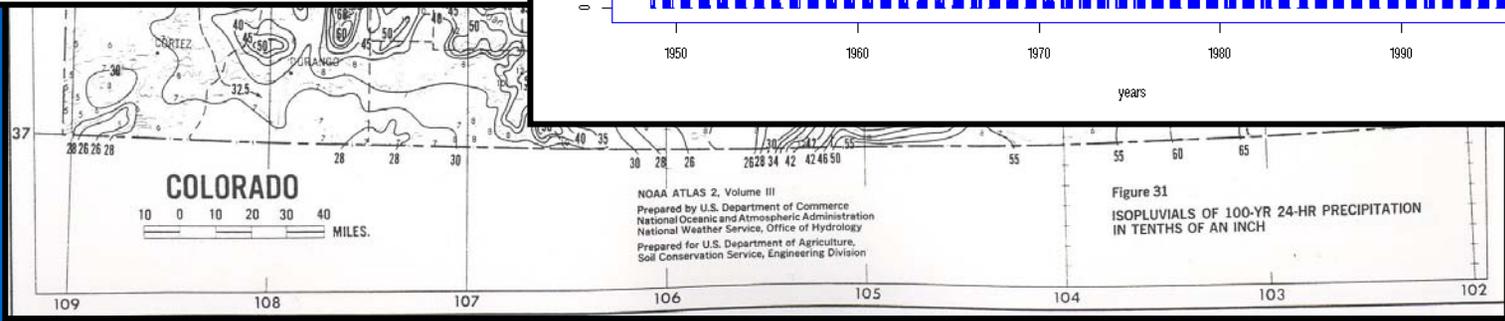
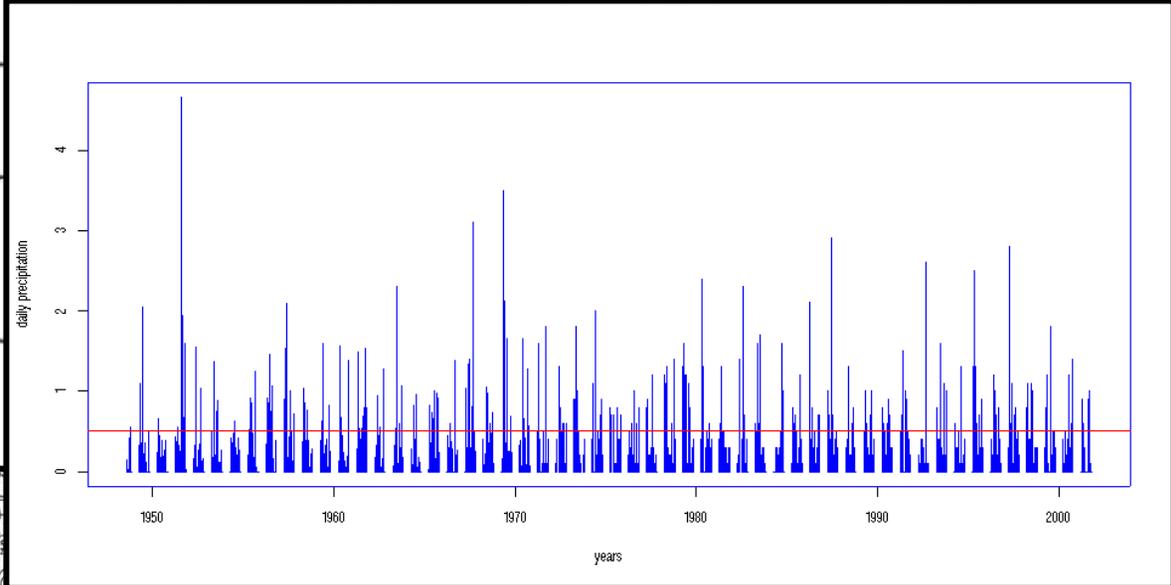
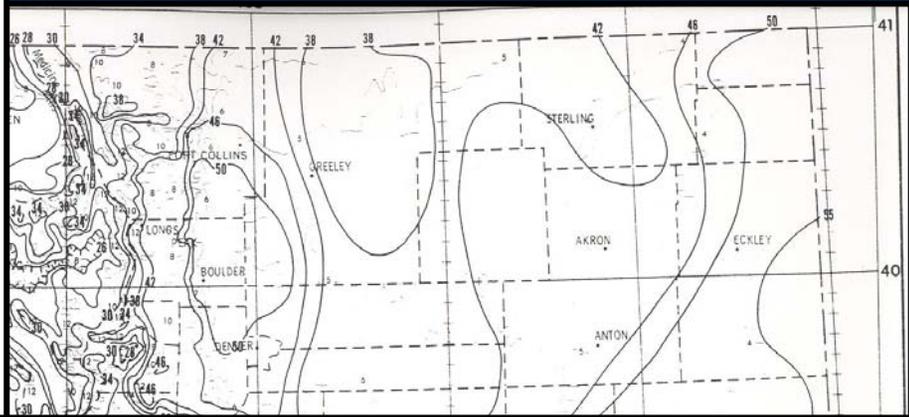
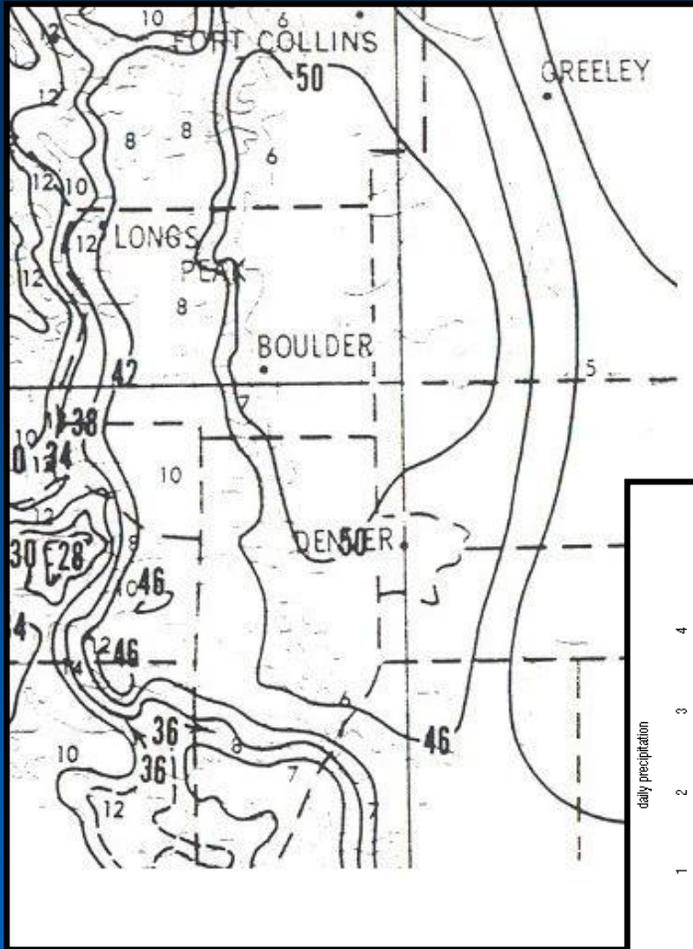
External Collaborators: Eve Gruntfest, U. Colorado, Colorado Springs

