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Projected intensification of sub-daily rainfall extremes in convection-permitting climate model simulations over North America: Implications for future Intensity-Duration-Frequency curves

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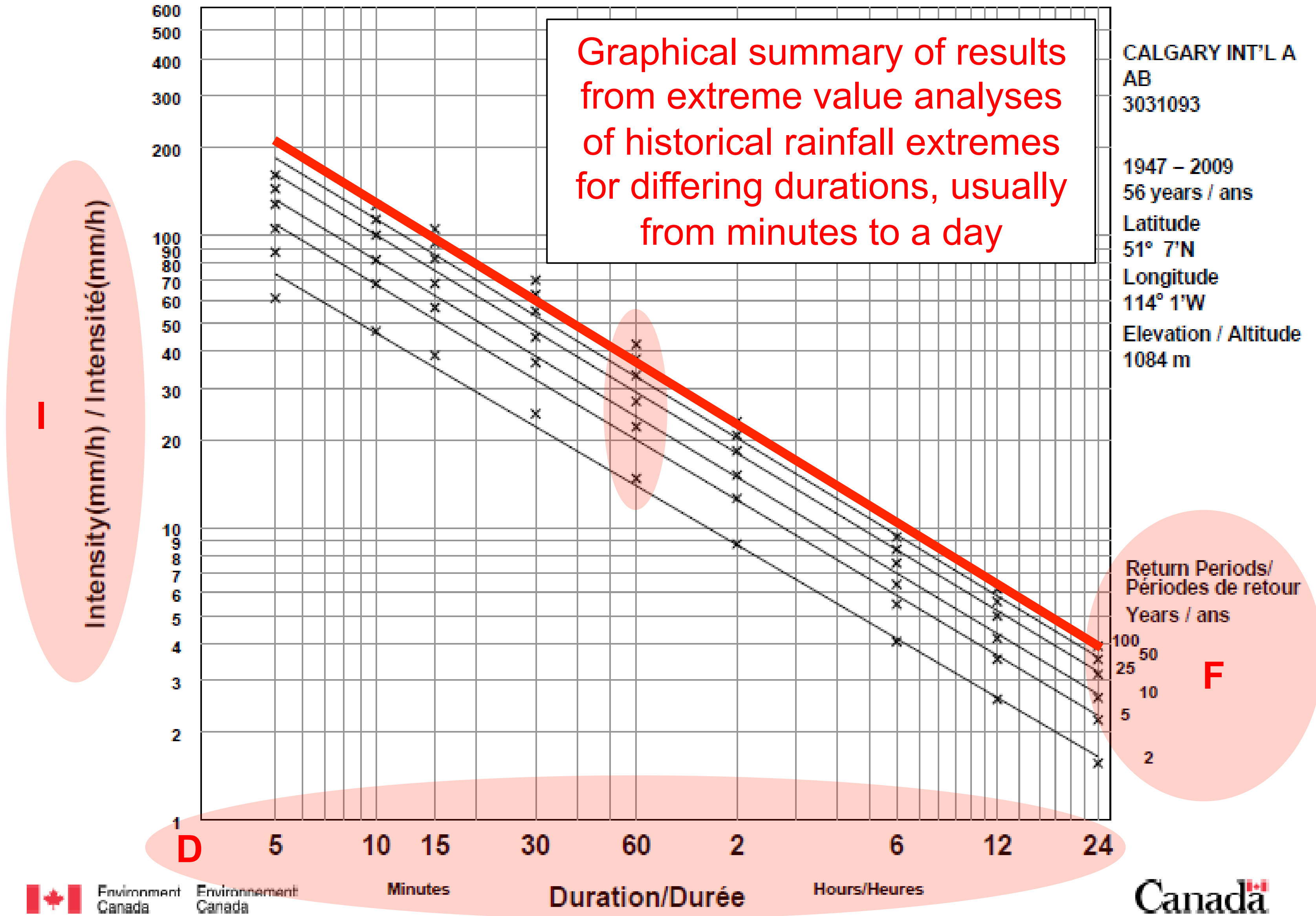
Intensity-Frequency-Duration curves

- If you asked a municipal engineer what piece of climate information they wish they could get from a magical climate science crystal ball…
  - Future projections of rainfall Intensity-Duration-Frequency (IDF) curves for their jurisdiction
- What are IDF curves and why are they useful?

Short Duration Rainfall Intensity–Duration–Frequency Data

2014/12/21

Données sur l'intensité, la durée et la fréquence des chutes de pluie de courte durée



