Environment and Climate Change Canada
Environnement et Changement climatique Canada

CHANGES IN EXTREME PRECIPITATION

Xuebin Zhang, Climate Research Division

Canada

Understanding the causes

Climate Change Detection and Attribution

- Objectives:
  - diagnosing the existence of forced changes in the observed climate record and
  - assessing the roles of various possible contributors to those observed changes
- Scientific and policy relevance:
  - Comprehensive evaluation of our understanding of how the climate system responds to anthropogenic interference
  - Dedicated chapter in every IPCC assessment report
  - Underpinning several high-level findings of the AR5
  - Underpinning attribution assessment across a range of variables and regions
  - Constraining near-term projection
  - Constraining climate system parameters including Transient Climate Response (TCR) and the Transient Climate Response to Emissions (TCRE)

Some definitions

- *Detection* of change is the process of demonstrating that the climate or a system affected by the climate has changed in some defined statistical sense
- *Attribution* is the process of evaluating the relative contributions of multiple causal factors to a change or event with an assignment of statistical confidence
- Casual factors refer to *external influences*
  - Climate: *anthropogenic* and/or *natural*
  - Systems affect by climate: *climate change*

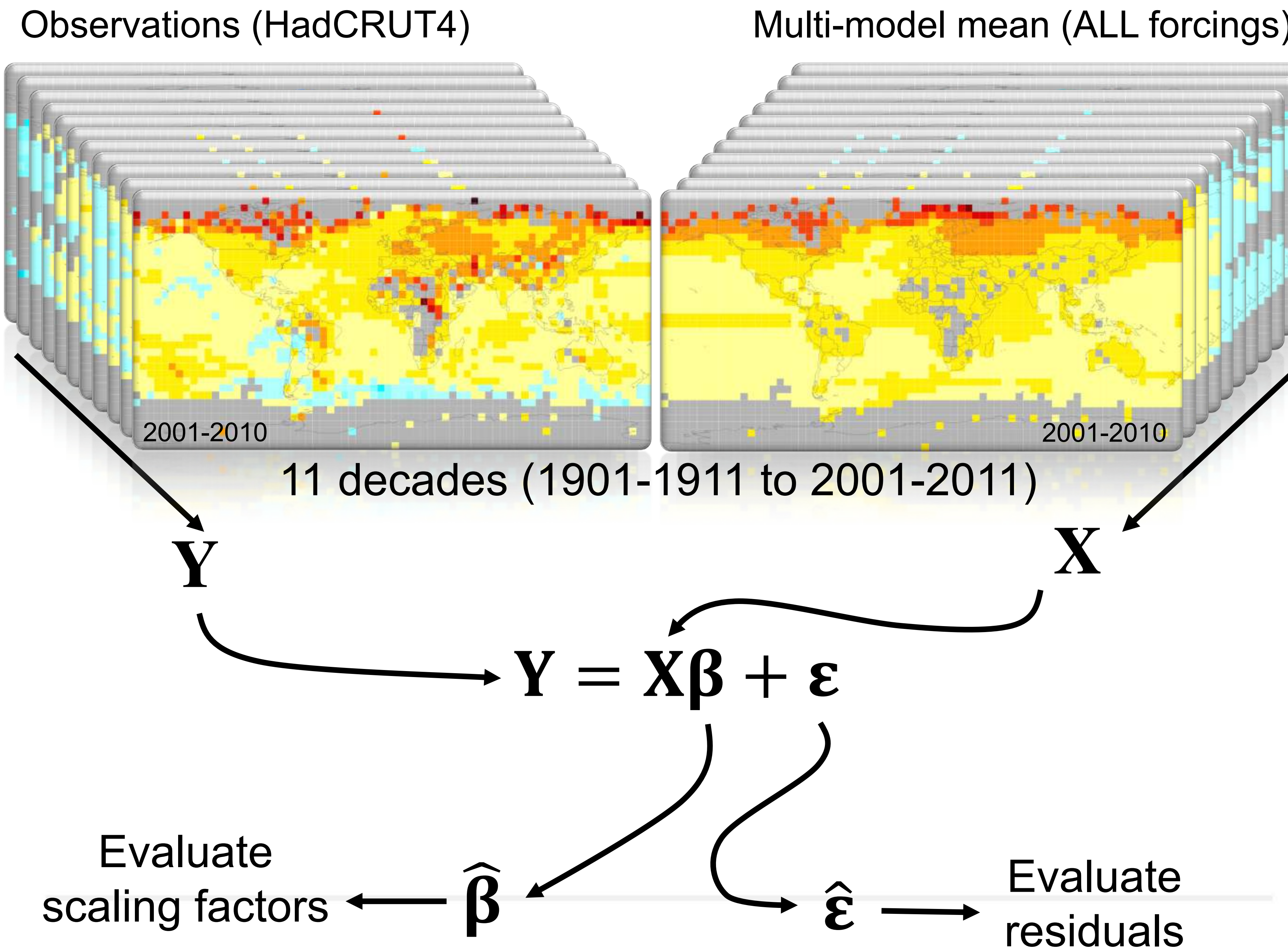
[IPCC Good Practice Guidance Paper on Detection and Attribution, 2010]

Four core elements

1. Observations of climate indicators
2. An estimate of external forcing
   - how external drivers of climate change have evolved before and during the period under investigation
   - e.g., GHG and solar radiation
3. A quantitative physically-based understanding of how external forcing might affect these climate indicators.
   - normally encapsulated in a physically-based model
4. An estimate of climate internal variability
   - often, but not always, derived from a physically-based model

General assumptions

- Key forcings have been identified
- Signals are additive
- Noise is additive
- The large-scale patterns of response are correctly simulated by climate models



After Weaver and Zwiers (2000)

Detection and attribution

- Standard D&A paradigm involves 3 equations:

