BaySys Team 2 Update

Freshwater Systems

Tricia Stadnyk, P.Eng.
Team 2 Academic Lead
All-Hands Workshop, Winnipeg, MB

14 November 2019

Team 2: Freshwater Systems

Objectives

To investigate the role of freshwater timing and magnitude on the freshwater-marine coupling in Hudson Bay as a means of understanding the relative contributions of regulation and climate change to the system

2.1) Continental-scale hydrologic modelling

2.2) Uncertainty assessment of Nelson River discharge

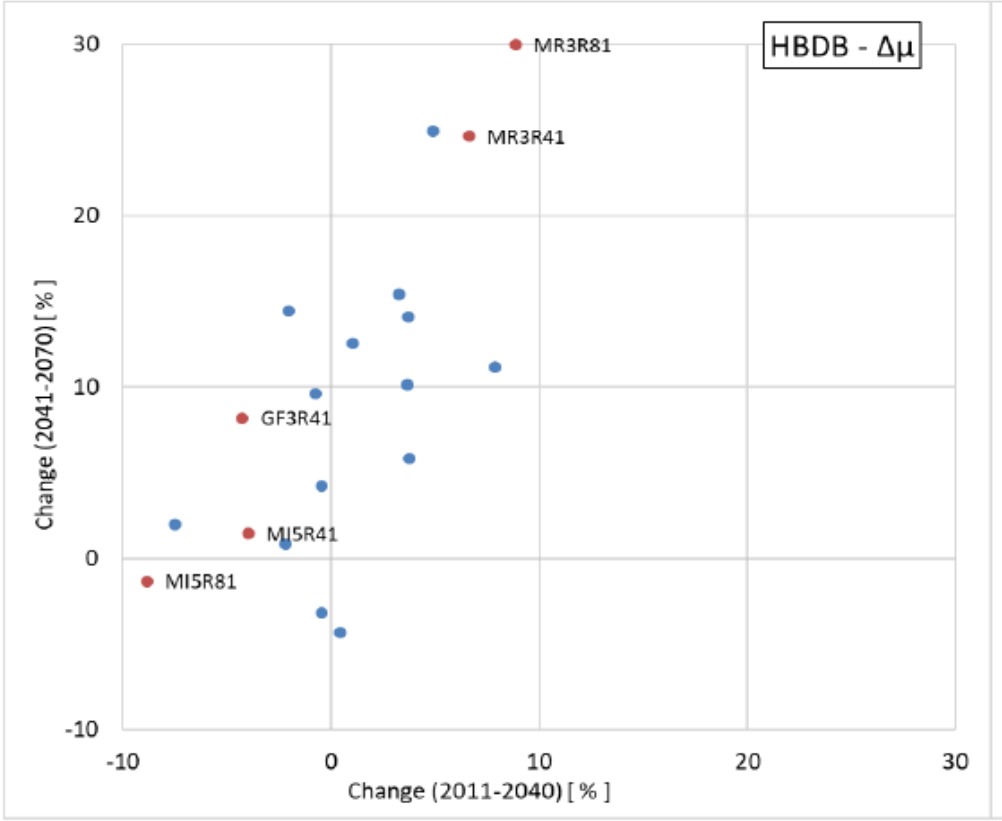
2.3) Regulated modelling

2.4) Uncertainty and sensitivity assessment

University of Manitoba

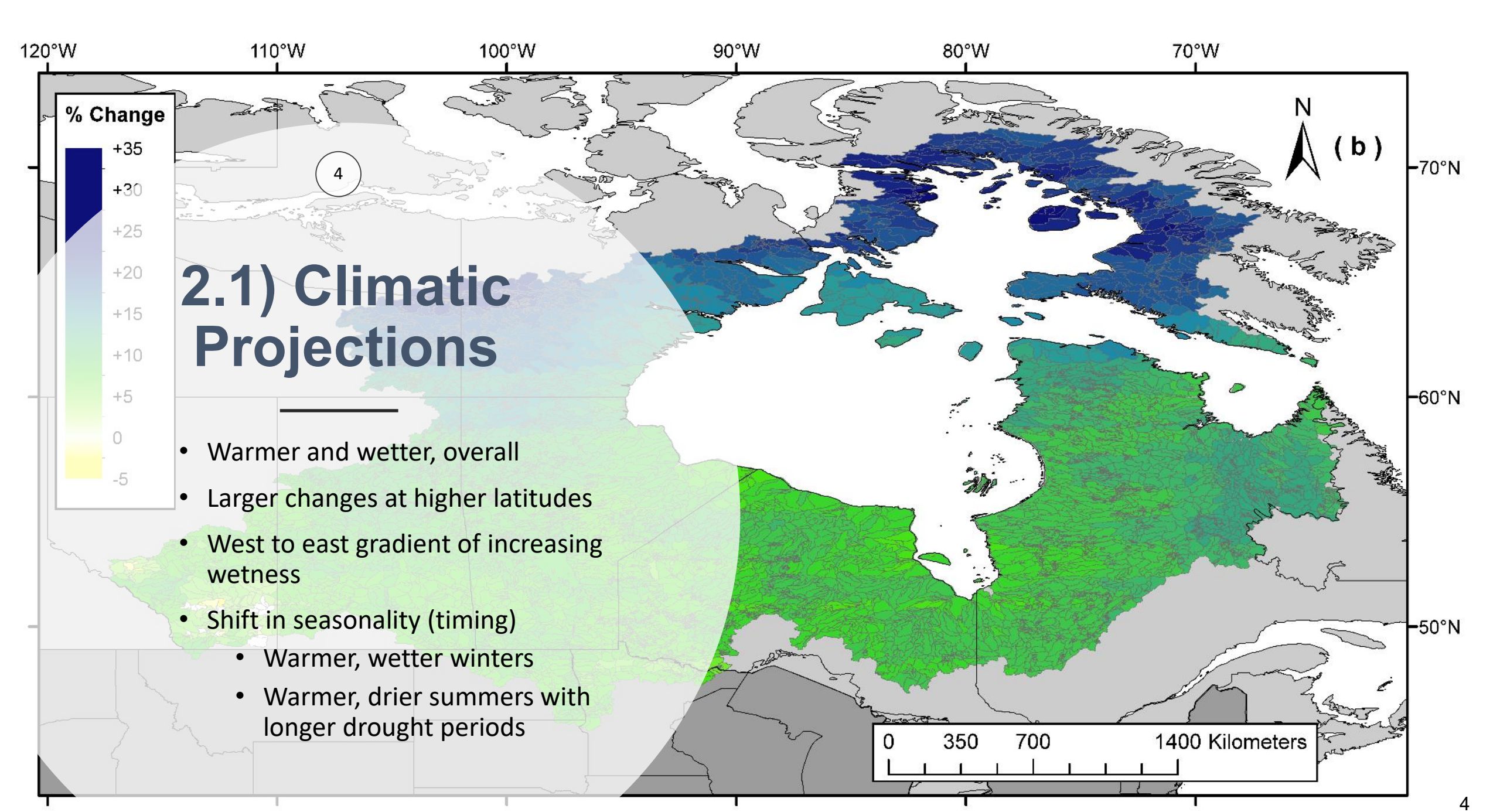
2.1) Climate Simulations