Influence of Climate Variability and Uncertainty on Flood Hazard Planning in Colorado

Standard tool for assessing flooding hazards is the *Colorado Precipitation-Frequency Atlas for the Western US, NOAA (1973)*, giving contours of rain rates for various return periods.

The atlas has few measures of statistical uncertainty

NCAR Team: M. Downton, M. Crandell, O. Wilhelmi, R. Morss, U. Schneider, E. Gilleland



Extremes Analysis of Boulder Daily Precipitation

- Simplest analysis is fitting a *generalized extreme value distribution* to the annual maxima
- An *exceedance over threshold* model can account for seasonality and other covariates
- A common summary is the *return time*:
e.g., the size of an event whose average time to occur is 100 years

Analysis Using *Extremes Toolkit*

The screenshot displays the Extremes Toolkit R package interface. The main window shows the results of a GEV fit for the variable 'ymax'. The fit is successful, with the following parameters and standard errors:

	MLE	Stand. Err.
MU: (identity)	1.29163	0.07793
SIGMA: (identity)	0.51051	0.05837
Xi: (identity)	0.09693	0.09983

The negative log likelihood is 51.9026. The fit is saved as 'gev.fit1'. A diagnostic plots dialog box is open, showing the data object 'boulder_yearly' and the fit 'gev.fit1'. The R Graphics window displays four diagnostic plots:

- Probability Plot:** A plot of Model vs. Empirical values, showing a strong linear relationship.
- Quantile Plot:** A plot of Empirical vs. Model values, showing a strong linear relationship.
- Return Level Plot:** A plot of Return Level vs. Return Period, showing a non-linear relationship with confidence intervals.
- Density Plot:** A plot of the density function $f(z)$ vs. z , showing a distribution with a peak around $z=1.5$.

```
Extremes Toolkit
File Plot Analyze
*****
GEV fit
-----
Response variable: ymax

Convergence successful!
MU: (identity)      MLE      Stand. Err.
SIGMA: (identity)  1.29163  0.07793
Xi: (identity)     0.51051  0.05837
                  0.09693  0.09983

Negative log likelihood: 51.9026
*****

Saved as:
gev.fit1

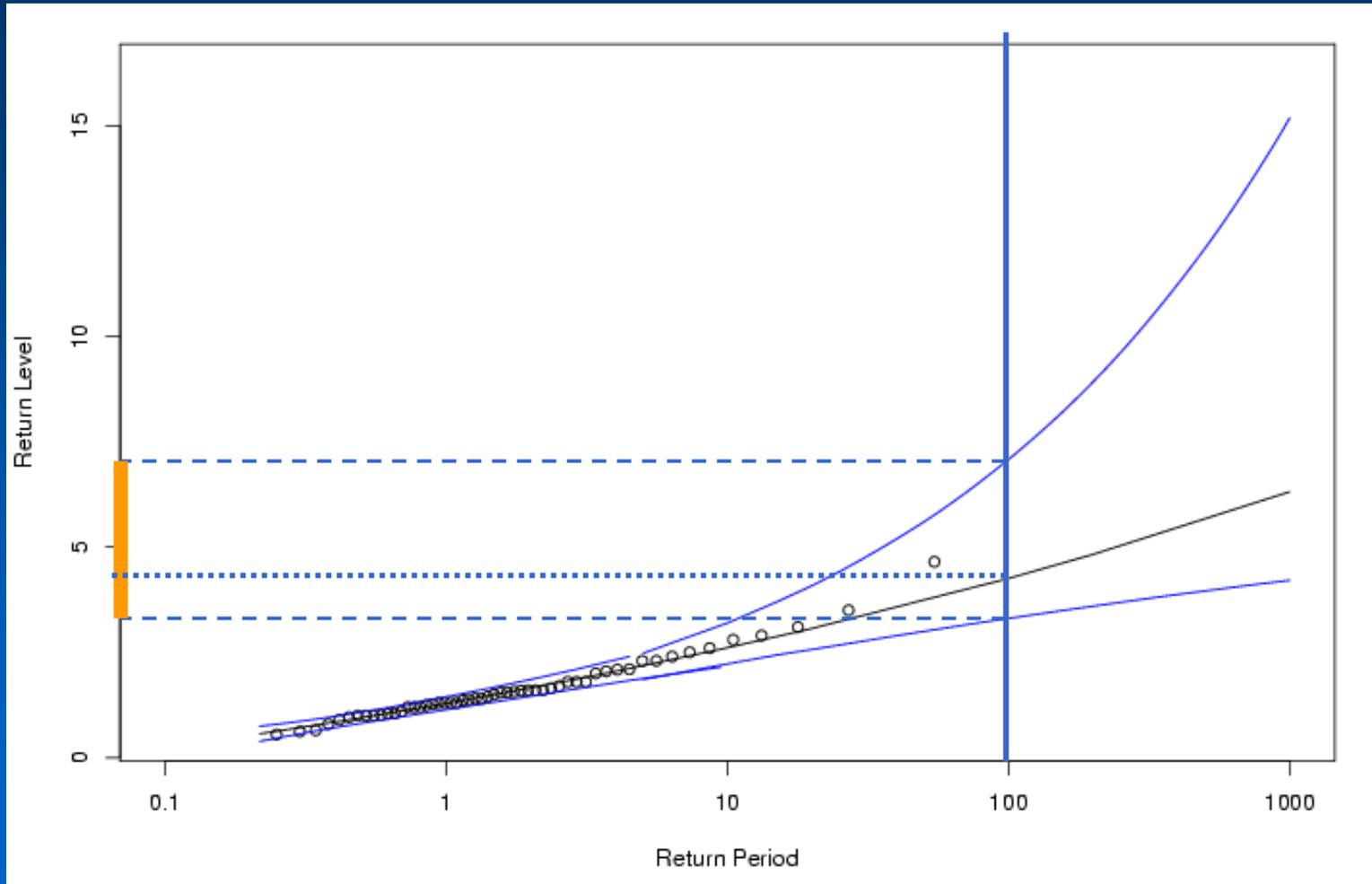
gev.diag(z)
Arguments:
  z: An object returned by 'gev.fit'.
Value:
For stationary models four plots are produced: a probability plot, a quantile plot, a return level plot and a fitted density.
For non-stationary models two plots are produced: a probability plot and a residual quantile plot.

See Also:
'gev.fit', 'gev.prof'

Examples:
data(portpirie)
ppfit <- gev.fit(portpirie[,2])
gev.diag(ppfit)

>
> png()
>
```

Inference for the 100 Year Return Level for Boulder



Managing Wildland Fire Risks: Climate and Weather Information, Extremes and Uncertainty

...to contribute to the development of a methodology for examining the effects of uncertainty and the value of weather and climate information for the effective management of wildland fire risks.

NCAR Team: K. Miller, R. Katz, R. Wagoner

External Collaborators: A. Cullen, U. of Washington; S. Kane, NSF

Downscaling of Extreme Weather/Climate Phenomenon

...to downscale severe thunderstorms (those containing large hail, strong wind, or tornadoes) using upper air variables from reanalysis, regional models, and global models.

NCAR Team: J. Bresch, R. Katz

External Collaborators: [H. Brooks, NOAA/NSSL](#), C. Anderson, Iowa State U.