Observed change –

$$\mathbf{Y} = \mathrm{Y}^{Forced} + \boldsymbol{\varepsilon}$$

Simulated (multi-model) change –

$$\widetilde{\mathbf{X}}_i = \mathrm{X}_i^{Forced} + \boldsymbol{\Delta}_i$$

Relationship between observed and simulated signals –

$$\mathrm{Y}^{Forced} = \sum_{i=1}^{s} \beta_i \mathrm{X}_i^{Forced}$$

- Assumes residuals are Gaussian

A worked example

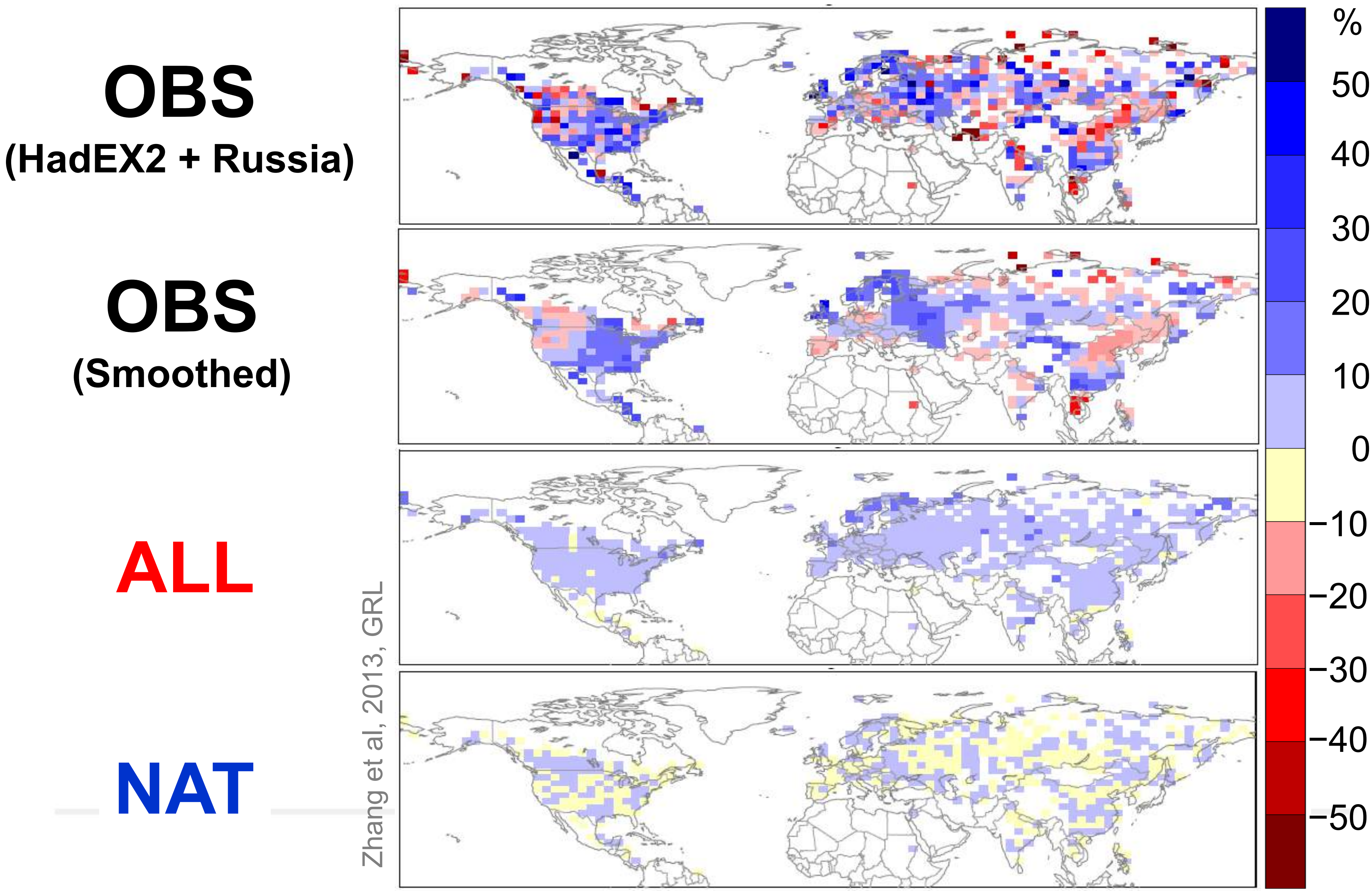
Zhang et al. 2013

- Transform to a probability index
  - Fit an extreme value distribution locally
  - Apply probability integral transform
  - Transformed values have approximately the uniform distribution
  - Time and area averaging produces Gaussian values
  - Could use simpler transforms
- Apply standard D&A paradigm

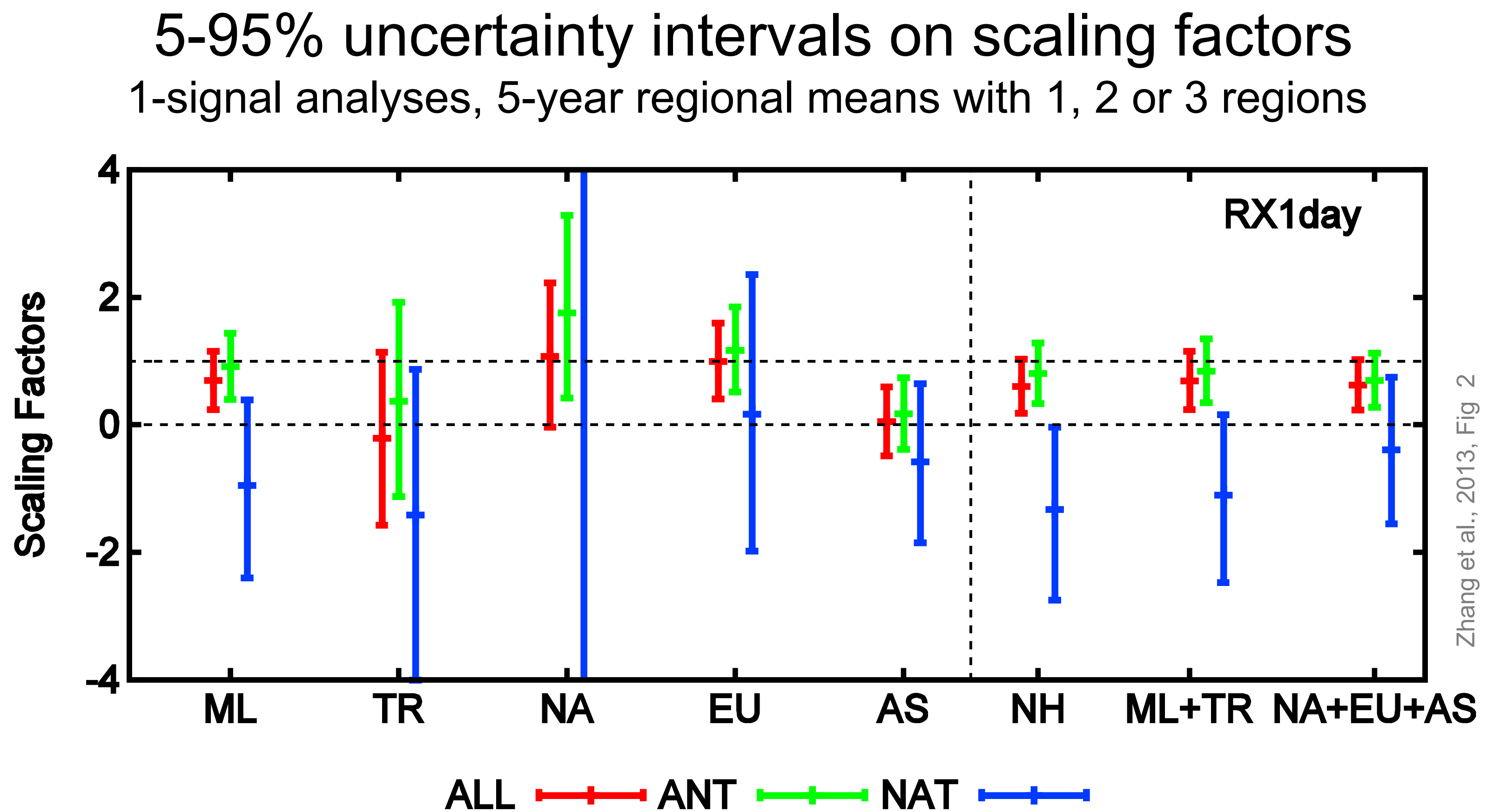
Some details of Zhang et al, 2013

- Variables:RX1day, RX5day, 1951-2005
- Observational data: HadEX2 (Donat et al, 2012) augmented with Russian station data, transformed
- Estimation of signals and natural variability: Multi-model signals and control runs (54 ALL runs, 14 GCMs; 34 NAT runs, 9 GCMs; >15K years control, 31 GCMs)
- Space-time regression: 1-D time evolution (5-year means, domain averaged), and 2-D space-time evolution (5-year means, regionally averaged, 2 regions including ML/TR or 3 regions including NA, EU and AS)
- Total least squares method

PI Trends (RX1D; 1951-2005)