- Ensemble of 19 simulations representing the variability of >87% of the entire suite of simulations
- Selected based on 10 different criteria or climate signatures
- Runoff non-linearly correlated to climate



- Δ annual mean temp
- Δ annual mean precip
- Δ spring mean temp
- Δ summer mean temp
- Δ fall mean temp
- Δ winter mean temp
- Δ spring mean precip
- Δ summer mean precip
- Δ fall mean precip
- Δ winter mean precip

University of Manitoba

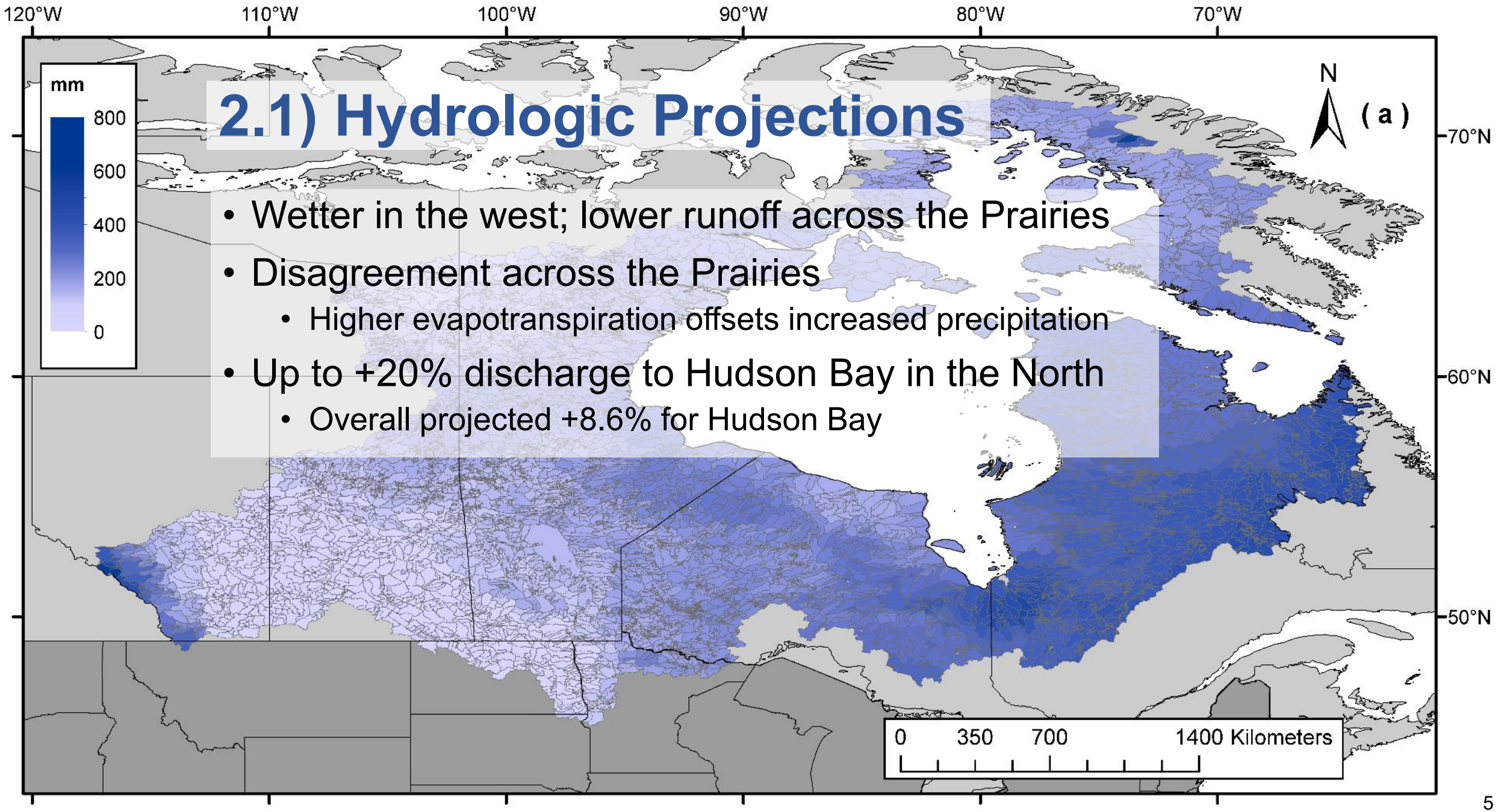


2.1) Climatic Projections

- Warmer and wetter, overall
- Larger changes at higher latitudes
- West to east gradient of increasing wetness
- Shift in seasonality (timing)
  - Warmer, wetter winters
  - Warmer, drier summers with longer drought periods

