Some approaches to detecting human influence on extremes

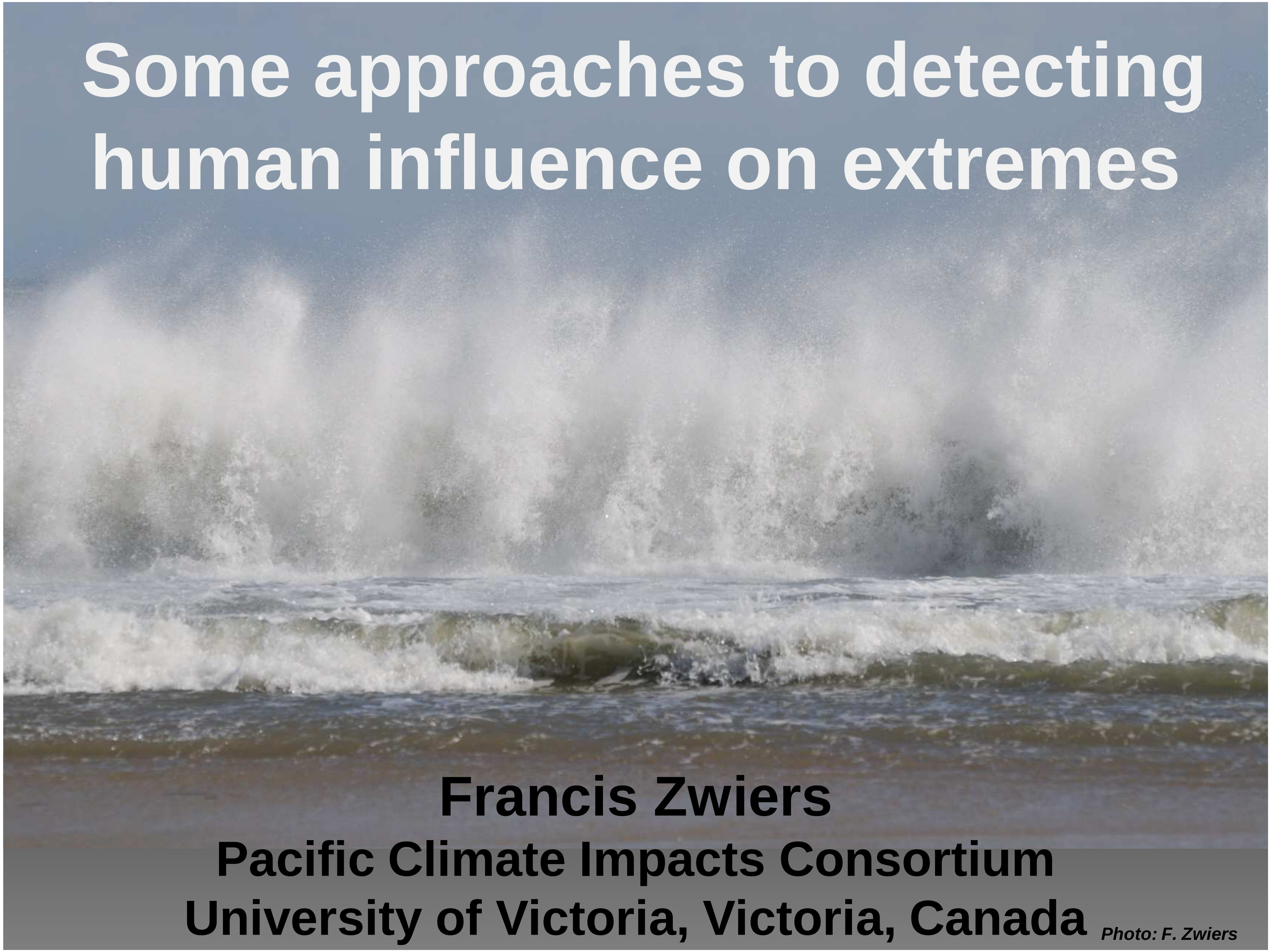

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Photo: F. Zwiers

Outline

- Introduction to detection and attribution
- Observed changes in temperature and precipitation extremes
- Four detection and attribution approaches used for extremes
- Discussion

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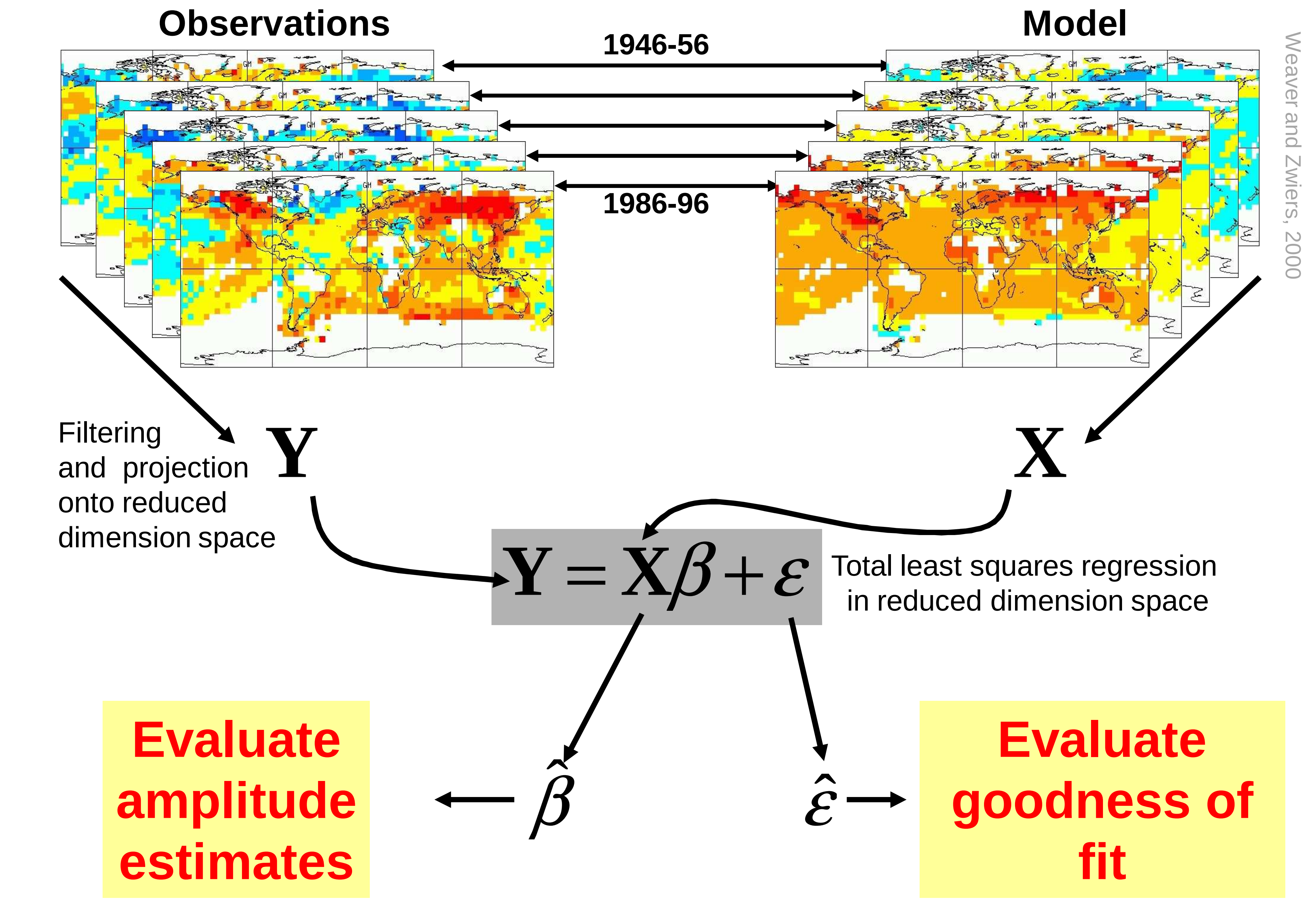