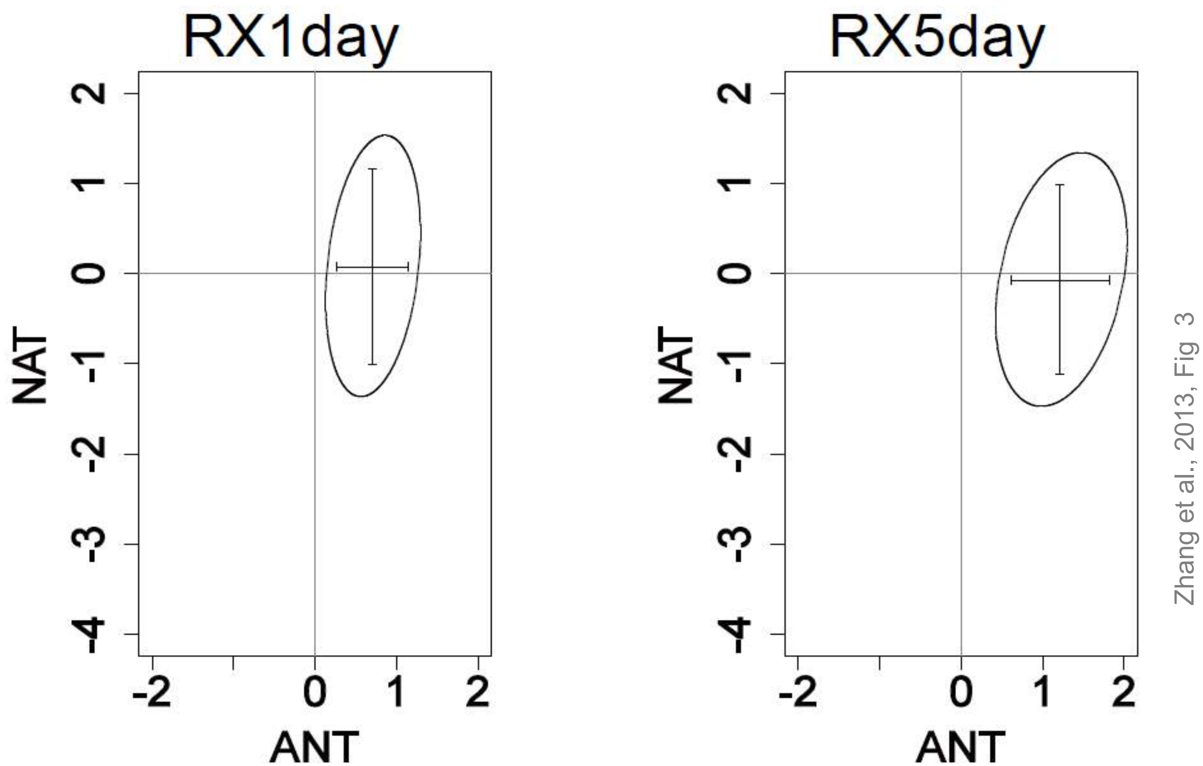


Detection results – 1951-2005



ML – mid-latitudes, TR – tropics, NA – North America, EU – Europe, AS - Asia

Detection results – 1951-2005 2-signal analyses



- Space-time (3 regions, 5 year means → 33-dim problem)
- 54 ALL runs (14 models), 34 NAT runs (9 models)

Global scale detection and attribution

We can detect the human influence on precipitation extremes using formal detection and attribution methods:

- Climate models that include anthropogenic external forcing intensify precipitation similarly to observed
- Climate models with only natural external forcing fail to intensify precipitation

Attributed intensification:

- 3.3% increase over 55 years due to human effects
  - uncertainty range [1.1 – 5.8]%
- 5.2% increase per degree of warming
  - uncertainty range [1.3 – 9.3]%

Estimated waiting time for 1950’s 20-year event:
~15-yr in the early 2000’s

Zhang et al., 2013 (see also Min et al 2011)

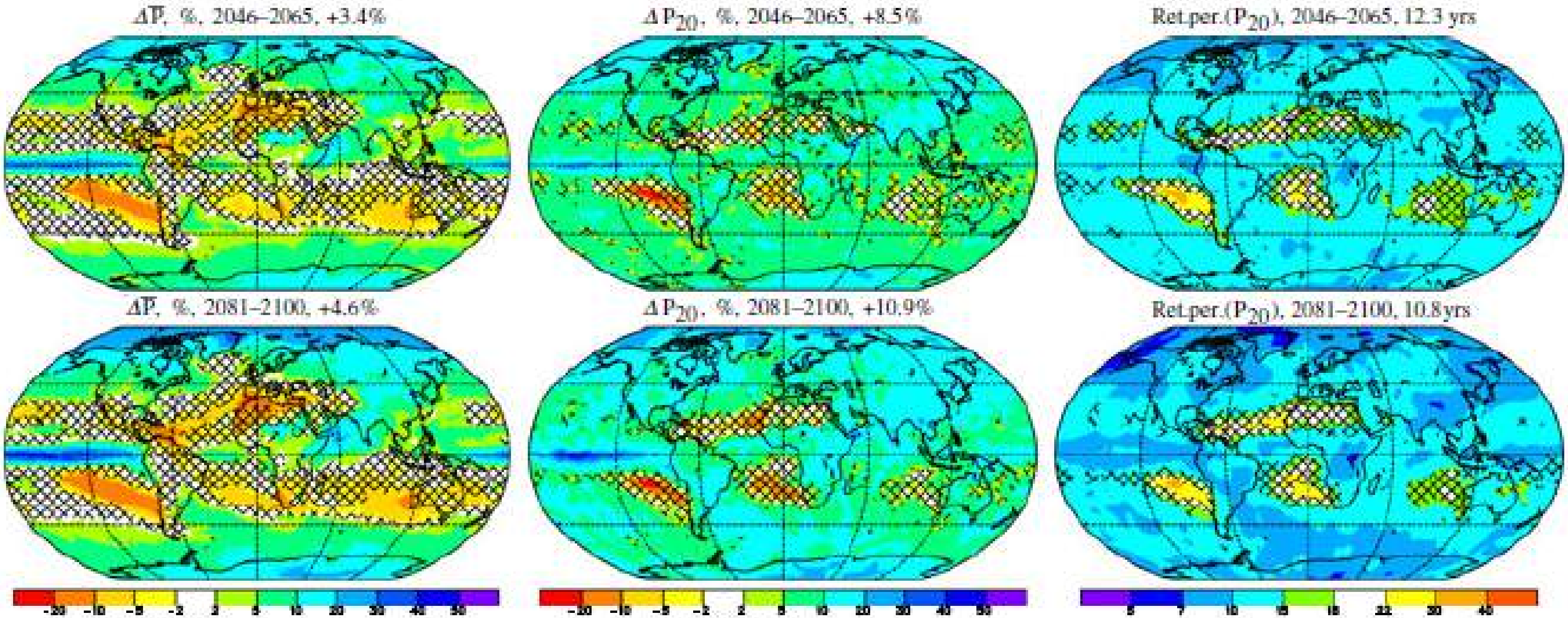


Fig. 4 *Top row:* The CMIP5 multi-model median relative change (%) in the annual mean precipitation rate (*left*) and in 20-year return values of annual extremes of daily precipitation (*middle*) simulated in 2046–2065 relative to 1986–2005 in the RCP4.5 experiment. The corresponding median of return periods, in years, for 1986–2005 20-year events is shown in the *right panel*. *Bottom row:* The same as above but for the 2081–2100 period. Global averages, or global medians for the return periods, are indicated in the titles. Changes that are not significant at the 5% level are indicated by cross-hatching