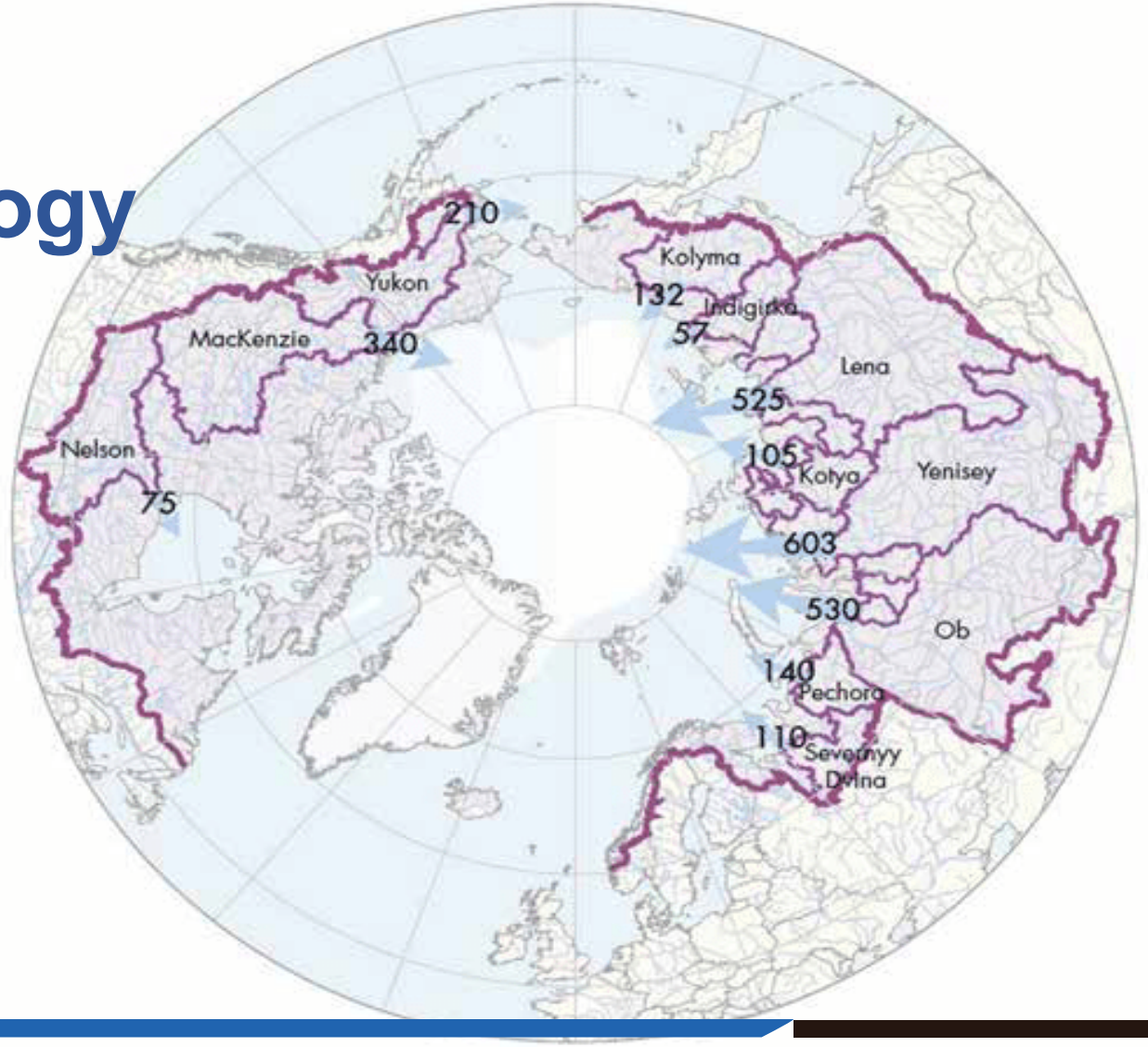
2.1) Hydrologic Projections

- Wetter in the west; lower runoff across the Prairies
- Disagreement across the Prairies
  - Higher evapotranspiration offsets increased precipitation
- Up to +20% discharge to Hudson Bay in the North
  - Overall projected +8.6% for Hudson Bay



2.1) Far Field Hydrology

- A-HYPE used to simulate pan-Arctic hydrology
  - Driven by sub-set of 5 NEMO climate simulations
- Statistical trend analysis for 12 largest rivers
  - Comparison to Hudson Bay trends
  - Overall increasing trend

