On the challenges and prospects of estimating past and future rainfall extremes

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Photo: F. Zwiers

Outline

- Recent status of science on precipitation extremes
  - Historical change
  - Projections based on global models
- The challenge of accounting for non-stationarity in local and regional engineering design
  - Binning scaling
  - Temperature scaling
- Review/discussion

- Additional topics – time permitting
  - Storms
  - Hydrological Cycle
  - Riverine Flooding

Historical Change

Photo: F. Zwiers

Precipitation extremes

- Observational studies suggest intensification is occurring
- Expectation of intensification is supported by attribution of
  - atmospheric warming
  - corresponding atmospheric water vapour content increase
  - large scale changes in mean precipitation
  - ocean surface salinity changes
- There are only a few “detection and attribution” studies of long-term changes in extreme precipitation
  - detect human influence at the ”global” scale
- Considerable challenges remain in understanding regional precipitation change (e.g., Sarojini et al., 2016)
- Local detection of change is very hard

Detection and attribution results

We can also detect the human influence on precipitation extremes over land:

- Climate models with anthropogenic external forcing intensify extreme precipitation similarly to observed
- Climate models with only natural external forcing do not intensify precipitation

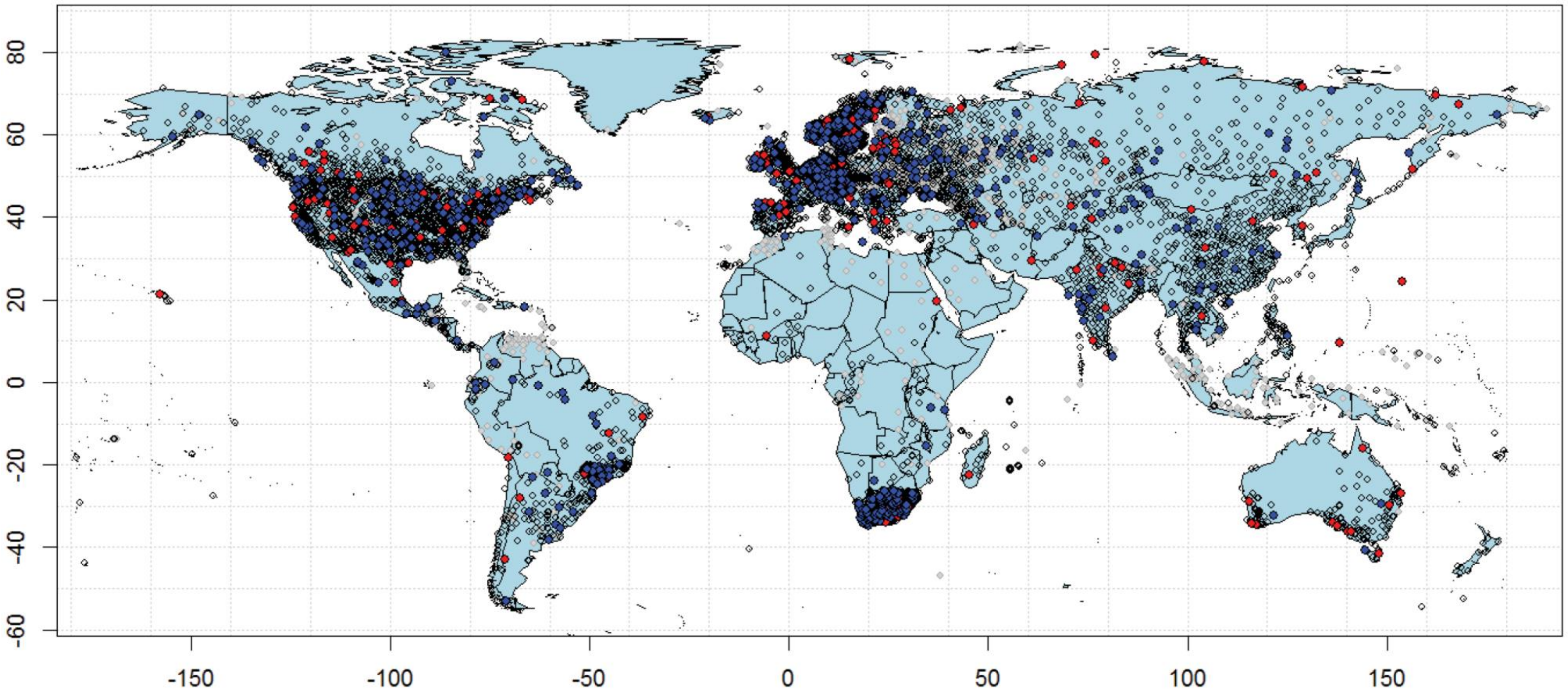
Attributed intensification in annual maximum 1-day precipitation:

- 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)

Local detection of change is very hard



- 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); see also Barbero et al., 2017 for a similar study of US data

