Challenges in understanding and projecting changes in extreme precipitation

Photo: F. Zwiers

Francis Zwiers
Pacific Climate Impacts Consortium
University of Victoria, Victoria, Canada

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Outline

- Introduction
- Observed trends
- Causes
  - Model assessment
  - Detection and attribution
- Challenges – can we exploit scaling relationships?
- Discussion
- Projections (time permitting)

Acknowledgements: Xuebin Zhang and colleagues at ECCC

Photo: F. Zwiers

Introduction

Calgary flood, 2013

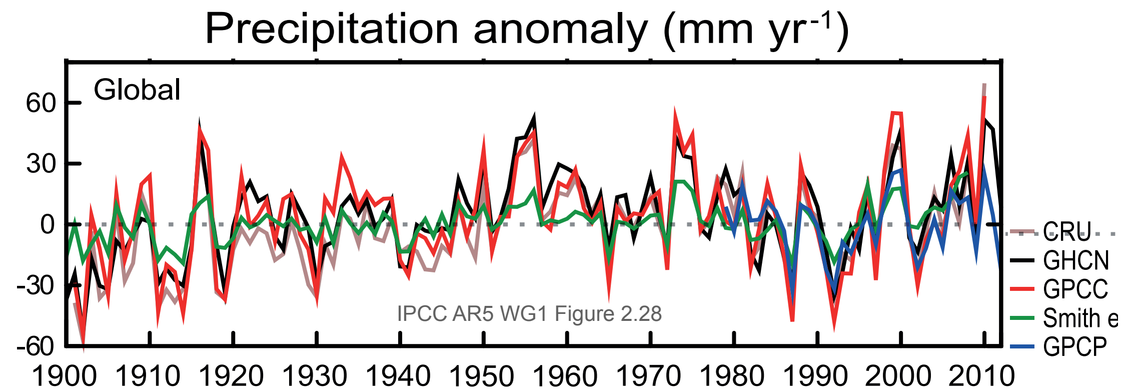
- 100,000 displaced, 5 deaths
- 2nd costliest (?) disaster event in Canadian history
- Estimated $5.7B USD loss ($1.65B USD insured)

Calgary East Village (June 25, 2013), courtesy Ryan L.C. Quan

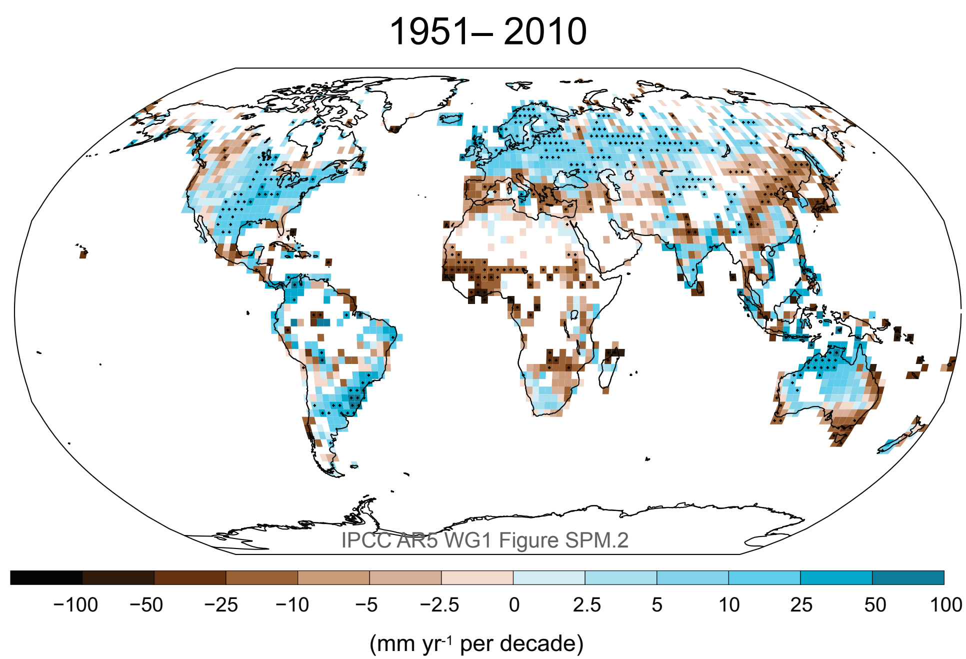
Observed changes

Changes in mean precipitation

Global mean anomaly in annual accumulation

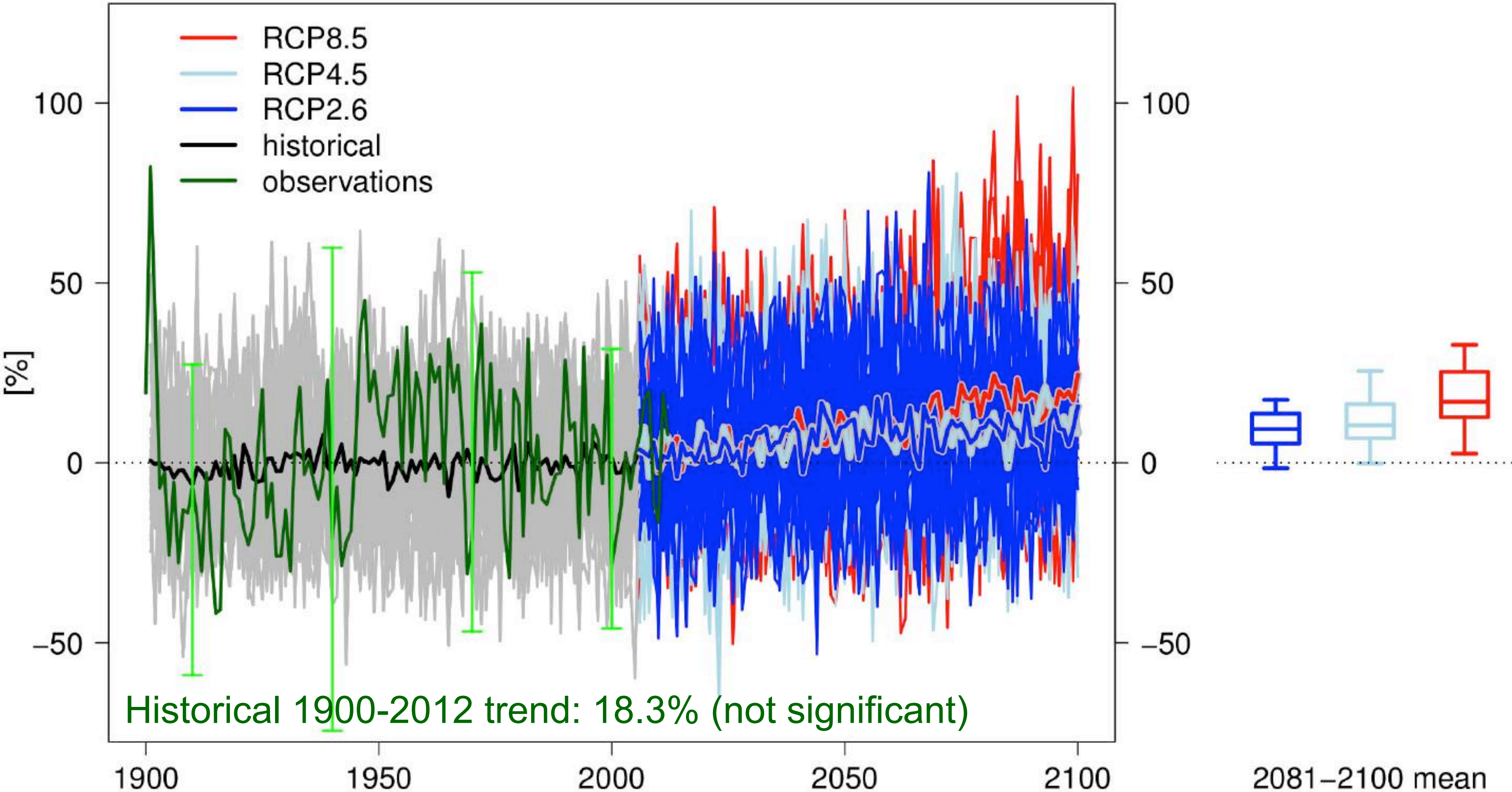


Trend in annual accumulation (GPCC)