Kharin et al. 2013

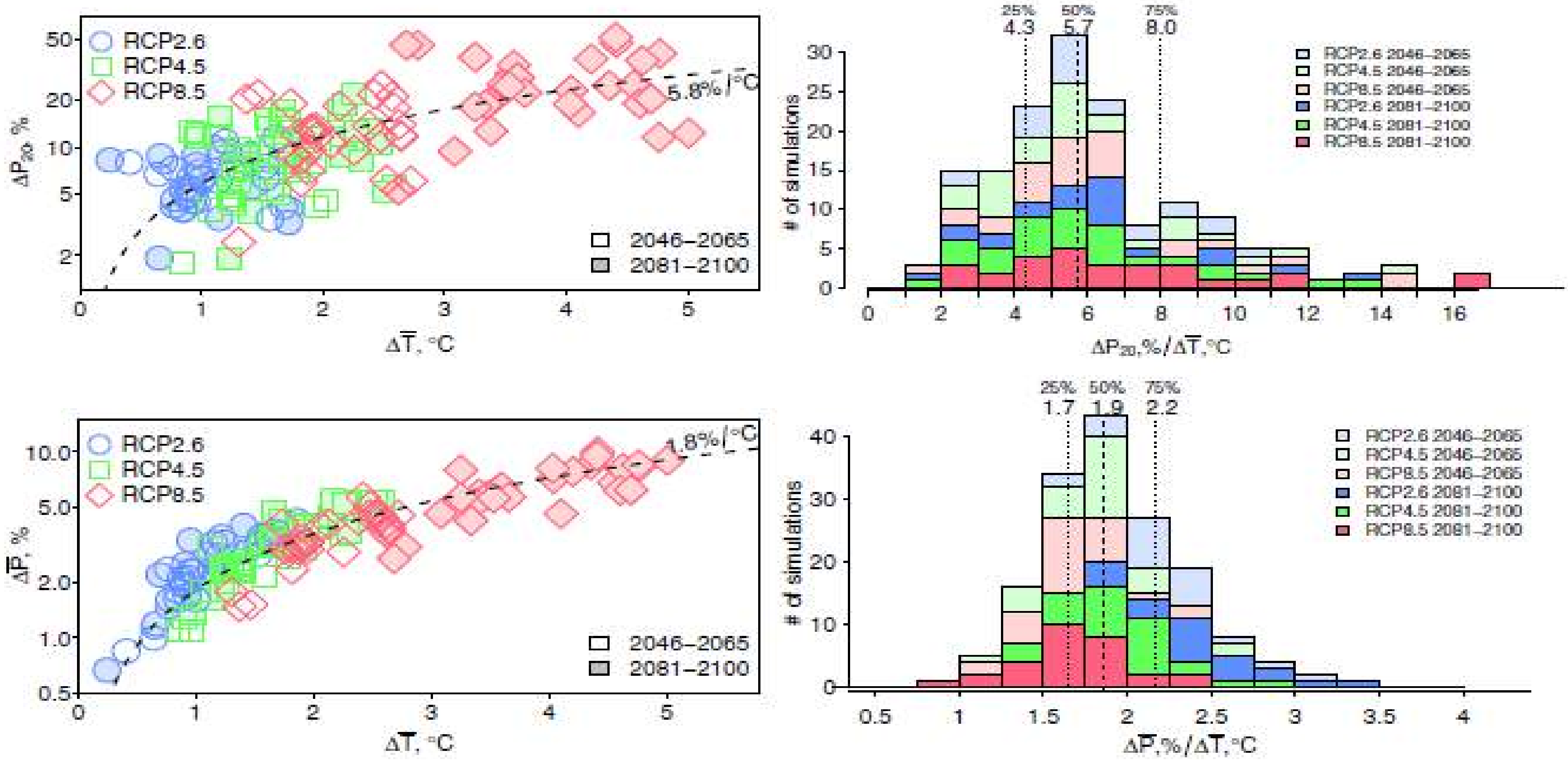
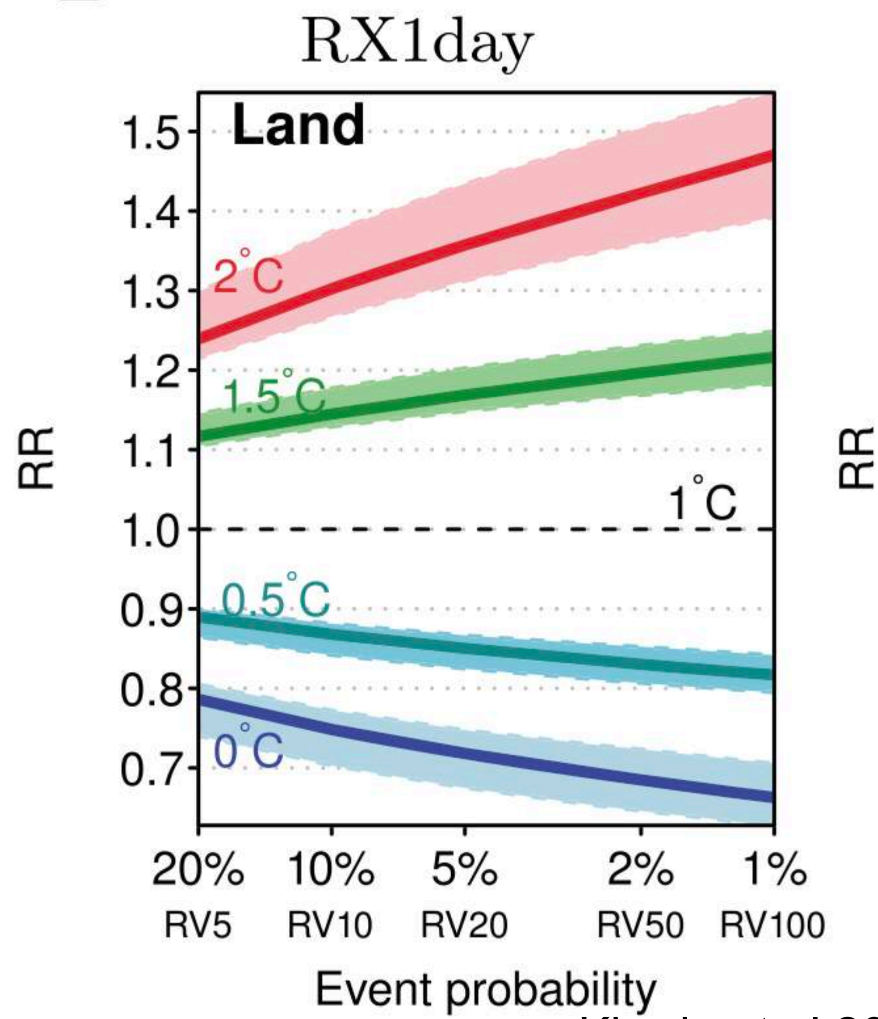


Fig. 5 *Top left panel:* Relative changes (%) in globally averaged 20-year return values of annual daily precipitation extremes (ΔP_{20}) plotted on a log scale as a function of globally averaged changes in annual mean near surface temperature ($\Delta\overline{T}$, °C) simulated by the CMIP5 models in the RCP2.6, RCP4.5 and RCP8.5 experiments in 2046–2065 and 2081–2100. The linear regression fit is indicated by the *dashed line*. *Top right panel:* Histogram of extreme precipitation sensitivities $\Delta P_{20}/\Delta\overline{T}$, %/°C, simulated by the CMIP5 models in the three scenarios and two time periods. The median value (50%) and inter-quartile range (25–75%) is indicated by the *vertical dashed* and *dotted lines* respectively. *Bottom panels:* the same as above but for changes in global annual mean precipitation ($\Delta\overline{P}$) instead of ΔP_{20}

Kharin et al. 2013

Changes in the risk will not be uniform

- Larger increase with stronger warming
- Larger increase with rarer events



Kharin et al 2018

PART II

WHEN THE RUBBER MEETS THE ROAD …

Substantial changes may have occurred but …

- Changes are difficult to estimate locally or regionally based on historical data
  - historical estimation cannot and should not be extrapolated to the future in a very simple manner
- Climate model simulations are not panacea
  - Lack of proper processes, still relatively low resolution
  - Signal is still weak, a lot of data are needed to provide robust projection
  - Model output at local/regional scale should not be used literally

Impacts are local/regional, adaptation also requires local/regional specific projection

Wind, sea ice, sea level

Wind

Short duration extreme rainfall

extreme rainfall at various duration

Stationary paradigm for infrastructure design

- Collect annual maximum (e.g., peak flood) data
- Fit the data to a probability distribution say Generalized Extreme Value distribution $G(x; \mu, \sigma, \xi)$ assuming i.i.d, using various methods such as MLE or L-Moment
- Infer from the fitted distribution the $1/p$-year return value as $G^{-1}(1-p; \mu, \sigma, \xi)$
- Use the return value as a design value based on stationarity assumption: climate has not changed in the past and will not change in the future

Some quotes

- Milly et al. (Science 2008)
  - “Stationarity is dead: whither water management?”
- Lins and Cohn (AWARA, 2011)
  - “Stationarity: wanted dead or alive?”
- Serinaldi and Kilsby (AWR, 2015)
  - “Stationarity is undead: uncertainty dominates the distribution of extremes”

Stationery is dead –Milly et al. 2008 (Science)

- Stationarity assumption
  - Foundational to the design of almost all existing infrastructure
  - Natural systems fluctuate within an unchanging envelope of variability
  - Any variable has a time-invariant probability density function (PDF) whose parameters can be estimated based on historical observations
  - PDF for the past can represent the PDF for the future
  - PDF estimation has errors which are reducible by additional observations, more efficient estimators etc.
- Stationarity has long been compromised
  - Human changes in the environment
- Stationarity is dead and cannot be revived
  - Substantial changes in the climate due to anthropogenic influence
  - Climate change will continue to the foreseeable future

A nonstationary paradigm

- Fit the data to nonstationary GEV $G(x; \mu(t), \sigma(t), \xi)$ using MLE method, where μ and $ln(\sigma)$ can be assumed as a linear function of covariates such as time (t)
- Infer from the fitted distribution the $1/p$-year return value as $G^{-1}(1-p;$ μ(t), σ(t), ξ), Return value is a function of t
- The risk of failure will not be the same during the designed live span of the structure