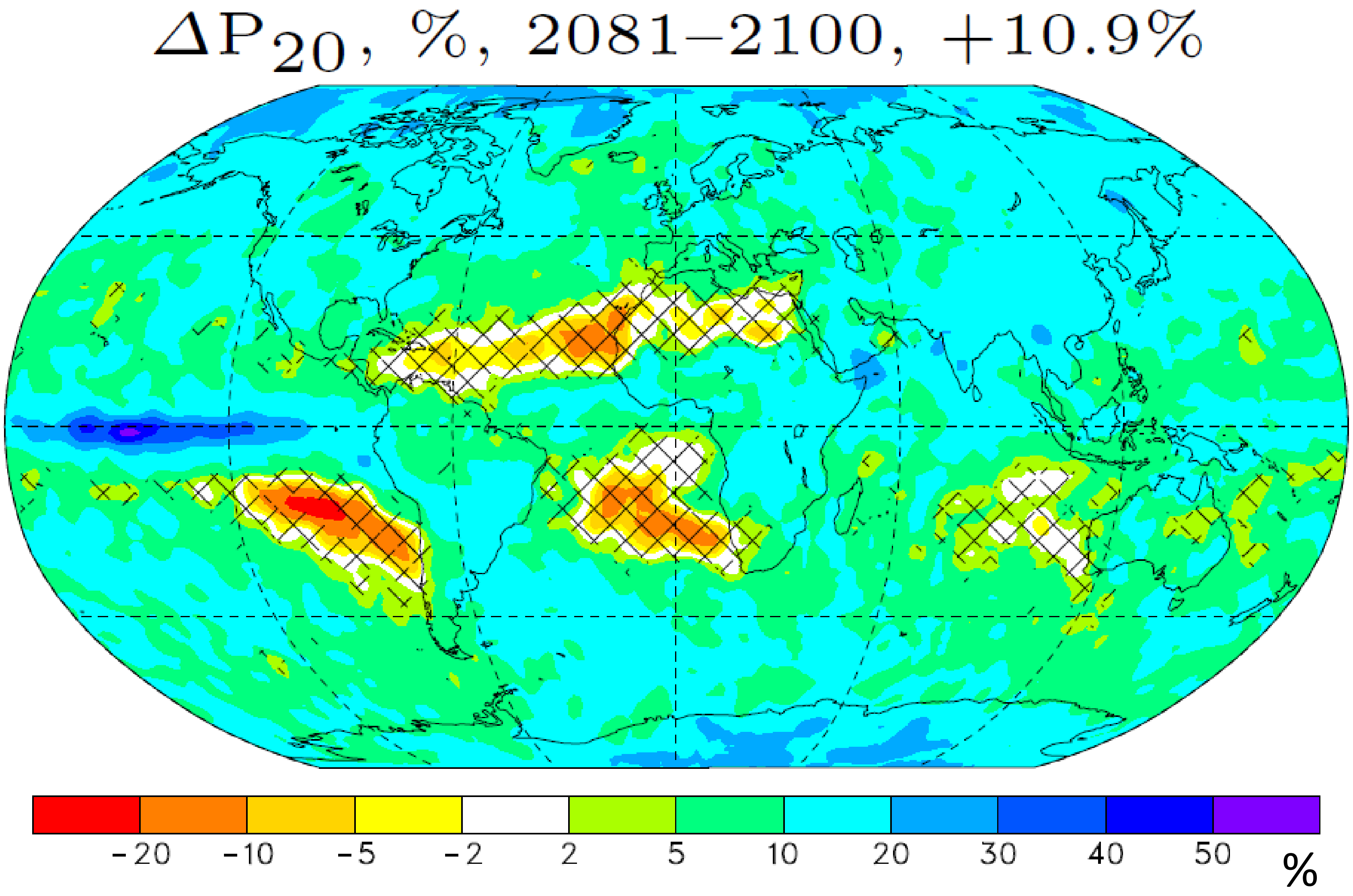
Projections

Photo: F. Zwiers

Projection of change in 20-year 1-day event

CMIP5 RCP4.5

Change in 20-yr extremes relative to 1986-2005

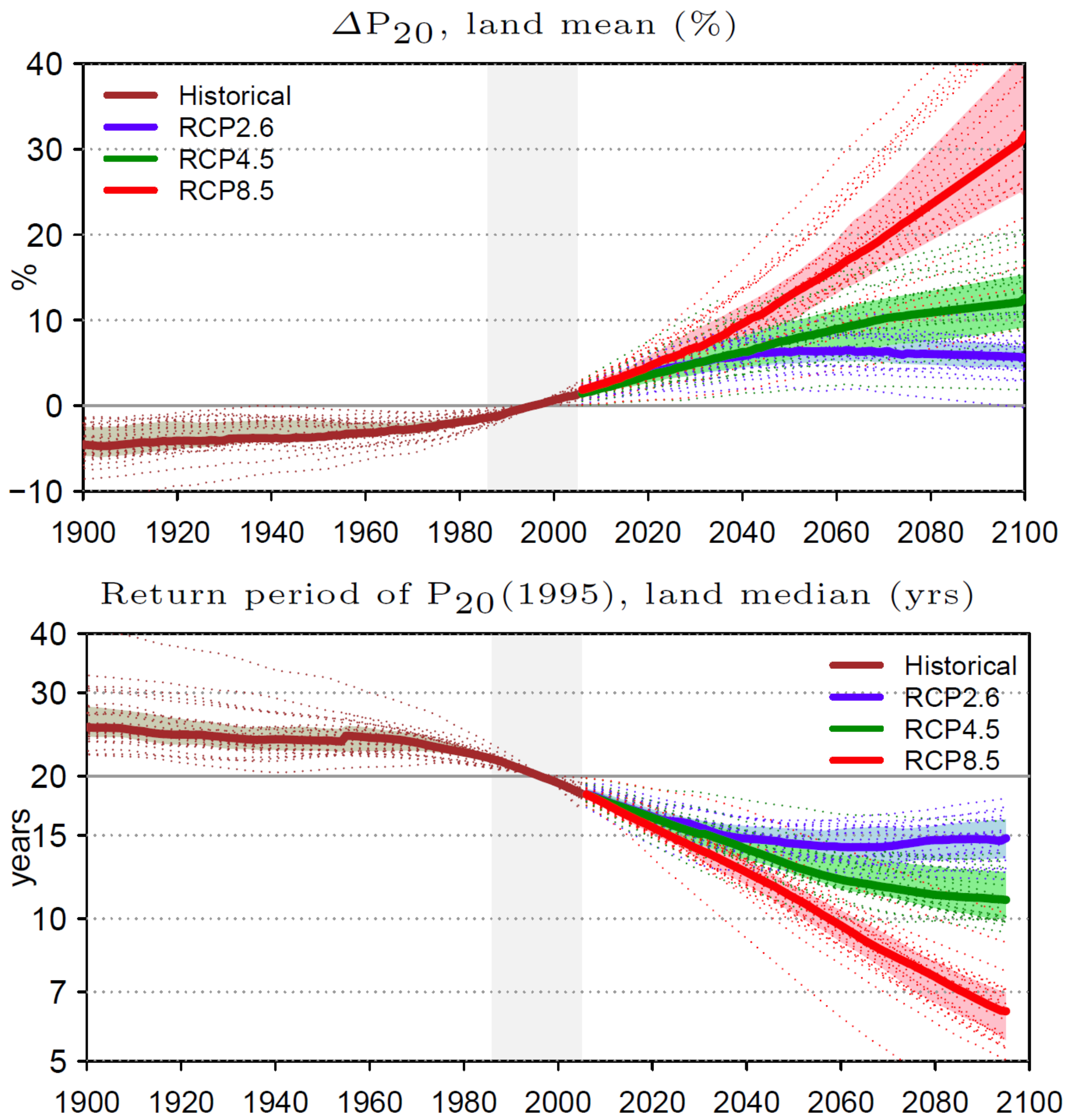


Kharin et al (2013, Fig. 4)

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)

Constraining local/regional precipitation change – a challenge

Photo: F. Zwiers

If you don’t trust models, can you use the observations?

- Two options considered in the literature include:

  a) Binning scaling, i.e., tabulating high percentiles of precipitation conditional on temperature

  b) Local/regional non-stationary statistical models, pooling information from similar location (e.g. using regional frequency analysis)

Binning scaling

Zhang et al., Nature Geo, 2017

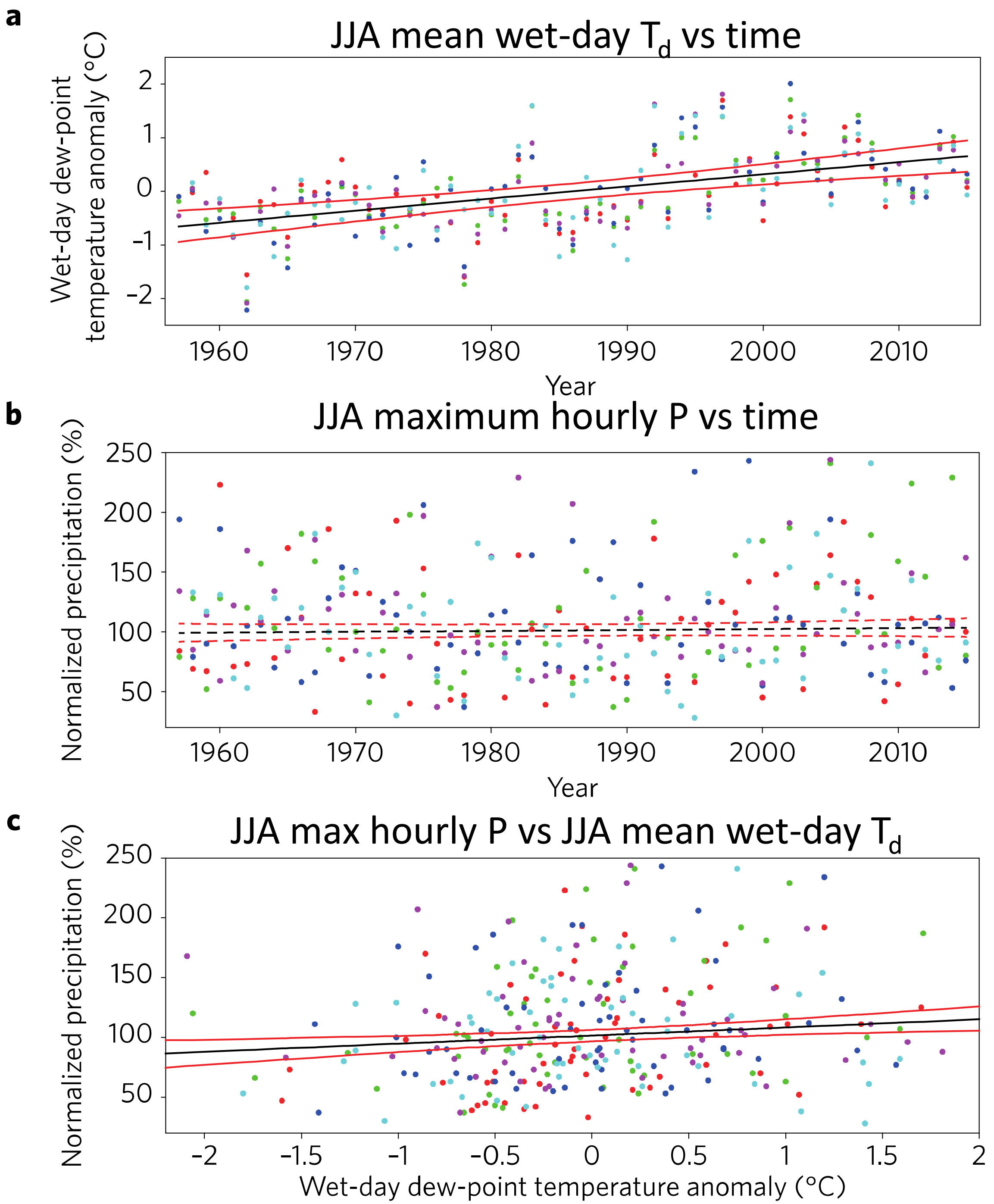
Photo: F. Zwiers

Dewpoint temperature (T_d) and hourly rainfall (P) at 5 stations in the Netherlands (1957-2015; colours indicate stations)