Estimating Severe Thunderstorm and Tornado Climatology

- Relationships between observed weather and observed and reanalysis soundings from US, east of Rocky Mountains
- Apply results to global NCAR/NCEP reanalysis
 - Every other grid point over non-water, non-ice locations, one time per day
 - 1997-1999
 - Uses sounding time closest to late afternoon

Estimating severe thunderstorm and tornado climatology

- Severe thunderstorms with at least 5 cm hail, 120 km/h wind gusts or F2 or greater tornado (~10% biggest events in US)
- Severe occurrence related to Sfc-6 km vertical shear of horizontal winds and convective available potential energy (cape)
- Tornado occurrence (conditional on severe occurrence) based on Sfc-1 km vertical wind shear and lifted condensation level

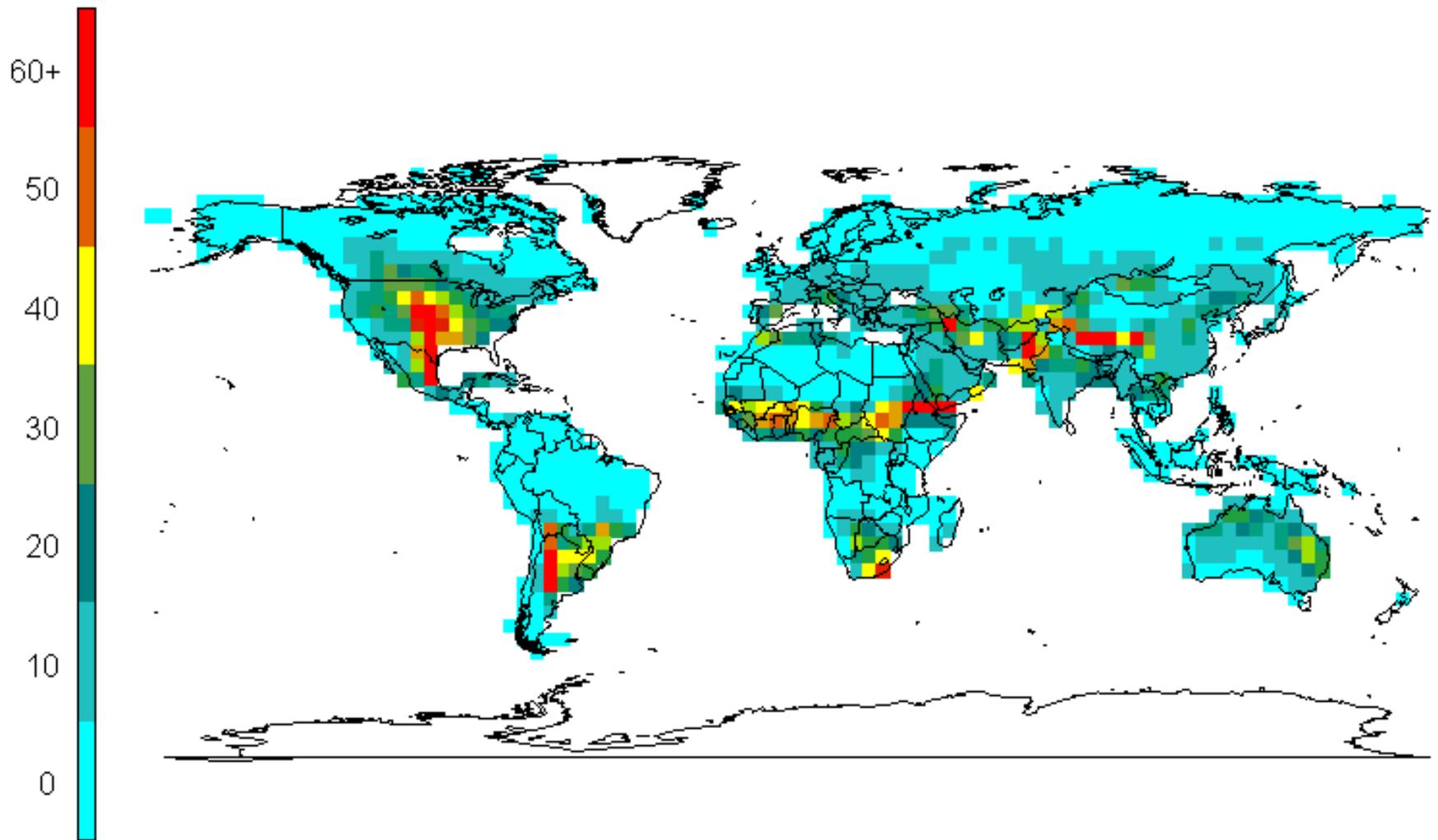
Cautionary notes

- Pattern is important, not the magnitude
- Result is for favorable *environments*
 - Storms may not initiate at all
 - Probability of severe occurring, given all the ingredients =6.0%
 - Probability of severe occurring, given no ingredients=0.06%
- Tornado environments may be biased towards large outbreaks (shifted a little too far east in US)