Observations
Model
1946-56
1986-96
Weaver and Zwiers, 2000
Filtering and projection onto reduced dimension space
Y
X
$\mathbf{Y} = \mathbf{X}\beta + \varepsilon$
Total least squares regression in reduced dimension space
$\hat{\beta}$
$\hat{\varepsilon}$
Evaluate amplitude estimates
Evaluate goodness of fit

From a statistical perspective

- Have a more or less Gaussian setup

$$Y \mid X \sim \eta(X\beta, \Sigma)$$

Y	Space-time observations vector (decadal means)
X	Space-time signal matrix (one column per signal)
β	Vector of scaling factors
Σ	Covariance structure

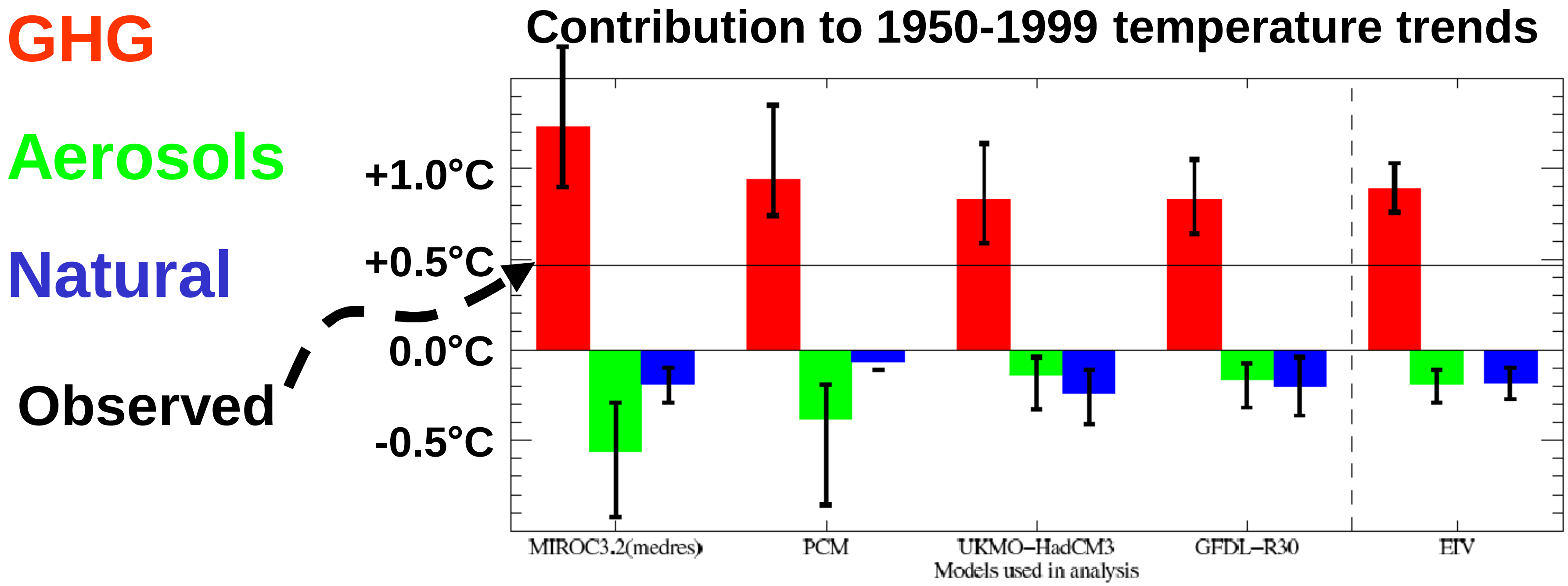
From a statistical perspective

- Have a more or less Gaussian setup

$$Y \mid X \sim \eta(X\beta, \Sigma)$$

- But ... we don't use Gaussian assumption to make inferences about β
- Use a Monte-Carlo simulation approach

Surface temperature attribution

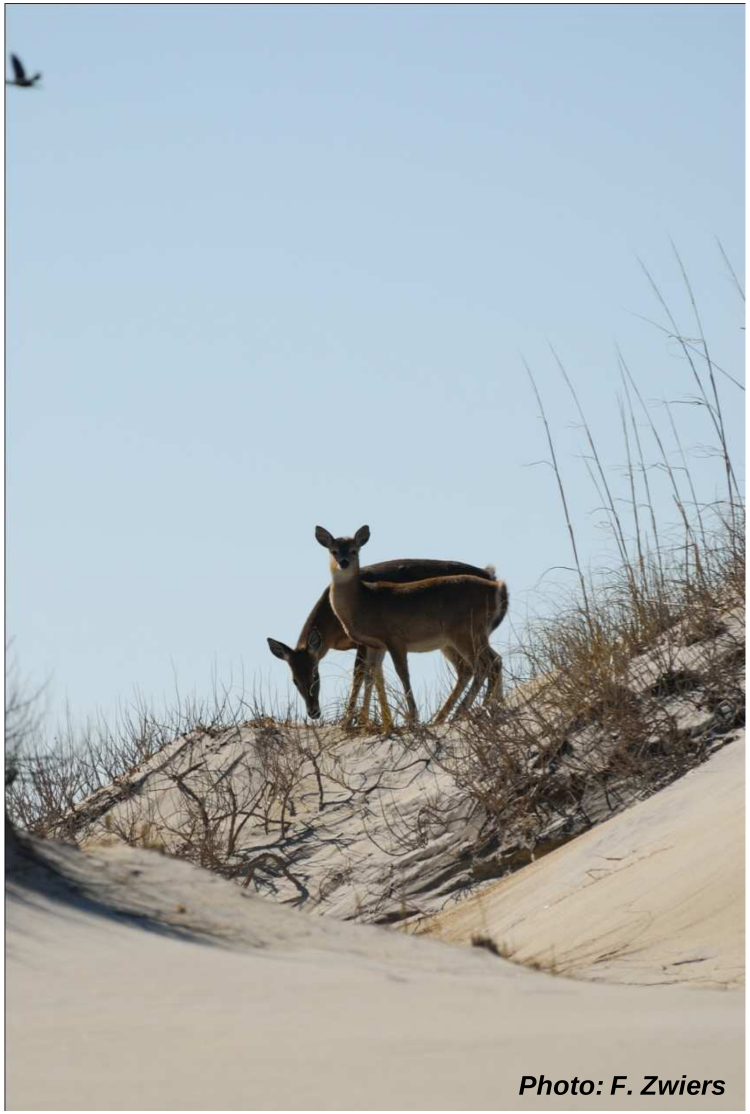


IPCC, 2007

IPCC – most of the observed warming over the last 50 years is *very likely* to have been due to the increase in greenhouse gas concentrations