Historical and future changes in BC - Winter (DJF)

Precipitation change relative to 1986-2005

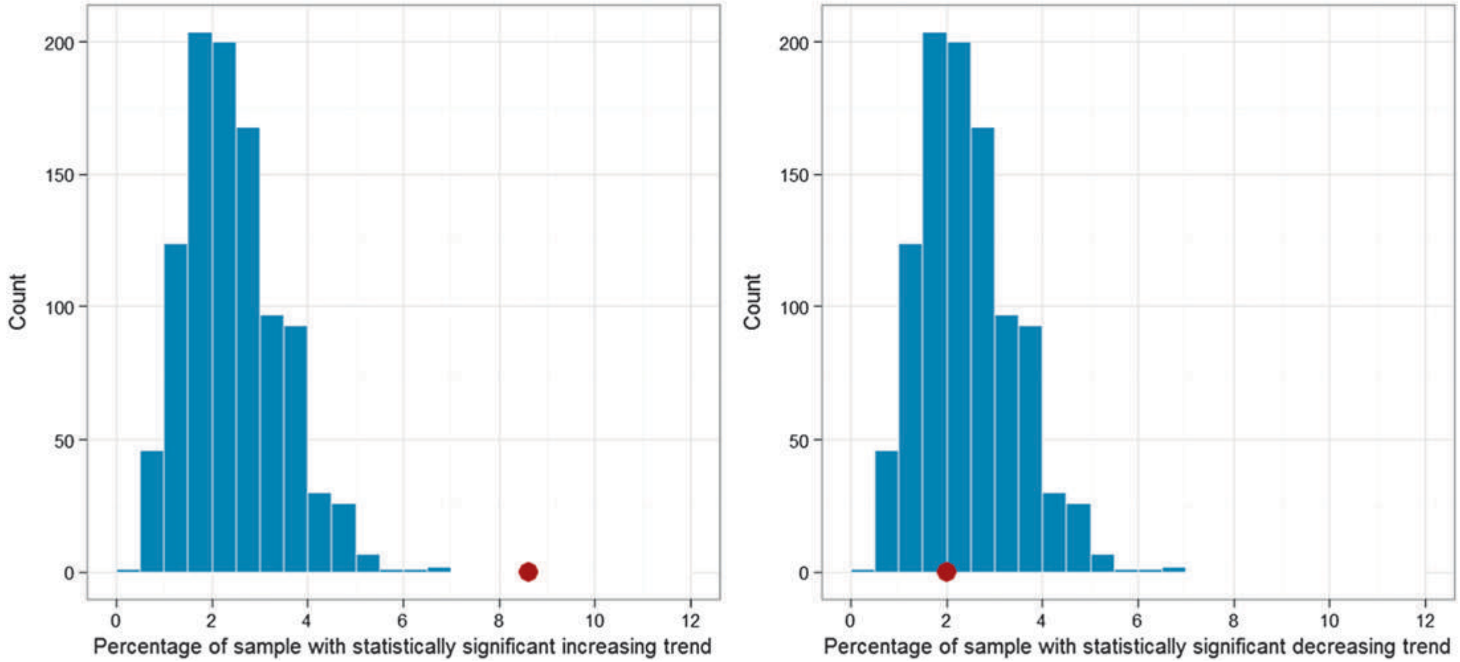


Changes in mean precipitation

- Overall, uncertain due to the state of the data
- Do have several studies that indicate there has been human influence on the distribution of precipitation at very large scales
- Provides some basis for thinking there might also be discernable changes in extremes (since to zeroth order, precipitation variability is proportional to the mean)

Annual maximum 1-day precipitation trends, 1900-2009

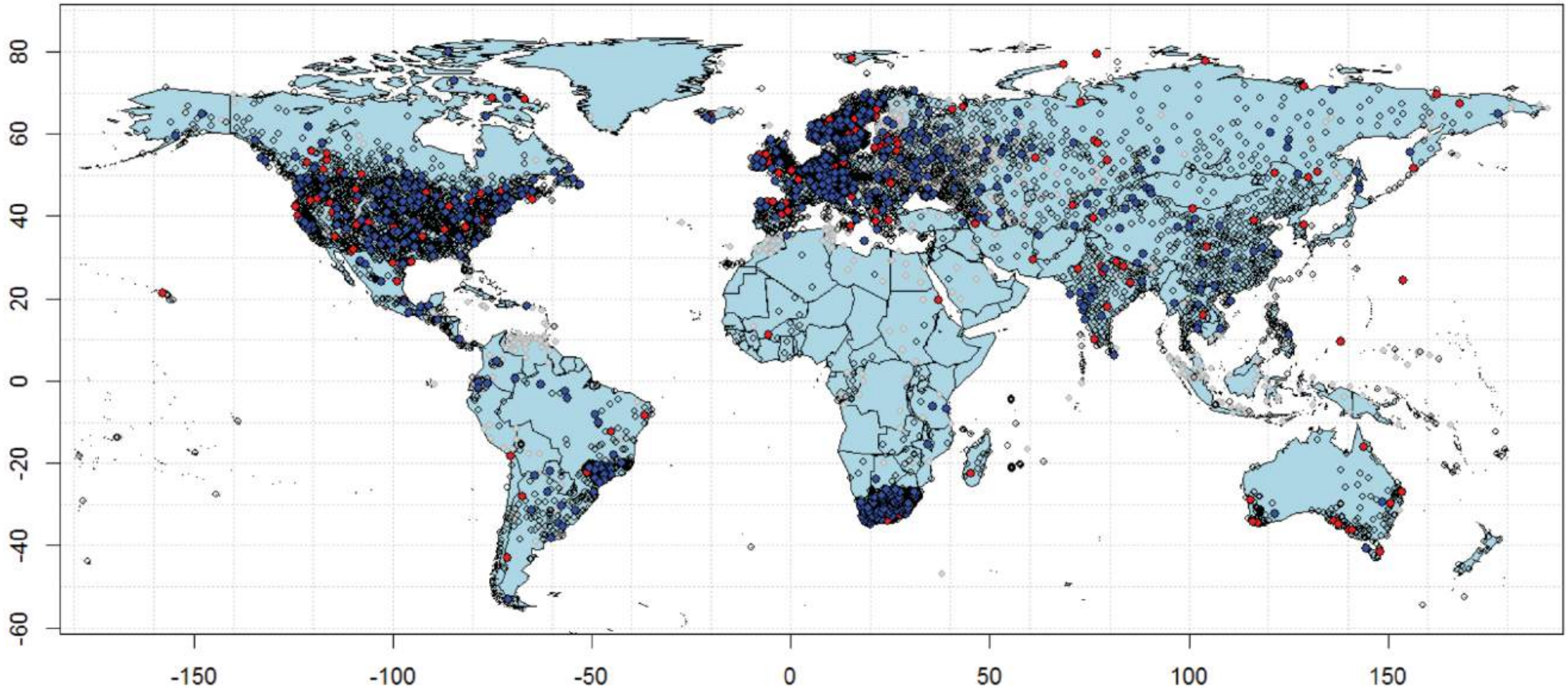
Percentage of significant Mann-Kendall trend tests based on 8376 GHCN-D stations with 30-years or more data (median length 53 years)



Westra et al 2013, Fig. 3

- Tests conducted at the 5% level (two sided)
- 8.6% showed significant increasing trends (red dot, left)
- 2.0% showed significant decreasing trends (red dot, right)
- Increasing trends substantially more frequent than expected by random chance (blue bootstrap distributions for rejection rate).