a) Significant warming

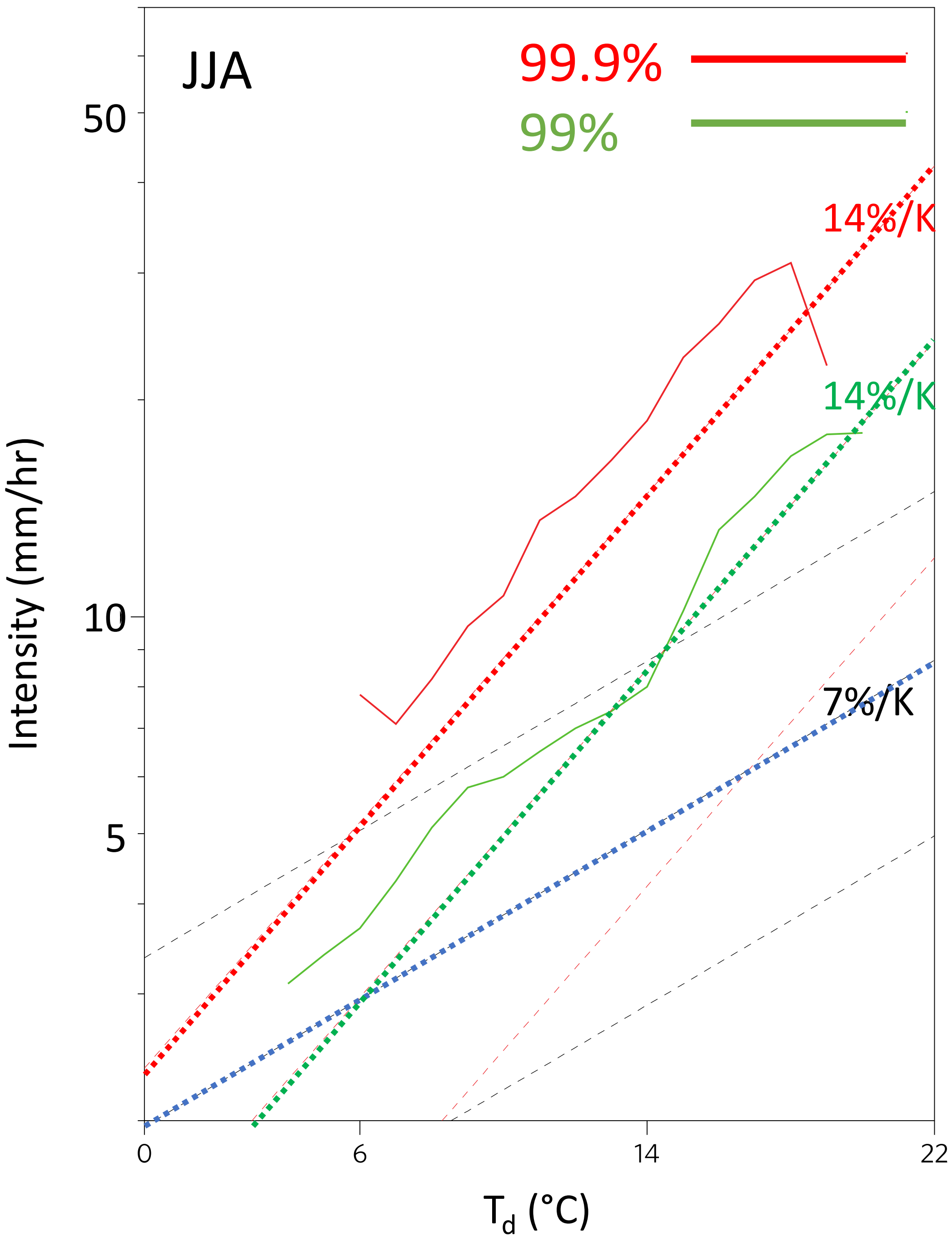
b) No discernable trend in extreme hourly P

c) Significant (but noisy) relationship between T_d and summer max hourly P (we estimate ~6.8% intensity increase for a 1°C increase in T_d)



Conditional hourly rainfall percentiles (conditional on wet-day T_d) at 5 NLD stations for 1957-2015

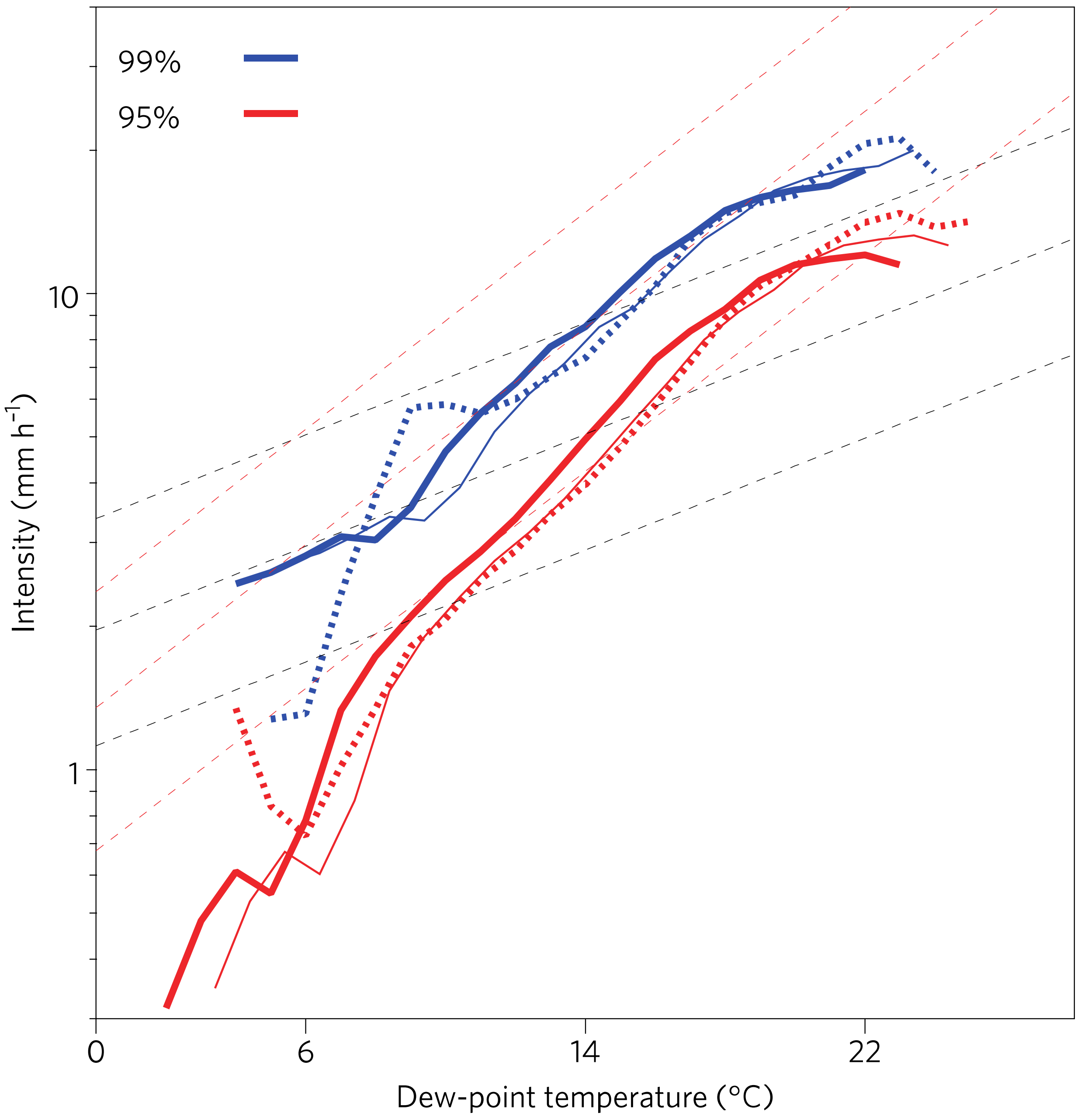
- Strong super Clausius-Clapeyron (CC) scaling is evident
- And warming is evident
- Why don't we see significant long-term change in extreme hourly precipitation?
- Can we use binning scaling to project future change in extreme hourly P?