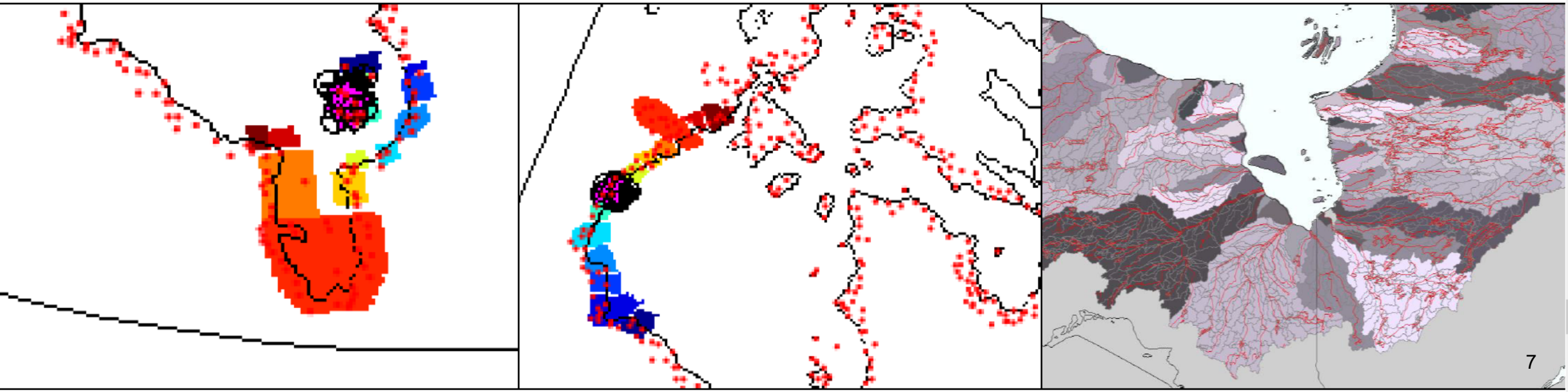


Catchment area of the Arctic Ocean, showing the annual discharge (cubic kilometers) of major rivers (Source: CAFFs Arctic Flora & Fauna - 2001)

University of Manitoba

2.1) Interfacing HYPE with NEMO

- Polygons cover multiple river outlets
  - Freshwater averaged over polygon; 100 polygons for 398 river outlets
- Spatial mapping algorithms by volume in each time step
  - Larger the volume by time step, the more that's added farther from the coast
  - Errors if too much freshwater is added to any polygon in one time step