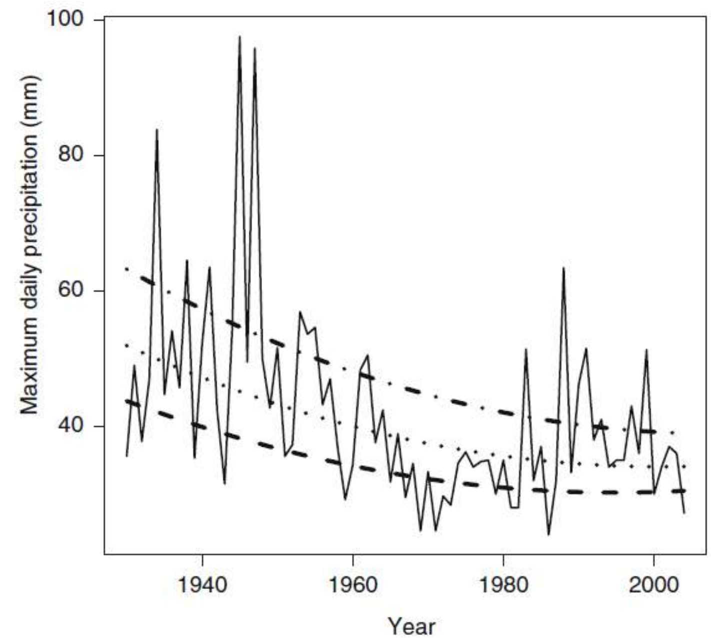
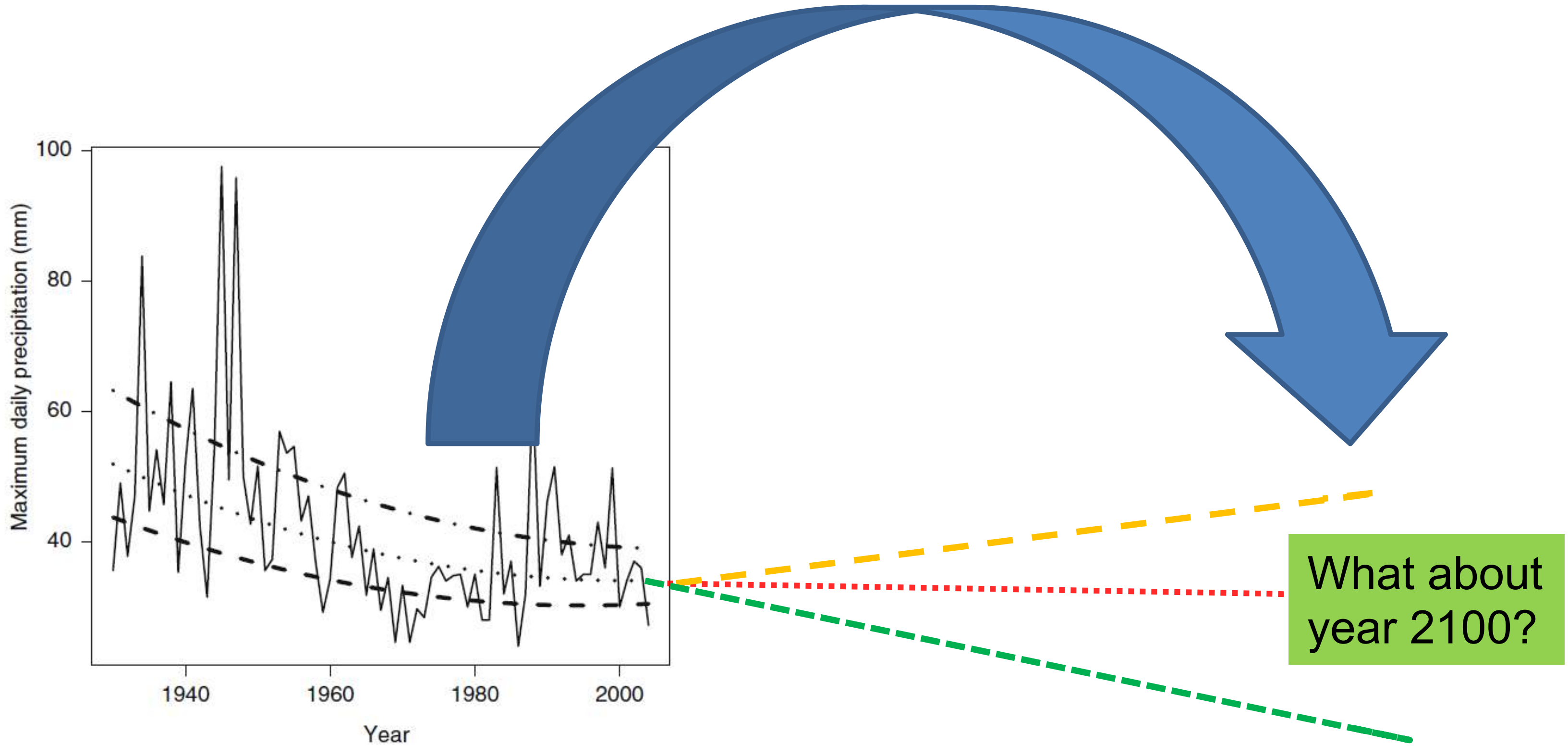


Fig. 2.6 Winter (May–October) time series of maximum daily precipitation amount (mm) at Manjimup, Western Australia during 1930–2004, along with selected quantiles [0.25 (*dashed curve*), 0.5 (*dotted curve*), 0.75 (*dot-dashed curve*)] for fitted nonstationary GEV distribution with quadratic trend in location parameter and linear trend in log-transformed scale parameter

Inherent difficulty in the nonstationary paradigm: The need for extrapolation



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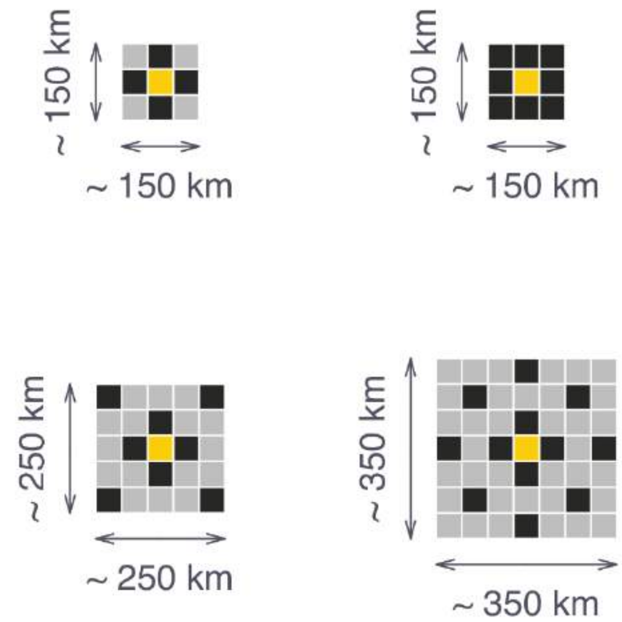
HOW MUCH INFORMATION IS NEEDED TO CONSTRAIN EXTREME PRECIPITATION PROJECTION AT LOCAL SCALE?

--CHAO LI ET AL. (2018)