Conditional hourly precipitation percentile in Rossby Centre RCM (ENSEMBLES)

- Thick curves – historical climate
- Dotted curves – future climate
- Thin curves – historical, scaled by CC rate

- Models shift the binning scaling curve upwards and to the right (at the CC rate)
- Annual or seasonal max precipitation increases at the CC rate where thermodynamics dominate
- Long return period extremes increase at the CC rate, not the super-CC rate



Temperature scaling using RFA

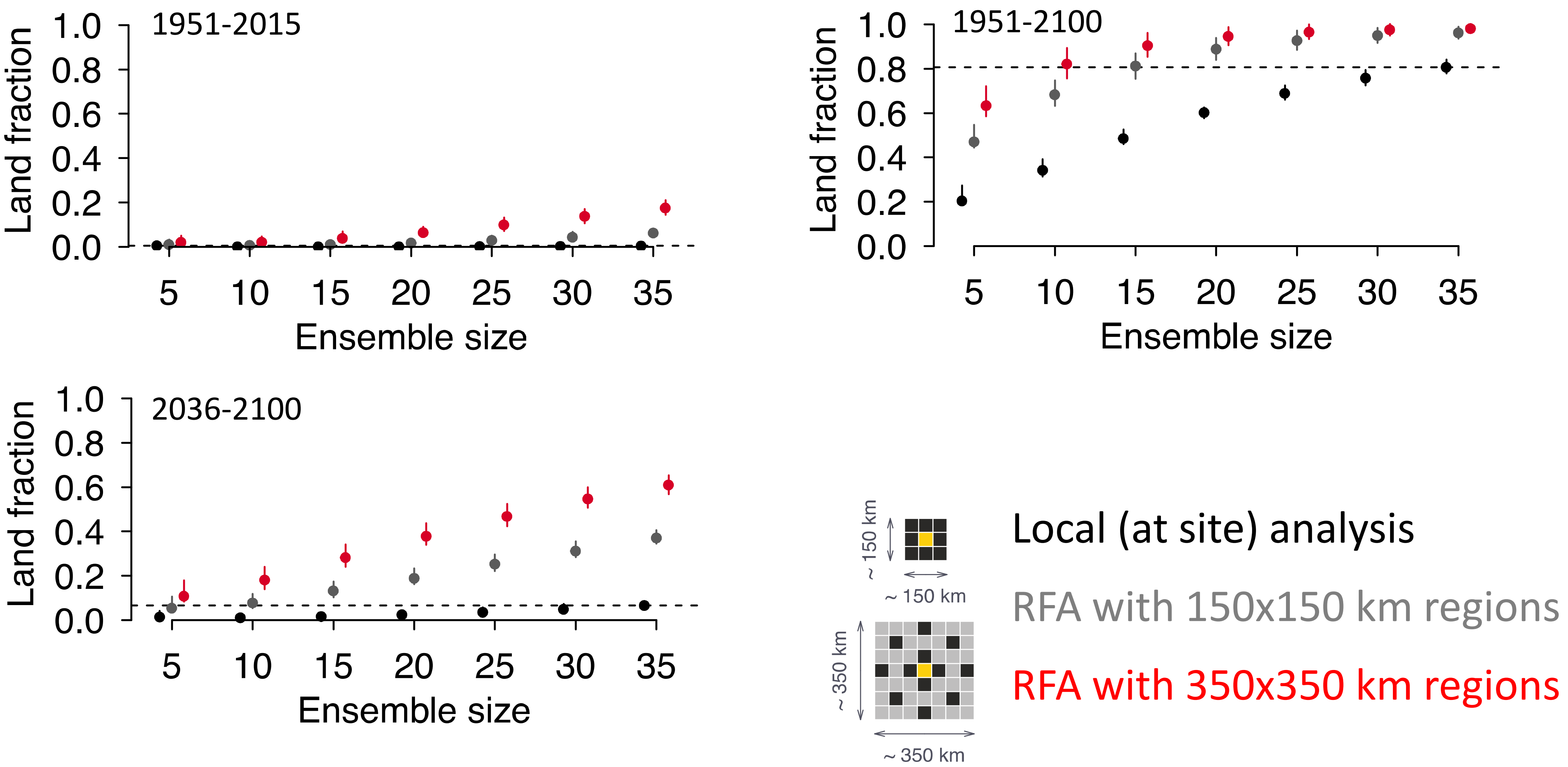
Chao Li, et al., in review

Photo: F. Zwiers

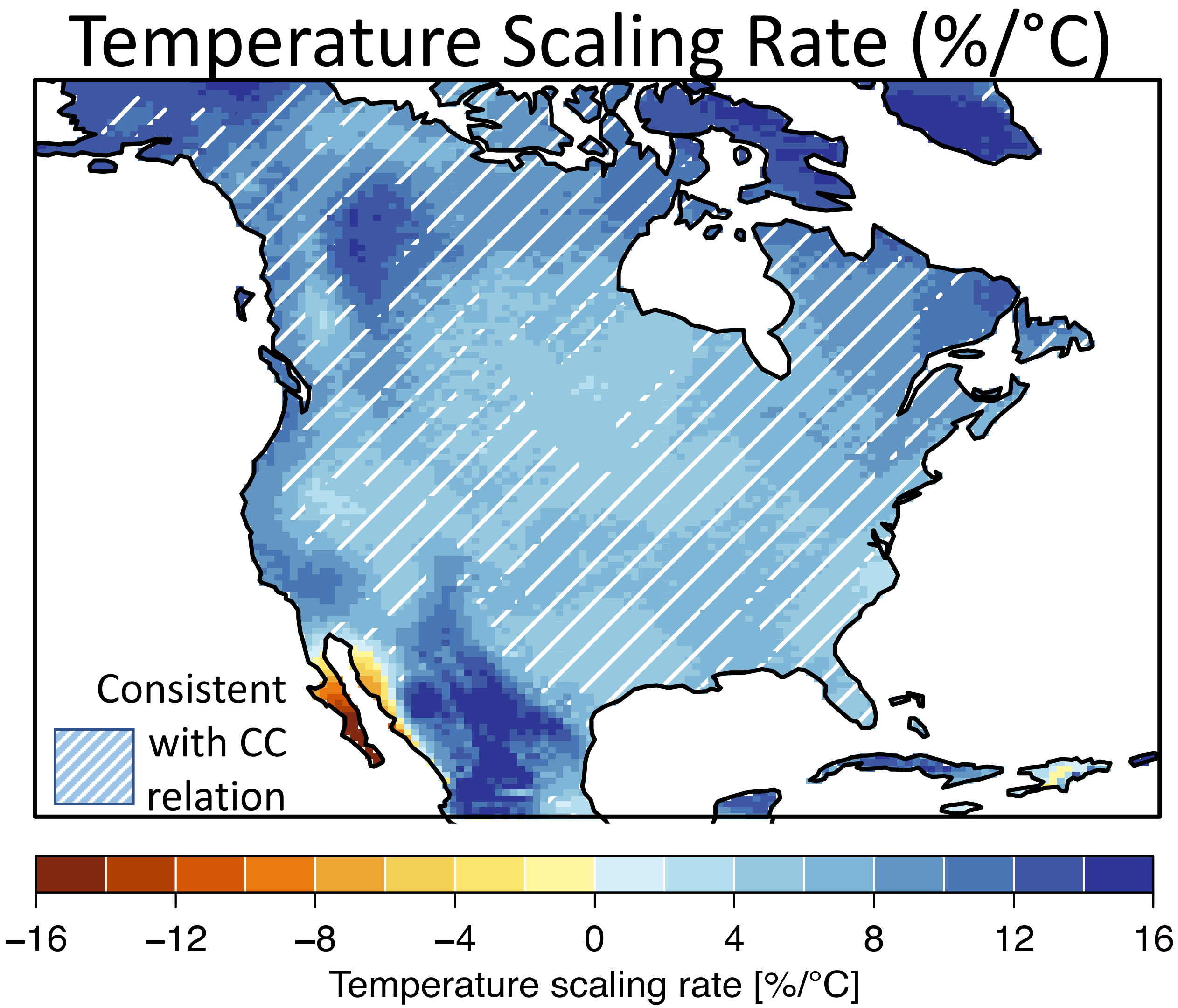
Questions and approach

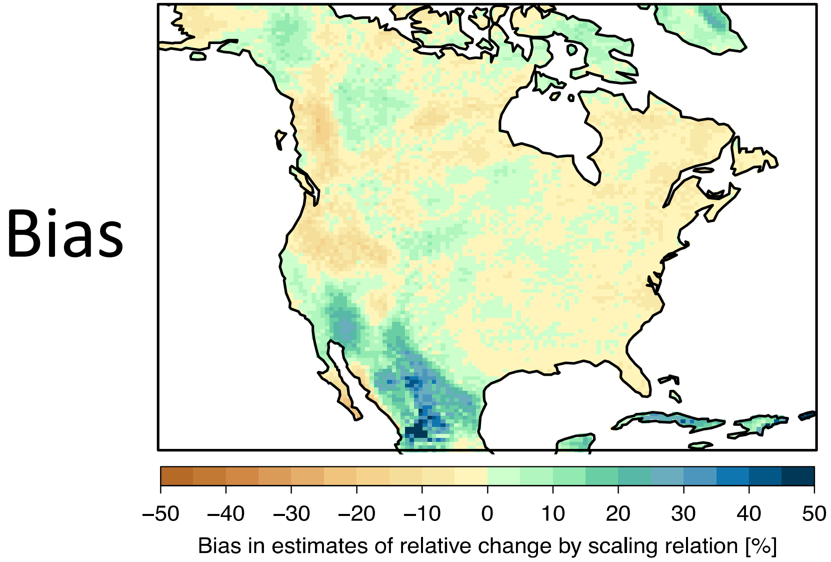
- Are individual, 65-year rainfall records sufficient to reliably estimate how extreme rainfall is changing with warming?
- If not, can some variant of regional frequency analysis come to the rescue?
- How much data is really needed to confidently identify the impact of warming?
- Framework for answering these questions
  - A large ensemble of 35 regional climate simulations for North America
  - Based on CanESM2/CanRCM4, 1951-2100, 50 km spatial resolution
  - Historical period (1951-2015) provides 35x65 = 2275 annual maxima
  - Entire period provides 35x150 = 5250 annual maxima
- Fit non-stationary statistical extreme value models at individual grid boxes and in 350x350 km regions (using the “index flood” approach)

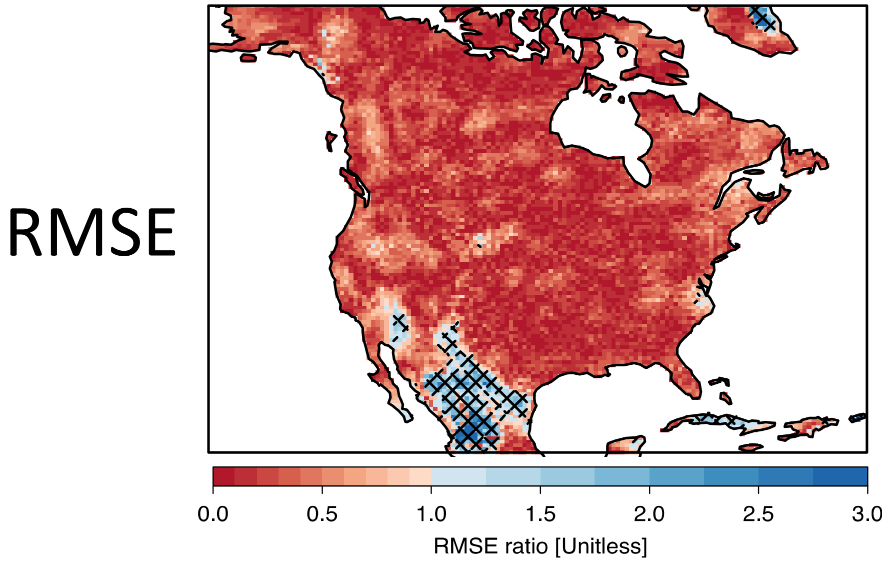
Proportion of grid boxes where the magnitude of the 100-year 1-hour event is well estimated by temperature



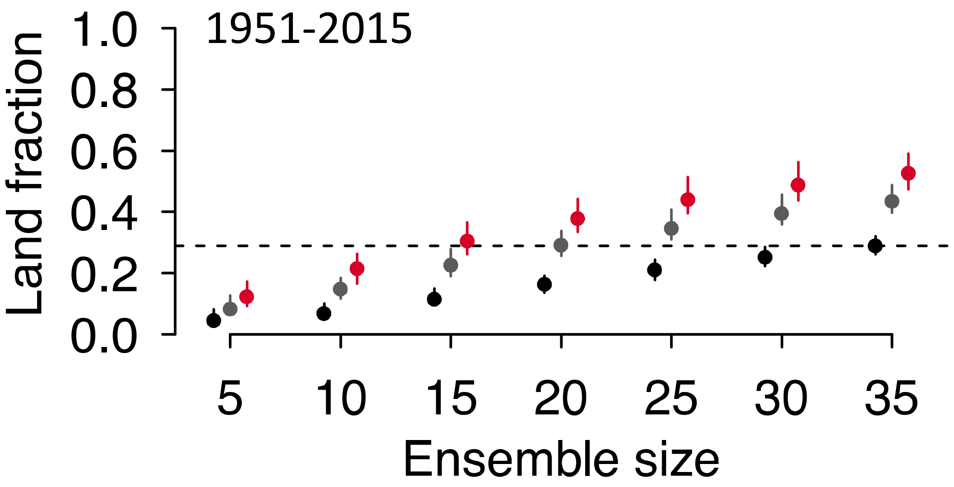
Results for 100-year annual maximum hourly rainfall