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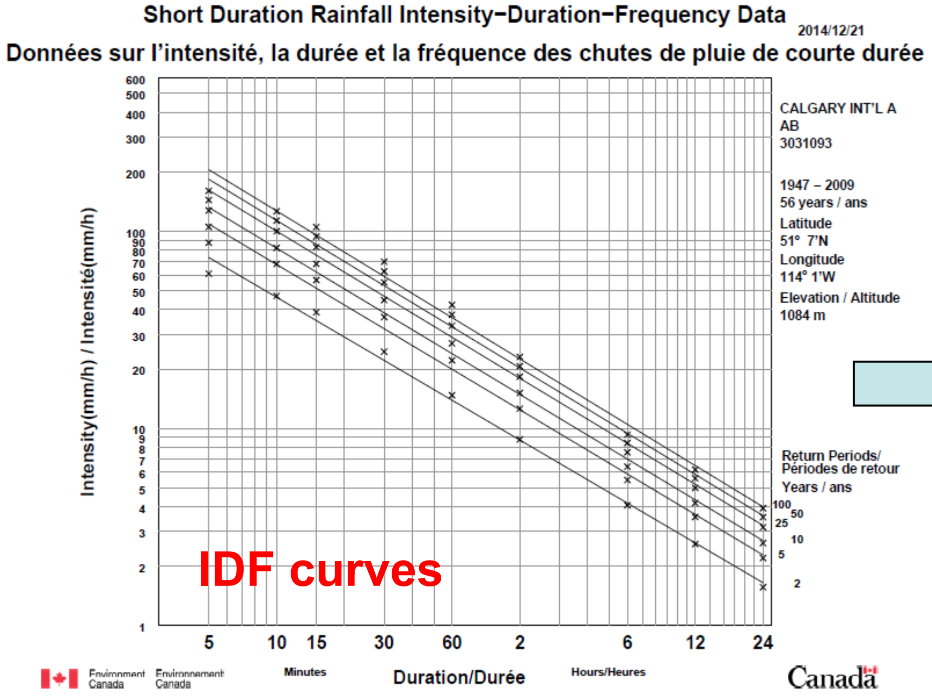

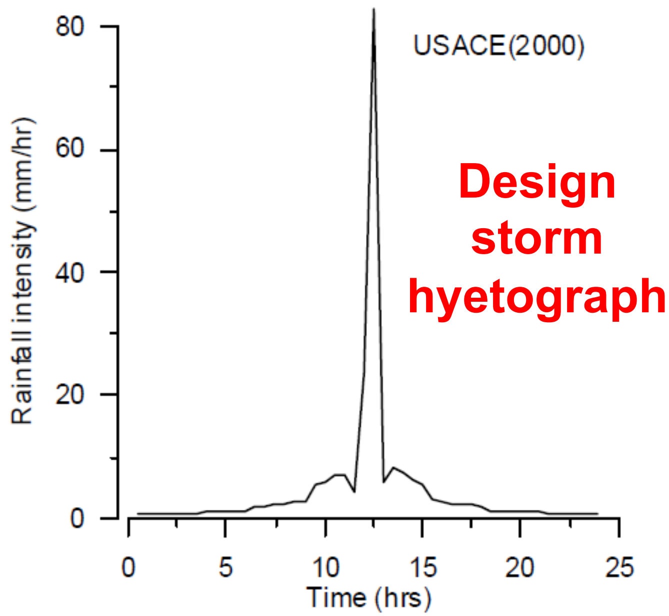

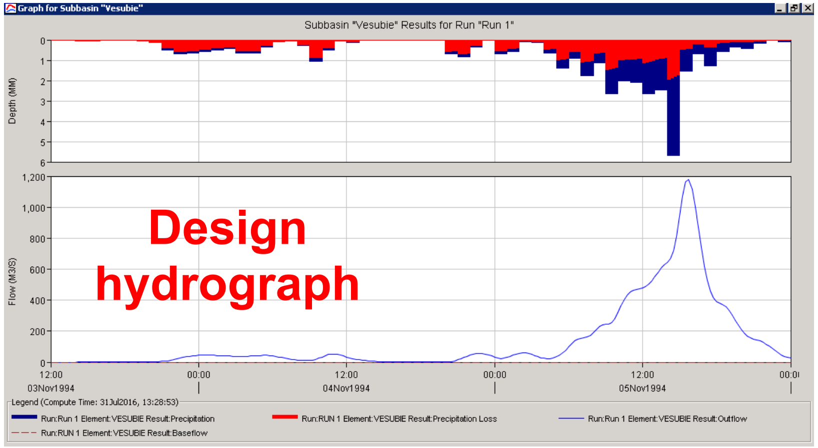

Infrastructure design

Climate change along with long lifetime of structures means designing not for current climate, but for future…