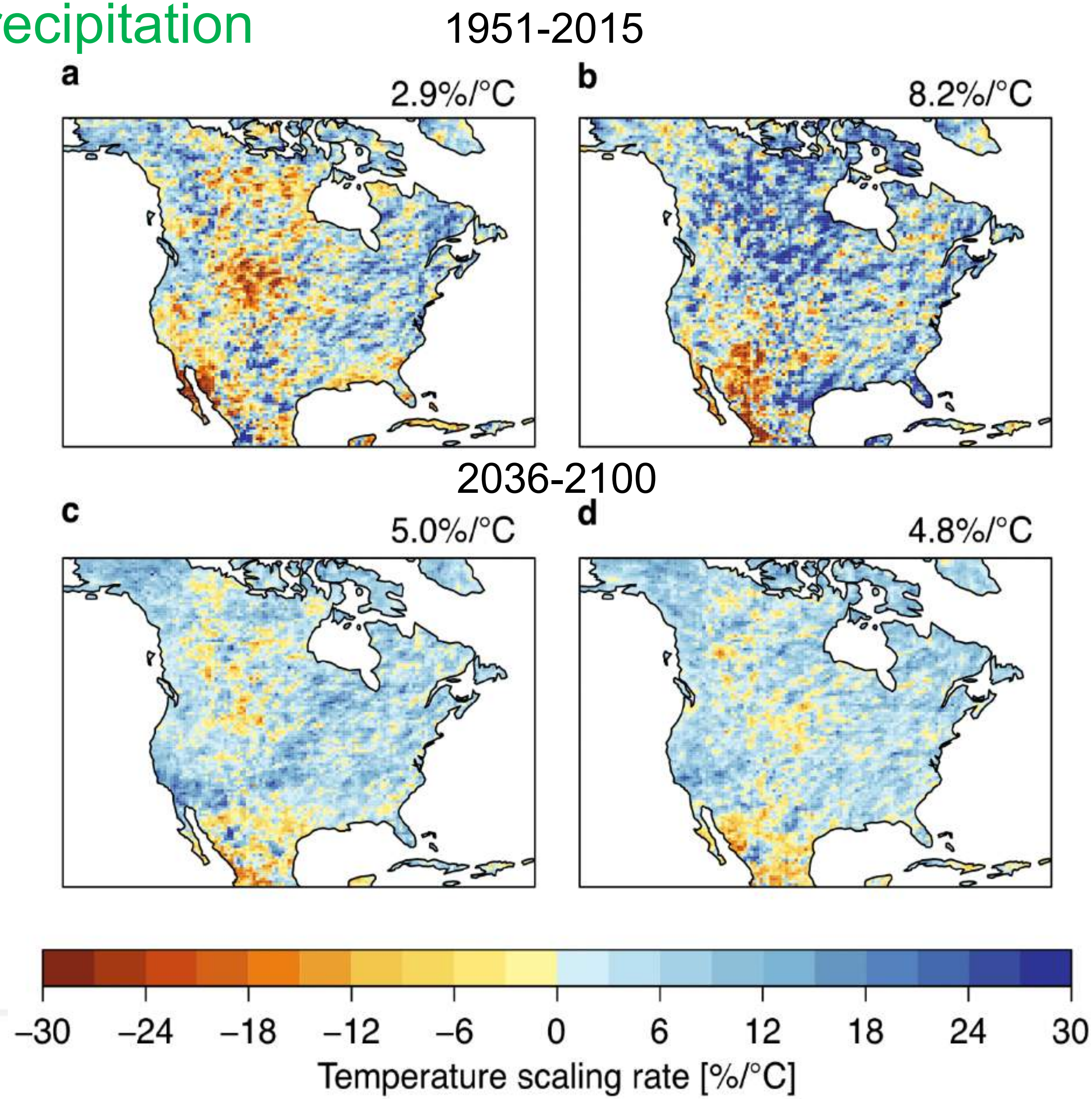
Estimation of temperature scaling of extreme precipitation: data and method

- Hourly precipitation from 35 ensemble CanRCM runs at c.a. 50 km resolution for 1950-2100 over North America, driving by CanESM2 simulations under rcp8.5
- Fitting generalized extreme value distribution to annual maxima with global mean temperature as co-variate, with different levels of spatial pooling



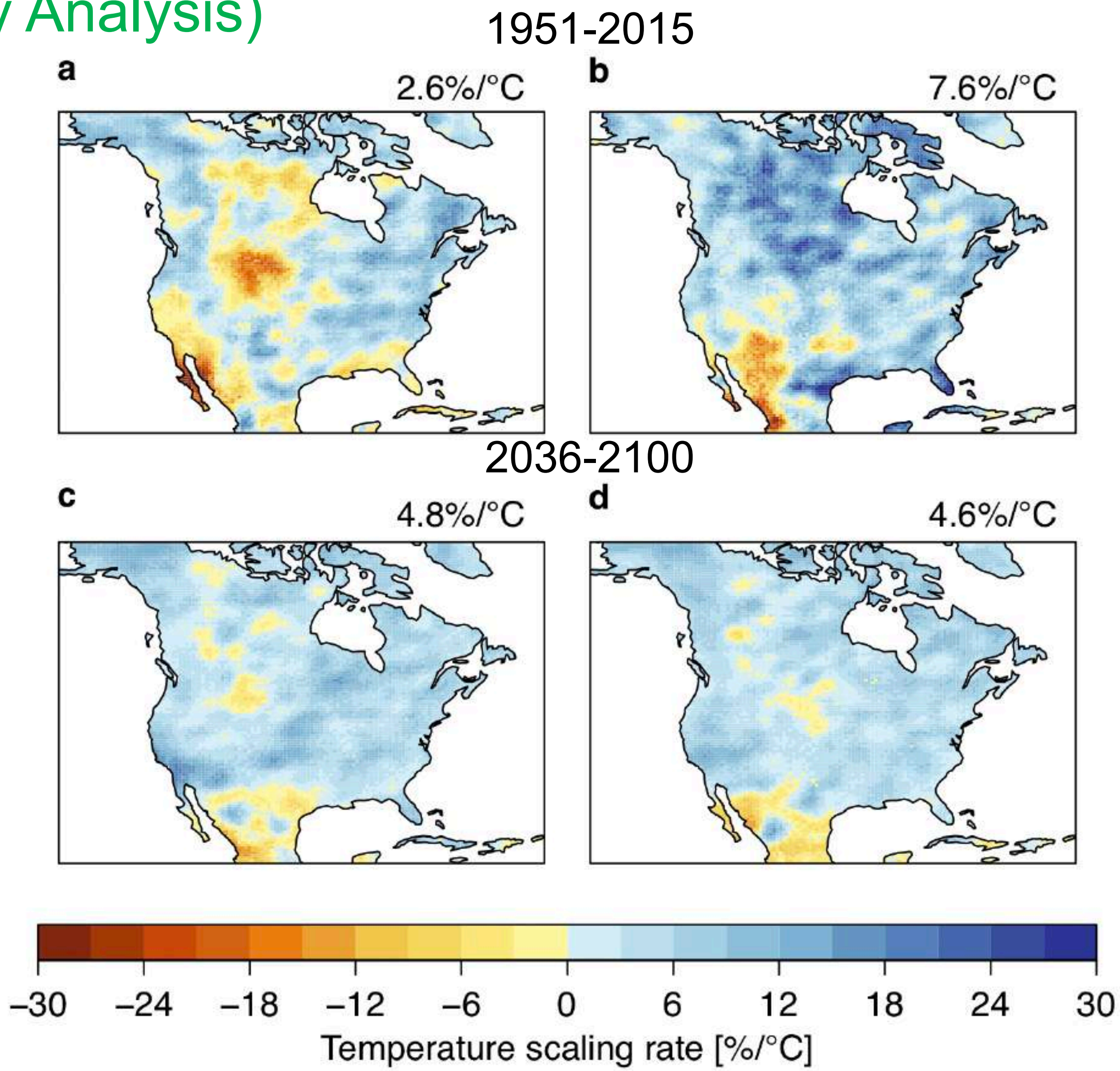
Temperature scaling of annual maximum 12-hour precipitation (at site analysis)

- estimated from 65-year periods from single CanRCM4 runs (at site)
- At site analysis of single 65-year records is insufficient to identify temperature scaling relationships (or more generally
- It is insufficient to reliably quantify non-stationary behaviour), even during periods with strong external forcing and response.