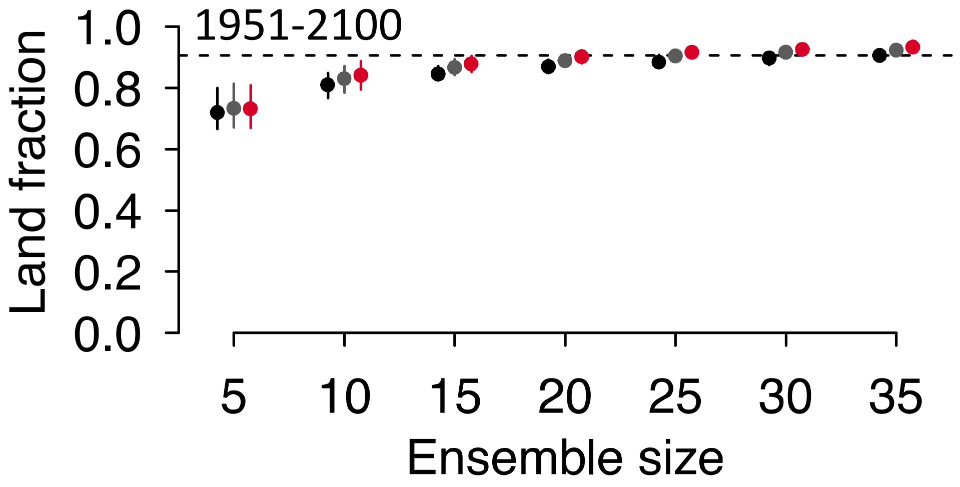


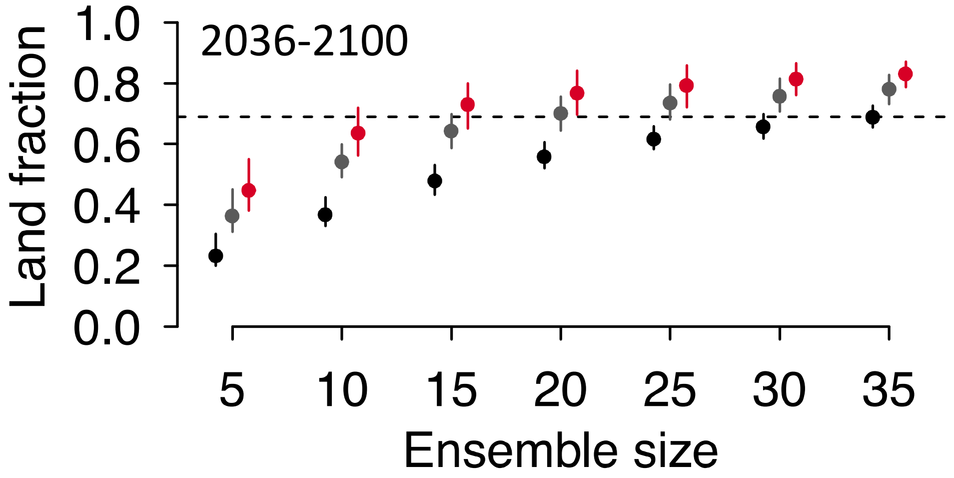


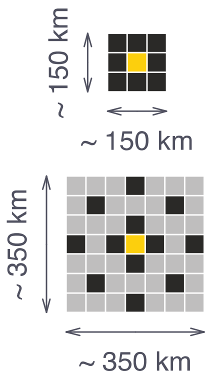


Proportion of grid boxes where the magnitude of the 2-year 1-hour event is well estimated by temperature