Assessment of association between annual maximum 1-day precipitation and global mean temperature

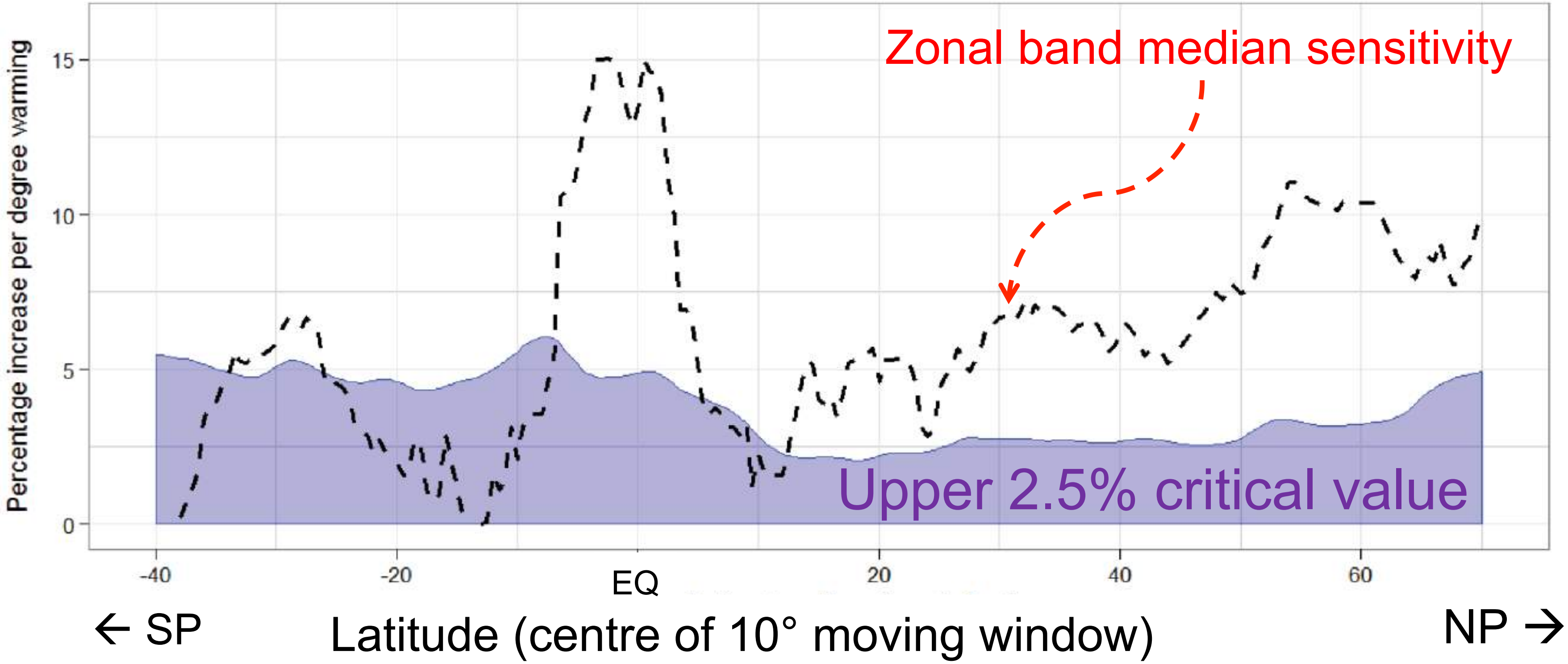


- 8376 stations with > 30 yrs data, median length 53 yrs
- Significant positive (10.0% of stations, expect 2.5%)
- Significant negative (2.2% of stations, expect 2.5%)
- Estimate of mean sensitivity over land is ~7%/K

Westra et al (2013, Fig. 5)

Link with global mean temperature

- Use global mean temperature as a covariate in an extreme value analysis using the GEV distribution
- 64% of locations show a positive association
- Estimate of mean sensitivity over land is ~7%/K



Westra et al (2013, Fig. 5)

IPCC assessment of changes in extremes

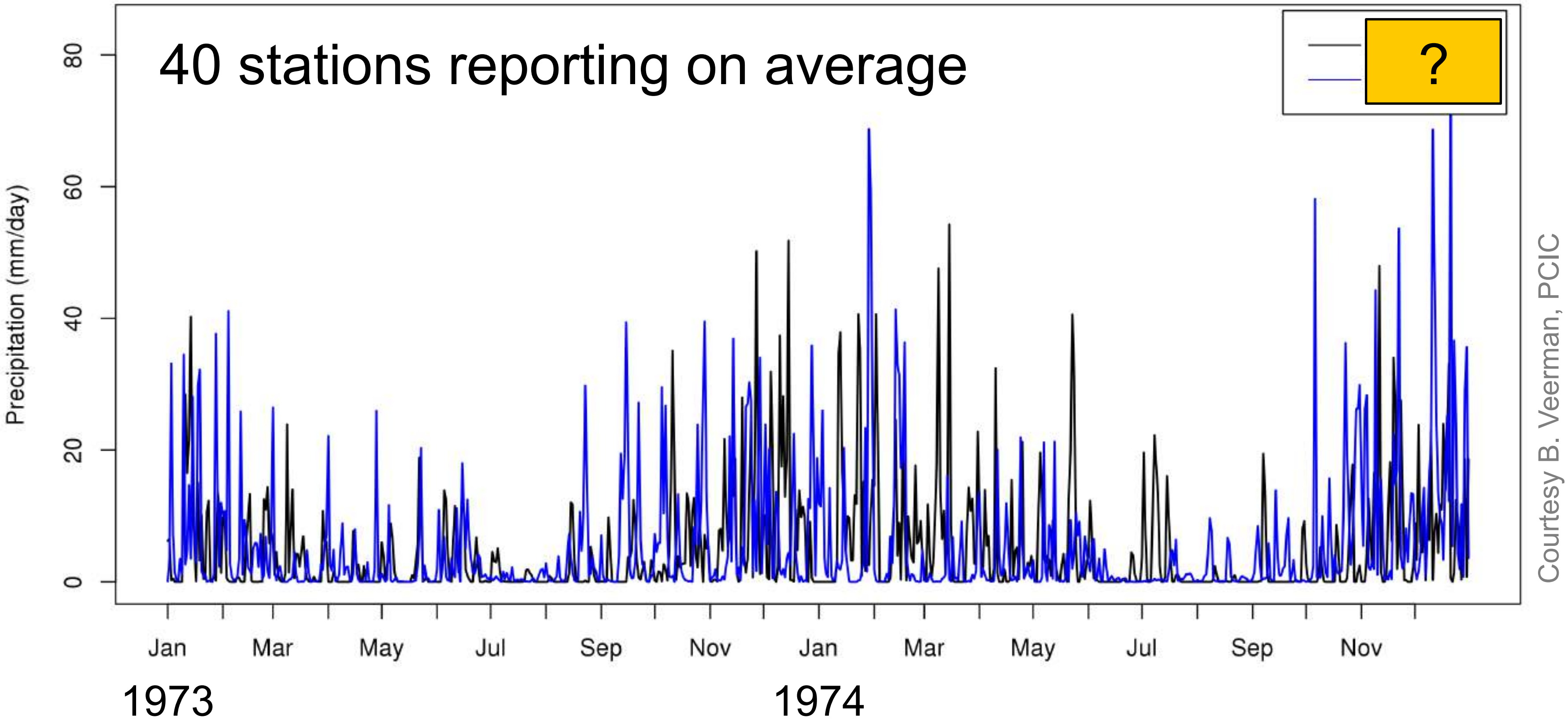
- Heavy precipitation:
  - Frequency has *likely* increased in more land regions than where it has decreased.
- Intensity of heavy precipitation:
  - Confidence varies regionally, *very likely* has intensified in North America.