Short Duration Rainfall Intensity−Duration−Frequency Data

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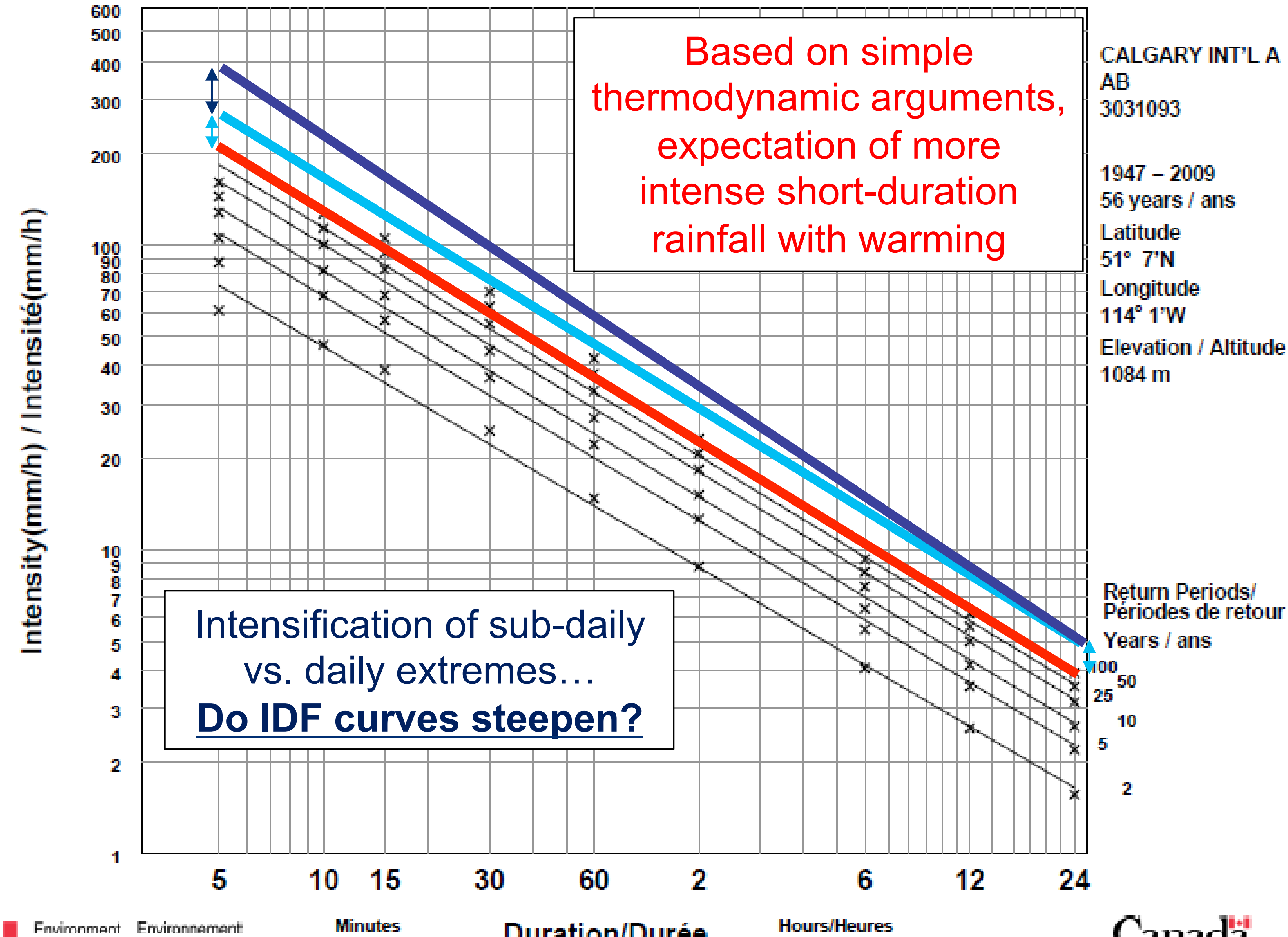

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Credible projections of short-duration precipitation extremes require high resolution models

"…high-resolution convection-permitting models may provide more realistic representation of the local storm dynamics that are important for reproducing the magnitude of extreme local precipitation measurements. The use of **convection-permitting models**, in combination with **advanced statistical methods that make better use of** spatial **information**, may be required to reliably project future changes in short-duration precipitation extremes"

Zhang et al. (2017 NGEO)

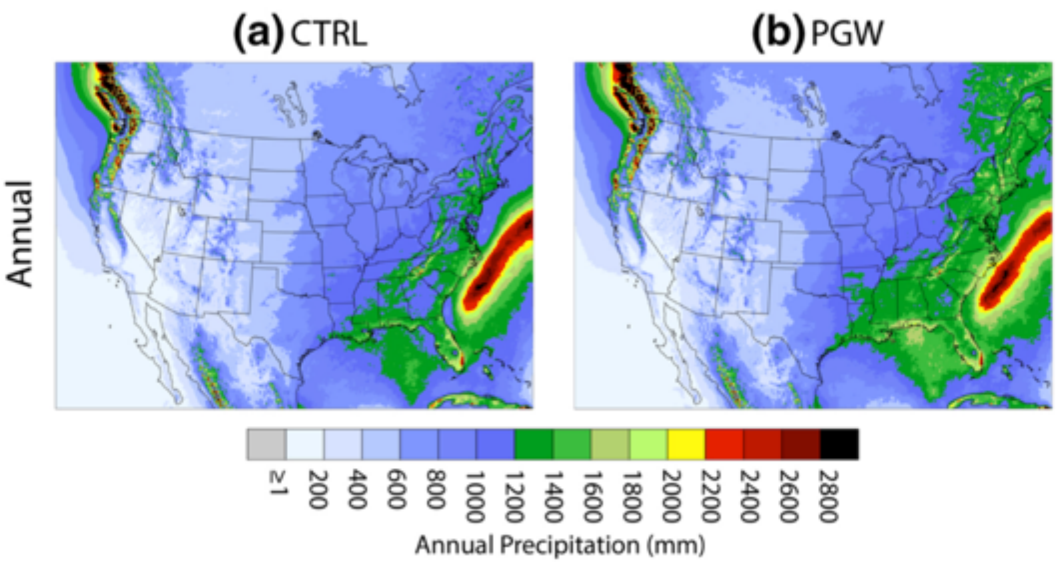
NCAR HRCONUS WRF simulations

Clim Dyn (2017) 49:71–95
DOI 10.1007/s00382-016-3327-9

CrossMark

Continental-scale convection-permitting modeling of the current and future climate of North America