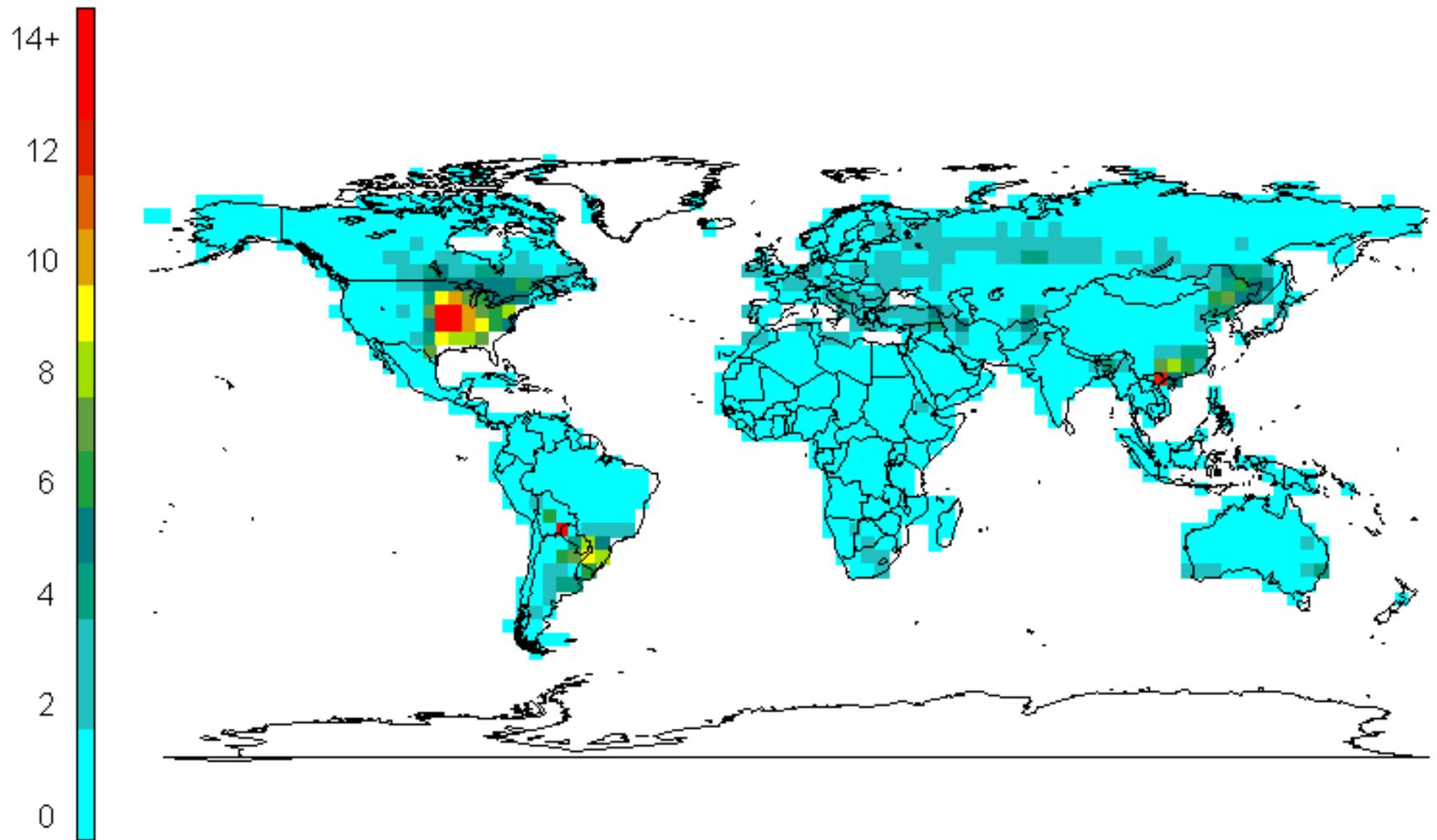
Future plans

- Look at all soundings from reanalysis
 - Trends?
 - Interannual variability
- Do same with global climate models, regional climate models, scenarios of future climate

Days per Year with Favorable Severe Parameters



Days per Year with Favorable Tornado Parameters



Analysis of Extreme Wind Events in Northern Alaska

...as part of an integrated assessment of impacts of climate variability on the north slope of Alaska, analyze damaging extreme wind events associated with storms. Determine trends in extremes using extreme value theory and explain presence of trends.

NCAR Team: L. O. Mearns, M. Pocerich, C. Tebaldi

External Collaborators: M. Lynch, U. Colorado

Extreme Value Statistics

To estimate the return level and frequency of high wind events, extreme value statistics are used. This involves estimating the parameters of the Generalized Extreme Value (GEV) distribution. These analysis have been performed by season. Tasks that will be addressed in the study include

- Analyse the wind data for the presence of trends with respect to time.
- Seek covariates or other dependent variables to explain the presence of trends.

Wind at Barrow Alaska - Data sources

Hourly data from the NWS (1945 - 2002). When the data was collected with greater frequency, only one observation was taken per hour.