A few features

- Ultimate small sample problem
- Fingerprints to look for are from models.
- Error covariance structure also from models (eg., control runs)
- Do generalized linear regression (optimize signal-to-noise ratio)
- Take some aspects of signal uncertainty into account using either a total least squares or errors-in-variables approach



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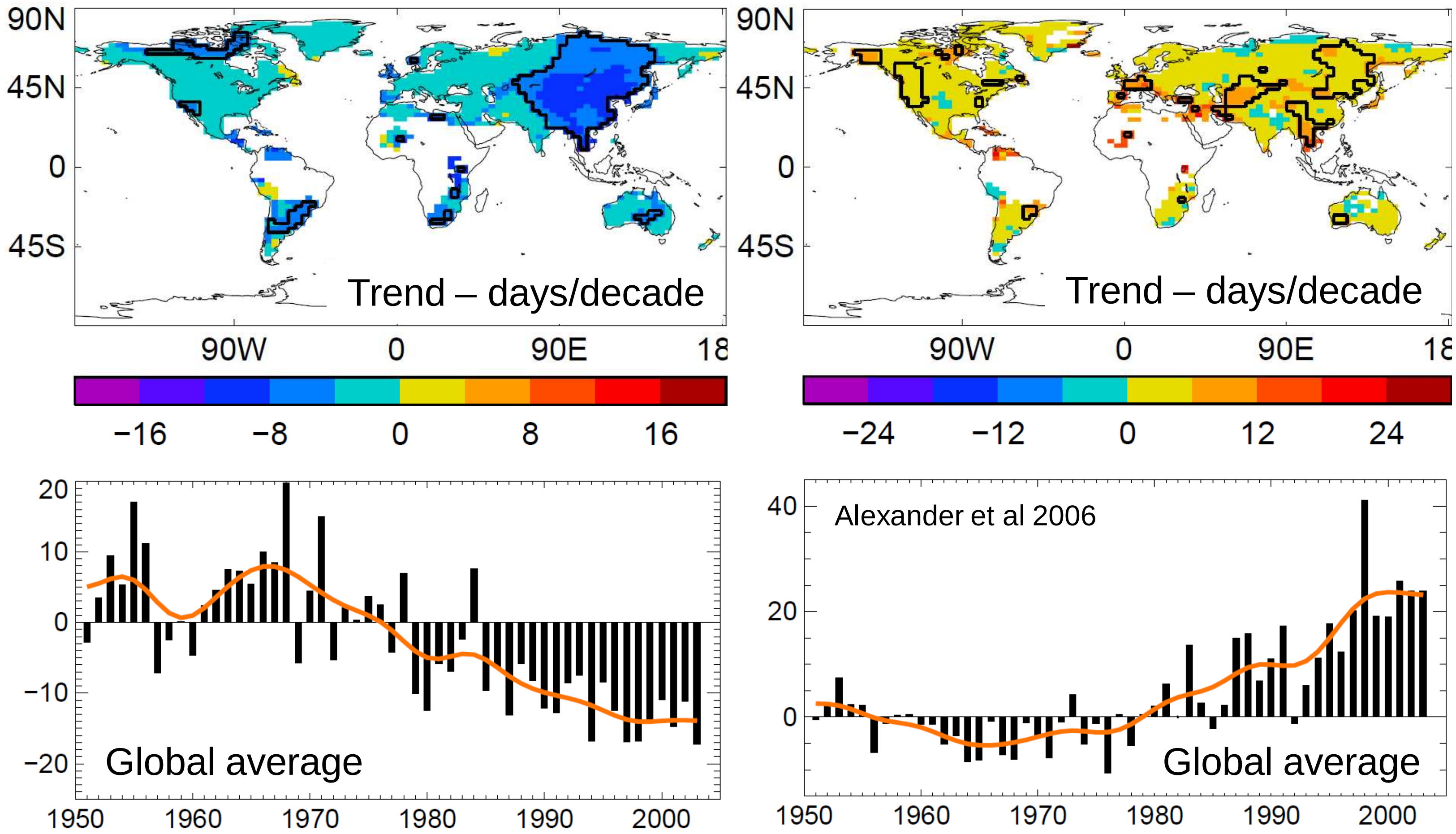
Temperature extremes – 1951-2003

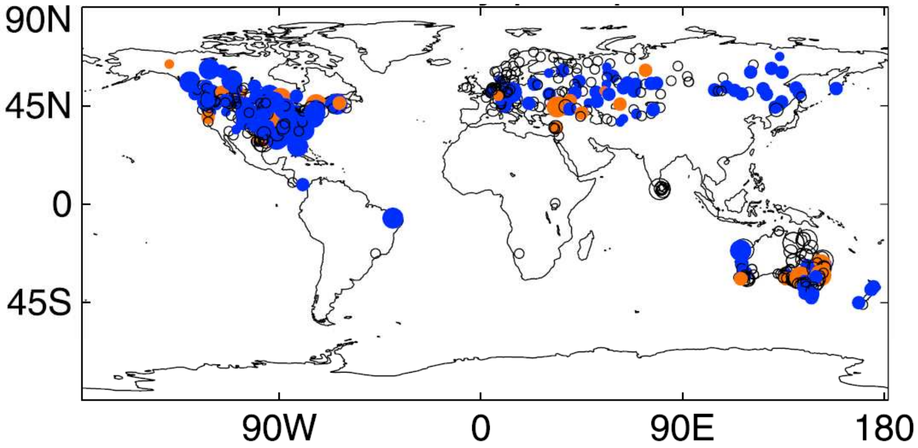
DJF Cold Nights (days below 10th percentile)

JJA Warm Days (days above 90th percentile)