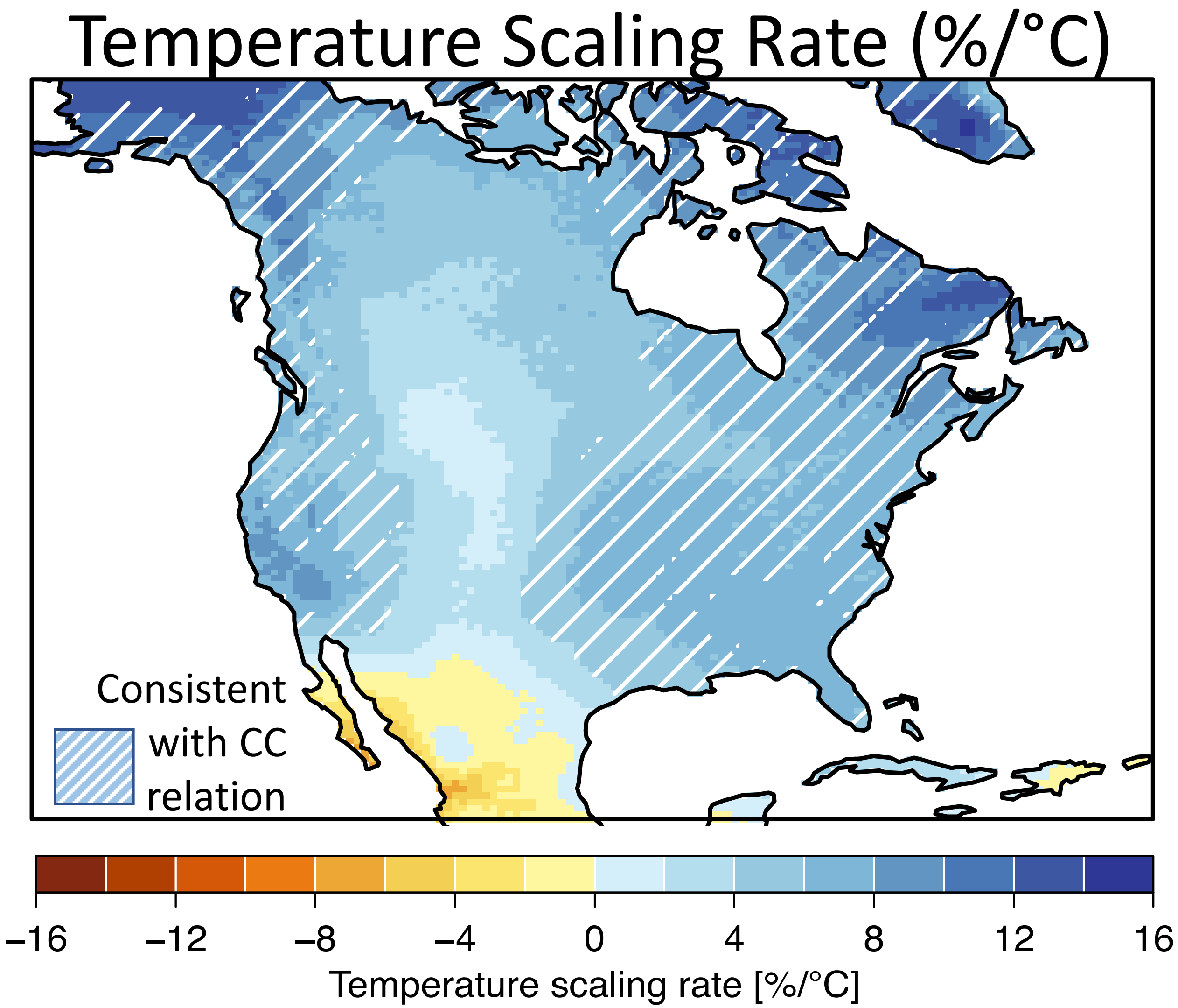


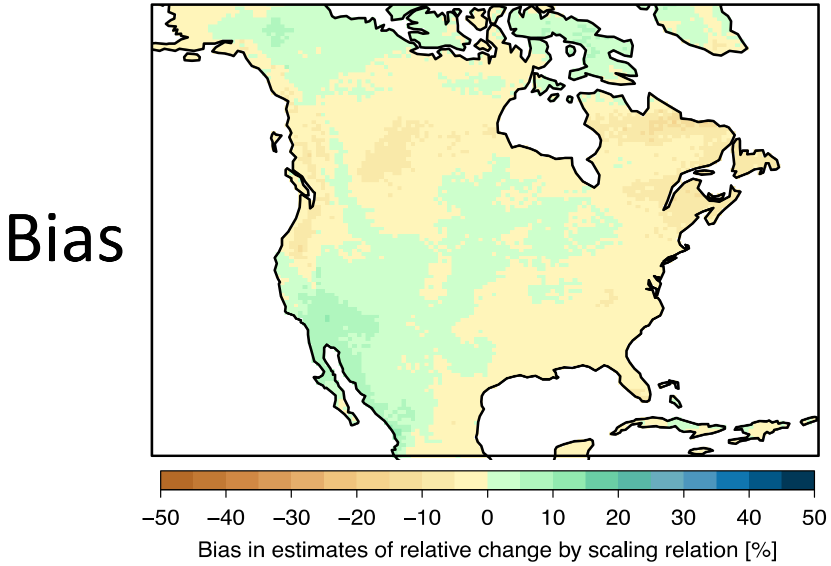
Local (at site) analysis

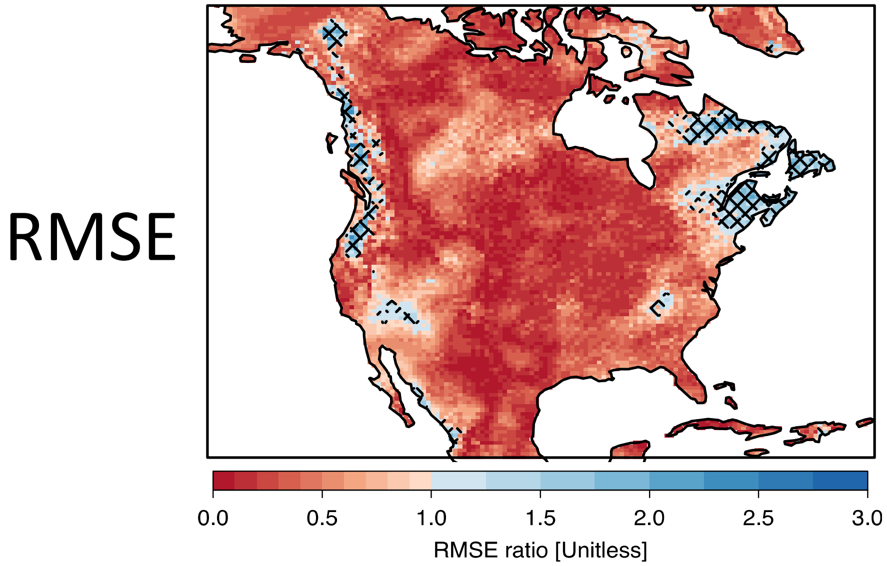
RFA with 150x150 km regions

RFA with 350x350 km regions

Results for 2-year annual maximum hourly rainfall







What do we learn from this?

- At site analysis based on single records not sufficient
- RFA helps a bit, but still doesn’t provide enough information to describe non-stationarity well
- Temperature scaling is effective over most of North America (there are some areas where thermodynamics alone don’t describe simulated changes in extreme precipitation well)
- But … need much more than a single 65-year record to reliably identify such relationships

Review/Discussion

Photo: F. Zwiers

Review/Discussion

- Evidence suggests that we are intensifying precipitation extremes and altering flood regimes
- Definitive statements about storm activity and other aspects of the hydrological cycle remain difficult
- The engineering community increasingly recognizes the need to account for a changing climate, which alters environmental “loads” to which infrastructure is exposed
  - Wind/temperature/snow/rainfall/ice loading, etc
- Stationarity is dead, but nevertheless, it is challenging to reliably and defensibly account for non-stationarity in local and regional engineering design

Photo: F. Zwiers


Additional topics
Photo: F. Zwiers

Storms

Photo: F. Zwiers (Ucluelet)

Storms

- Some evidence of attributable change in surface pressure distribution (indicative of long-term circulation change)