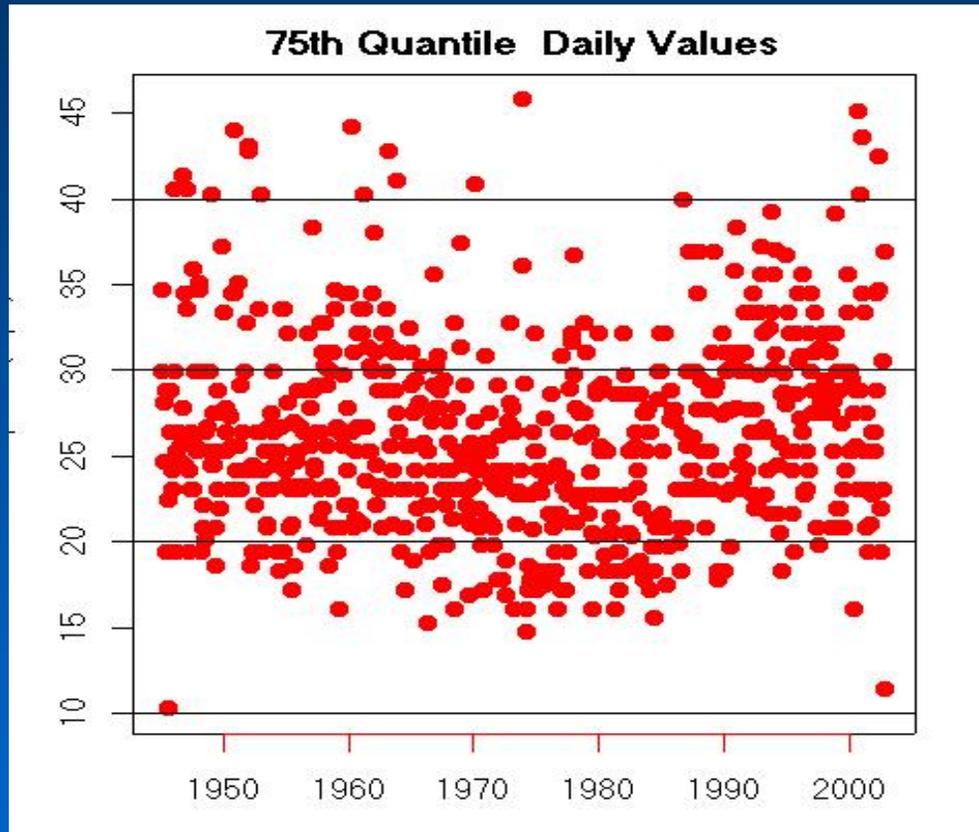
Daily statistics - To summarize the hourly data on a daily basis, the following statistics were used.

- Maximum daily wind-speed

- 75th percentile daily wind-speed. Since periods with sustained winds appear to cause the greatest damage, this was done to capture days with a greater duration of high winds.

Wind Speed Barrow, Alaska

75th Percentile Daily Wind speed – max monthly values



Seasons

Analyses were performed using the following definition of seasons.

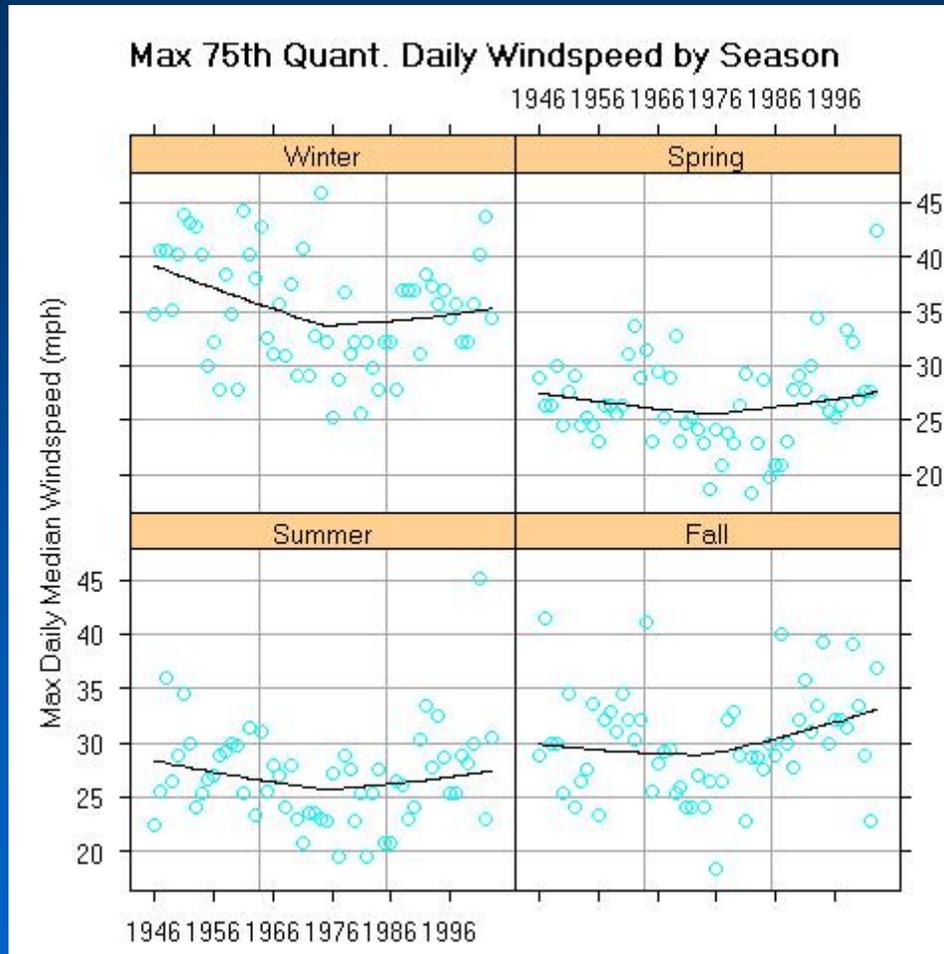
- Winter - November to March
- Spring - April and May (Spring Whaling)
- Summer - June to August
- Fall - September and October (Fall Whaling)

