# Practical issues in updating IDF curves for future climate: Climate models, “Physics”, ….

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# 2 | PRESENTATION
## Thanks

- Dr. Abhishek **GAUR**, Post Doctoral Fellow
- Dr. Andre **SCHARDONG**, Post Doctoral Fellow

- Data – Environment and Climate Change Canada
  - Dr. Zhang Xuebin; Dr. Ka-Hing Yau; Dr. Gordon McBean
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# 3 | CONCLUSIONS

- There is a clear practical need for updating IDF relationships for climate change
- Challenges in projecting precipitation extremes remain
- Use of the IDF_CC tool is a recommended option
  - The Clausius-Clapeyron scaling rate (7% per $^{0}$C) clearly **does not apply** for stations used in this study and **should not be arbitrarily applied** to derive IDF curves for future
  - The IDF_CC better captures uncertainty from the GCMs
- Recommendations
  - Use the IDF_CC tool – live with the process uncertainty
  - Move from risk based decision making to process based engineering
  - Switch from risk to resilience

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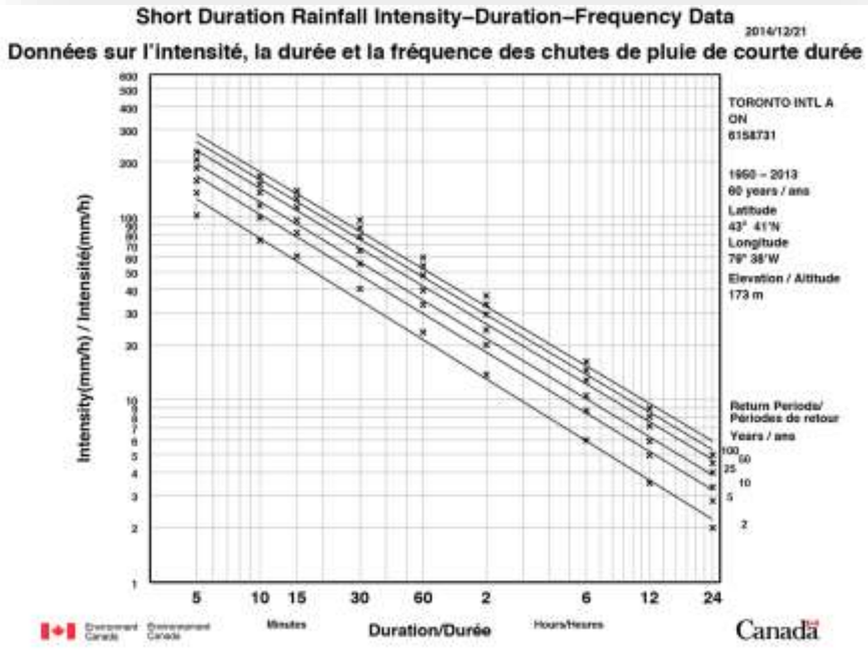
# PRESENTATION
## Outline

- Needs of engineering practice
- Comparison
  - Precipitation based climate models use (IDF_CC)
  - Physics-based temperature scaling
  - Experiments
- Practical issues
  - Uncertainty
  - Needs for a new decision making paradigm
- Guidelines
  - From risk-based to performance-based engineering
  - From risk to resilience
- Conclusions

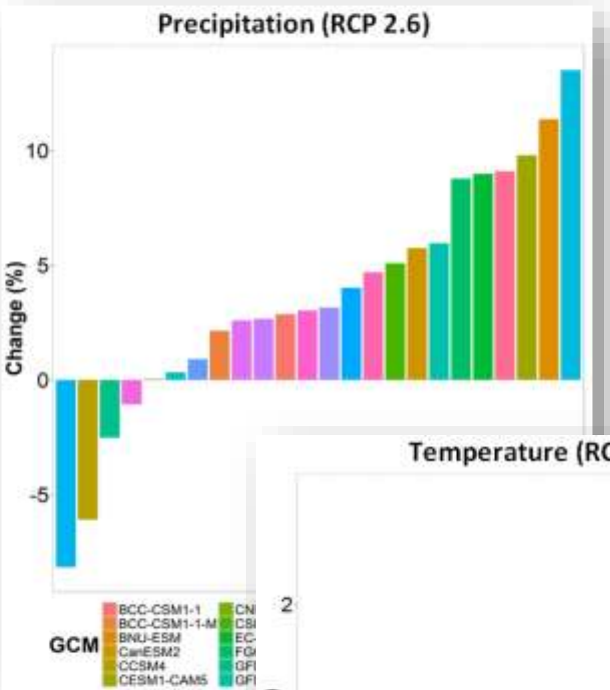
# 5 | NEEDS OF ENGINEERING PRACTICE
## Changing conditions

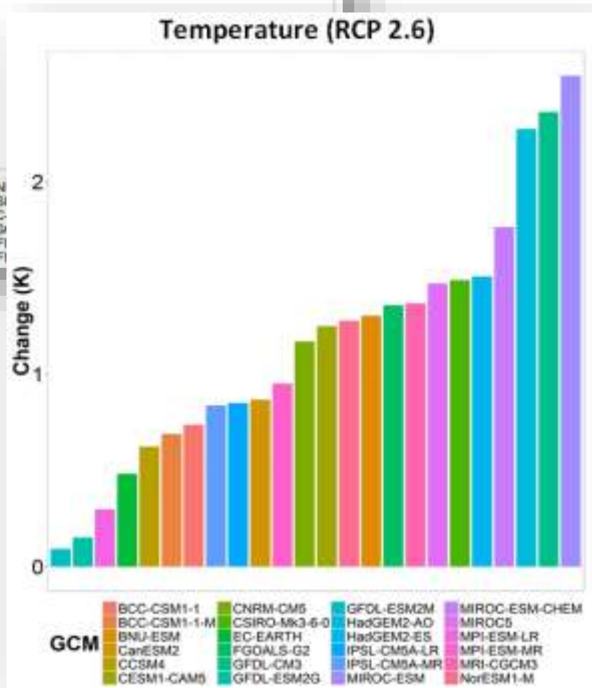


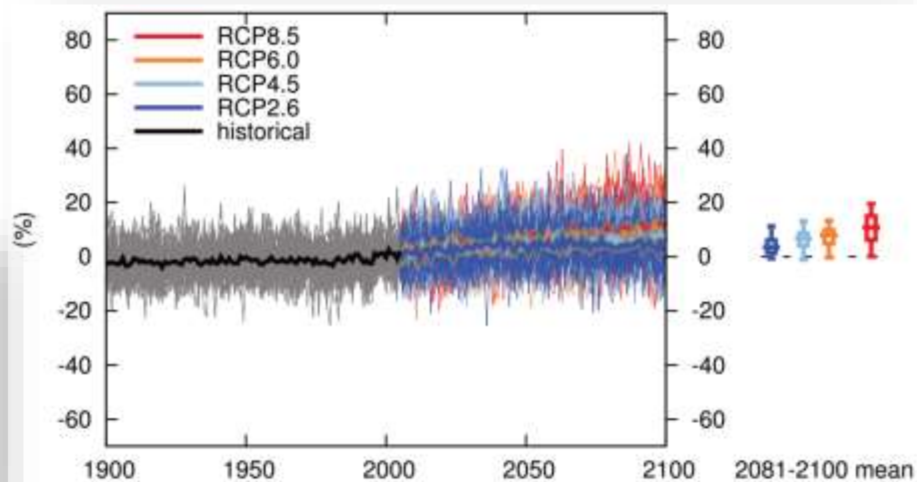

| Extreme Rainfall Event | Total Rainfall Amount (mm) | Duration (hr) | 1 Hr Max. Intensity (mm/hr) |
|---|---|---|---|
| Peterborough (Trent U), July 14-15, 2004 | 250.0 | 16.5 | 87.2 |
| Toronto (Finch Ave), August 19, 2005 | 153.4 | 12.5 | 116.6 |
| Hamilton (Stoney Creek), July 25-26, 2009 | 135.5 | 35.0 | 60.8 |
| Mississauga (Cooksville), August 4, 2009 | 68.0 | 1.0 | 68.0 |
| Westcentral GTA (Pearson), July 8, 2013 | 126.0 | 3.0 | 96.0 |
| Hurricane Hazel, 15 October, 1954 | 285.0 | 48.0 | 52.5 |
| 100 Year Design Storm | 118.0 | 24.0 | 50.0 |

- "Development, Interpretation and Use of Rainfall Intensity-Duration-Frequency (IDF) Information: A Guideline for Canadian Water Resources Practitioners" *Canadian Standards Association (2012)*
- Major reasons for increased demand for rainfall IDF information is climate change
- Updating IDF curves highly technical
  - municipalities may lack expertise and resources