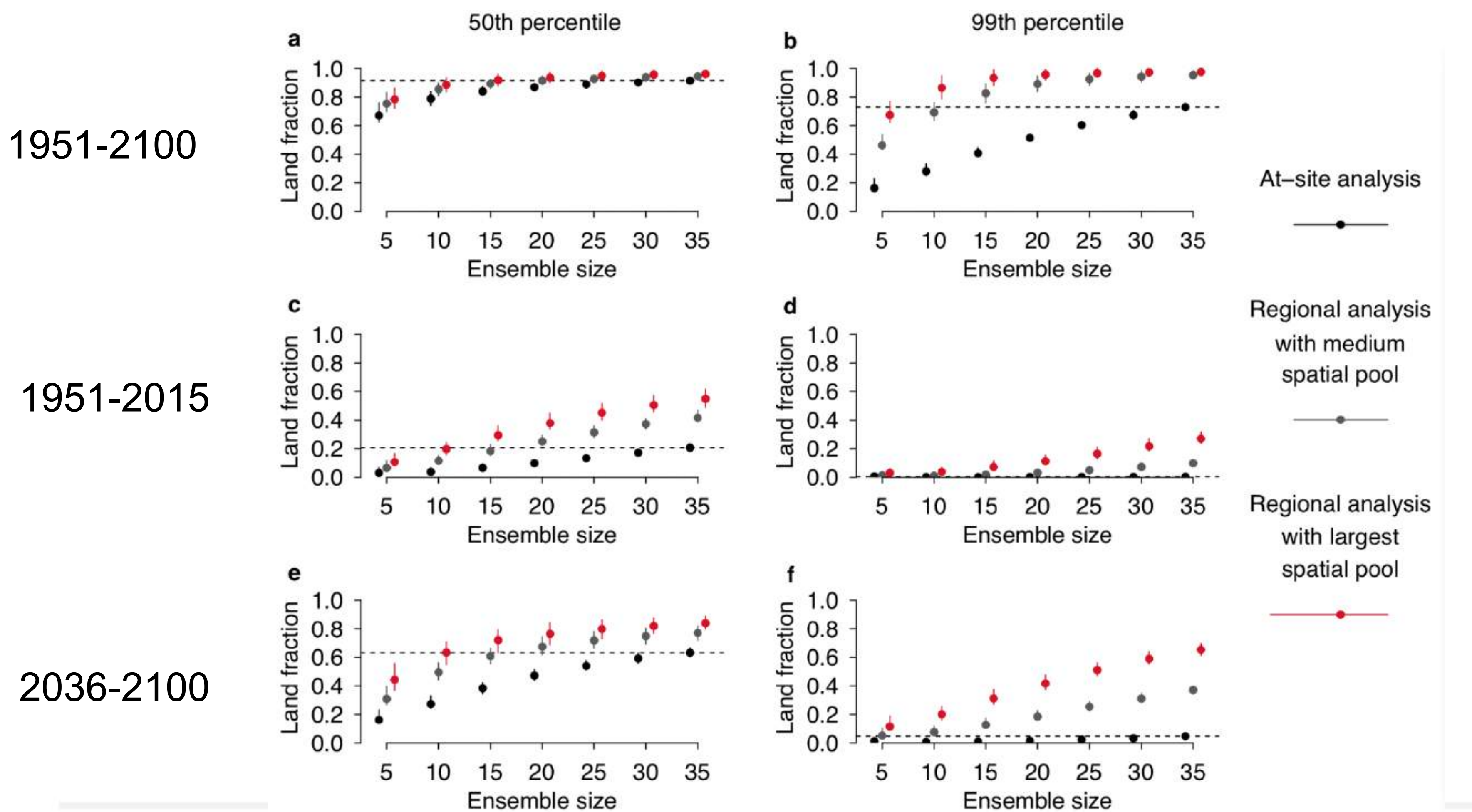


Temperature scaling of annual maximum 12-hour precipitation (Regional Frequency Analysis)

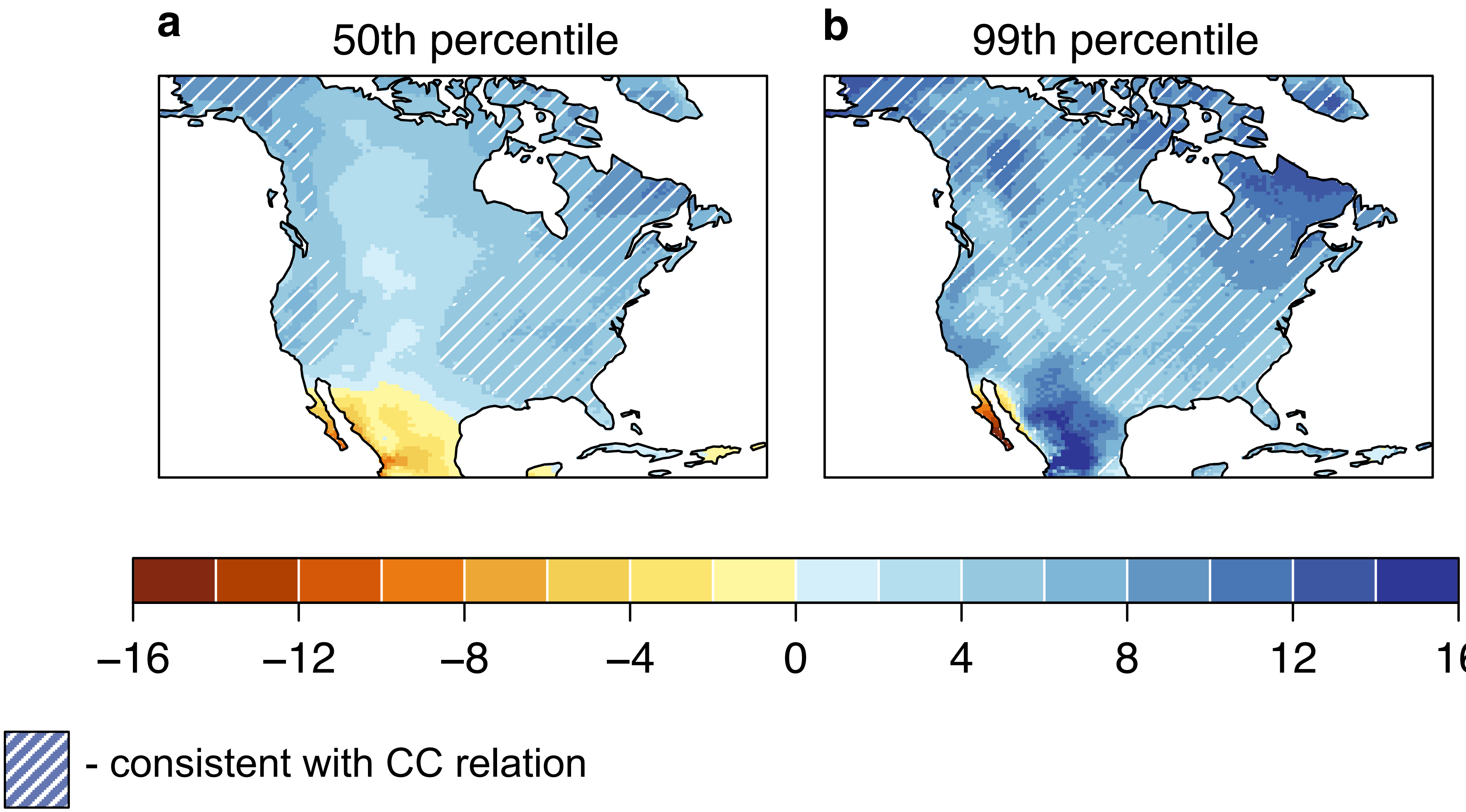
RFA of single 65-year records is still insufficient to robustly identify temperature scaling relationships, but …
… it may help in identifying large scale features associated with individual realizations of low frequency teleconnected variability.



Fraction of North America with robustly constrained temperature scaling estimates (annual max 12-hour precip)



Strength of temperature scaling for annual maximum 12-hour precipitation based on 35 simulations