IPCC WG1 AR5 Table SPM-1

Model assessment

Photo: F. Zwiers

Mean daily precipitation in the MIROC4h grid box centered on 49.1N, 123.2W (Vancouver)



For some evaluation of CMIP5 models wrt precipitation extremes see

- for indices, Sillmann et al (2013, JGR),
- for long-period return values, Kharin et al (2013, Climatic Change)

Detection of human influence

Photo: F. Zwiers

Detection and attribution

- Standard D&A paradigm involves 3 equations:

Observed change –

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

Simulated (multi-model) change due to i_{th} type of forcing –

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

Relationship between observed and simulated signals –

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

✸ Assumes residuals are Gaussian

Detection and attribution

- Adaptation to extremes
  1. Indices + standard paradigm
  2. Transform to a probability index + standard paradigm
     - Fit GEV distribution locally
     - Apply probability integral transform
  3. Use standard paradigm to make inferences about changing extreme value distribution parameters
  4. Include covariates in EV distribution parameters

http://www.wcrp-climate.org/index.php/ictp2014-about

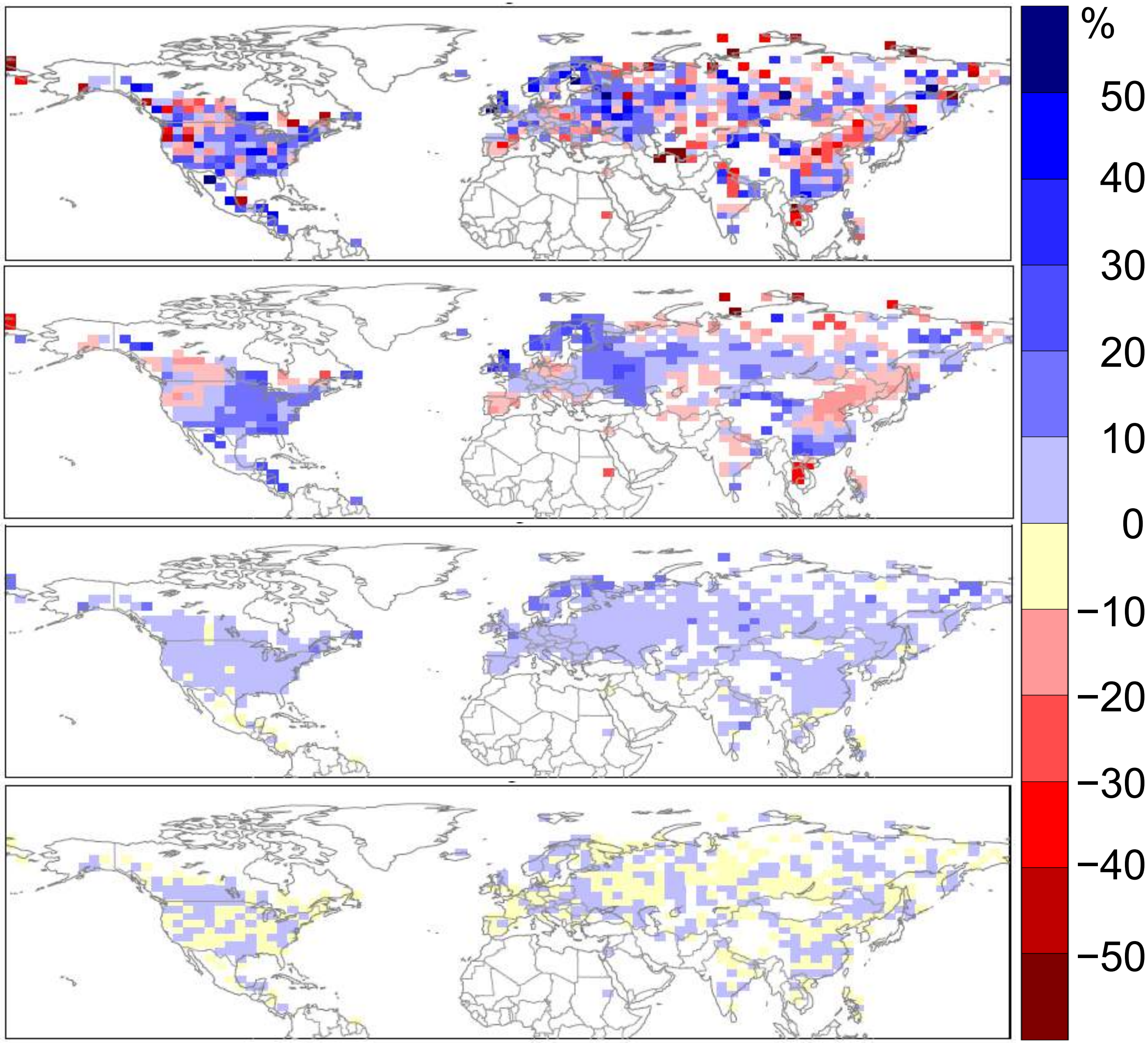
PI Trends (RX1D; 1951-2005)

OBS
(HadEX2 + Russia)

OBS
(Smoothed)

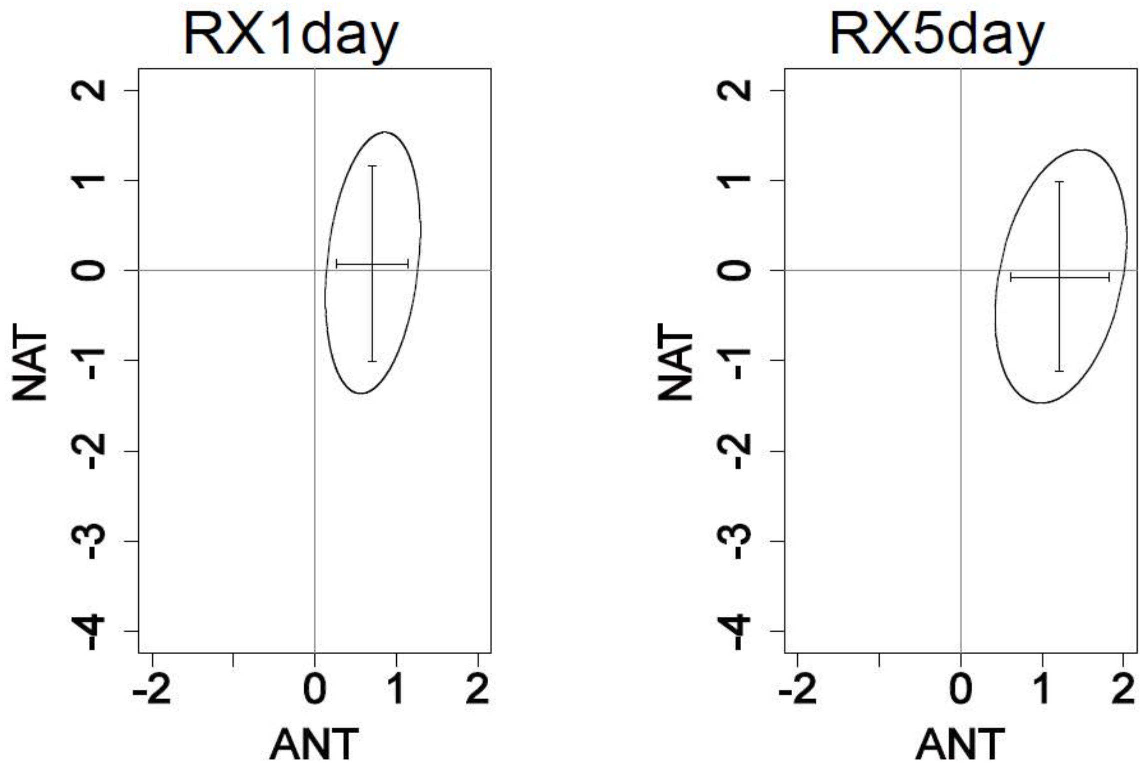
ALL

NAT



Zhang et al, 2013, GRL

Detection results – 1951-2005



Zhang et al, 2013, GRL

- Space-time (3 regions, 5 year means → 33-dim problem)
- 54 ALL runs (14 models), 34 NAT runs (9 models)
- No dimension reduction (>15000 years control, 31 models)