# 6 | NEEDS OF ENGINEERING PRACTICE
## Challenges



# NEEDS OF ENGINEERING PRACTICE

Options

- Use of precipitation and global climate models:
  IDF_CC tool
  https://www.idf-cc-uwo.ca/
- Use of precipitation and regional climate model:
  Ontario Climate Change Data Portal
  http://www.ontarioccdp.ca/
  Northeast Regional Climate Center, Cornell University
  http://ny-idf-projections.nrcc.cornell.edu/#dialog_box
- Use of temperature: physics based approach

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# COMPARISON

## IDF_CC tool vs. physics based approach

- IDF_CC tool
  - widely used – 730 registered users; 7,600 sessions a year; 764 EC stations; 136 user created station; detailed user survey
  - ICLR hosting
  - permanent updating of the tool database
  - work on the tool improvement to meet the needs of the users
  - well documented: Srivastav et al, 2014; 2014 (a); Schardong et al, 2014; Simonovic et al, 2016; Sandink et al, 2016; and Simonovic et al, 2016(a)
- Physics-based temperature scaling
  - proposed as the more robust approach: Zhang, 2017; Zwiers, 2017 in NRC 2017

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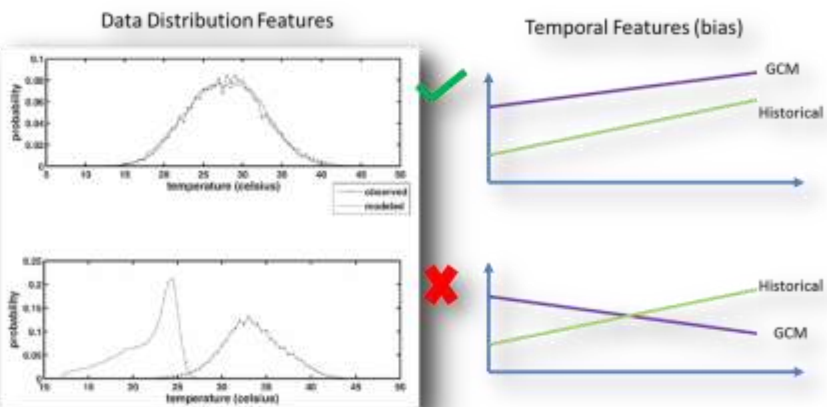
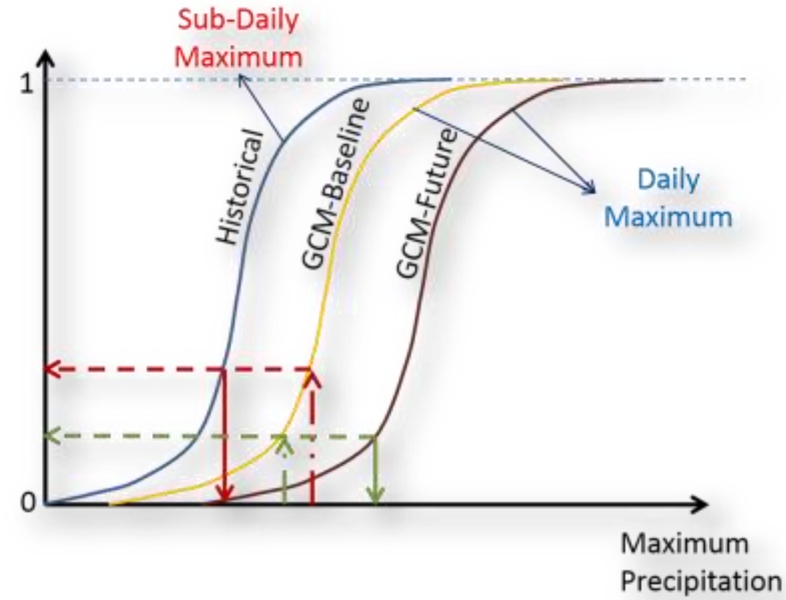
# 9 | COMPARISON
## IDF_CC tool

- Choice of climate input (*Quantile Regression Skill Score Method*)
  - Selection of GCM model
  - Selection of RCP
  - Selection of model run
- Downscaling (*Equidistant Quantile Matching Algorithm*)
  - Spatial downscaling
  - Temporal downscaling

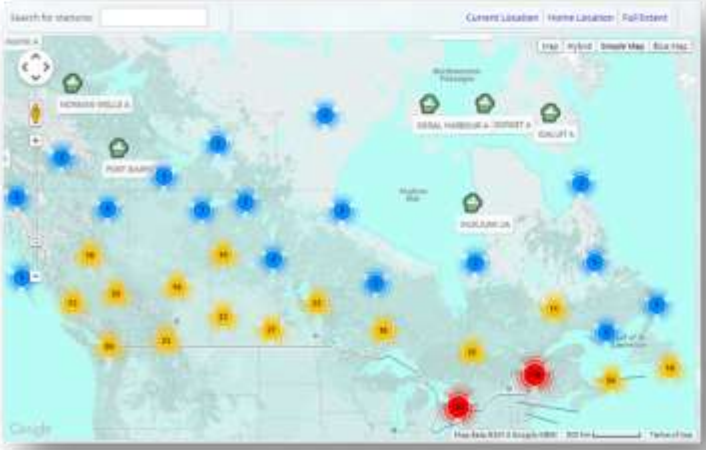


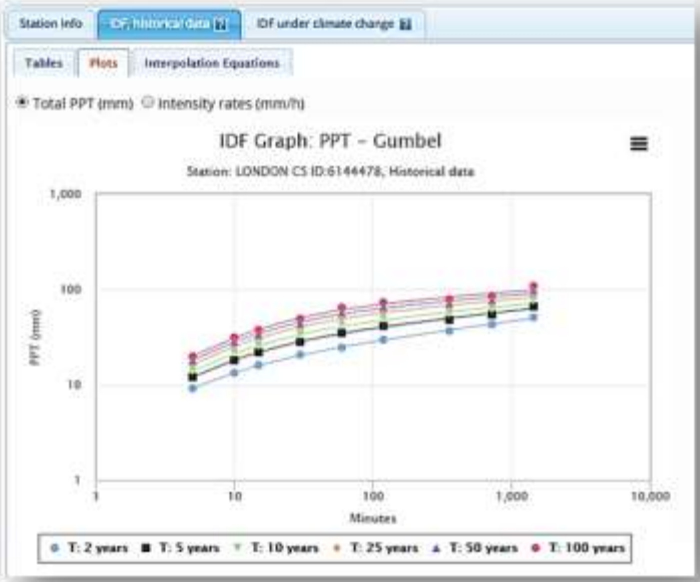




$$X^{STN,future} = a_1 \times \left[ \frac{X^{GCM,future} - b_2}{a_2} \right] + b_1$$

# COMPARISON
## IDF_CC tool

- Database:
  - IDF repository from EC (700 stations)
  - User provided stations and data
  - 24 GCMs; RCP2.6, RCP4.5, RCP8.5; multiple GCM runs
- User interface:
  - Google maps
  - Data manipulation
  - Results visualization
- Models:
  - Statistical analysis algorithms
  - GCM skill score algorithm
  - IDF update algorithm
  - Optimization model



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# COMPARISON
## Physics based approach

- Use of temperature as a predictor for updating IDF curves.
- Assumption and hypothesis:
  - Increase of precipitation extremes at a rate of ~7 % per $^0$C, assuming constant relative humidity indicated by the Clausius-Clapeyron (C-C) relationship
- Claims “use of physics”
- “Lower uncertainty” in the projected IDF curves

- Experiment 1 - Analysis of the empirical relations between daily maximum precipitation and daily temperatures and comparison with the ~7% the C-C scaling
- Experiment 2 - Comparison of IDF curves derived from the theoretical Clausius-Clapeyron (C-C) scaling (~7% rate) with the IDF_CC tool

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# COMPARISON

## Physics based approach

- The Clausius-Clapeyron (C-C) describes the increase in the saturation water vapor pressure associated with warming as:

$$\frac{\partial e_s}{\partial T} = \frac{L_v}{R_v T^2}$$

Where:

$e_s$: is the saturation water vapor pressure

$L_v$: is the latent heat of vaporization ($2.5 \times 10^6$ J kg$^{-1}$ at 0°C)

$T$: is the absolute atmospheric temperature in Kelvin

$R_v$: is the gas constant (461.5 J kg$^{-1}$ K$^{-1}$)

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# COMPARISON

## Physics based approach

- In the August–Roche–Magnus approximation, $e_s$ can be related to temperature $T^*$ (in °C) by:

$$e_s = 6.1094 . exp\left[\frac{17.625 . T^*}{T^* + 243.04}\right]$$

  - Saturation water vapor pressure is directedly related to relative humidity.
  - Assuming constant relative humidity, this would lead to an increase of moisture available to rainstorms at the Clausius-Clapeyron rate of ~ 7 % per °C (Westra et al., 2014)