Implications: Historical trends should not be extrapolated into the future

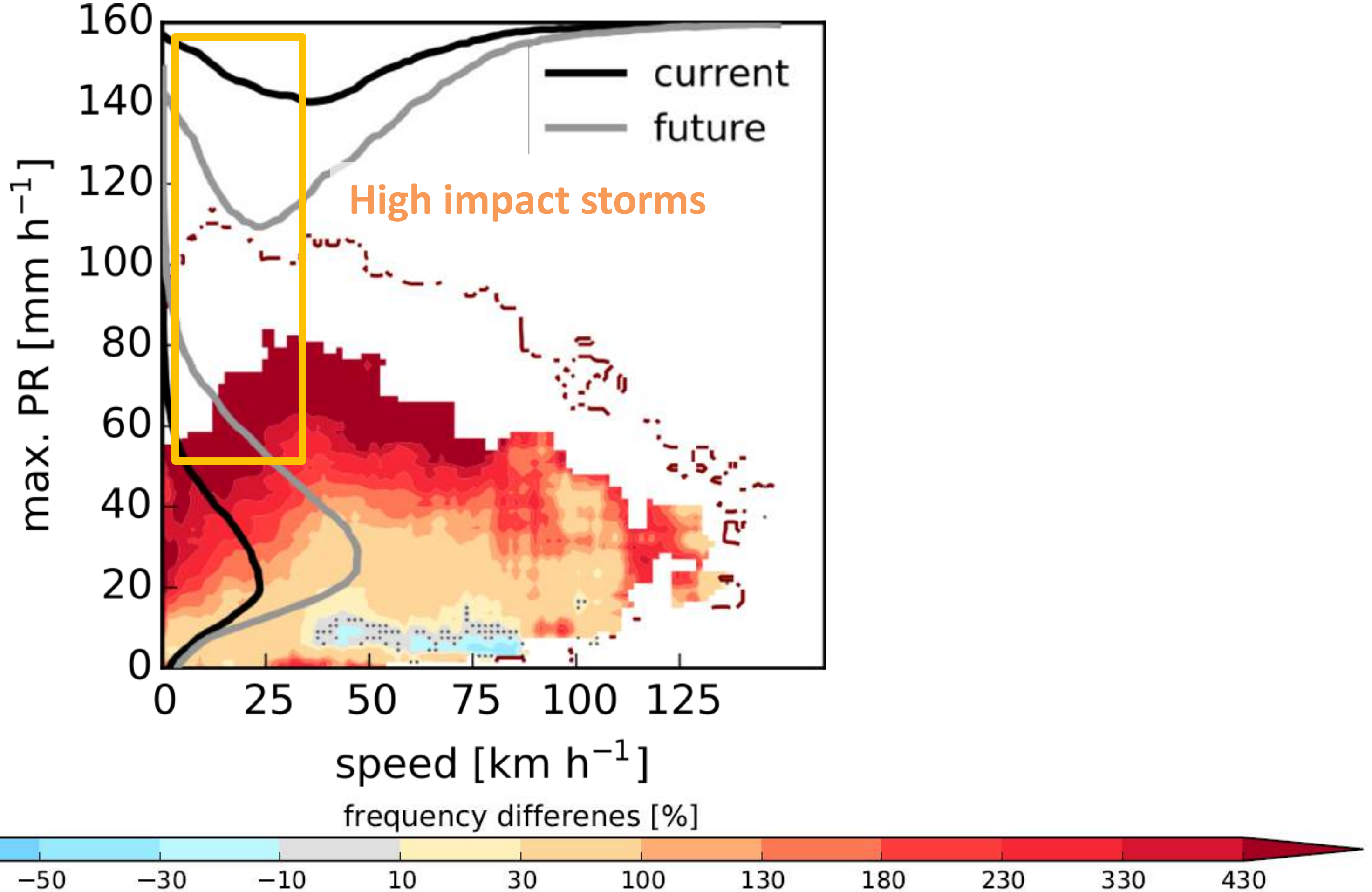
- Estimates of local scale changes based on available observation are highly uncertainty
  - ➢ Historical trend cannot be extrapolated into the future
  - ➢ Fitting GCM/RCM output to historical data will unlikely to produce robust future projection
- Records with lengths of many multiples of the length of observations are needed
- It is feasible to construct change factors based on relationship between regional/local changes and the levels of global warming

It’s not just the change in precipitation intensity …

Changes in Storm speed

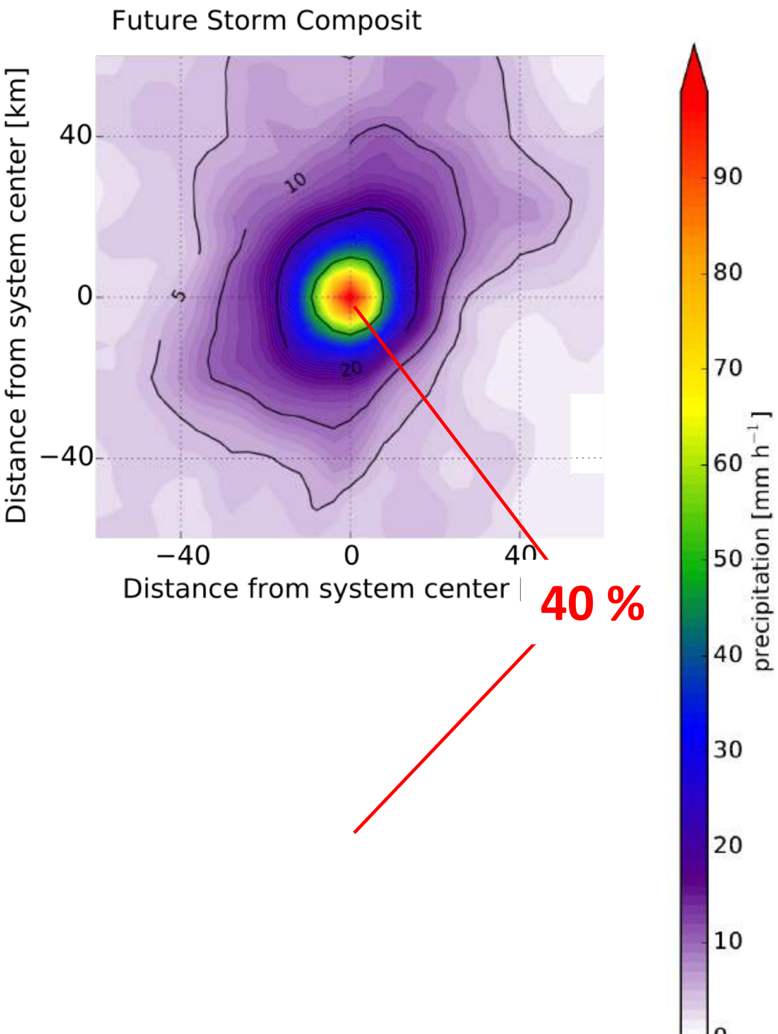
Canada - Conditional Distribution

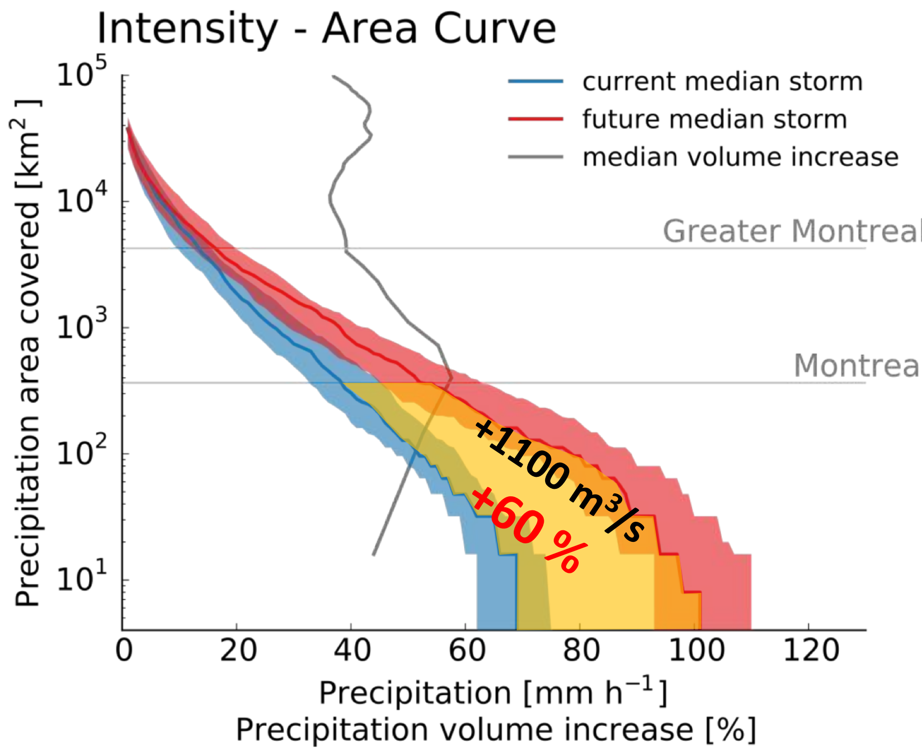
Storm speed conditioned on max. precipitation



From Andreas Prein

Storm rain volume – Canada





From Andreas Prein

Some take home messages

- There is a clear evidence at the global scale of anthropogenic influence on extreme precipitation.
- At the regional and local scales, changes in extreme precipitation are not easily identified.
- Models project intensification of extreme precipitation in the future but model projections should not be used at its face value in many applications.
- Various statistical methods have been used to detect, to attribute and to project changes in extreme precipitation. These methods always come with assumptions. Understanding the assumptions are key to proper application of these methods.