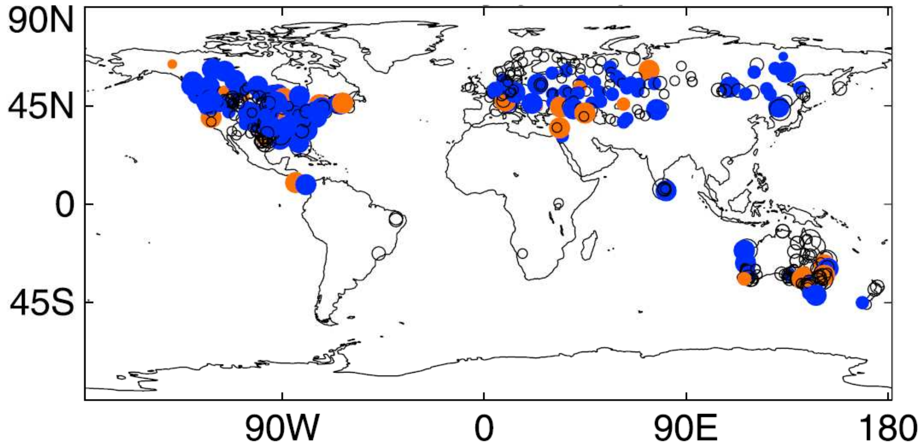


Extreme precip trends – 1901-2003

Trend in annual maximum one-day precipitation amount



Trend in annual maximum 5-day precipitation amount



Trend – mm/century

- < 10 mm
- 10–20 mm
- 20–30 mm
- > 30 mm

Filled circles indicate trends significantly different from zero at the 5% level

Alexander et al 2006

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Approaches for D&A on extremes

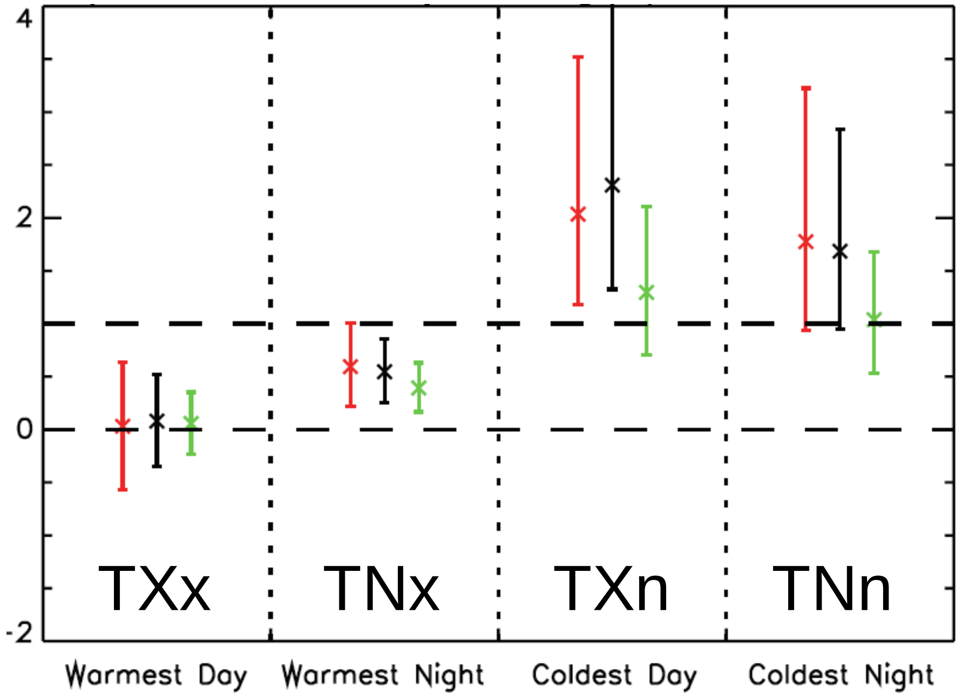
- Apply standard machinery
  - To indices of annual extremes
    - Hegerl et al 2004, J Climate
    - Christidis et al 2005, GRL
  - To suitably transformed annual extremes
    - Min et al 2010, accepted
  - To parameters of fitted extreme value distributions
    - Brown et al 2008, JGR
    - Christidis et al 2010, submitted
- Cast problem directly within framework of extreme value theory
    - Zwiers et al, 2010, in press, J Climate

1. D&A applied directly to indices

- Hegerl et al, 2004
  - Model-model assessment of potential detectability

- Christidis et al, 2005
  - Used Hegerl et al temperature indices
  - Detected human influence in 3 of 4 indices globally

Scaling factor on HadCM3 **ALL**, **ANT**, and **GHG** responses fitted to observed temperature extremes (1950-1999)



Christidis et al, 2005

D&A applied directly to indices

- Advantages
  - Approach is straight forward
  - Can optimize signal to noise ratio by accounting for spatial covariance structure of extremes indices
  - Can use model output to estimate uncertainties
- Disadvantages
  - Residuals have a skewed distribution
  - Potential losses in efficiency of estimators, bias, etc.

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2. D&A on transformed extremes

- Min et al 2010
- Annual maxima of 1-day (RX1D) and 5-day (RX5D) precipitation accumulations
- Fit GEV distributions (to obs and each model simulation separately)
- Apply probability integral transform to observations and model output
- Result is a collection of indices on (0,1) scale
- Apply standard D&A approach

$$P_{obs} \mid \mathbf{P}_{\mathrm{mod}} \sim \eta(\mathbf{P}_{\mathrm{mod}}\beta, \Sigma)$$

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D&A on transformed extremes

- Advantages
  - Partial solution to scaling issue for variables like precipitation
  - Can optimize signal to noise ratio by accounting for spatial covariance structure of extremes
  - Can use model output to estimate uncertainties
- Disadvantages
  - Results are difficult to interpret physically

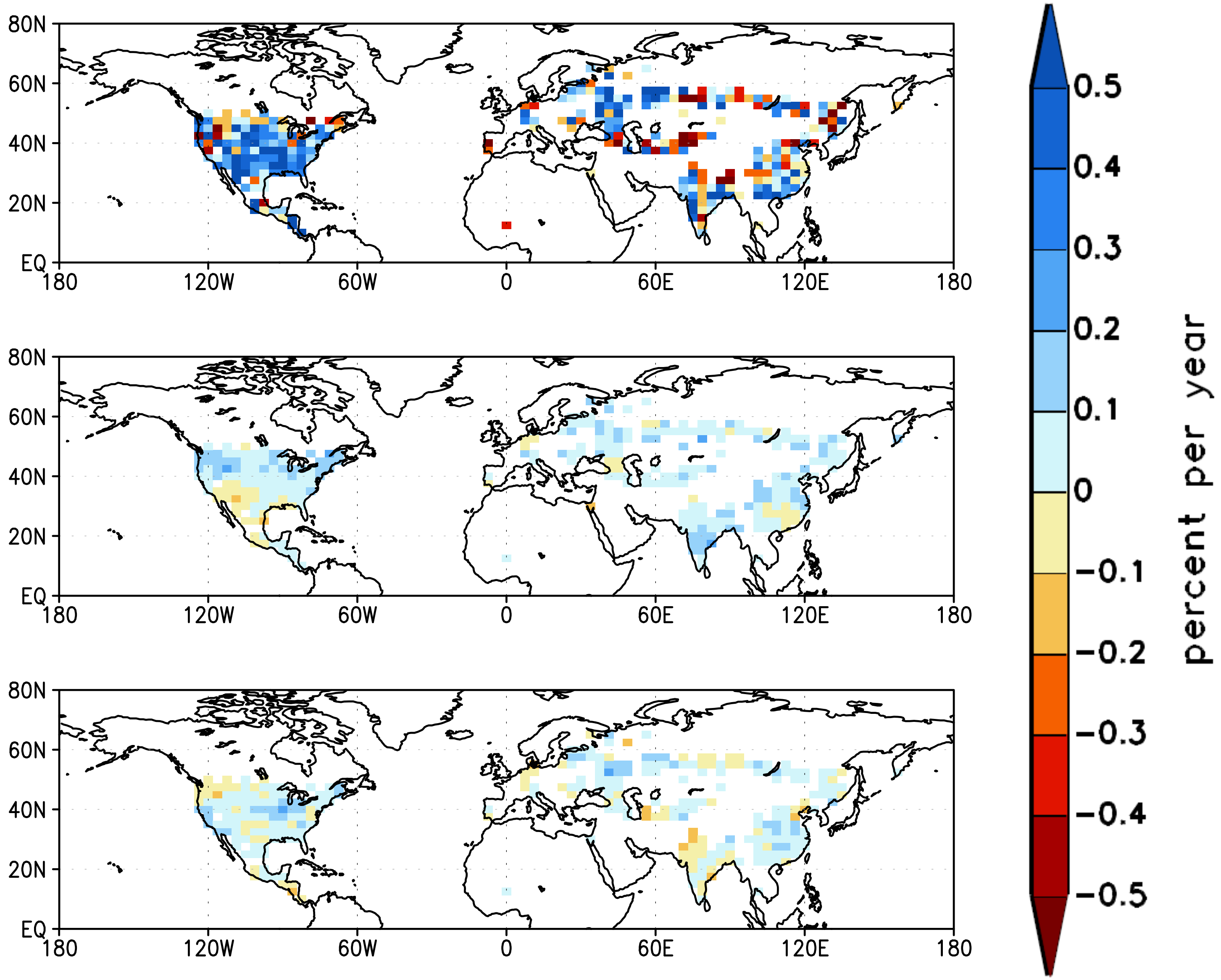
PI Trends (RX1D; 1951-1999)