Determining Trends

Using the data described above, the parameters for the GEV distribution are allowed to change with time. By adding parameters to the models, one can statistically determine whether the additional parameters are warranted. (This is done using the likelihood ratio that is chi-square distributed.)

Three alternative models are compared to the model without trends in the parameters. These are no trend, linear trend and a quadratic trend.

Wind-speed by Season



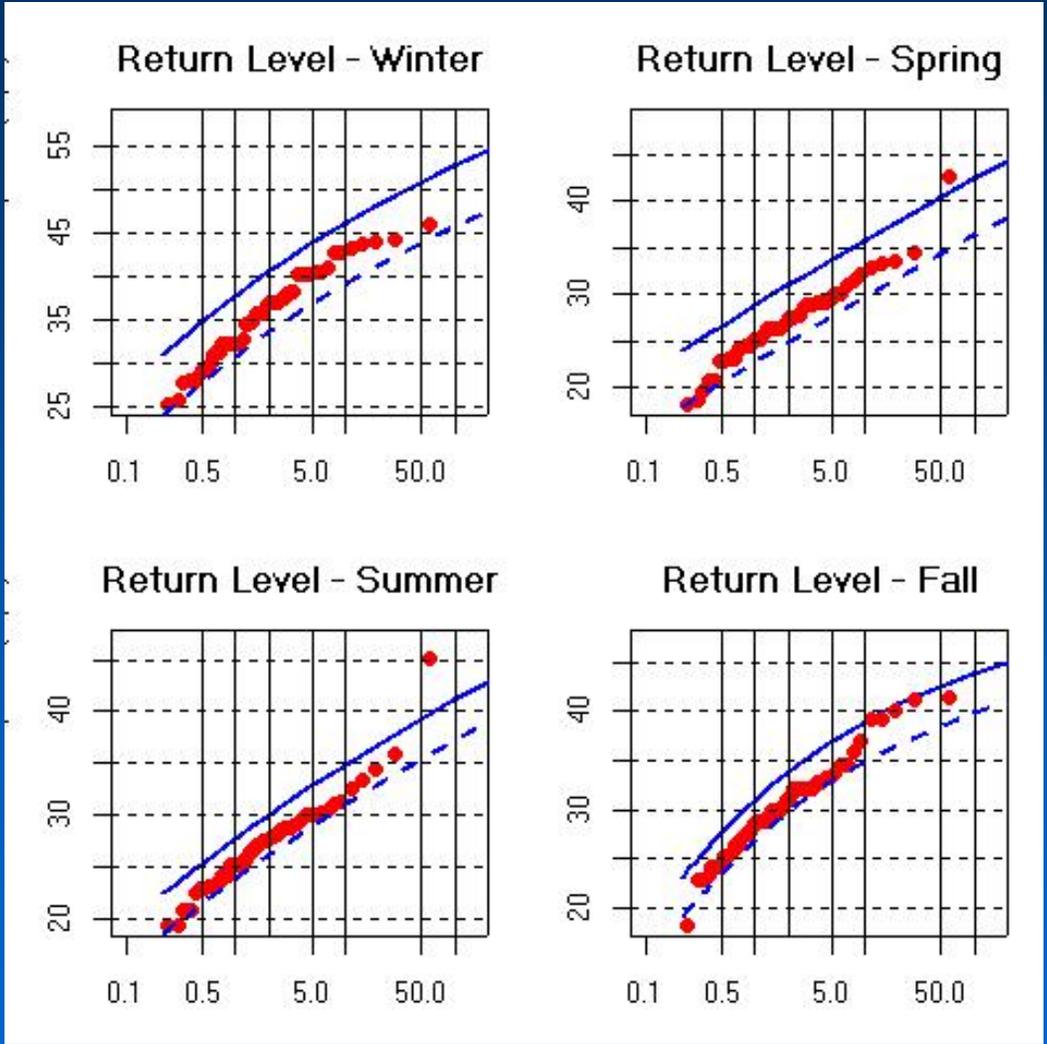
Note: The curve is a loess curve that estimates trends, but does not indicate significance.