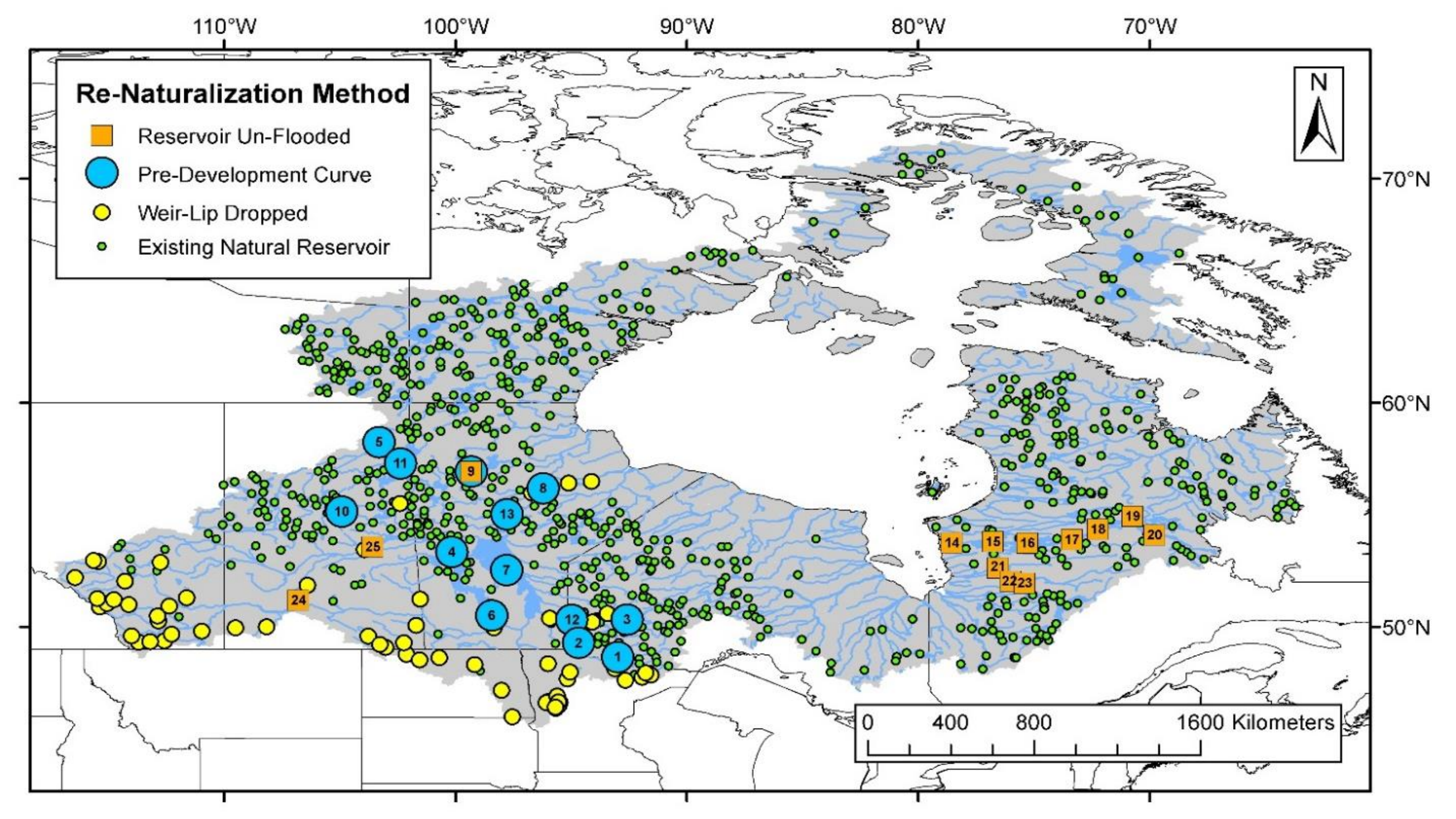


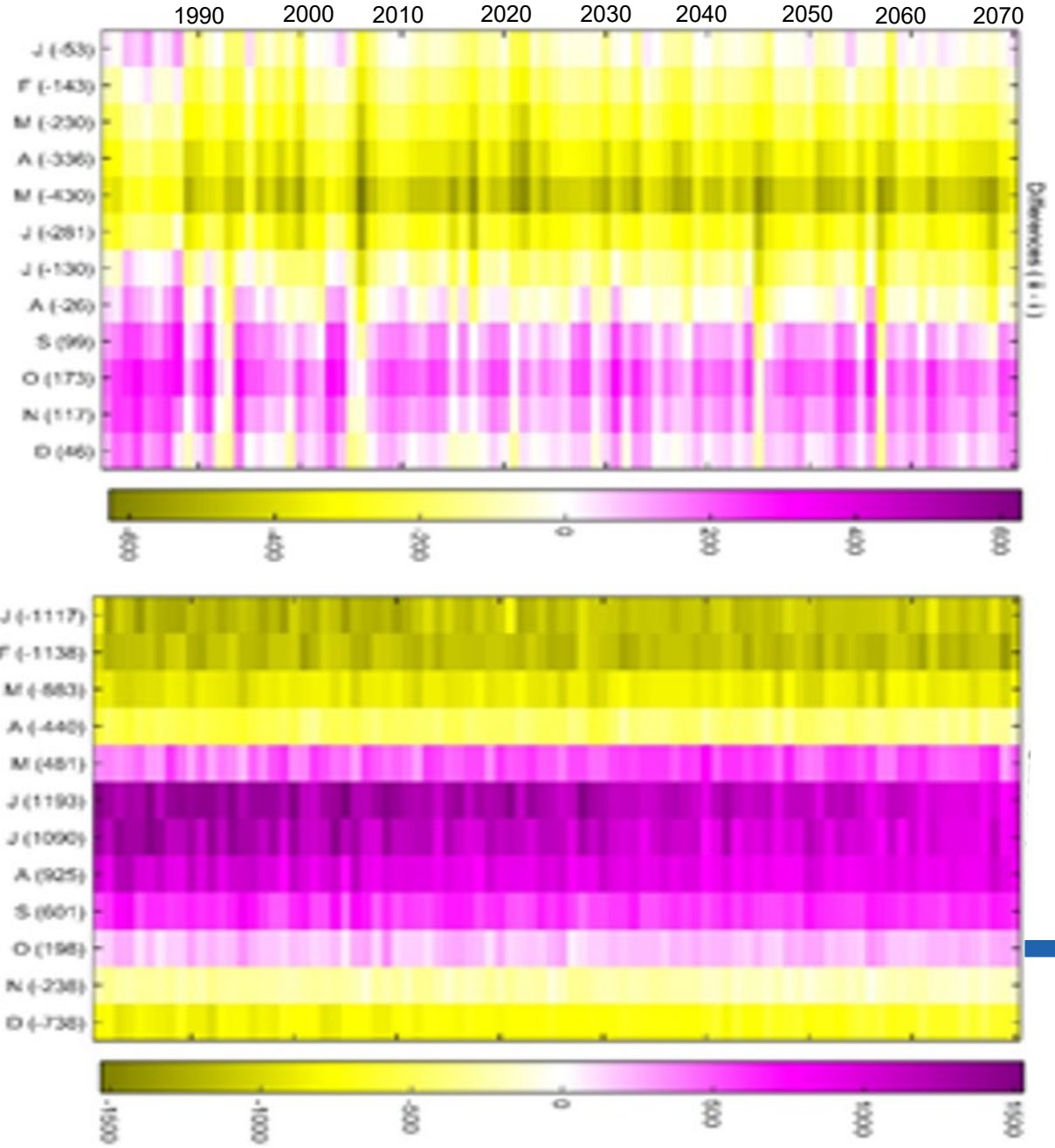
2.3) Regulation Modelling

- A-HYPE adapted to create H-HYPE in collaboration with Manitoba Hydro
  - Additional file per reservoir
- $H\text{-}HYPE_{AGILE}$ code compatible with future releases of W-HYPE
  - Single file for all reservoirs (RegData.txt)
  - Simpler parameterization, R tool

Model	Description	Parameters (single outlet)	Parameters (double outlet)
A-HYPE	Current default HYPE dam module	15	20
H-HYPE	Current BaySys HYPE regulation code	126	194
$H\text{-}HYPE_{AGILE}$	Proposed new HYPE regulation code	65	92

University of Manitoba


Re-Naturalization Method
Reservoir Un-Flooded
Pre-Development Curve
Weir-Lip Dropped
Existing Natural Reservoir
N
110°W
100°W
90°W
80°W
70°W
70°N
60°N
50°N
0
400
800
1600 Kilometers
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25



ΔDischarge (m^3s^{-1})