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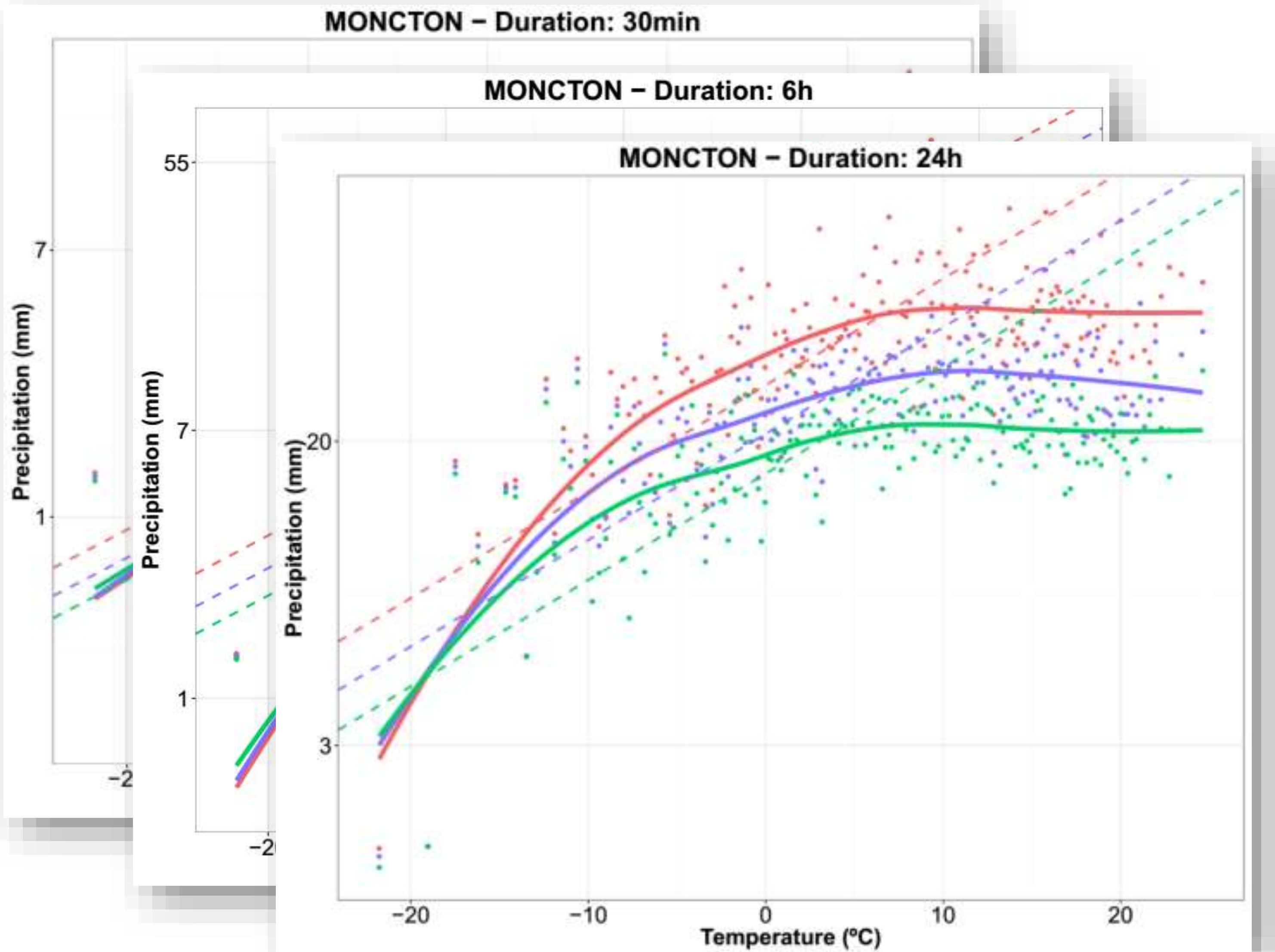
# COMPARISON

Physics based approach

- Experiment 1
  - Observed short duration daily precipitation maximums and average daily temperatures relations are extracted and validated against the Clausius-Clapeyron (7% C-C) scaling rate.
  - Short duration daily maximum precipitation considered:
    5, 10, 15, 30 min, 1, 2, 6, 12 and 24 hours
  - Analysis for 4 stations across Canada:
    - London CS (Ontario)
    - Moncton A (New Brunswick)
    - Brandon A (Manitoba)
    - Vancouver A (British Columbia)