Changhai Liu[1] · Kyoko Ikeda[1] · Roy Rasmussen[1] · Mike Barlage[1] · Andrew J. Newman[1] · Andreas F. Prein[1] · Fei Chen[1] · Liang Chen[3] · Martyn Clark[1] · Aiguo Dai[2] · Jimy Dudhia[1] · Trude Eidhammer[1] · David Gochis[1] · Ethan Gutmann[1] · Sopan Kurkute[3] · Yanping Li[3] · Gregory Thompson[1] · David Yates[1]



<u>Two 4-km runs</u>:

CTRL

ERAI (2000-2013)

PGW (end century)

ERAI + ΔCMIP5$_{RCP8.5}$

Intensification of sub-daily vs. daily extremes…
<u>Do IDF curves steepen?</u>

Challenge: despite large forced signal, dealing with short integrations

Generalized Extreme Value Simple Scaling

$$Pr(I_{D_0} \leqslant x) = \begin{cases} \exp\left\{-\left(1+\xi_0 \frac{x-\mu_0}{\sigma_0}\right)^{-1/\xi_0}\right\} & \text{if } \xi_0 \neq 0 \\ \exp\left\{-\exp\left(-\frac{x-\mu_0}{\sigma_0}\right)\right\} & \text{if } \xi_0 = 0 \end{cases}$$

$$I_D \stackrel{d}{=} \left(\frac{D}{D_0}\right)^{-H} I_{D_0}$$

D_0= reference duration (24-hr)

scaling exponent

$$\mu_D = \left(\frac{D}{D_0}\right)^{-H} \mu_0, \quad \sigma_D = \left(\frac{D}{D_0}\right)^{-H} \sigma_0, \quad \text{and } \xi_D = \xi_{D_0}$$

location0 scale0 shape

GEV

+

simple scaling (SS) → pooling by duration

=

4 parameter GEVSS

→ one shot estimation of IDF curves, <u>assuming a particular form</u>

Bayesian GEVSS estimation

$$i_{\mathrm{CTRL}}(D) \sim GEVSS(\mu_{0_{\mathrm{CTRL}}}, \sigma_{0_{\mathrm{CTRL}}}, \xi, H_{\mathrm{CTRL}})$$
$$i_{\mathrm{PGW}}(D) \sim GEVSS(\mu_{0_{\mathrm{PGW}}}, \sigma_{0_{\mathrm{PGW}}}, \xi, H_{\mathrm{PGW}})$$

$$D_0 = 24\text{-hr},\ D = \{1\text{-}, 3\text{-}, 6\text{-}, 12\text{-}, 24\text{-hr}\}$$

Likelihood

+

$$\mu_{0_{\mathrm{CTRL,PGW}}} \sim U(0.01\,\bar{i}_{0_{\mathrm{CTRL}}}, 2\,\bar{i}_{0_{\mathrm{CTRL}}})$$
$$\sigma_{0_{\mathrm{CTRL,PGW}}} \sim U(0.01\,\bar{i}_{0_{\mathrm{CTRL}}}, 0.5\,\bar{i}_{0_{\mathrm{CTRL}}})$$
$$\xi \sim N(0.114, 0.045)\ \text{(Papalexiou and Koutsoyiannis, 2013)}$$
$$H_{\mathrm{CTRL,PGW}} \sim U(0, 1)$$

Priors

- Fit GEVSS to pooled 1-hr, 3-hr, 6-hr, 12-hr, and 24-hr WRF annual maxima
- 100,000 samples from posterior distribution by Metropolis-Hastings MCMC
- standard convergence diagnostics (Geweke and Heidelberg-Welch) plus spot visual inspections of chain
- large number of grid points → chain thinned to 1000 samples