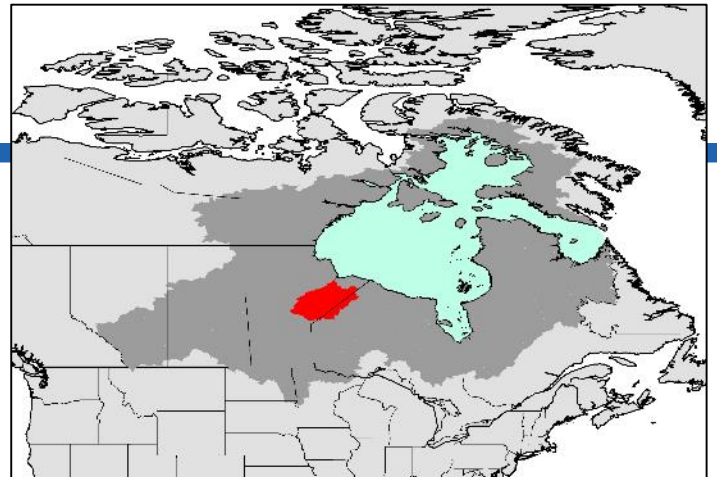
2.3) Future Regulation

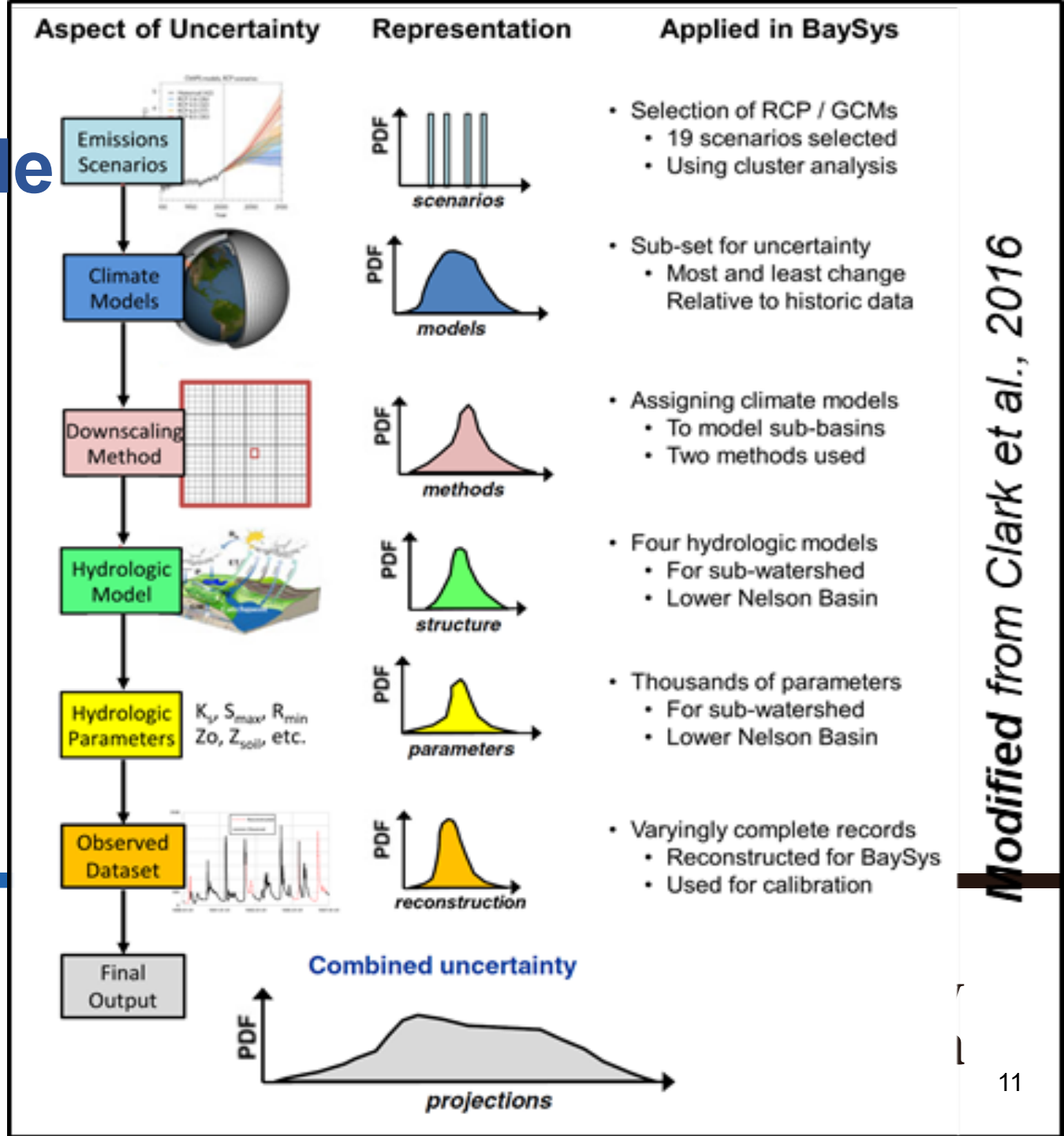
- Hydroelectric operations are the main source of intra-annual change, affecting the timing of freshwater flux
- Climate and upstream storage capacity control inter-annual variability of freshwater
  - Ability to buffer shorter-term changes
  - Visible between NCRB and LGRC basins