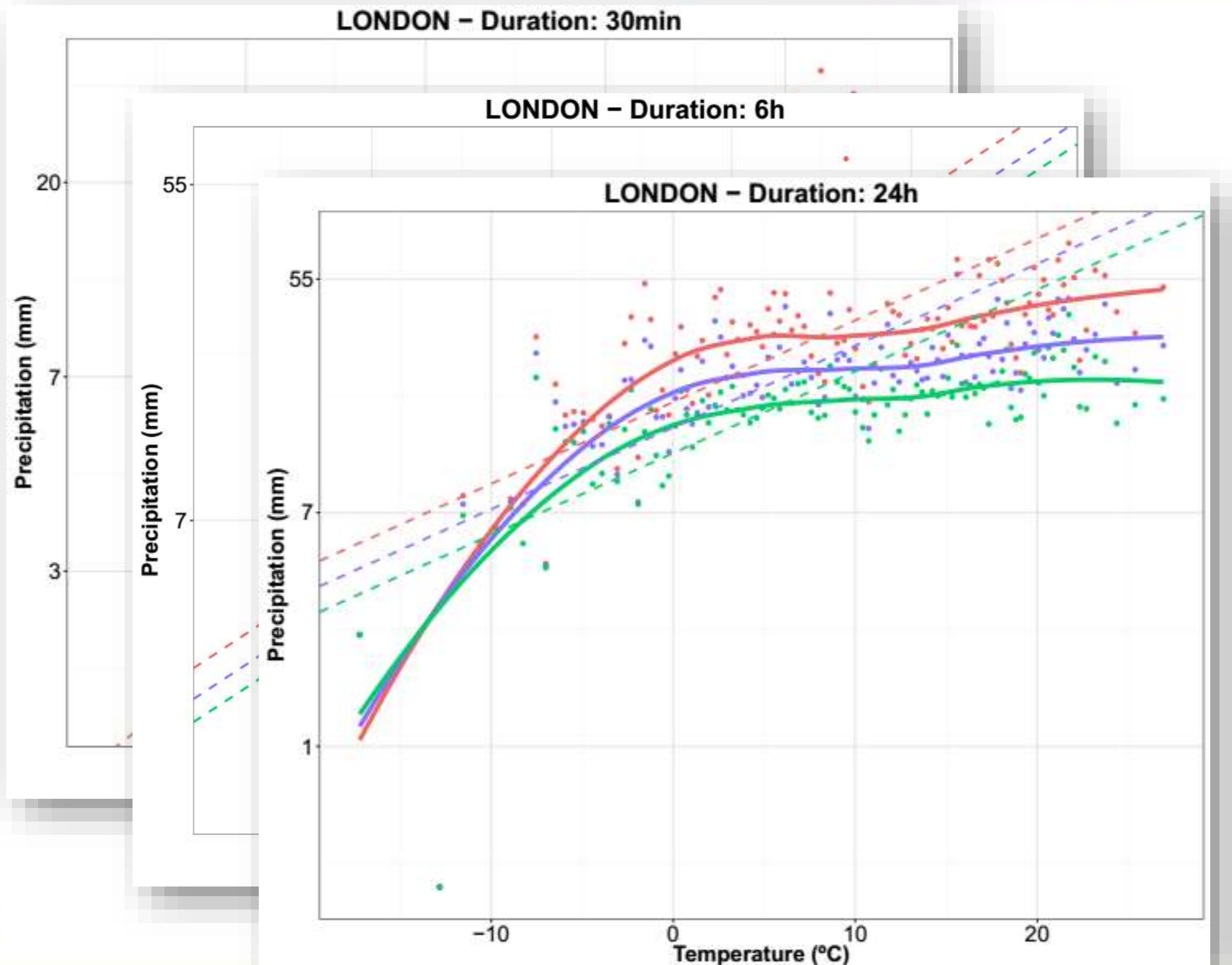
# 15 | COMPARISON

## Physics based approach



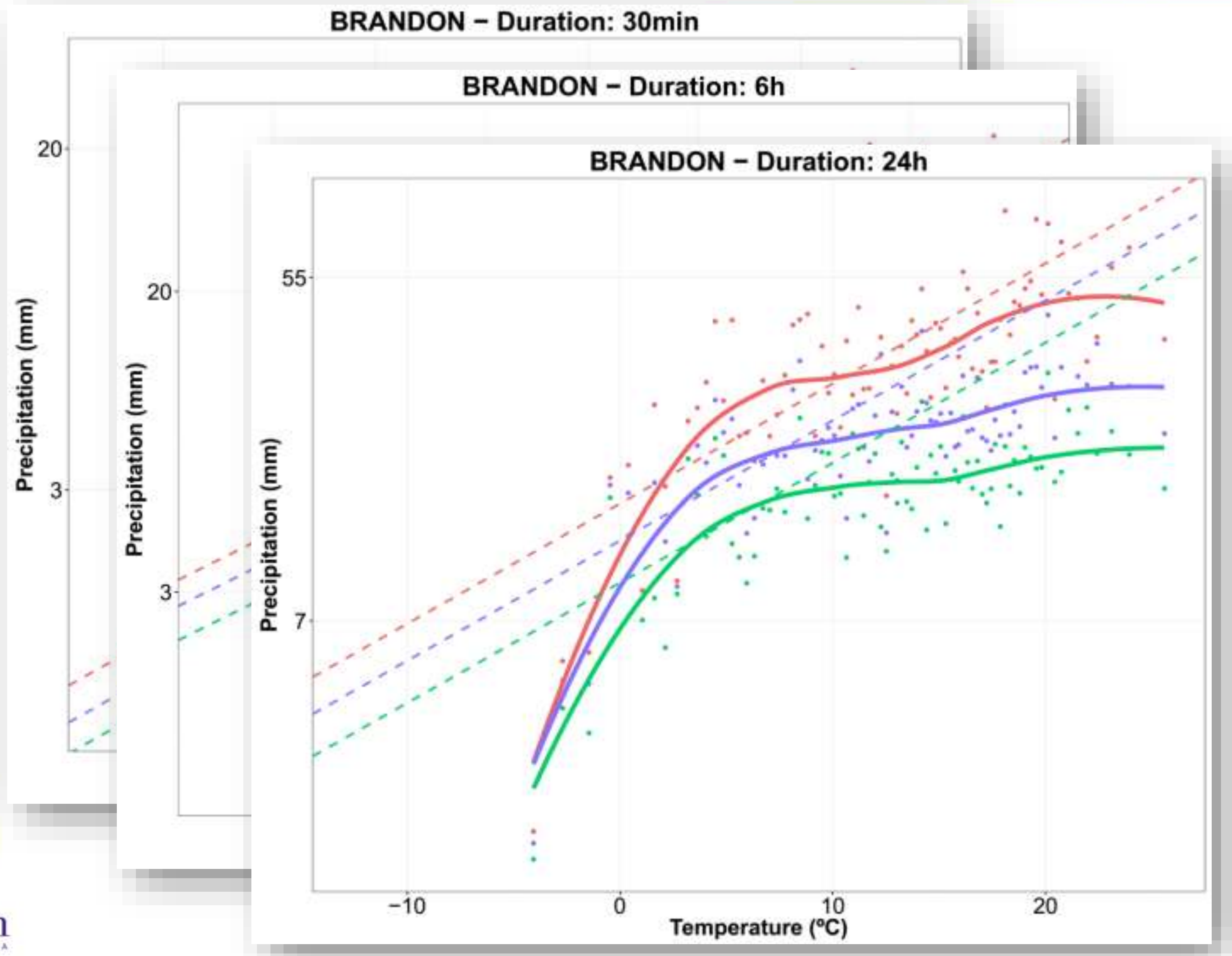
# COMPARISON

## Physics based approach

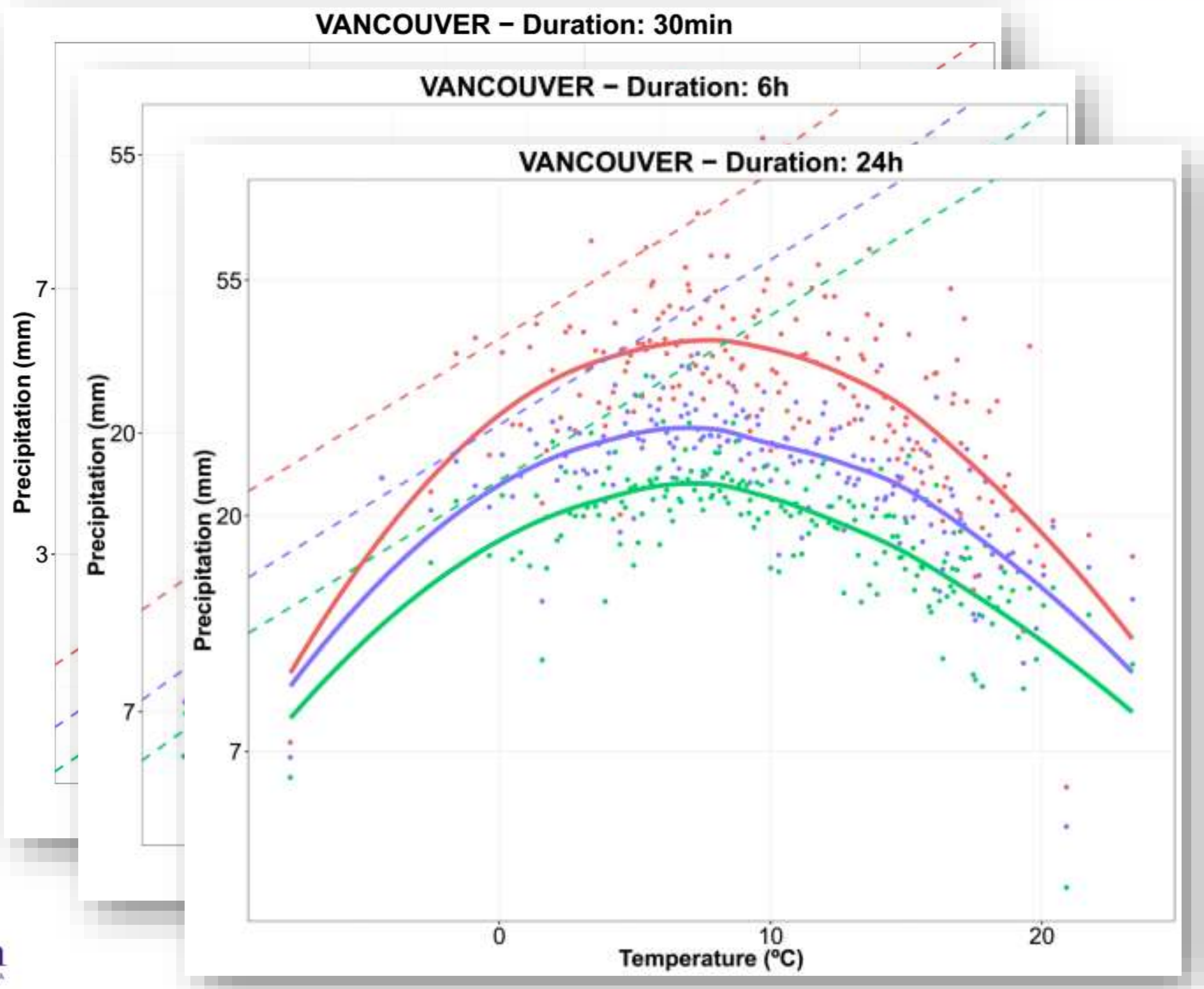


# 17 | COMPARISON

Physics based approach



# 18 | COMPARISON
## Physics based approach

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# COMPARISON

## Physics based approach

- Summary
  - The sub-daily daily maximum precipitation shows weak linear correlation to the daily temperature for most stations and durations. Only lower durations for **Moncton**, **London** and **Brandon** show correlations roughly identical to the theoretical C-C 7% per $^{0}$C rate.
  - For **Vancouver** station none of the sub-daily durations present linear correlation to temperature. For temperatures higher than 10 ºC negative slopes are observed.

- Conclusion
  - The Clausius-Clapeyron scaling rate **clearly does not apply** for any of the stations consider in this study, and **should not be arbitrarily applied** to derive IDF curves for future.