Statistical inference about parameters

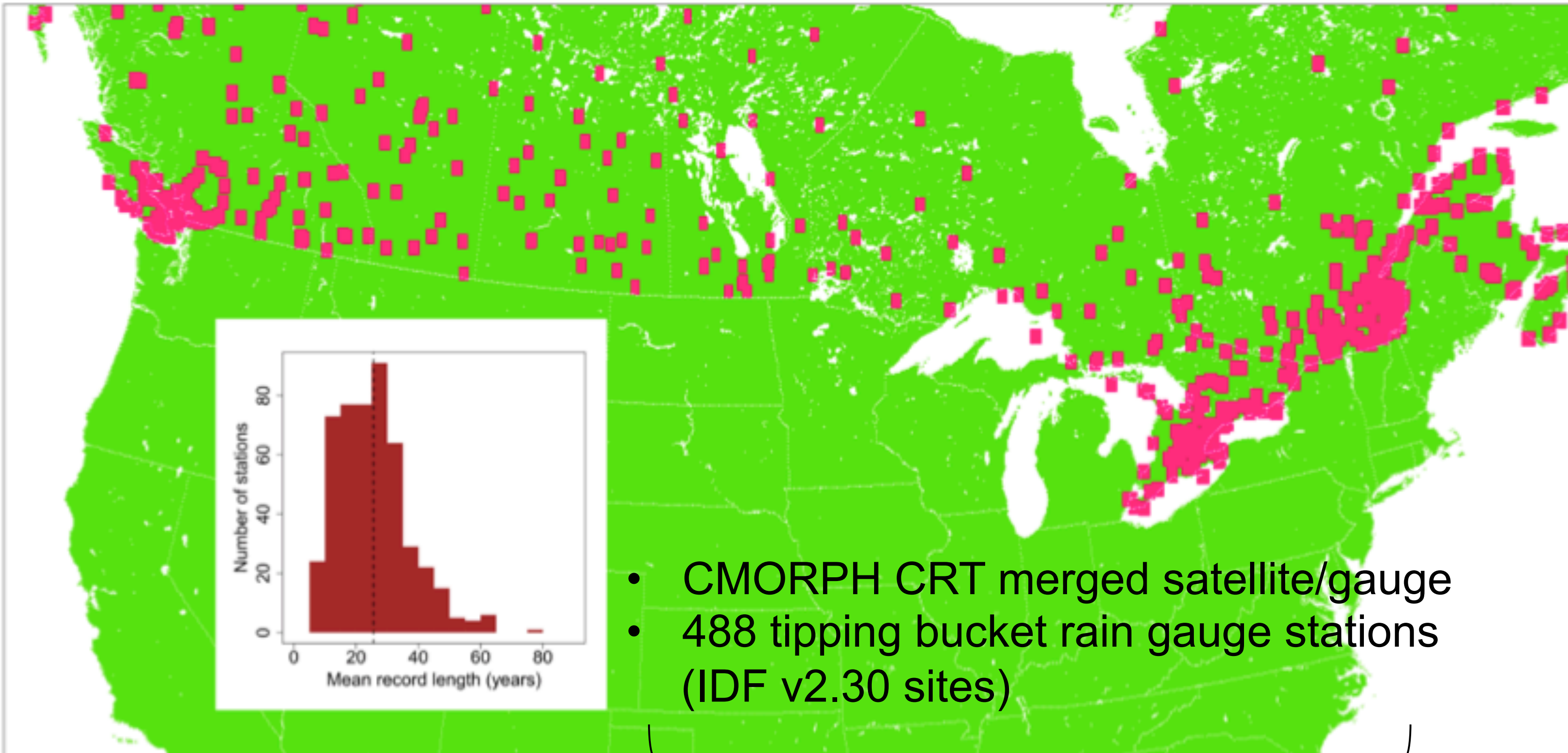
- ΔH(PGW-CTRL) > 0
- Δlocation0(PGW-CTRL) > 0
- Δscale0(PGW-CTRL) > 0

Intensification of sub-daily vs. daily extremes…
Do IDF curves steepen?

→ inference based on posterior distribution of differences

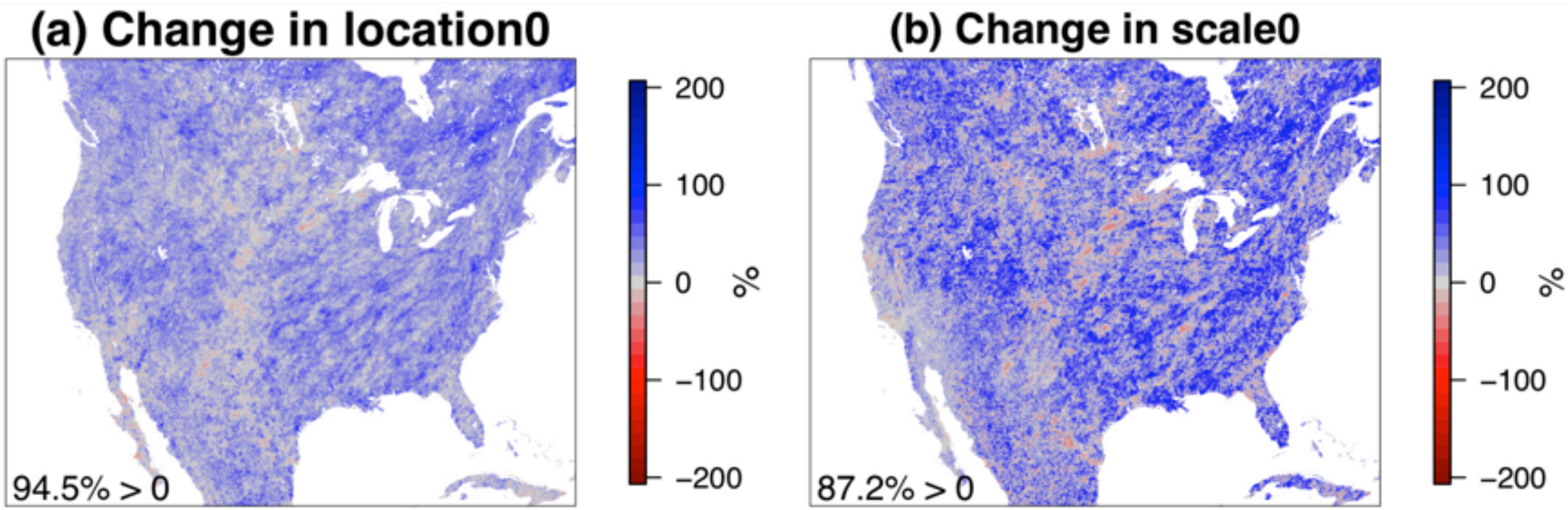
- posterior error probability (PEP) and Bayesian False Discovery Rate (FDR); takes into account multiple testing / field significance
- identify points w/ projected increase in GEVSS parameter while ensuring that no more than 10% are included by mistake