Examining both the max daily wind speed and the 75th Percentile Wind speed. Quadratic trends are detected for most seasons.

Data	Winter	Spring	Summer	Fall
Max daily	Quad	Quad	Quad	None
75 th Percentile	Quad	Quad	Quad	Quad

Note: With this data, a quadratic trend means that the predicted return values reached a low point in 1974 – higher return values occurring at the beginning and end of the data period.

Seasonal return levels for wind speed

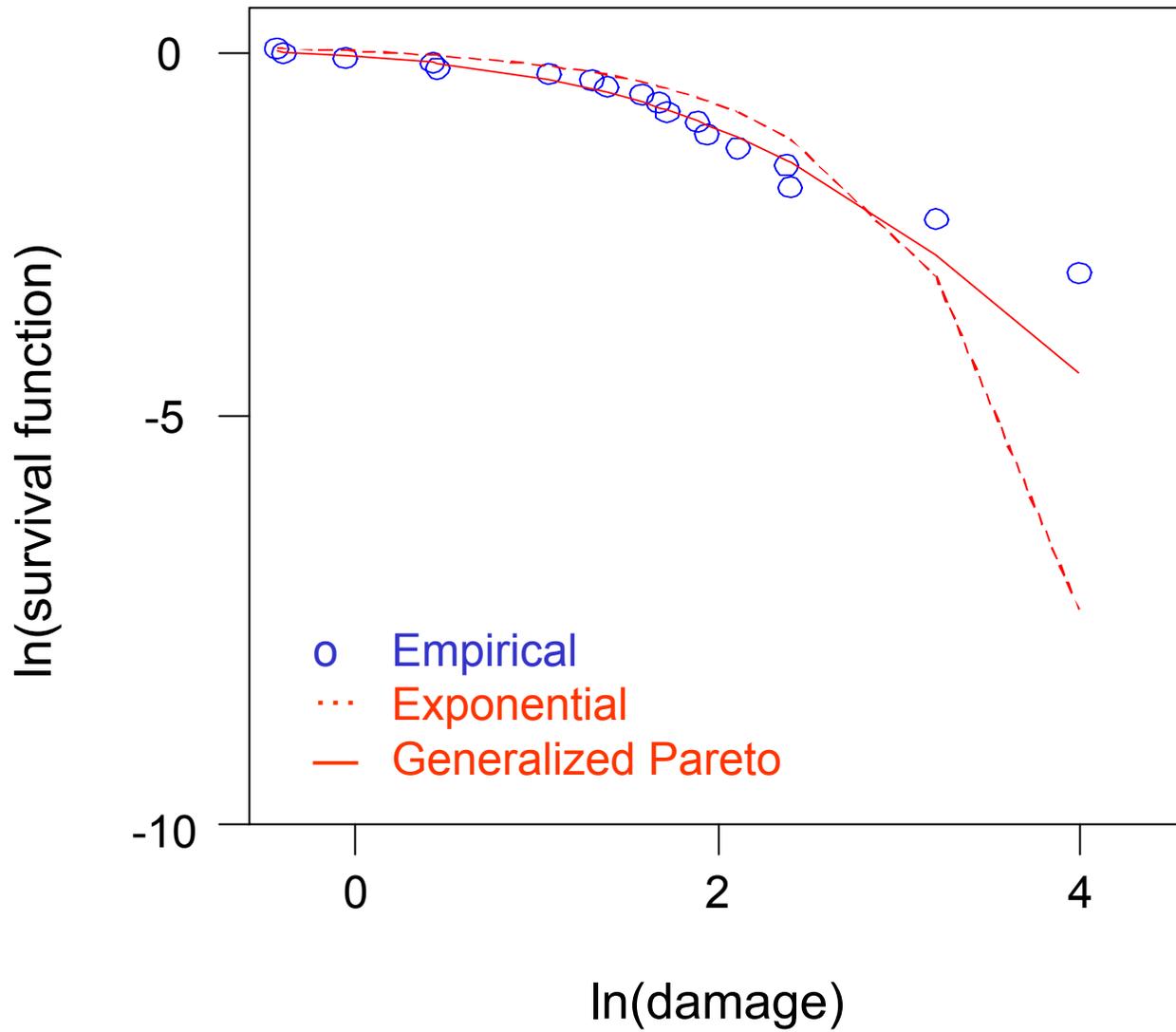


Solid line represents present return levels. Dashed line represent return levels as estimated in 1975.

Comments

- Wind magnitude and direction alone seems to be inadequate to describe storm events. Other sources of data such as tide level and amount of open water are being examined.
- To be more useful, a cause of the quadratic trend needs to be found. This is needed for future planning purposes.

Extreme High Hurricane Damage



NCAR Initiative on Weather and Climate Impact Assessment Science

Extreme Events

Linda O. Mearns
NCAR/ICTP

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