OBS

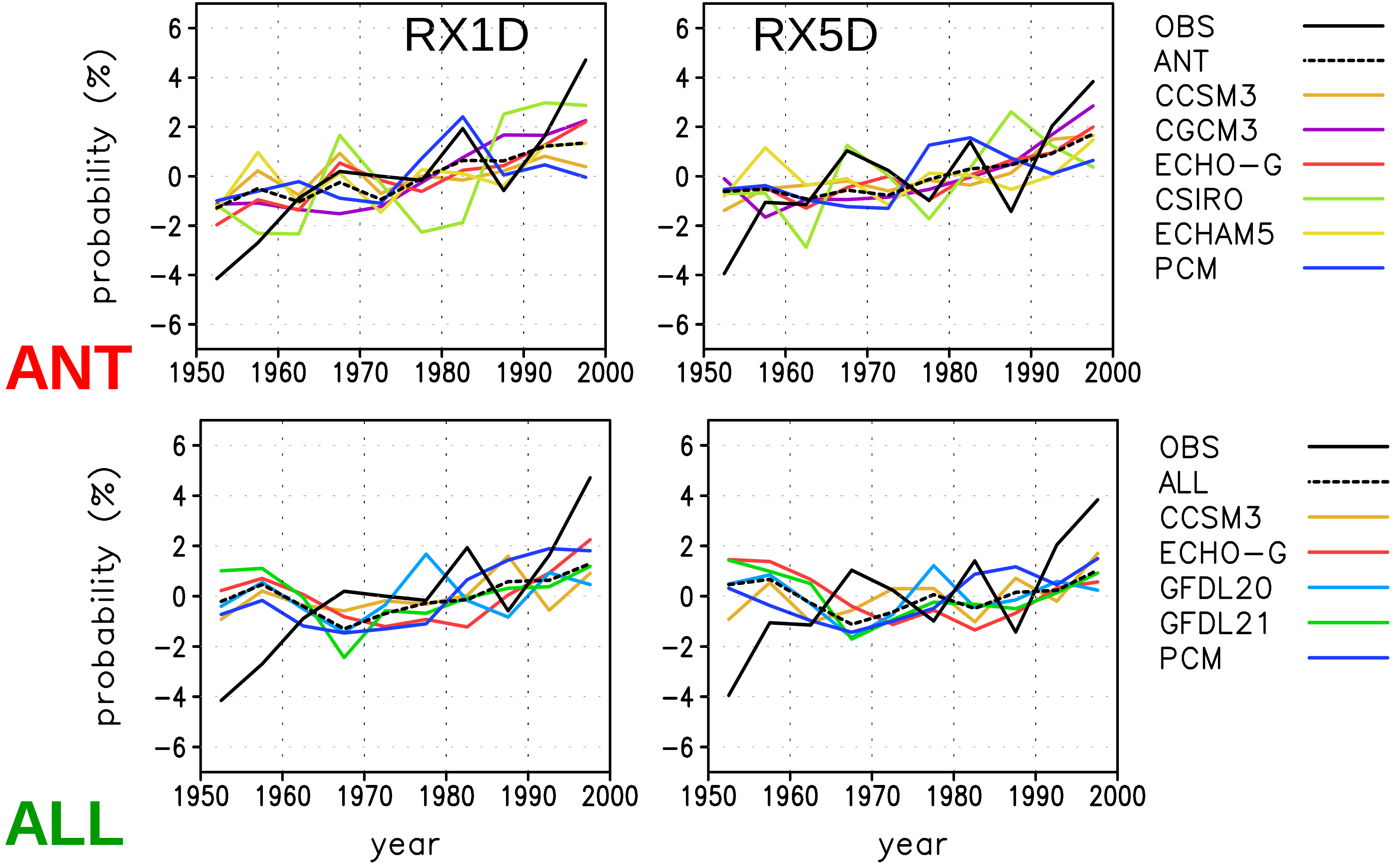
Models

ANT

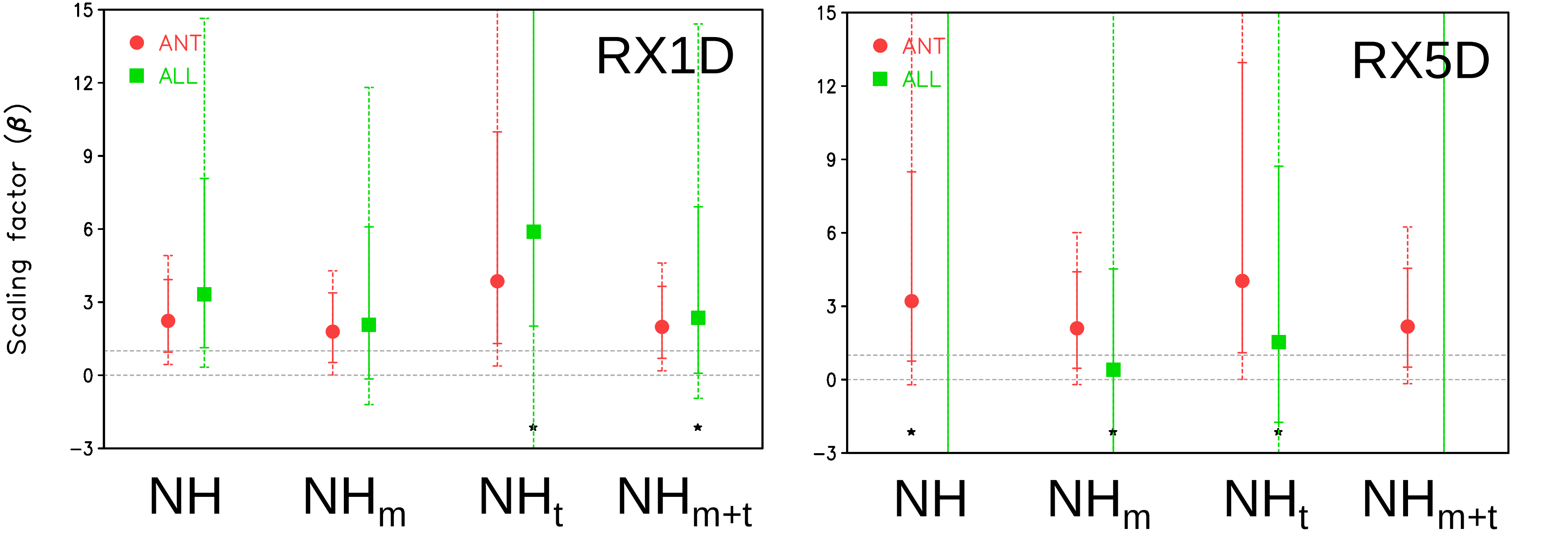
ALL



Spatially averaged 5-yr means



Detection results – 1951-1999



- ANT detectable for both RX1D and RX5D
- ALL detectable only for RX1D and less robustly
- ANT scaling factors near 2-3
  - ➔ model responses to ANT underestimated

3. D&A on GEV parameters

- Brown et al, 2008
  - Fit GEV distributions to annual temperature extremes
  - Include time as a covariate
  - Describe observed extremes
  - Show trend in location parameter inconsistent with internal variability
- Christidis et al, 2010
  - Apply D&A technique to trends in location parameter
  - Able to detect anthropogenic influence in all 4 temperature extremes indices


Photo: F. Zwiers

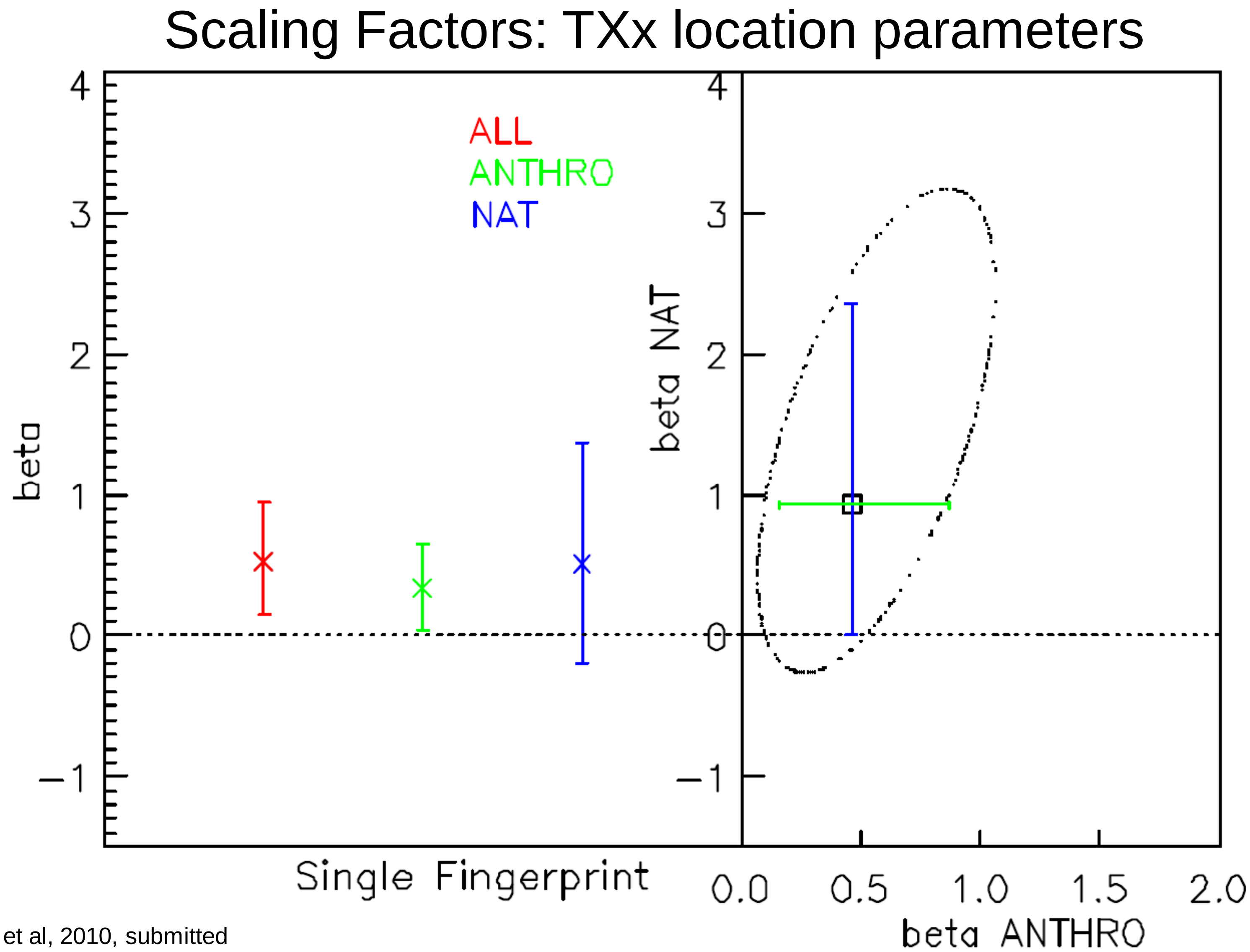
D&A on GEV parameters

- Advantages
  - Location and scale parameters in physical units
  - MLE parameter estimates ➔ approximately Gaussian

$$\hat{\mu}_{obs} \mid \hat{\mathbf{U}}_{\mathrm{mod}} \sim \eta(\hat{\mathbf{U}}_{\mathrm{mod}}\beta, \Sigma)$$

  - Can optimize signal to noise ratio by accounting for spatial covariance structure of extremes
  - Can use model output to estimate uncertainties
  - Apparently more powerful than direct detection on indices

TXx - 1950-99 location parameter trends



Christidis et al, 2010, submitted

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4. D&A in GEV framework

$$Y \mid X \sim GEV(X\beta, \Sigma, \Xi)^T$$

Y Space-time vector of annual extremes

X Space-time signal matrix (one column per signal)

β Vector of scaling factors

Σ Vector of scale parameters

Ξ Vector of shape parameters

} Note that these are vectors

How do we get the signal?