Model evaluation: gridded and in situ



- CMORPH CRT merged satellite/gauge
- 488 tipping bucket rain gauge stations (IDF v2.30 sites)

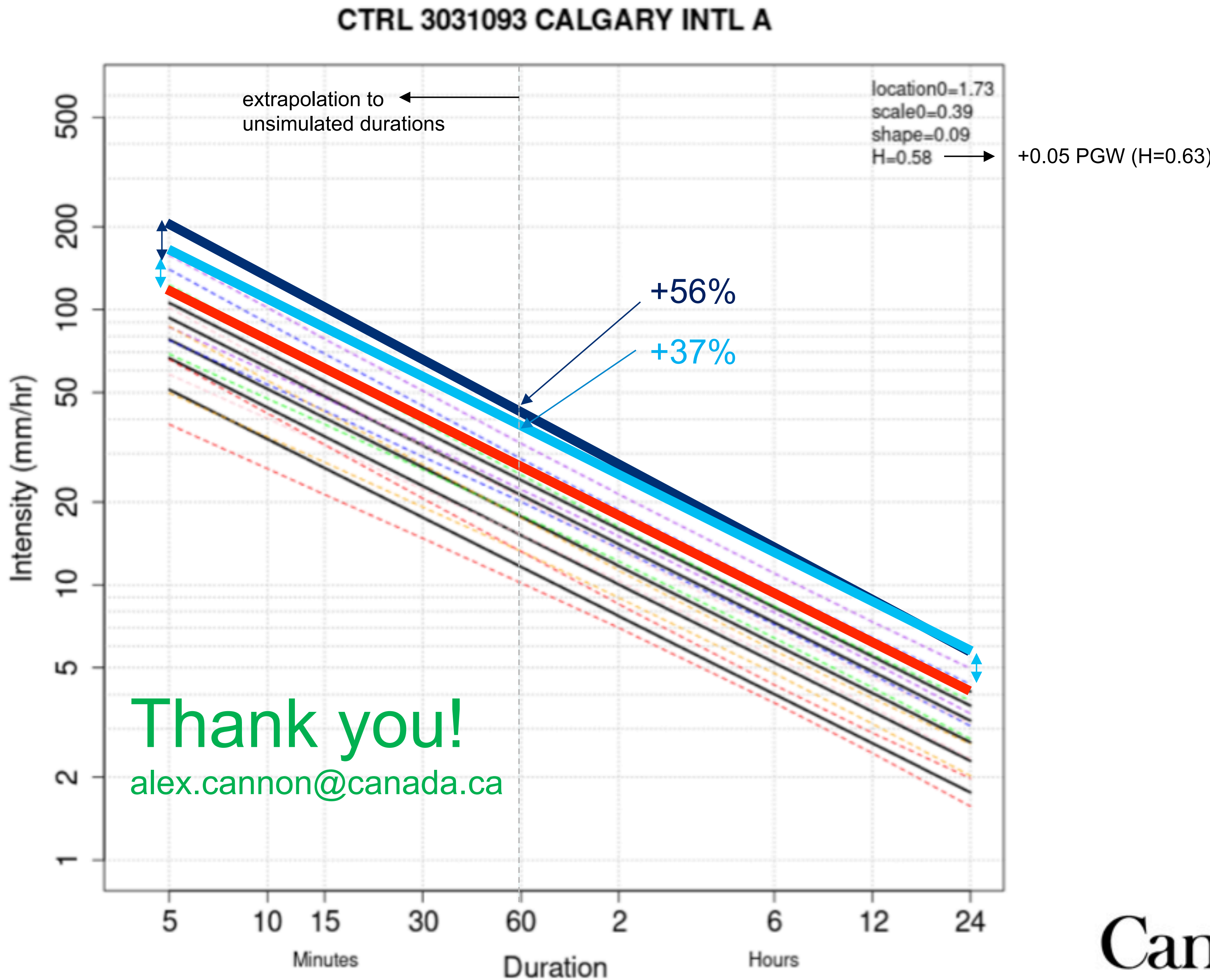
S8. Modeling for Extremes (S. Innocenti Thu 15:30)


(a) Change in location0
94.5% > 0
200
100
0
−100
−200
%
(b) Change in scale0
87.2% > 0
200
100
0
−100
−200
%

Bayesian False Discovery Rate (FDR)

Control FDR at 10% level → identify points with projected increase (decrease) in GEVSS parameter with no more than 10% included by mistake:

• ΔH(PGW-CTRL) > 0	→ 39.1%	8.7x	Median +0.05 PGW
○ ΔH(PGW-CTRL) ≤ 0	→ 4.5%		
• Δlocation0(PGW-CTRL) > 0	→ 99.6%	99.6x	
○ Δlocation0(PGW-CTRL) ≤ 0	→ 1.0%		
• Δscale0(PGW-CTRL) > 0	→ 88.2%	18.4x	
○ Δscale0(PGW-CTRL) ≤ 0	→ 4.8%		



Thank you!