University of Manitoba

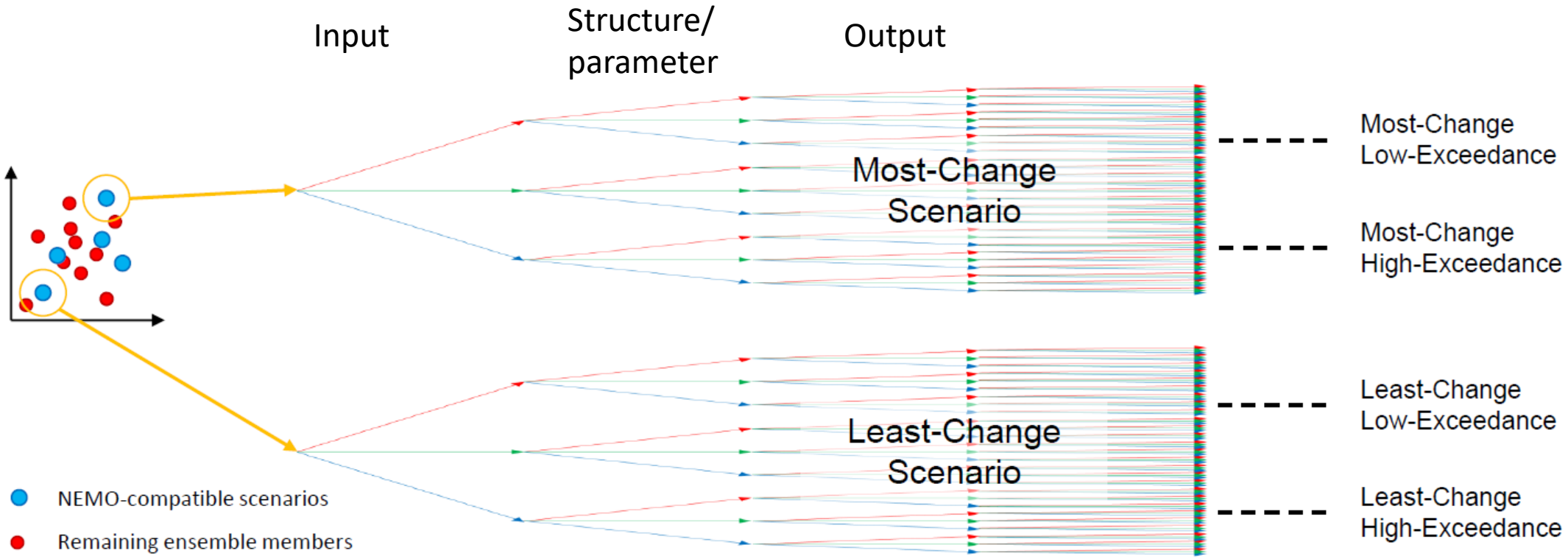
2.2) Uncertainty Cascade

- Identify relative importance of uncertainty components using Nelson River
  1. Input data
  2. Model structure
  3. Model parameters
  4. Output data
- Extrapolate to greater HBDB





2.4) Total Uncertainty: Hydrologic ‘Storylines’



2.4) Final Output: Team 2

Freshwater Scenarios

Most-change and least-change uncertainty envelope derived for each scenario and time period combination

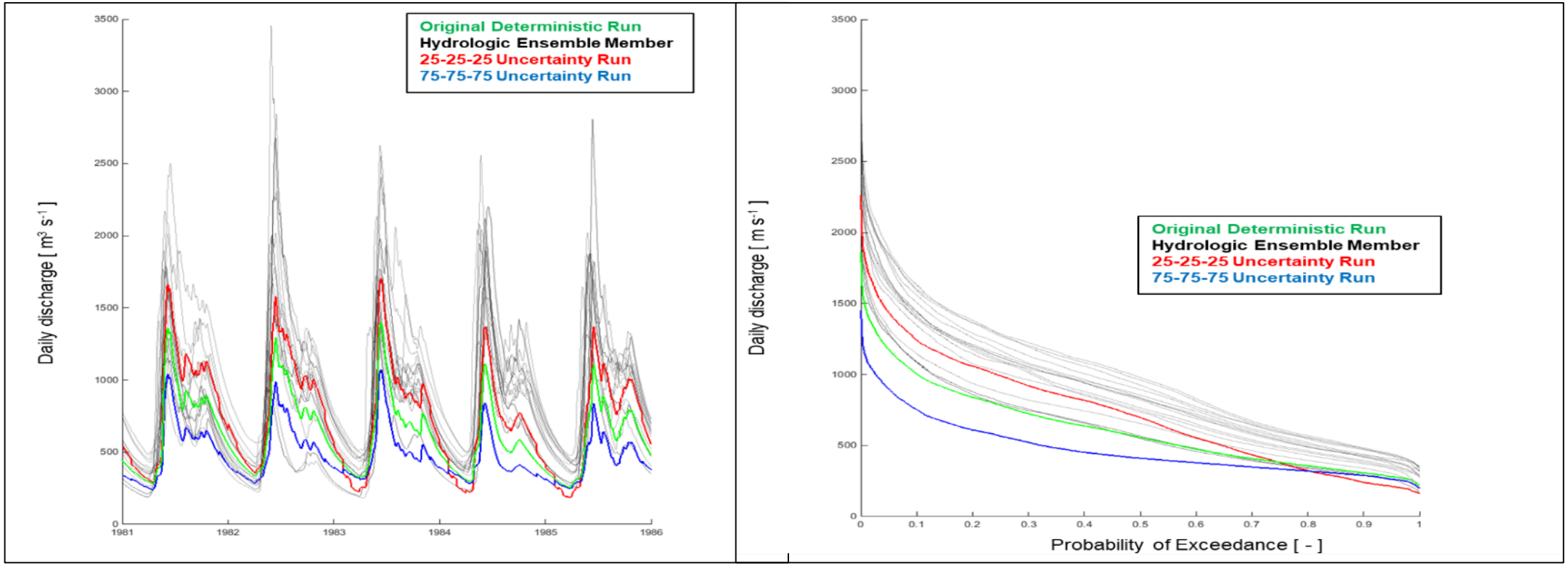
Production runs under-way

	Historic (1981-2010)	Future 2030: 2021-2050 2050: 2041-2070
Regulated	**Regulation only** Should resemble observations	**Regulation + CC** Future regulated[1] flow
Unregulated	**Climate-driven past** Today's flows if regulation never existed	**Climate-only** Today's flows altered only by future climate

[1]Future regulation holds hydropower development and energy demand constant

University of Manitoba

E.g., Variability in Freshwater Flux



University of Manitoba

Summary

Significant Contributions

- Modelled regulated hydrology for $^{1}/_{3}$ of Canadian continent
- Development of re-naturalized scenarios to compare with regulated observed flows (under same climate)
- Separation of climate and regulation effects on freshwater
- Dynamic coupling of climate-hydrologic-ocean models
- Variability in flux described by ensembles of 64 hydrologic storylines
- 6 peer-reviewed publications (4 submitted, 8 in prep.); 4 theses

University of Manitoba

Summary

Significant Findings

- Timing and magnitude of freshwater into Hudson Bay is changing and may increase by up to 20% in the future
- Arctic freshwater increases up to 26% in the future
- Higher winter flows, and lower summer flows driven by changing climate, coupled with hydroelectric regulation, are flattening the seasonal hydrograph
- Hydropower regulation impacts the intra-annual timing of the freshwater entering Hudson Bay

University of Manitoba

Publications

Déry S, Stadnyk TA, MacDonald, M., Sharma B. 2016. Recent Trends and Variability in River Discharge across Northern Canada. *Hydrol. and Earth Sys. Sci.* 20(12): 4801-4818.