Interpretation

- Estimate PI for RX1day increased 4.0 [1.4 – 6.8]% over 1951-2005 *due to anthropogenic forcing*
- Implies
  - RX1day intensification of 3.3 [1.1 – 5.8] %
  - Sensitivity of 5.2 [1.3 – 9.3] %/K
  - Waiting time for early 1950's 20-year event reduced to ~15 years
  - Fraction of Attributable Risk ≈ 25%
- For extremes
  - Primary response appears to be thermodynamic
  - Station data do not allow us to see a dynamic response
  - Offsetting effects of GHGs and aerosols may be too subtle to detect with current methods

IPCC attribution assessment (AR5)

- It is *very likely* that anthropogenic forcing has contributed to the observed changes in the frequency and intensity of daily temperature extremes on the global scale since the mid-20th century.
- There is *medium confidence* that anthropogenic forcing has contributed to a global-scale intensification of heavy precipitation over the second half of the 20th century in land regions.
- There is *low confidence* in attributing changes in drought, tropical cyclone.

IPCC WG1 AR5 Table SPM-1

Practical applications:
Engineering design values

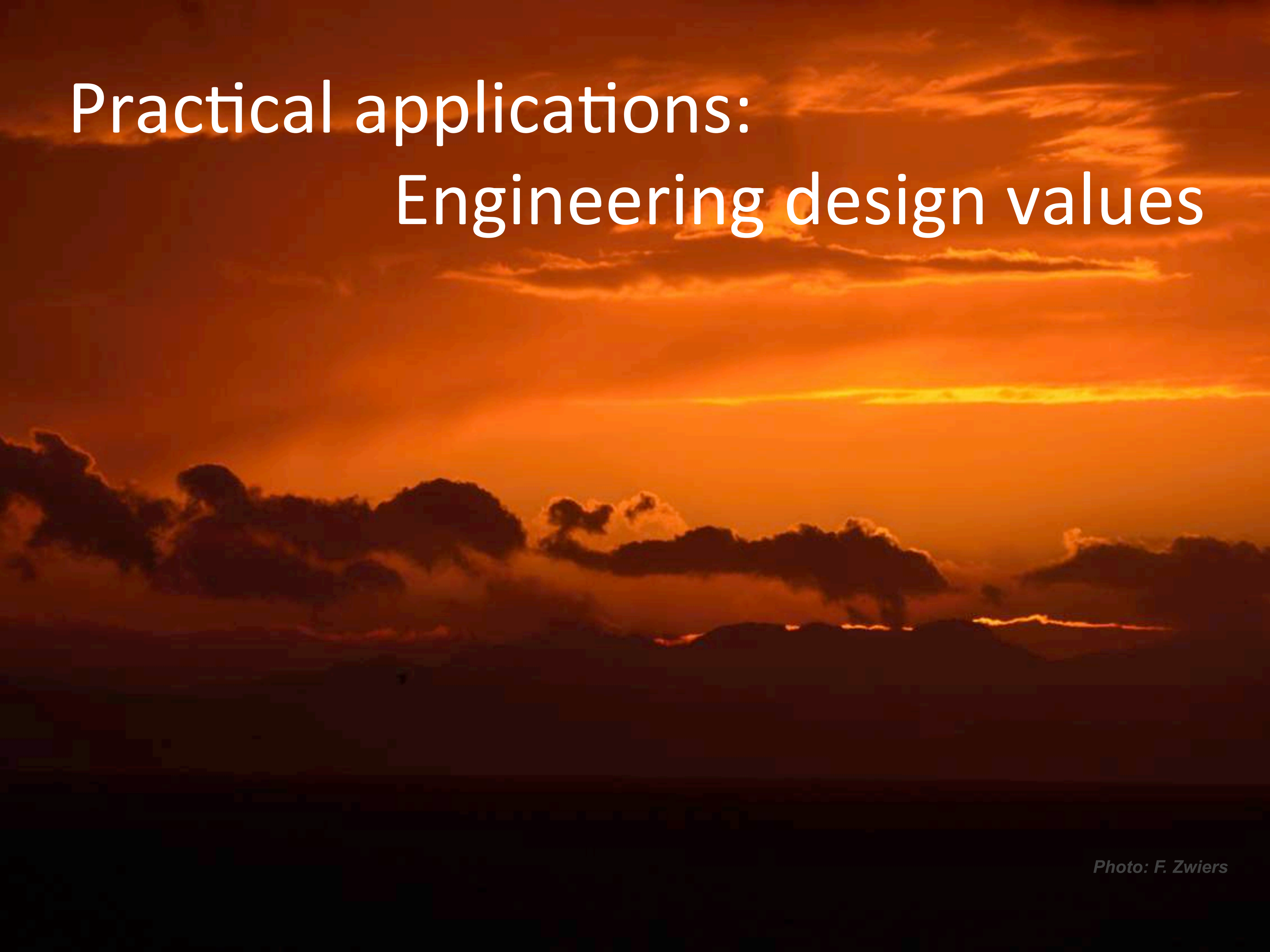


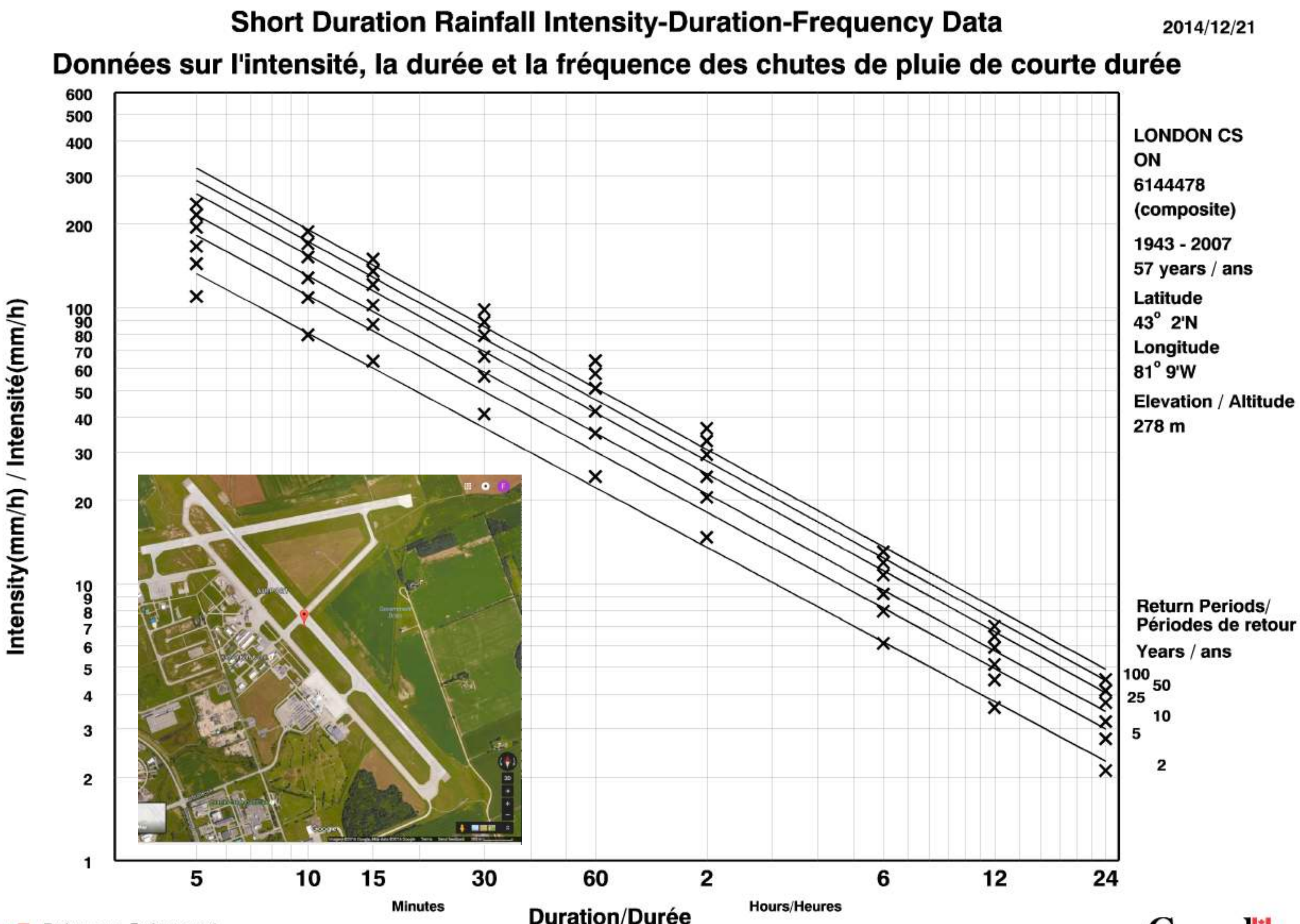
Photo: F. Zwiers

Engineering design values

- IDF curves
  – Typically calculated locally assuming stationarity
  – A collection of curves for different return periods that describe expected intensities as a function of accumulation period (from 5 minutes to 24 hours).
  – Sometimes exploit empirical scaling between extremes of daily accumulation and sub-daily accumulations
- PMP
  – Engineering concept used to ensure dam safety