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# COMPARISON

7% C-C vs IDF_CC tool

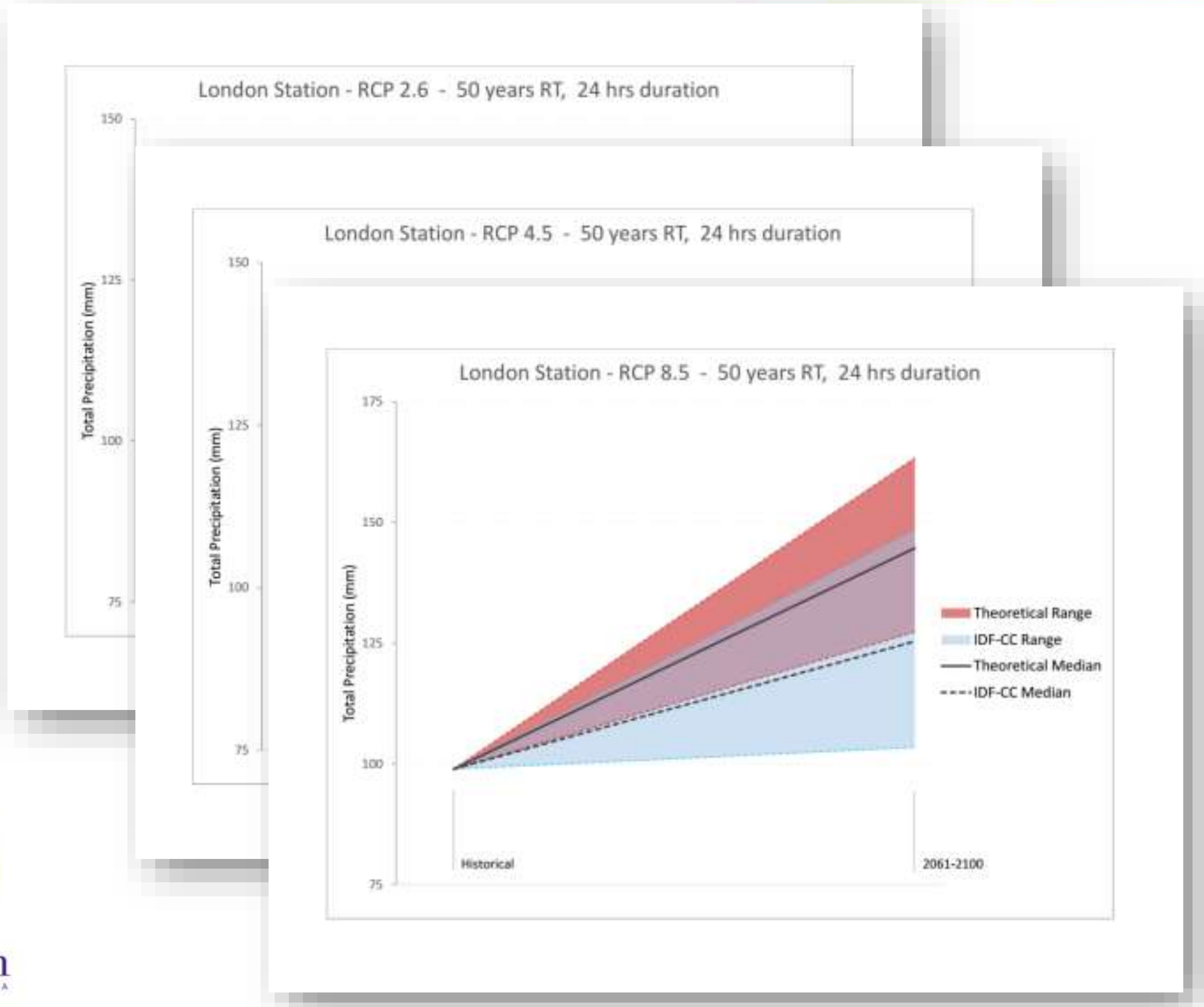
- Experiment 2

  - 358 selected stations across Canada with at least 20 years of observed data

  - Difference in projected changes (total precipitation): 7% C-C vs. IDF_CC is analyzed for the ensemble of all GCMs, RCP 2.6, 4.5 and 8.5, 2 to 100 years RT and durations: 5, 10, 15, 30 min, 1, 2, 6 and 24hrs

  - Difference in projected uncertainty: 7% C-C vs. IDF_CC is analyzed for the ensemble of all GCMs, RCP 2.6, 4.5 and 8.5, 2 to 100 years RT and durations: 5, 10, 15, 30 min, 1, 2, 6 and 24hrs. Some plots are presented.

# 21 | COMPARISON
## 7% C-C vs IDF_CC tool



# COMPARISON

7% C-C vs IDF_CC tool

- Difference in **projected changes (total precipitation)**

  - Difference (%) = $\frac{P_{7\%C-C} - P_{IDF\_CC}}{P_{IDF\_CC}} \times 100$

  - Plots for RCP 2.6 and 8.5, 50 and 100 year RT and 24 hrs duration

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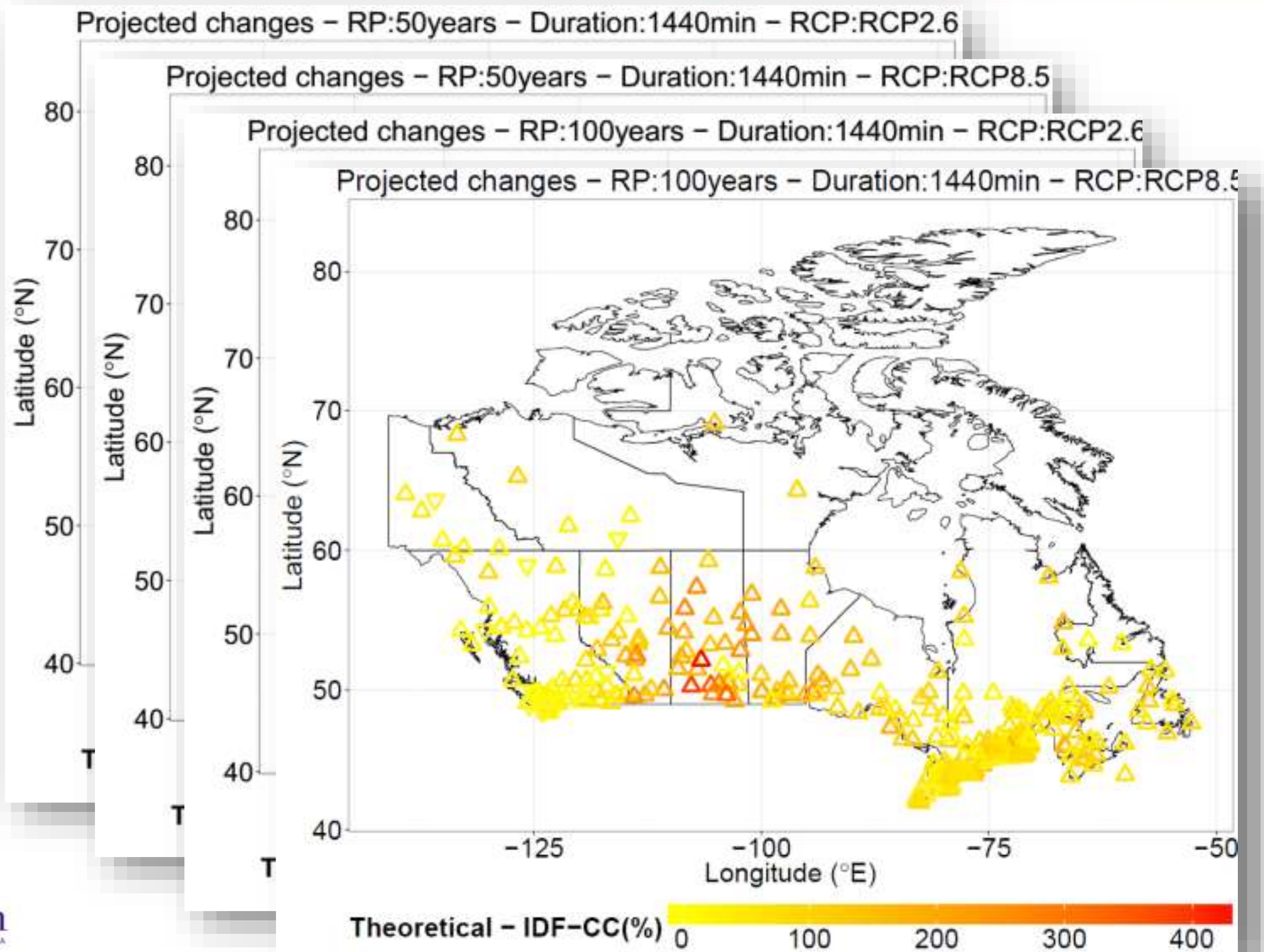
# COMPARISON

7% C-C vs IDF_CC tool



# COMPARISON

7% C-C vs IDF_CC tool

- Difference in **projected uncertainty (%)**

  - Diff. (%) = $\frac{[(P_{q95,7\%C-C} - P_{q5,7\%C-C}) - (P_{q95,IDF\_CC} - P_{q5,IDF\_CC})]}{(P_{q95,IDF\_CC} - P_{q5,IDF\_CC})} \times 100$