- Typically have ensembles of 20th century simulations from a given model
  - M ensemble members ➔ M annual extremes per year
- Assume that signal changes slowly
  - If roughly constant within decades ➔ 10M annual extremes per decade
- Fit GEV to these decadal samples at grid boxes
- Retain the decadal fields of location parameter estimates as signal
- Average across multiple models to reduce signal uncertainty
- Currently consider only one signal at a time (either ALL or ANT)

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How do we fit the GEV to obs?

- Express signal in decade j at gridbox k as

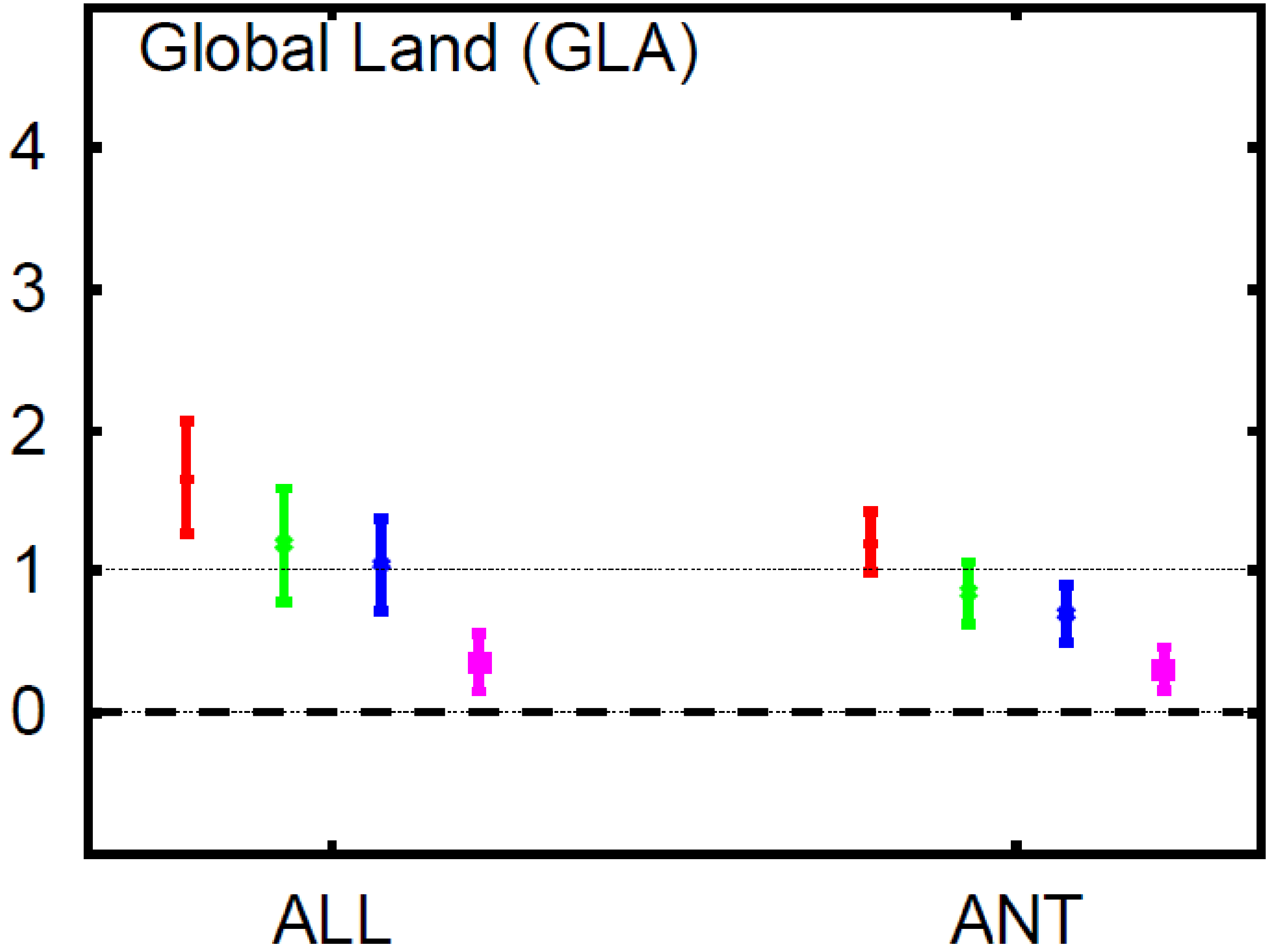
$$\mu_{1,k} + \beta \Delta \hat{\mu}'_{j,k}$$

- Note that same scaling factor β is used everywhere

- Obtain mle for β by profile likelihood technique

$$-l = \sum_k \{10N \log(\sigma_k) + (1 + \frac{1}{\xi_k}) \sum_{j=1}^{N} \sum_{l=1}^{10} \log(1 + \xi_k (\frac{X_{10(j-1)+l,k} - \mu_{1,k} - \beta \Delta \hat{\mu}'_{j,k}}{\sigma_k}))\}$$