  – Used to estimate maximum water input into a reservoir
  – Calculation often involves maximizing the product of precipitable water and precipitation efficiency within a given storm domain

IDF curve example – London CS

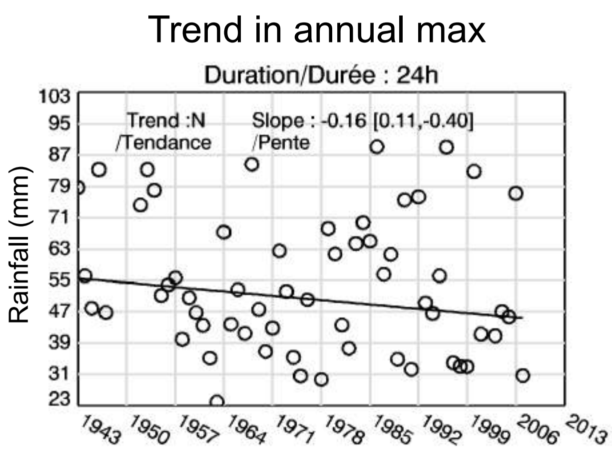
CS = Composite Station

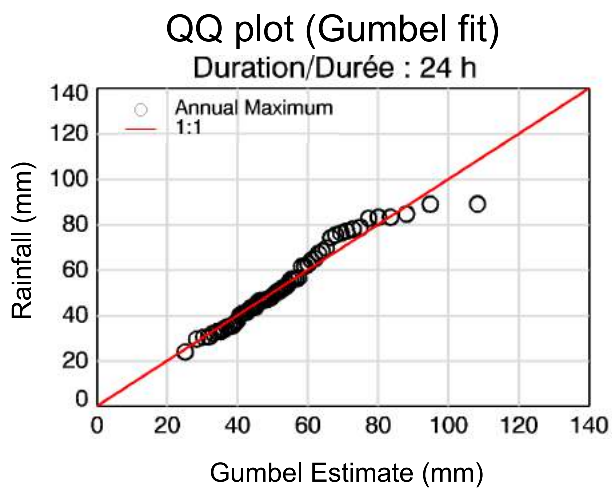


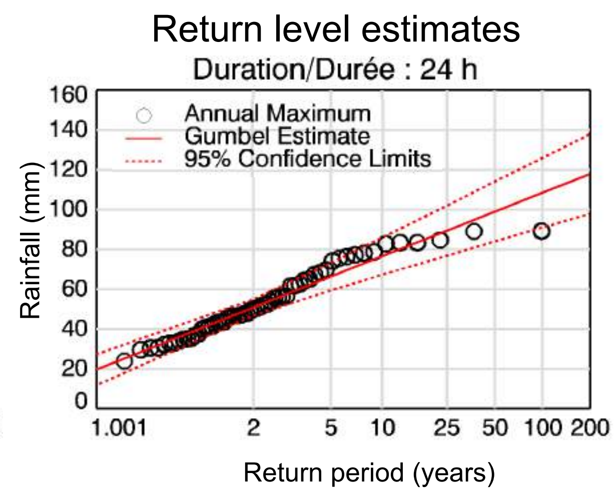
Environment Canada Environnement Canada

Canada

IDF curve diagnostics – London CS







- Trend not statistically significant
- Gumbel fit “reasonable”, but fitted distribution seems to have a heavier tail than observed
- Contrary to the general observation that observed precipitation is mildly heavy tailed
- Possible artefact of a composite station?
- Fit seems better at shorter accumulations

A few of the many research questions

- How do we account for nonstationarity?
- How do we borrow information from nearby locations?
- Do climate models reproduce observed heuristic scaling relationships between precipitation extremes at different accumulations?
- At what space and time scales can we reliably exploit scaling between precipitation and other better understood and simulated variables (e.g., temperature)?
- Will scaling relationships change in the future?
- Can temperature scaling be used
  - to predict sub-daily extremes at locations without sub-daily data
  - to project future changes in sub-daily extremes?
- Can we provide a firm statistical footing for the calculation of PMP to enable reliable uncertainty estimation?
- How should the practitioner community design for changing risks – and whose interests should they protect in doing so?