- Few, if any, D&A studies of long-term change in position of extratropical storm tracks, storm frequency or intensity
- Models (eg, broad range of frequency biases in the occurrence of explosive extra-tropical cyclones in CMIP5 class models – Seiler and Zwiers, 2015a, 2015b)
  - Dynamical downscaling with a regional climate model helps reduce this bias somewhat (Seiler et al, 2017)
- Projections do not show large increases in storm frequency, but suggest that the intensity of the strongest storms may increase
- Some evidence that extra-tropical storm tracks will shift somewhat poleward (e.g., Seiler and Zwiers, 2015b)

Terrestrial hydrological cycle

Photo: F. Zwiers **(Canmore, AB)**

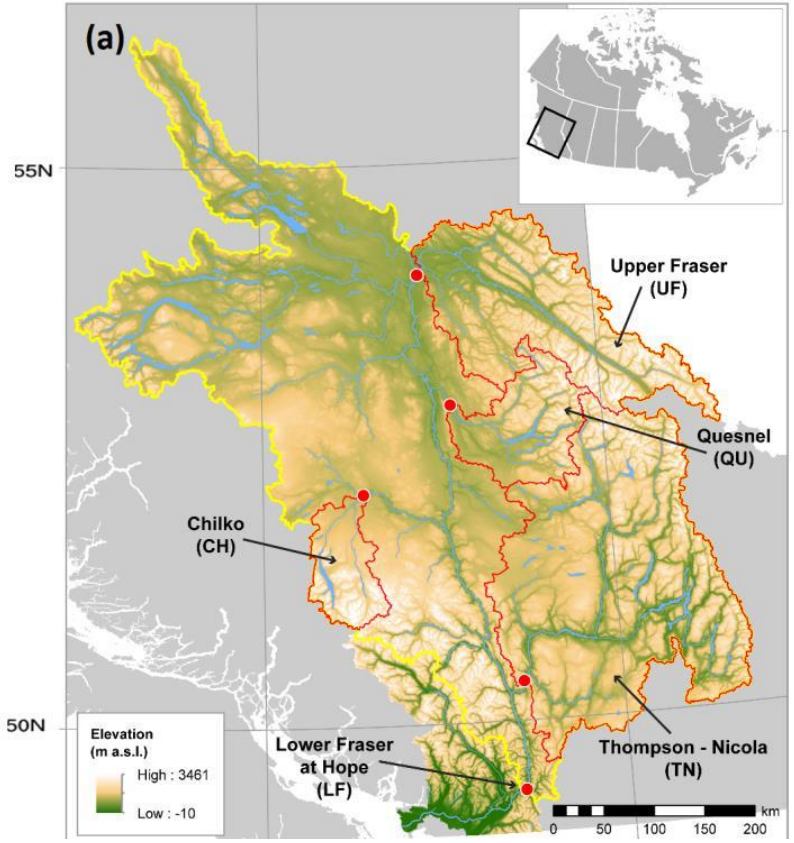
Hydrologic extremes

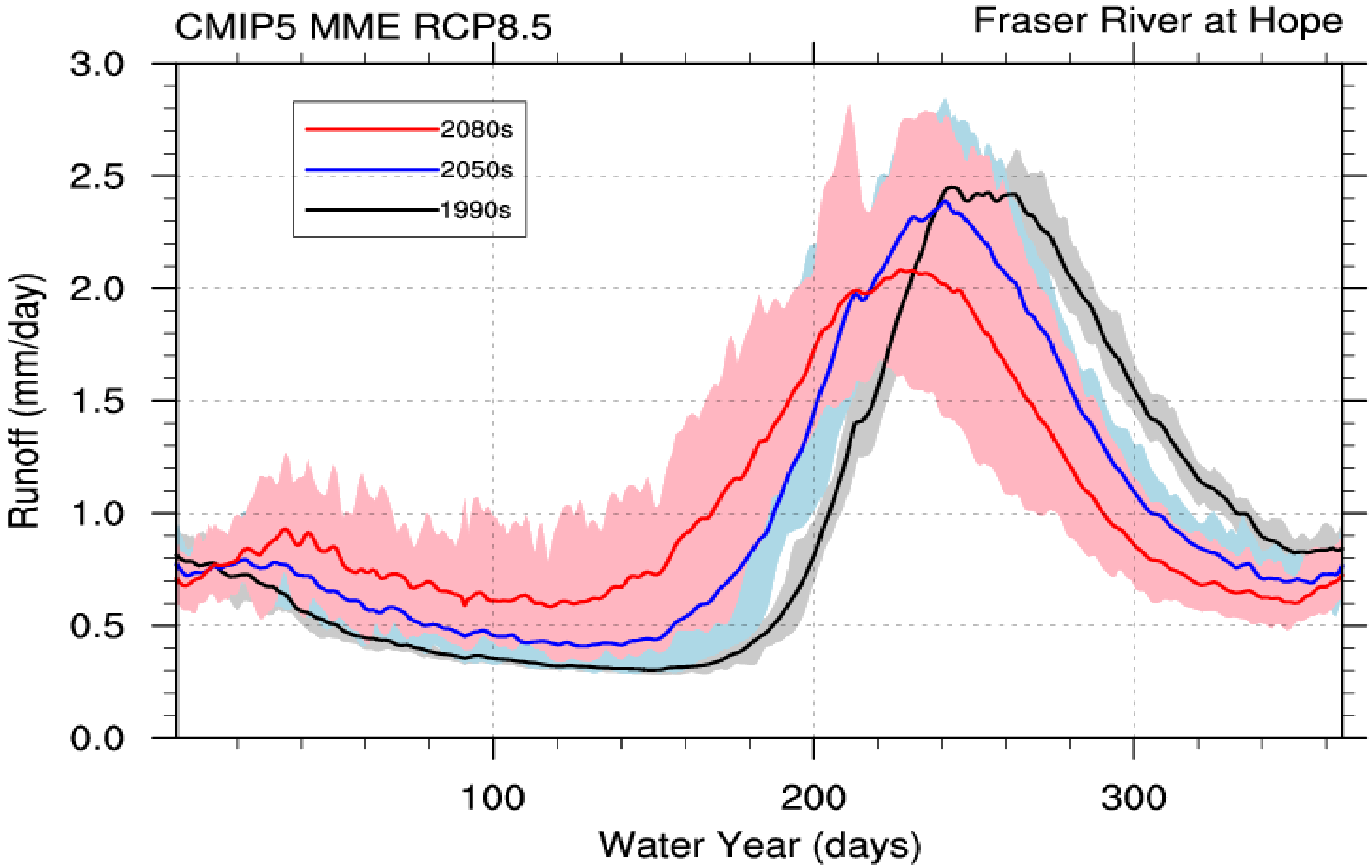
- Few studies linking change in mean hydrologic conditions to GHGs
  - Barnett et al, 2008, Fyfe et al., 2017 (Western US)
  - Najafi et al, 2016, 2017 (part of British Columbia)
  - Detect the effect of warming on snowpack and/or streamflow characteristics
  - Also detect the effect of warming on snow cover extent
  - Complex spatial variation in hydrologic sensitivity (Grieve et al, 2014; Kumar et al, 2015) complicates robust detection of responses (Kumar et al, 2016)
- IPCC assessed low confidence in the understanding of historical changes in drought and only medium confidence in modelling evidence that suggests a likely intensification of drought
- There is greater confidence in projected changes in extreme precipitation, and therefore flash flooding in smaller basins