Results: Global



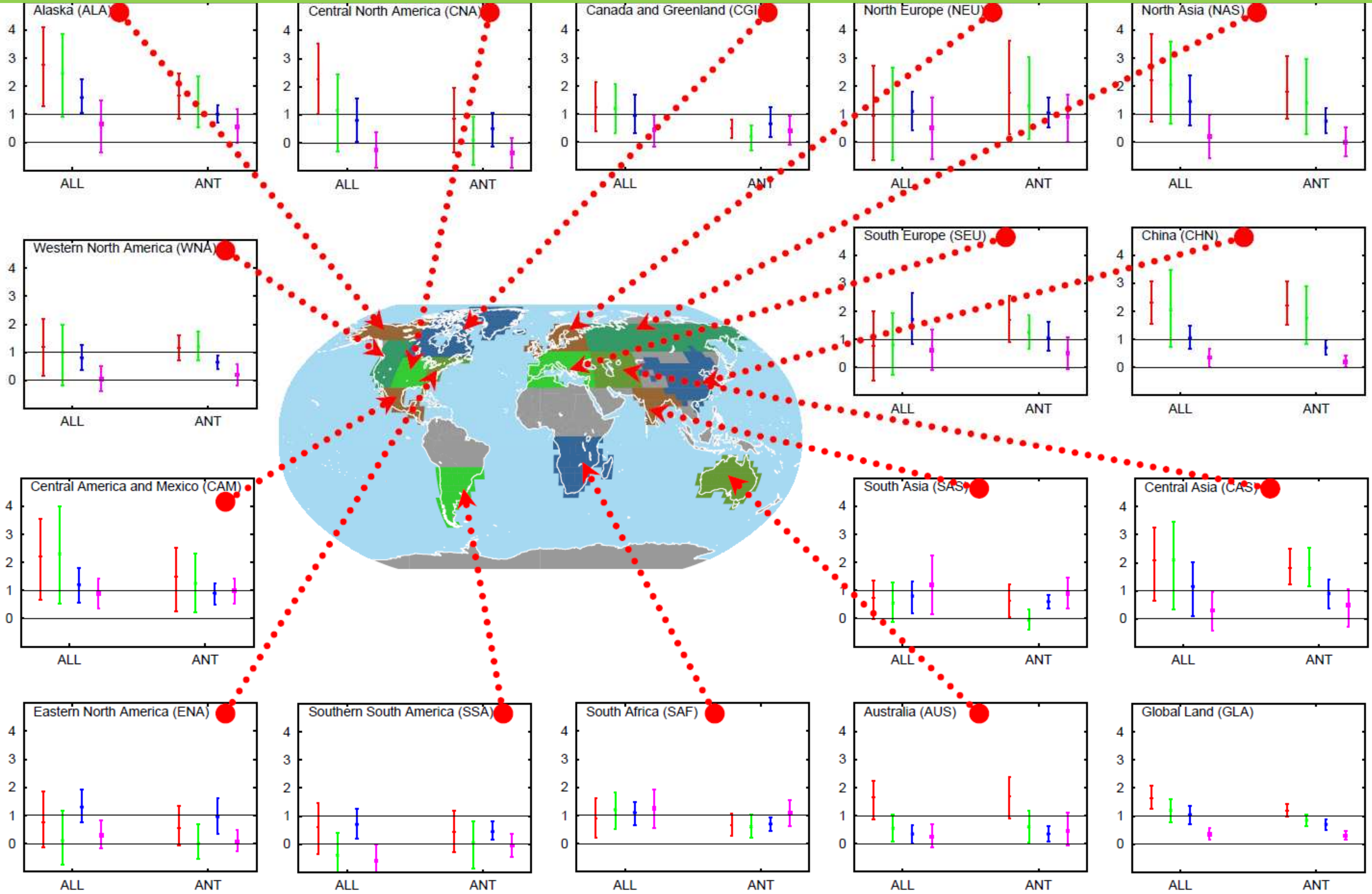
TNn
Coldest night

TXn
Coldest day

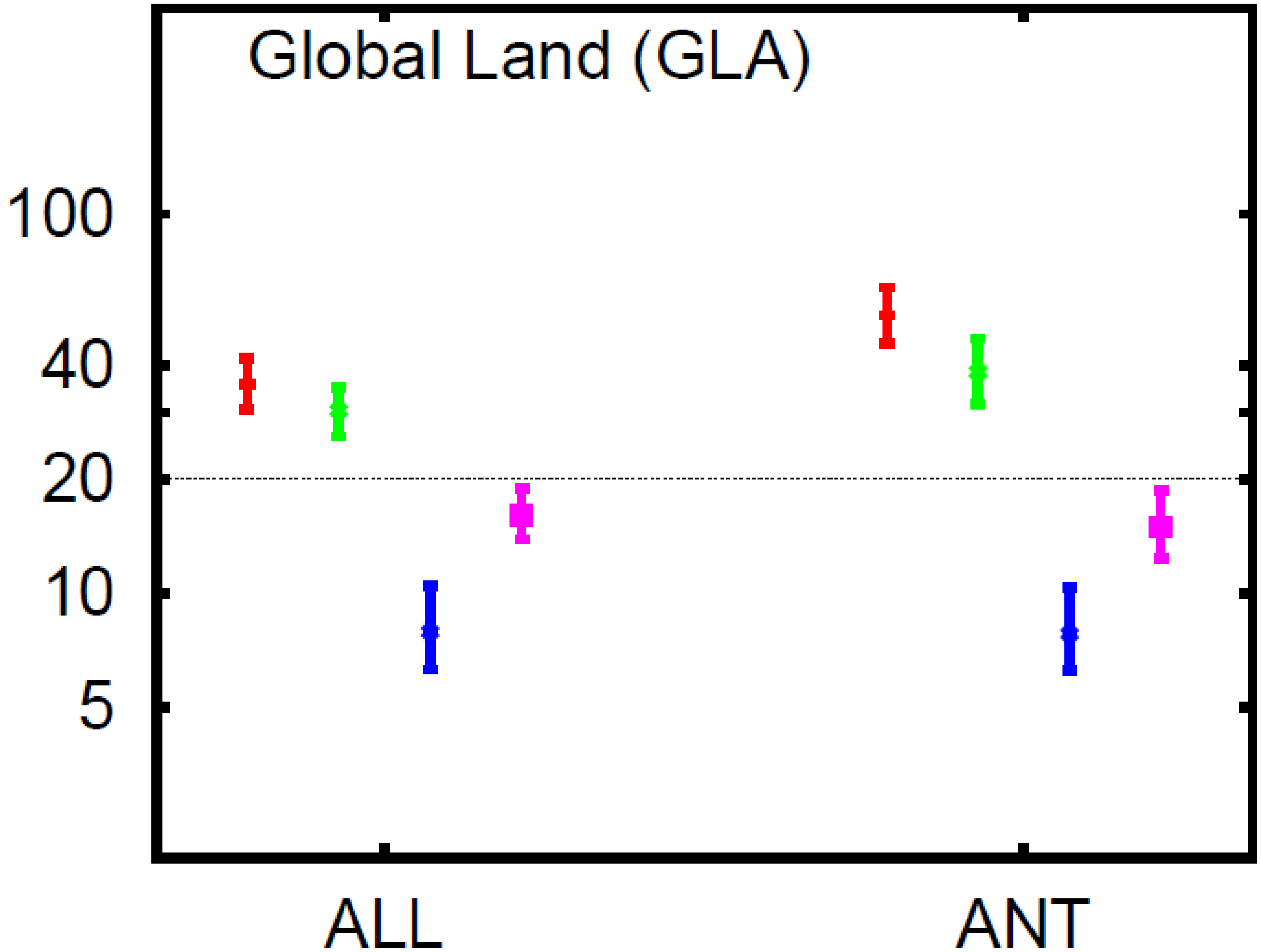
TNx
Warmest night

TXx
Warmest day

Results: Regional



Implied change in waiting times (1990's vs 1960's)



TNn
Coldest night

TXn
Coldest day

TNx
Warmest night

TXx
Warmest day

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A few features / limitations

- Assume that external forcing causes changes in the location parameter in time and space
- Further assume that scale and shape parameters are constant in time
- Unable to explicitly represent spatial or temporal dependence
- Unable to reduce dimension so as to include only scales where variability of extremes is well simulated
- Uncertainty estimates obtained via block bootstrap approach

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Discussion

- Considered four approaches
- Have not assessed which approach results in most efficient detection
- Ability to model spatial dependence in extremes remains limited
- Thus detection on suitably transformed data or on EV distribution parameters currently remains preferable
- Nevertheless, advantages to further developing detection approaches within EVT framework
- Should be able to calculate FAR directly
- Potentially a constraint on projections of future extremes

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Discussion

- “Extremes” is a much broader topic, not all of which is amenable to extreme value theory
  - Tornadoes
  - Tropical cycles
  - Drought
  - ...
- Advert
  - WCRP Open Science Conference
  - Denver, CO, USA
  - Oct 24-28, 2011
  - Oral and poster sessions on extremes
  - http://www.wcrp-climate.org/conference2011/

The End

Photo: F. Zwiers