“Binning” scaling

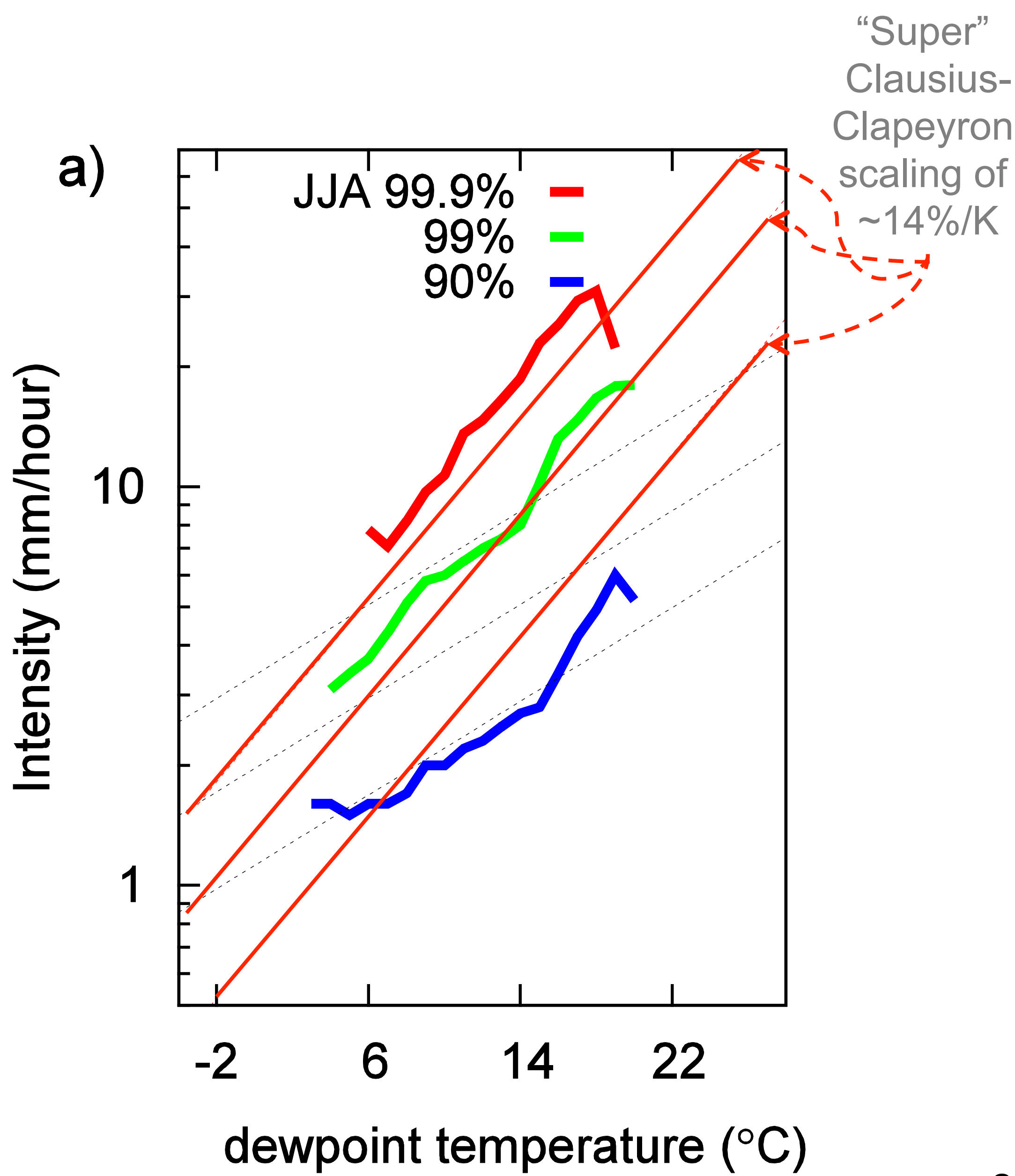
Photo: F. Zwiers

Binning Scaling

Idea:

Find a relationship between high *conditional percentiles* of hourly precipitation and the conditional wet-day mean dew point temperature

- Known as the “binning method” of Lenderink and van Meijgaard, 2008
- Bins are usually 2°C wide
- Example to right is for 5 stations in the Netherlands



Binning scaling

- Does it provide a reliable means for projecting change in sub-daily precipitation extremes?
- Binning sensitivity seems to contradict
  - Observed and projected long-term changes in daily extremes (first part of the talk; ~7%/°C)
  - Observed relationship between annual max hourly extremes and antecedent dew point temperature (significant and ~6-7%/°C as opposed to 14%/°C)
  - Observed long term trends (or lack there of) in wet-day dew point temperature (significant) and annual max hourly precip extremes (not significant)

Summary/Discussion

Photo: F. Zwiers

Discussion

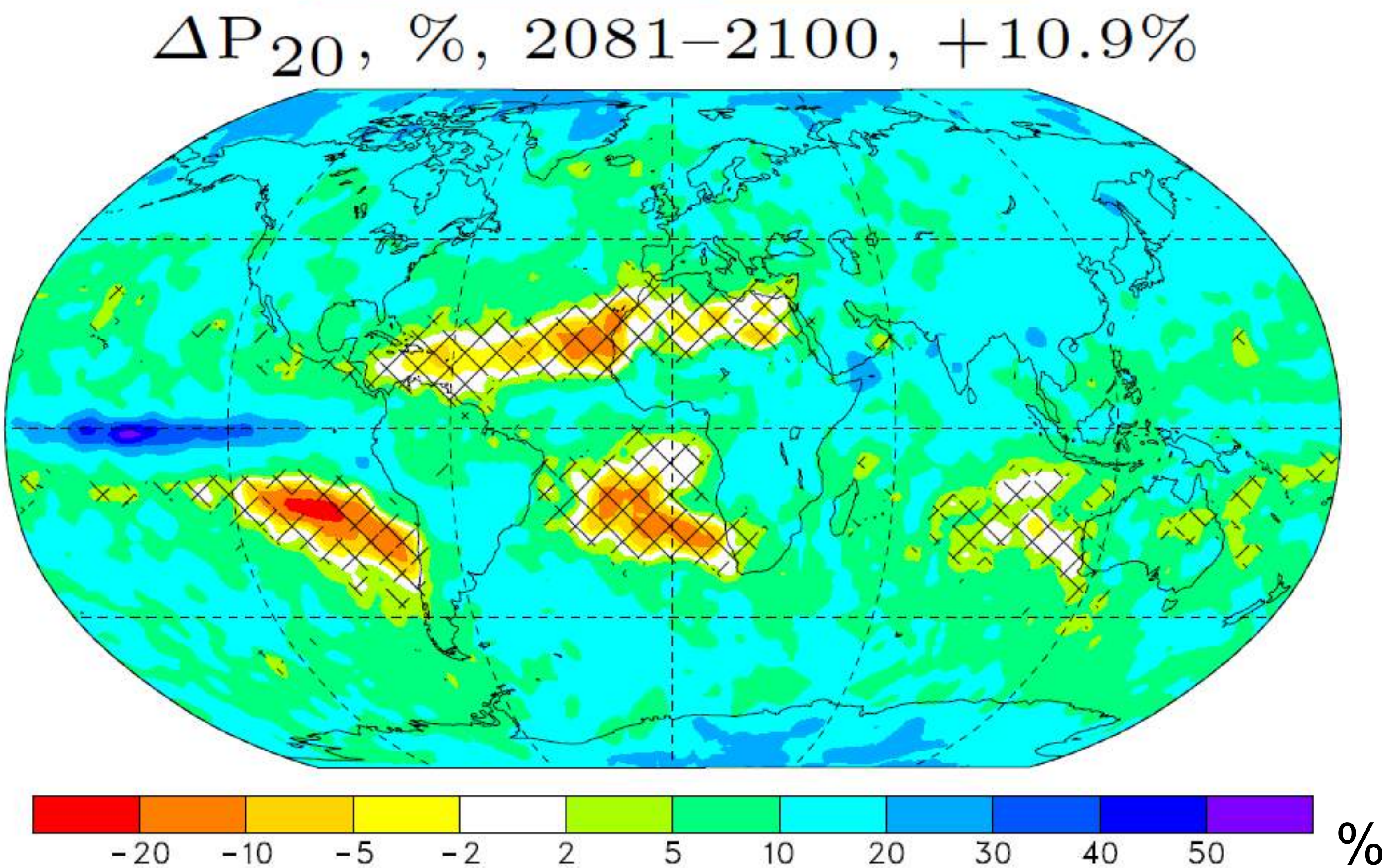
- Conditional percentiles are not annual extremes, and the annual extreme does not consistently occur at the same temperature
- Translating a statement about how a binning curve might change in the future into a statement about how annual extreme events (and thus risk) might change is non-trivial.
- No magic bullet – conservative advice to practitioners in the Northern mid-latitudes would be to use Clausius-Clapeyron or slightly higher.
- But this is still contingent upon having robust, reliable, IDF curves and PMP estimates for the current climate.