  - Plots for RCP 2.6 and 8.5, 50 and 100 year RT and 24 hrs duration

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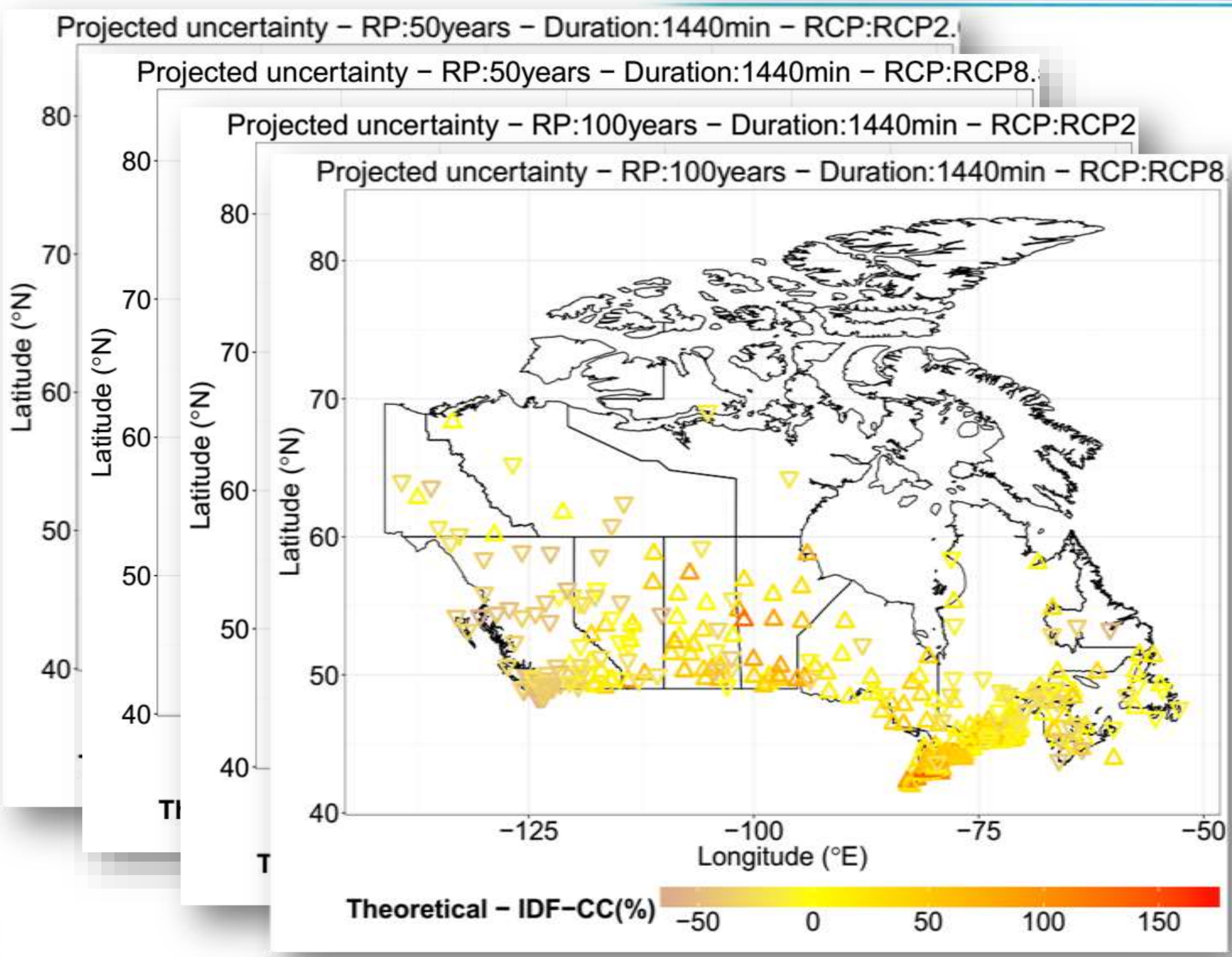
# COMPARISON

7% C-C vs IDF_CC tool



# COMPARISON

## 7% C-C vs IDF_CC tool

- Summary
  - Theoretical 7% C-C scaling is resulting in higher values of projected changes for the future compared to the IDF_CC tool for RCP 4.5 and 8.5 - specially in the prairies. For RCP 2.6 the results are mixed
  - For RCP 2.6 the IDF_CC is resulting in lower uncertainty, and for RCP 4.5 and 8.5, the uncertainty is lower for the 7% C-C.

- Conclusions
  - The IDF_CC **better captures uncertainty** from the GCMs.
  - The 7% C-C does not produce a single future IDF curve. The uncertainty range **may be even larger** than the resulting from the IDF_CC tool.

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# COMPARISON

So what?

- Conclusions
  - Live with the process uncertainty
  - Adapt the decision making process
- Questions from the practice
  - Standardization?
  - How to deal with the uncertainty? (communication and understanding)
  - What to do for ungauged sites?
- Recommendations
  - Use IDF_CC tool
  - Move from risk based decision making to process based engineering
  - Switch from risk to resilience

# PRACTICAL ISSUES

Regulatory approach

- Standardization
  - PEI (Transportation, Infrastructure, and Energy Dept) example:

*"The impact of climate change is to be considered in the planning and design of new subdivisions and developments to prevent any flood related damages to structures and properties. This approach requires the use of future climate data instead of historical data in the design of stormwater systems, as historical data does not represent future climate anymore and it may underestimate climate risk and its impact. Future climate data can be generated or obtained using available resources and studies, the University of Western-Ontario IDF CC Tool is one of these resources and it is recommended for generating future rainfall data. However, if consultant/engineer prefers other resources or specific global climate models to generate rainfall data, TIE will review the proposed information and advise if it coincides with the recommended tool. The Tool can be found at: www.idf-cc-uwo.ca . To generate future data from IDF CC Tool, using an ensemble of all models is recommended to avoid variability in data generated from individual models. Also, future data should be generated based on RCP 4.5 and RCP 8.5 scenarios."*

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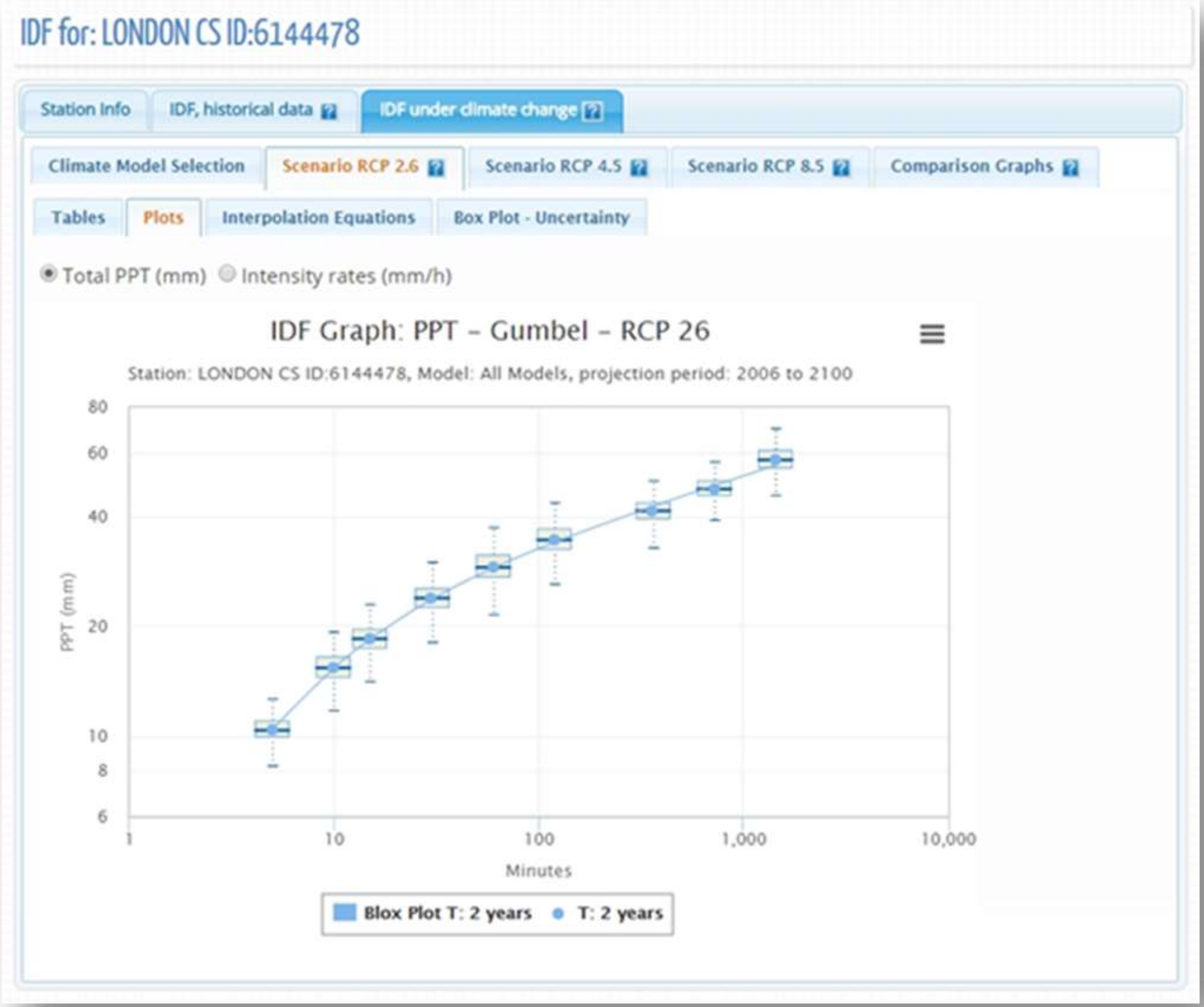
# PRACTICAL ISSUES