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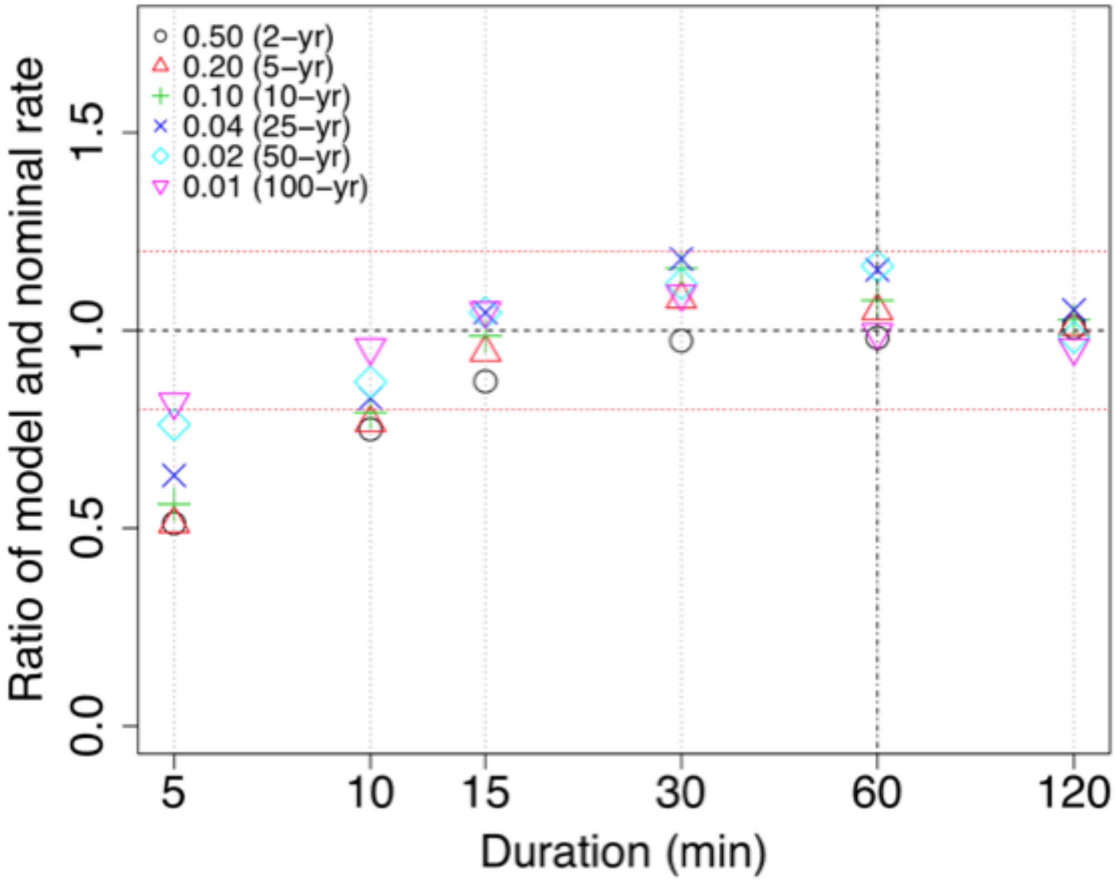
Validity of the GEVSS model