Riverine Flooding

Figure 2.8: Alexandra Bridge during Flood of 1894

Projected Fraser River streamflow under RCP 8.5

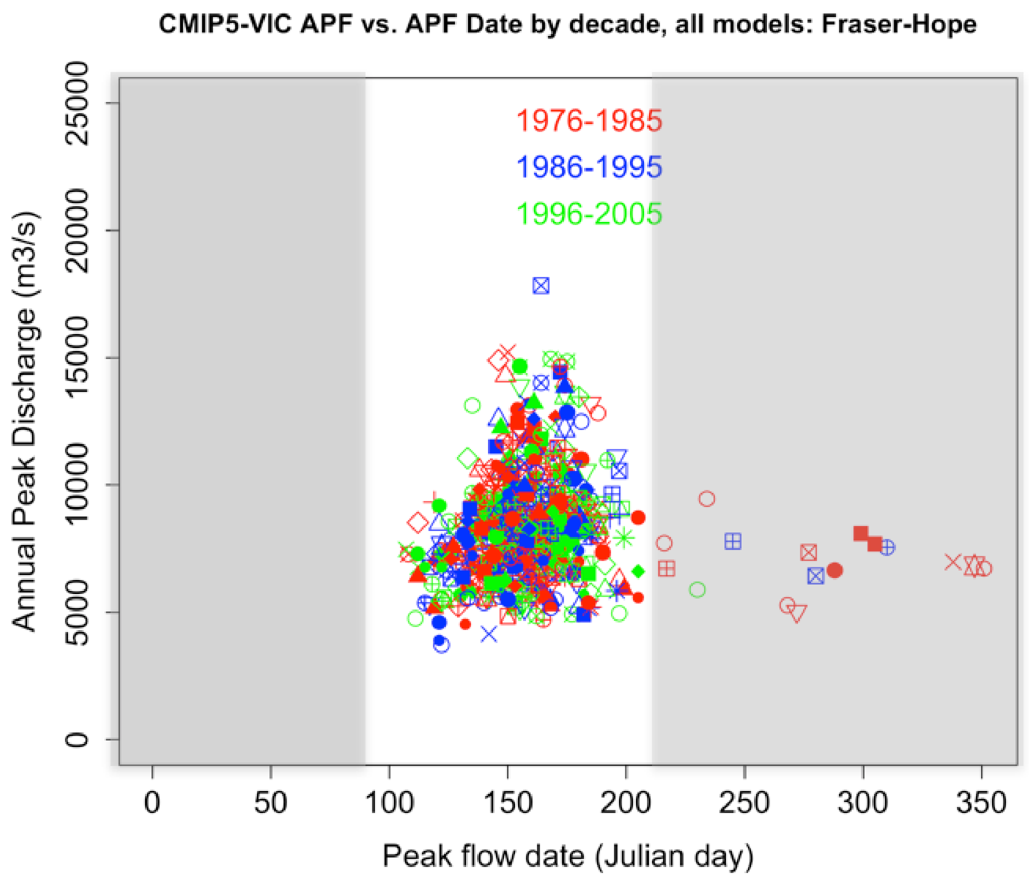




Courtesy Siraj Ul Islam

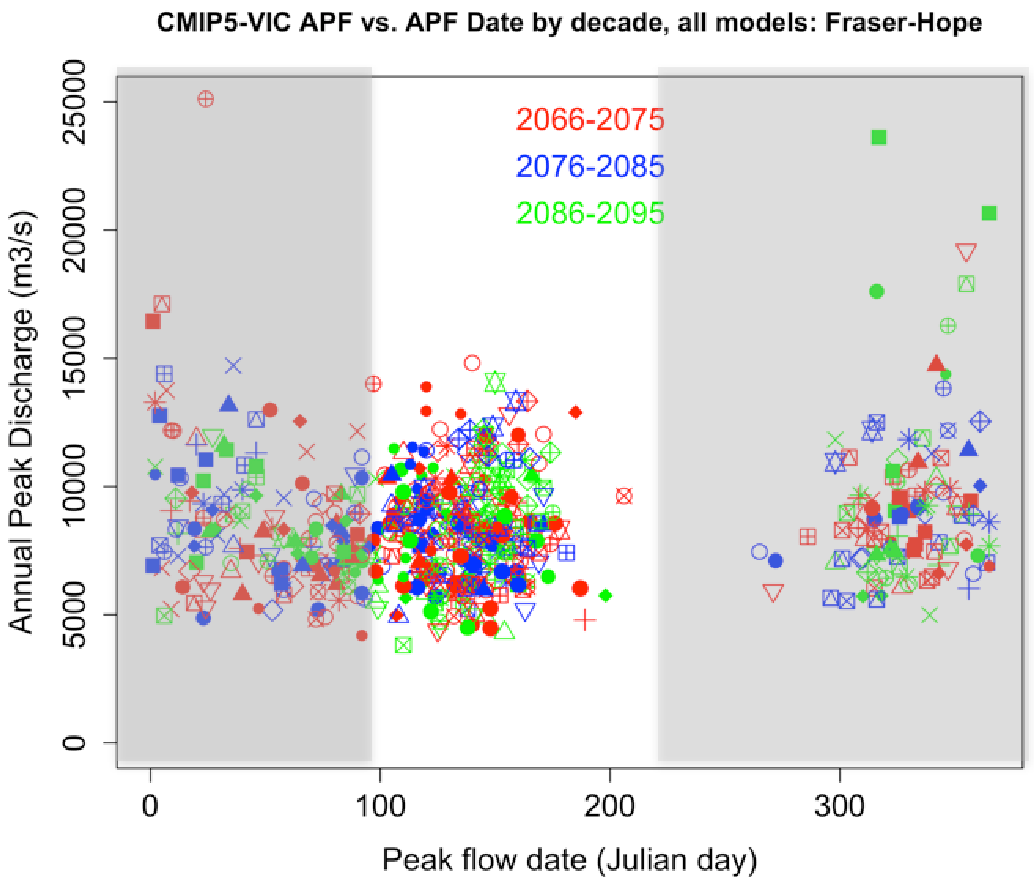
Annual peak flow timing and magnitude

Late 20th century



Days 1-90 & 215-365: 16 occurrences over 10 different runs (2.5% of total = 630)

Late 21st century



Days 1-90 & 215-365: 167 occurrences over all 21 runs (27% of total = 630)

Courtesy Charles Curry