## Uncertainty communication and understanding

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# PRACTICAL ISSUES

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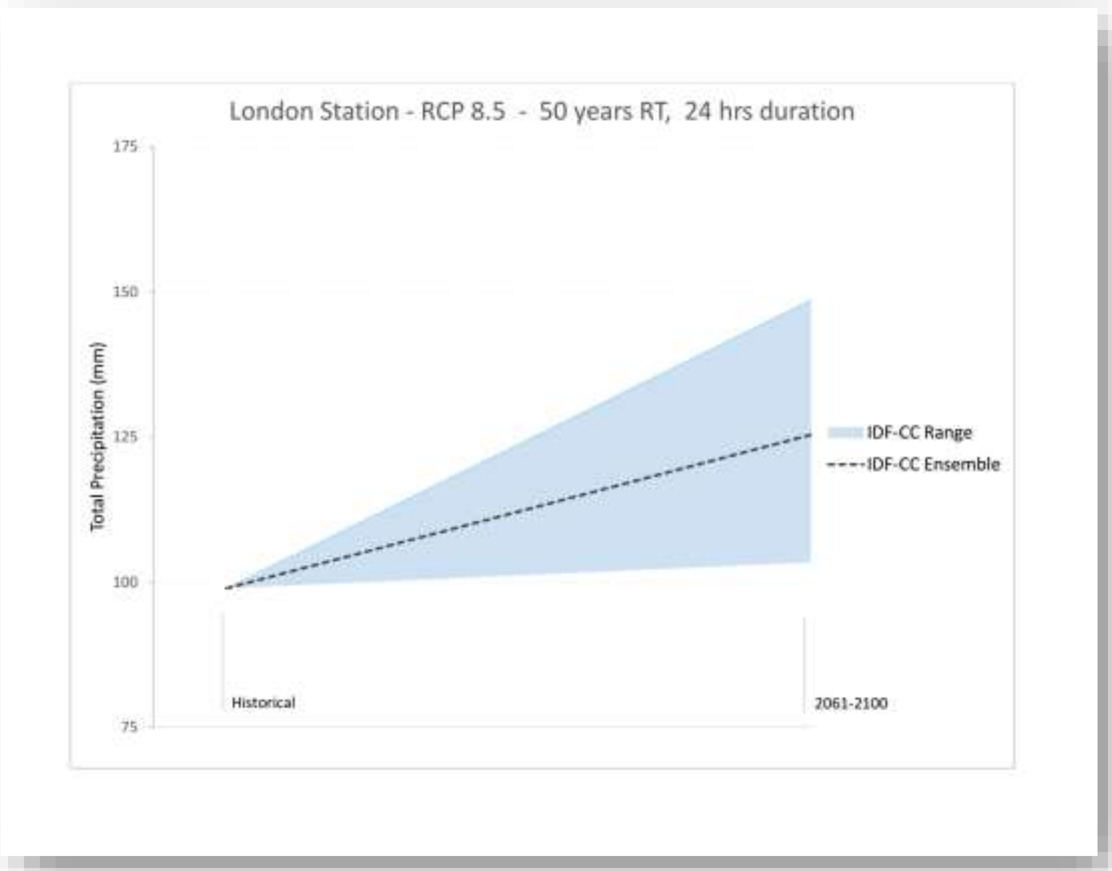


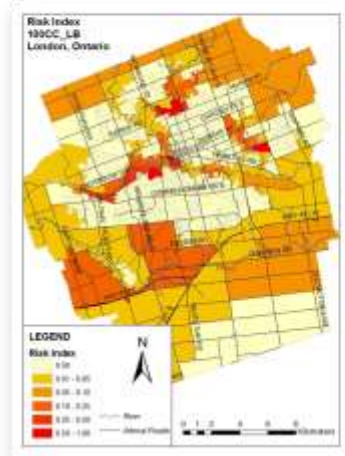


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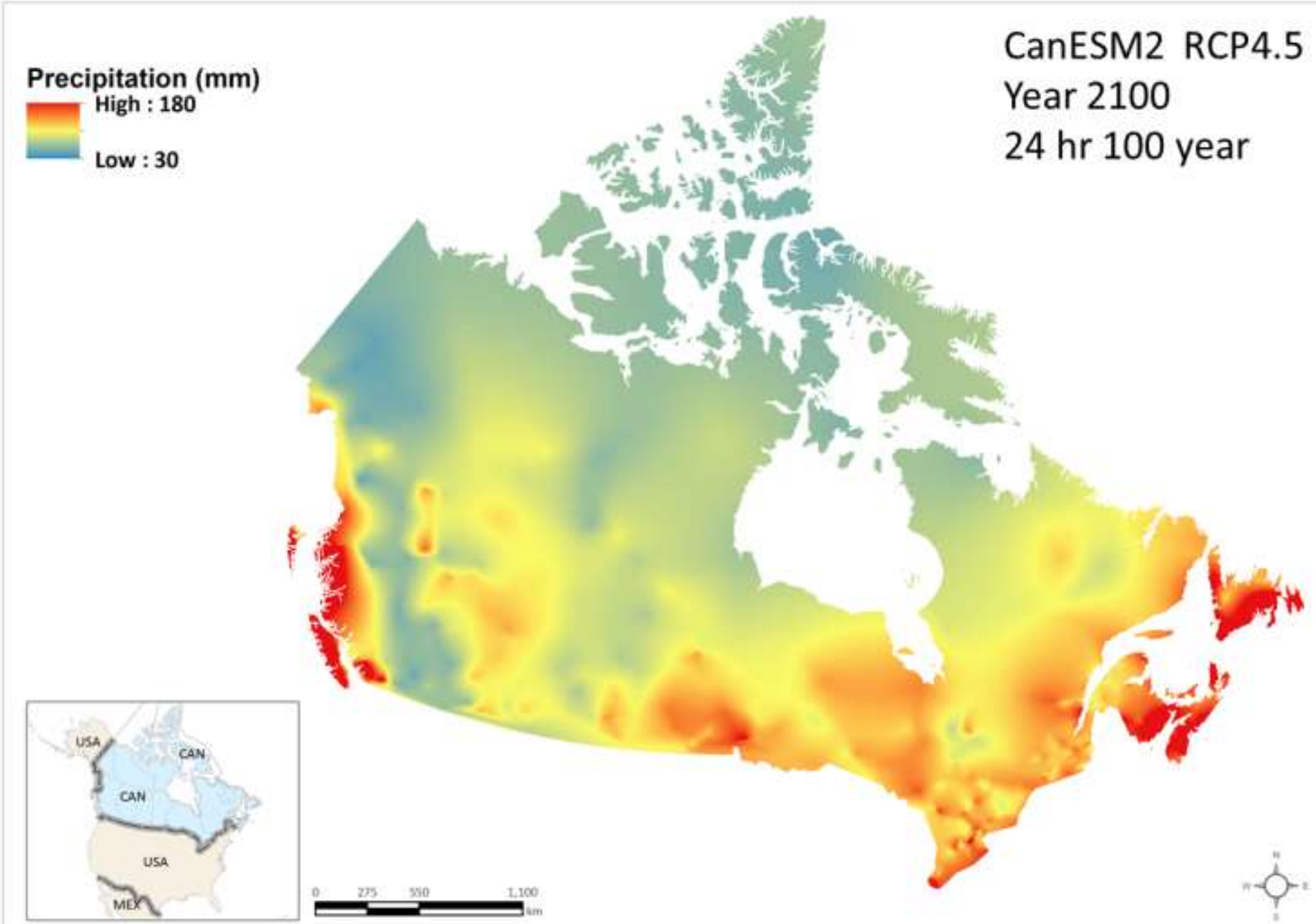
# PRACTICAL ISSUES