Déry, S.J., T.A. Stadnyk, M. MacDonald, K. Koenig, C. Guay. 2018. Flow alteration impacts on Hudson Bay river discharge. *Hydrol. Process.* 32(24): 3576-3587.

Lilhare, R., Dery, S. J., Pokorny, S., Stadnyk, T. A., & Koenig, K. A. 2019. Inter-comparison of multiple hydro-climatic datasets across the Lower Nelson River Basin, Manitoba, Canada. Atmosphere-Ocean. https://doi.org/10.1080/07055900.2019.1638226

Lilhare, R., Pokorny S., Déry S. J., Stadnyk T. A., and Koenig K. Submitted. Sensitivity analysis and uncertainty assessment in water budgets simulated by the Variable Infiltration Capacity model for Canadian sub-arctic watersheds. In review, Hydrological Processes.

MacDonald, M., T.A Stadnyk, S.J Dery, D Gustafsson, K Isberg, B Arheimer. Submitted. Improved hydrologic model representation of landscape-based storage in the Hudson Bay Drainage Basin. Submitted to *Hydrol. Process.* HYP-17-0803

Macdonald, M., TA Stadnyk, SJ Dery, K Koenig. 2018. Impacts of 1.5°C and 2.0°C warming on pan-Arctic river discharge in the Hudson Bay Complex through 2070. *Geophys. Res. Lett.* 45(15): 7561-7570.

Pokorny, S., Stadnyk T., Lilhare, R., Ali, G., Dery, S., Koenig, K. Submitted. Towards assessing input data uncertainty in hydrologic models from ensemble-based gridded climate data. Submitted to *J. Hydromet.* JHM-D-19-0239.

Ridenour, N., Hu X., Jafarikhasragh S., Landy J.C., Lukovich J.V., Stadnyk T.A., Sydor K., Myers P.G., Barber D.G. 2019. Sensitivity of freshwater dynamics to model resolution and river discharge forcing in Hudson Bay Complex. *J. Marine Sys.* 196: 48-64.

Tefs, A.A.G.; MacDonald, M.K.; Stadnyk, T.A.; Koenig, K.A.; Hamilton, M.; Slota, P.; Crawford, J. Submitted. Simulating river regulation and reservoir performance in a continental-scale hydrologic model. Submitted to *The Journal of Environmental Modelling and Software*.

Book Chapters

Stadnyk, T.A., Déry S, MacDonald M, and Koenig K. 2019. Theme I: Physical Environment: iv. The Freshwater System. In ZA Kuzyk, and Candlish, LM *From Science to Policy in the Greater Hudson Bay: An Integrated Regional Impact Study IIRIS) of Climate Change and Modernization*. ArcticNet, Québec City, QC, Canada. 424 pp.

Theses

Pokorny, S. 2019. Assessing the relative contributions of input, structural, parameter, and output uncertainty in hydrologic modelling. MSc Thesis, Dept of Civil Engineering, University of Manitoba. 170 pp. http://hdl.handle.net/1993/34108

Tefs, A. 2018. Simulating hydroelectric regulation and climate change in the Hudson Bay drainage basin. MSc Thesis, Dept of Civil Engineering, University of Manitoba. 183pp. http://hdl.handle.net/1993/33613

Broesky, M. 2019. Analysing past, present and future trends of modeled pan-arctic freshwater discharge. BSc Thesis, Dept of Civil Engineering, University of Manitoba. 61 pp.

Lilhare, R. In preparation. Impacts of climate change on the lower Nelson River basin. PhD candidate, Environmental Science and Civil Engineering Programs, University of Northern British Columbia, Prince George, BC. Anticipated graduation Winter 2020.

Anticipated Publications (in preparation)

Déry, S. J., Stadnyk, T. A., Assani, A., Koenig, K. A. (in preparation). Hydropeaking effects on daily flows across Canada's principal regulated rivers. To be submitted to Environmental Research Letters.

Lilhare, R., Déry S. J., Stadnyk T. A., and Koenig K. (in preparation). Quantifying projected changes in water availability of the Lower Nelson River Basin, Manitoba, Canada", in preparation, Climatic Change.

Pokorny, S., Stadnyk, T. A., Ali, G. (In Preparation). A Conceptual Framework for the Estimation and Evaluation of Hydrometric Flow Data Uncertainty. To be submitted to Hydrology and Earth System Sciences.

Pokorny, S., Stadnyk, T. A., Ali, G., Déry, S. J. , Lilhare, R., Koenig, K. A. (In preparation). Cumulative Effects of Uncertainty on Flow Predictability in a Hydrologic Modeling Environment. To be submitted to Water Resources Research.

Pokorny, S., Tefs, A., Stadnyk, T. A., Ali, G., Koenig, K. A. (In Preparation). Projecting Hydrologic Modeling Uncertainty across Varying Basin Scales and Temporal Periods. To be submitted to Water Resources Research.

Tefs, A.A.G.; Stadnyk, T.A.; Koenig, K.A.; Déry, S.J.; Guay, C.; Thiemonge, N. (in preparation). Comparing the effects of climate change and hydro-electric regulation on Hudson Bay freshwater. To be submitted to *The Journal of the Canadian Water Resources Association*.

Tefs, A.A.G.; Stadnyk, T.A.; Koenig, K.A.; Déry, S.J.; Ali, G.; Guay, C.; Pokorny, S. (in preparation). Uncertainty in projections of freshwater supply to the Hudson Bay Complex: How quantifying uncertainty leads to greater confidence. To be submitted to *Journal TBA*.

Tefs, A.A.G.; Stadnyk, T.A.; Koenig, K.A.; Déry, S.J.; Guay, C.; MacDonald, M.K; Thiemonge, N. (in preparation). The changing face of freshwater to Hudson Bay: Modelling the effects of climate change and hydroelectric regulation (1981 to 2070). To be submitted to a special BaySys issue of *Elementa*.

University of Manitoba

University of Manitoba