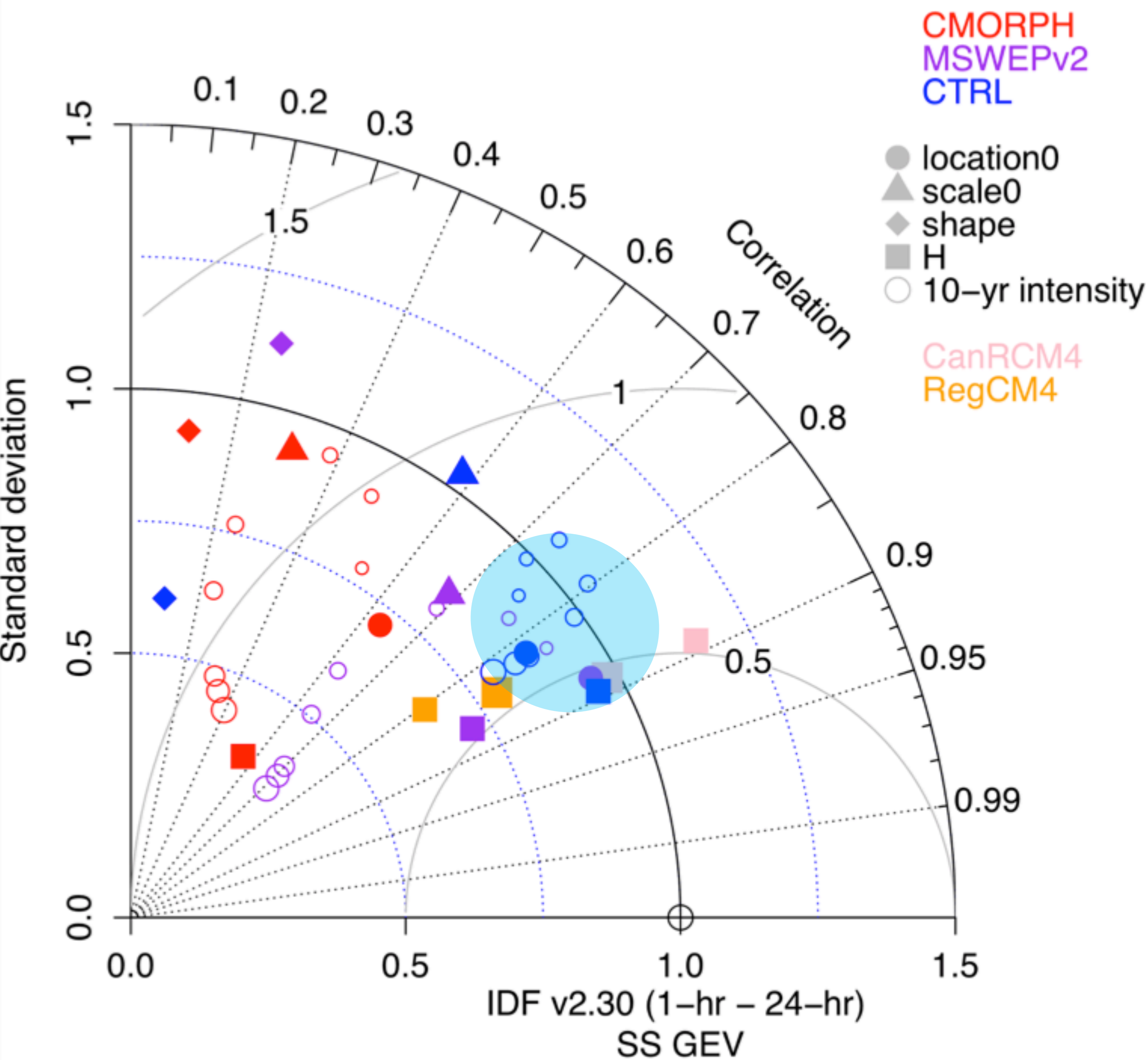


IDF v2.30:

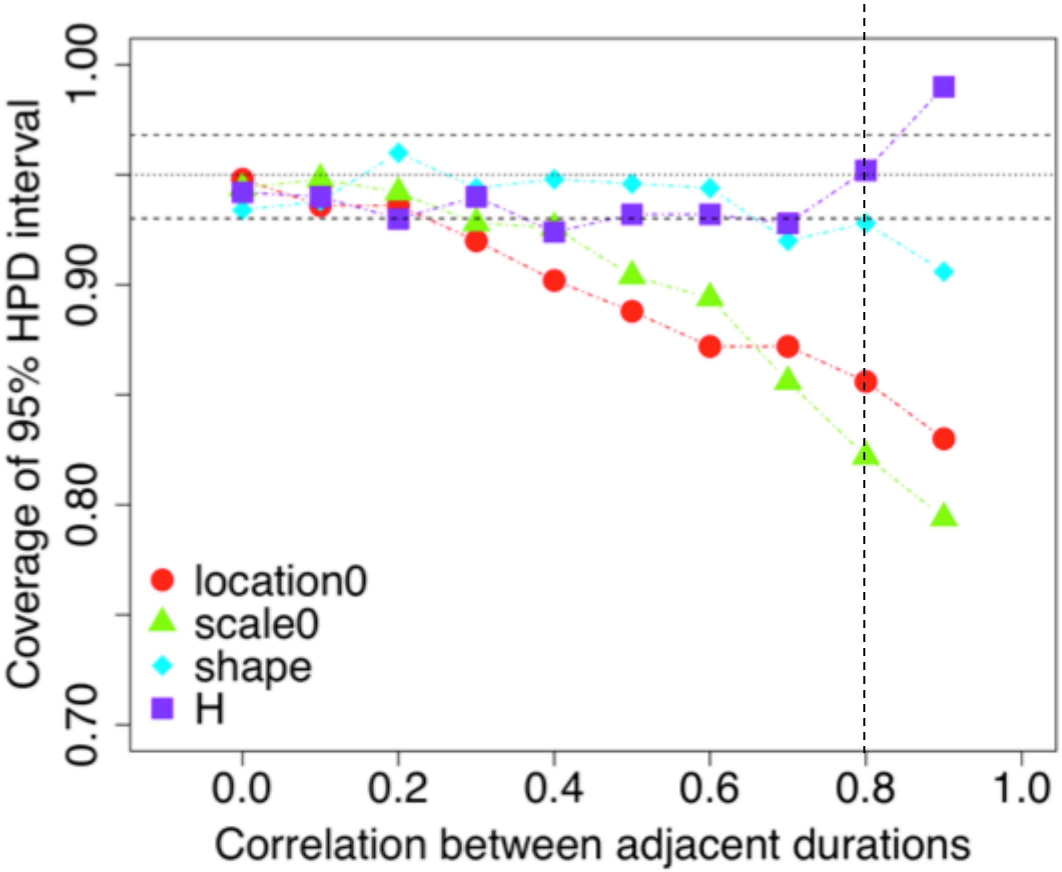
GEVSS fit to 1-hr to 24-hr durations and used to extrapolate to sub-hr durations

Innocenti et al. (2018) HESS

> 90% stations


CMORPH
MSWEPv2
CTRL
location0
scale0
shape
H
10−yr intensity
CanRCM4
RegCM4
Correlation
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.95
0.99
1.5
1
0.5
Standard deviation
0.0
0.5
1.0
1.5
IDF v2.30 (1−hr – 24−hr)
SS GEV

Inference and GEVSS misspecification



<u>Monte Carlo sim.</u>:

Independence likelihood assumption

Impact of lack of independence between durations on credible intervals