## Ungauged sites

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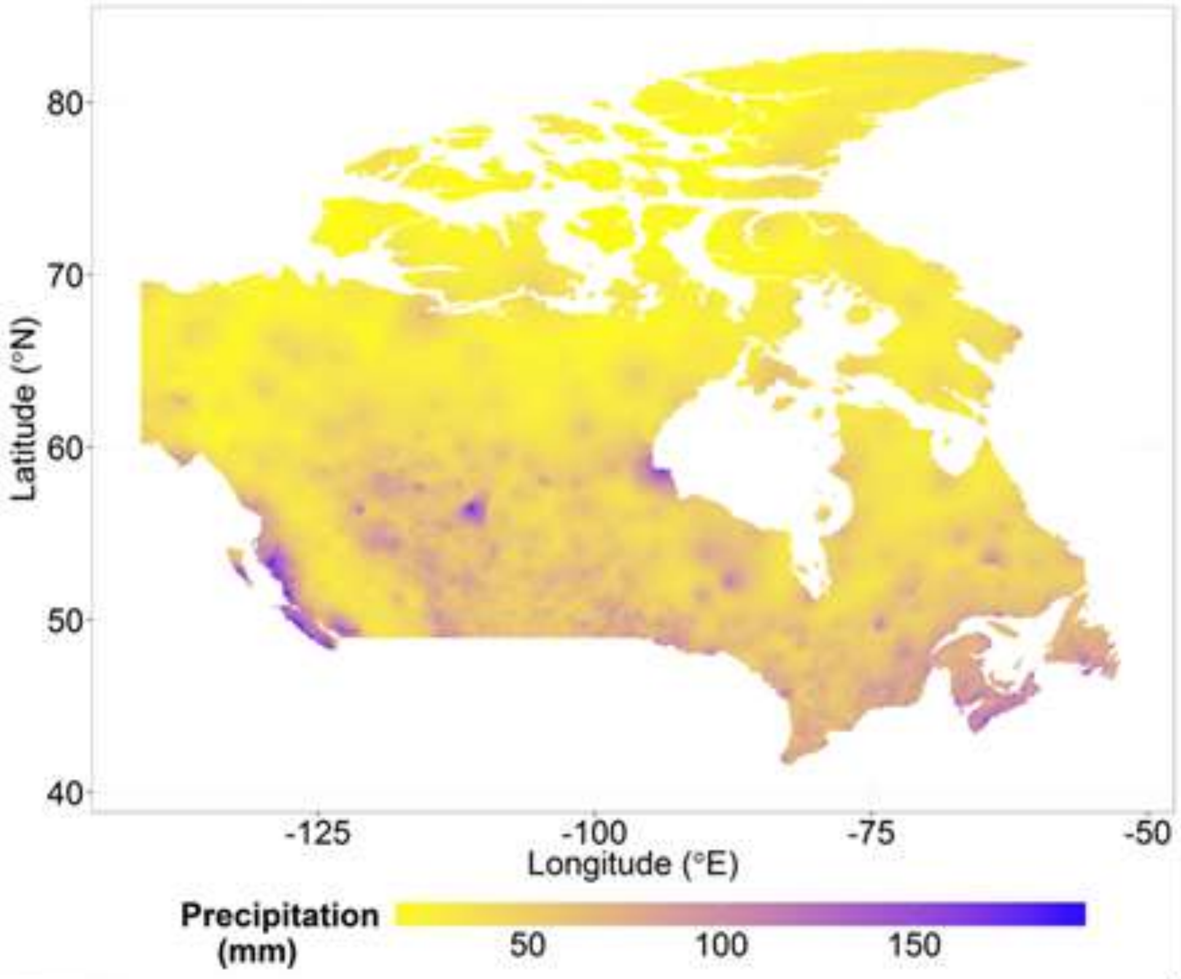
# PRACTICAL ISSUES

## Ungauged sites

- Development of a gridded short duration maximum precipitation dataset for the Canadian landmass
  - Methodology for historical data
  - 10 km grid
  - Mean annual precipitation, maximum annual precipitation, and mean annual convective available potential energy - regression with 24, 12, 6, 2, 1 hour, 30, 15, 10, 5 minute precipitation
  - Linear Regression (LR), Quantile Regression (QR) and Generalized Additive Model (GAM)
  - Evaluations based on RMSE, precipitation distribution and trend
  - Tested using 526 stations
  - *Climate Dynamics* - under review
- Implementation with the climate change projections

# PRACTICAL ISSUES

## Ungauged sites



# GUIDELINES

## Major transformation

- From codes and standards to process-based engineering
- From risk to resilience

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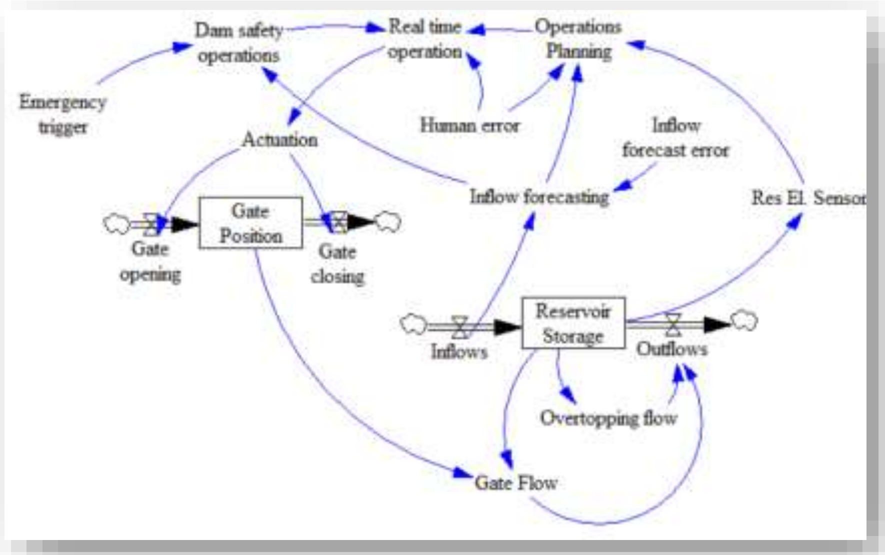
# GUIDELINES

## Major transformation

- From codes and standards to process-based engineering
  - Systems analysis
  - Probabilistic approach replaced with system simulation
  - Understanding system structure and relationships that result in system performance

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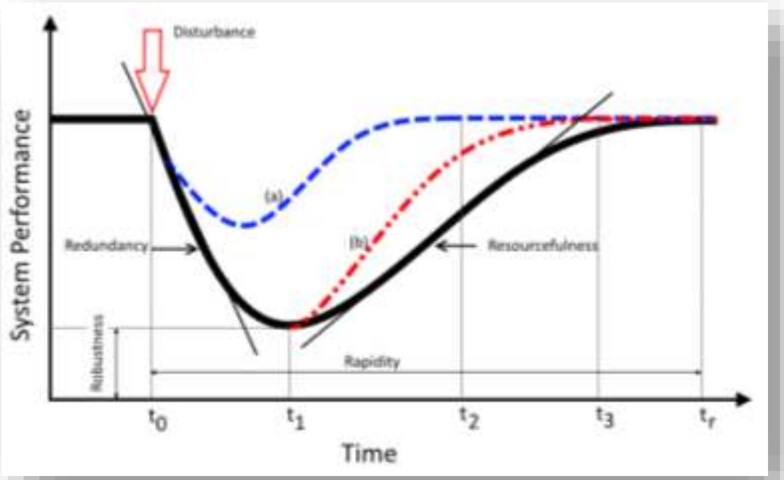
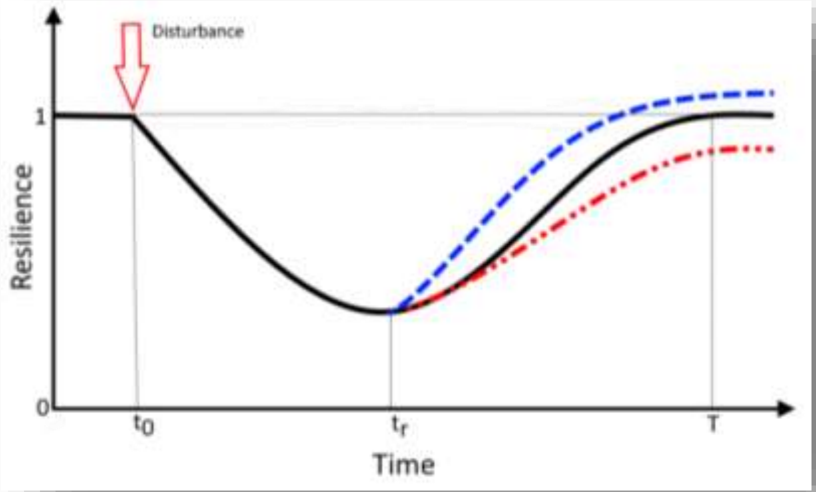
# Major transformation

- From risk to resilience
  - Quantitative description of system performance in response to changing conditions

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# 37 | CONCLUSIONS

- There is a clear practical need for updating IDF relationships for climate change
- Challenges in projecting precipitation extremes remain
- Use of the IDF_CC tool is a recommended option
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  - The IDF_CC better captures uncertainty from the GCMs
- Recommendations
  - Use the IDF_CC tool – live with the process uncertainty
  - Move from risk based decision making to process based engineering
  - Switch from risk to resilience

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# RESOURCES

- **Choice of distribution**
  - Millington, N., S. Das, and S.P. Simonovic (2011). The Comparison of GEV, Log-Pearson Type 3 and Gumbel Distributions in the Upper Thames River Watershed under Global Climate Models. *Water Resources Research Report no. 077*, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 53 pages. 85.
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# RESOURCES

- **IDF_CC tool**


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 RESOURCES

- **Resilience**


  - Simonovic, S.P., and A. Peck, (2013) "Dynamic Resilience to Climate Change Caused Natural Disasters in Coastal Megacities - Quantification Framework", *British Journal of Environment and Climate Change*, 3(3): 378-401.
  - Simonovic, S.P. (2016) “From risk management to quantitative disaster resilience: a paradigm shift”, *International Journal of Safety and Security Engineering*, 6(2):85-95.
  - Irwin, S., A. Schardong, S.P. Simonovic, and N. Nirupama, (2016) “ResilSIM - A Decision Support Tool for Estimating Resilience of Urban Systems”, *Water* – special issue Hydroinformatics and Urban Water Systems, 8(377):1-25.
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# RESOURCES

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