GCM based projections (if time permits)

Photo: F. Zwiers

CMIP5 RCP4.5 precipitation projections

Change in 20-yr extremes relative to 1986-2005

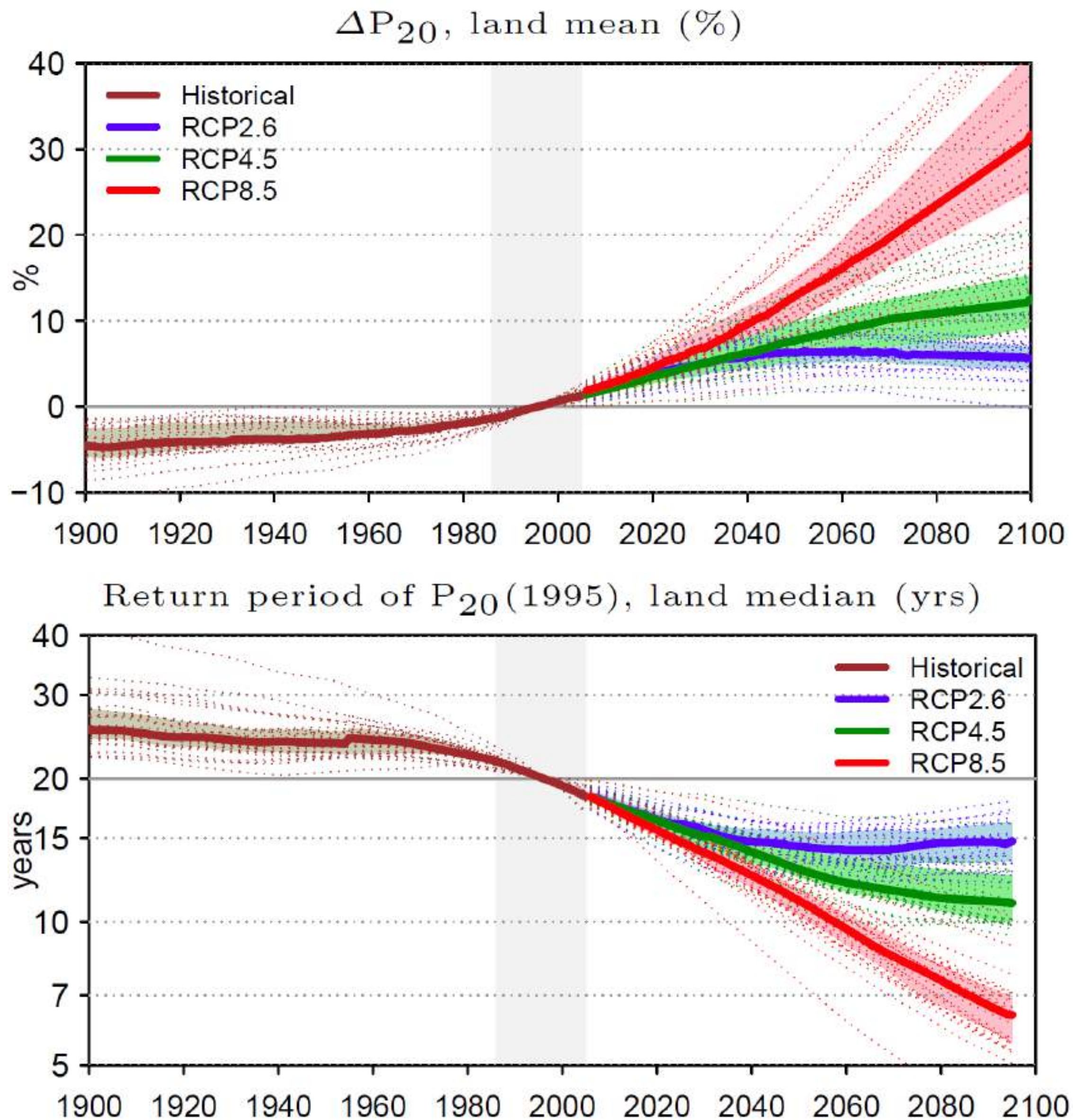


Kharin et al (2013, Fig. 4)

CMIP5 Projections of 20-yr 1-day events

Event magnitude
(relative to 1986-2006)

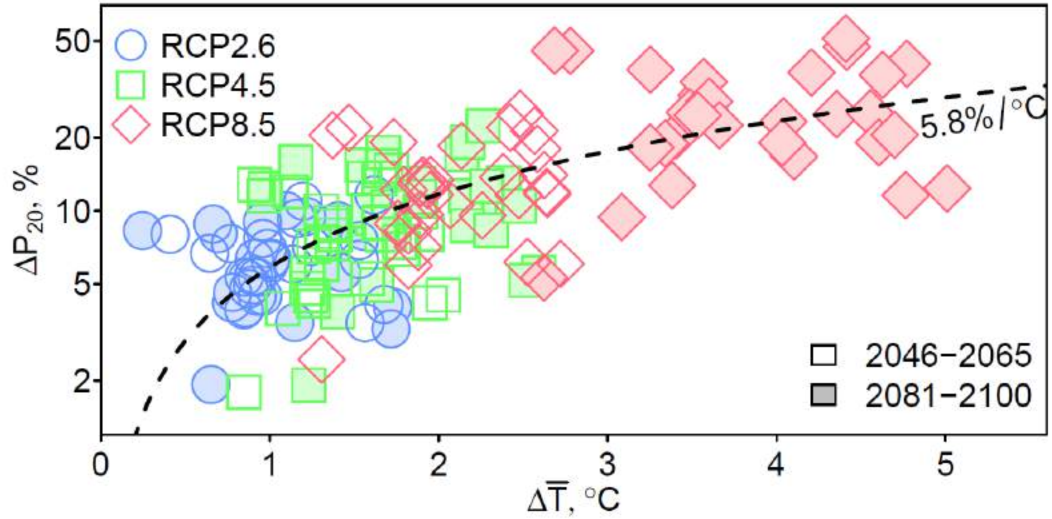
Return period
(relative to 1986-2006)



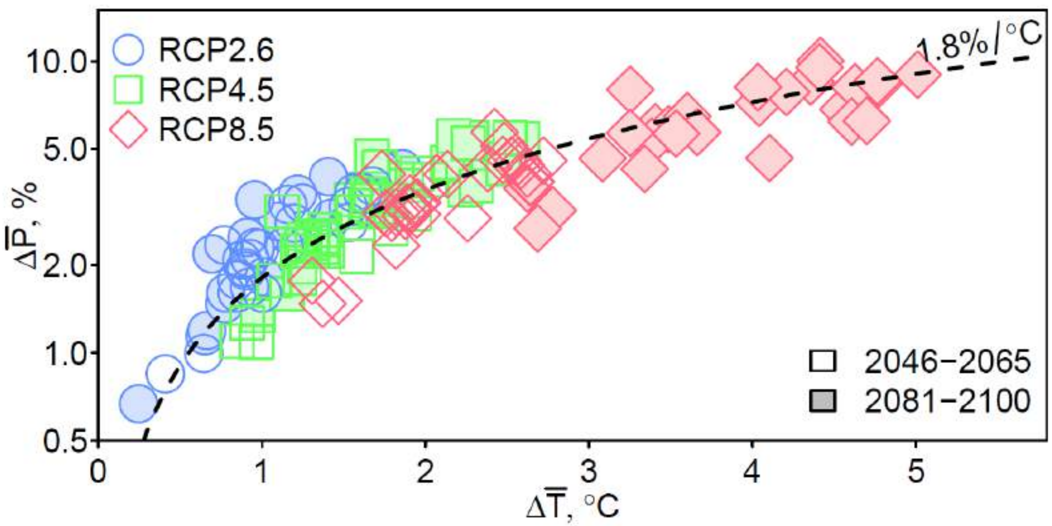
Kharin et al (2013, Fig. 2)

CMIP5 precipitation sensitivity

Planetary sensitivity of 20-year extremes



Sensitivity of global mean precipitation



Kharin et al (2013, Fig. 5)

Questions?

Photo: F. Zwiers