Proceedings

Best in Science

3rd Annual Symposium

Climate Change Modelling and Impact Assessment

November 27-28, 2014

Laboratory Services Branch Auditorium - 125 Resources Road, Toronto

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3rd Annual Symposium

Climate Change Modelling and Impact Assessment

EVENT PROGRAM

Nov 27-28, 2014

Laboratory Services Branch Auditorium

125 Resources Road, Toronto

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AGENDA

Thursday, November 27th

Time	Presenter	Title
8:30 - 9:00am	**REGISTRATION**	
9:00 - 9:15am	Anne Neary, Assistant Deputy Minister, ESSD	Welcome & Opening Remarks
9:15 - 9:30am	Ian Smith, Director, EMRB, Dr. Joseph Odumeru, Director, LaSB	Overview of the BIS and Climate Modelling and Monitoring Programs in Support of Climate Change Adaptation in Ontario

Session 1: Regional Climate Modelling in Ontario

Chair: Dr. John Liu, Environmental Monitoring & Reporting Branch

9:30 - 10:00am	Prof. Dick Peltier, University of Toronto/ SciNet	High Resolution Climate Projections and Associated Potential Impacts over the Great Lakes Basin Using the US WRF Model
10:00-10:30am	Prof. Xin Qiu and Prof. Huaiping Zhu, York University	High Resolution Probabilistic Projections over Ontario through Combined Downscaling Techniques Using All Available IPCC GCM and NARCCAP RCM Results
10:30 - 11:00am	**BREAK & POSTER VIEWING**	
11:00 - 11:30am	Prof. Gordon Huang, University Of Regina	High Resolution Probabilistic Projections over Ontario through Dynamic/Combined Downscaling Techniques Using UK PRECIS Model
11:30 - 12:30pm	**LUNCH & POSTER VIEWING**	

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Session 2: Climate Impact and Adaptation Assessment

Chair: Adam Socha, Laboratory Services Branch

12:30 - 1:00pm	Dr. Alemu Gonsamo, University of Toronto	Assessing Climate Change Impact on Carbon Cycles in Ontario's Far North Ecosystems
1:00 - 1:30pm	Prof. Brian Cumming, Queen's University	Assessment of Regional Climatic Change in Northwestern Ontario from Lake Sediments: Recent and Long-term Changes
1:30 - 2:00pm	Dr. Jill Crossman, Trent University	The Interaction between Nutrients and Climate Change in Lake Simcoe
2:00 - 2:30pm	**BREAK & POSTER VIEWING**	
2:30 - 3:00pm	Don Ford, Manager, Hydrogeology, Toronto and Region Conservation Authority	Climate Change Implications on Source Water Protection Water Quantity Risk Assessment
3:00 - 3:30pm	Prof. Wanhong Yang, University of Guelph	Developing a Place-Based Modelling Tool for Evaluating the Cost Effectiveness of Beneficial Management Practices in
3:30 - 4:00pm	Prof. Bill Gough, University of Toronto	Projecting Climate Change Impacts and Risks to Human Health in Ontario
4:00pm	**ADJOURNMENT**	

AGENDA

Friday, November 28th

Time	Presenter	Title
8:30 - 9:00am	**REGISTRATION**	
9:00 - 9:15am	Ian Smith, Director, EMRB	An Overview of Current Climate Change Research Initiatives by Other Ontario Ministries and External Partners

Session 3: Climate Change Research Initiatives in Ontario

Chair: Yvonne Hall, Environmental Monitoring & Reporting Branch

9:15 - 9:45am	John Liu, MOECC	High Resolution Regional Climate Modelling in Support of Adaptation in Ontario
9:45 - 10:15am	Jenny Gleeson, MNRF	Climate Change Vulnerability and Adaptation in Ecosystems in Ontario
10:15 - 10:45am	**BREAK & POSTER VIEWING**	
10:45 - 11:15am	Alex Rosenberg, OMAFRA	Climate Change Vulnerability and Adaptation in Agriculture Sector in Ontario
11:15 - 11:35am	David Lapp, Engineers Canada	PIEVC Assessment in Support of Climate Change Adaptation in Ontario
11:35 - 11:50pm	Vidya Anderson, MOHTLC	Ontario's Environmental Health Climate Change Framework for Action
11:50 - 12:00pm	Hani Farghaly, MTO	Vulnerability and Risk Assessment in Transportation Sector to Adapt to the Changing Climate in Ontario

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12:00pm - 1:00pm	**LUNCH & POSTER VIEWING**	
1:00 - 1:15pm	Grace Lo , MNDM	Vulnerability and Risk Assessment in the Changing Climate of Northern Ontario
1:15 - 2:15pm	**QUESTIONS & DISCUSSION** *Facilitator: James Scott, MOECC* • Question and answer session on the various Climate Change Research Initiatives presentations from Session III	
2:15 - 2:30pm	Dr. Joseph Odumeru, Director, LaSB, Ian Smith, Director, EMRB	Closing Remarks

PROJECTS

MOECC-funded "Best in Science" Projects related to Climate Change

2004-2014

Project Title	Investigator & Institution	Funding Year
Climate Effects on Vertical Structure in Lakes and Implications for Food Web Interactions	Shelley Arnott Queen's University	2006-2007
Determining the role of climate on recent changes in algal communities and water quality in reference lakes from the Experimental Lake Area, Northwestern Ontario	Brian Cumming Queen's University	2007-2008
Climate and nutrients: Using long-term data to explore the role of climatic variability on carbon, nitrogen and phosphorus retention by lakes	Peter Dillon Trent University	2007-2008
Predicting nutrient delivery by agricultural streams in the Lake Simcoe catchments: linking nutrient retention, nutrient saturation and climate change	Peter Dillon Trent University	2007-2008
The effects of climate change on zooplankton and fish communities among lakes of varying dissolved organic carbon concentration	Peter Dillon Trent University	2007-2008
Climate change effects on road salt management plan	Bahram Gharabaghi University of Guelph	2007-2008

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Assessing long-term effects of climatic and environmental changes on water quality in the Lake of the Woods (Ontario) using diatoms and other environmental proxies	John Smol Queen's University	2007-2008
Impacts of climate change on water quality and hydrodynamics in Ontario lakes	Leon Boegman Queen's University	2007-2008
Scenario Studies Using A Regional Climate Model To Assess Potential Impacts On Gaseous And Particulate Air Quality	John McConnell York University	2007-2008
The Location and Timing Matter: Assessing water quantity effects of agricultural management practices under climate change and adaptation options	Wanhong Yang University of Guelph	2013-2014 *In progress*
Assessment of Contaminants and Ecosystem Change in Aquatic Systems within the 'Ring of Fire' Prior to Resource Extraction: Have Natural Contaminant Levels been Affected by Recent Warming?	John Smol Queen's University	2013-2014 *In progress*

THANK YOU!

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“Best In Science” Program Overview

Dr. Joseph Odumeru, Director, Laboratory Services Branch
Ministry of the Environment and Climate Change

3rd Annual BIS Symposium - November 27-28, 2014

Objectives of “Best in Science”

- The **Best in Science Program** (BIS) was established in 2004 to encourage and support scientific research according to the following objectives:
  - Encourage and promote research that supports Ministry’s mandate of environmental protection and safety.
  - Invest in science that fosters best practices, develops innovative approaches to expand environmental protection tools, and supports environmental leadership in Ontario’s scientific research community
  - Support scientific collaboration and knowledge transfer that proactively contributes to healthier communities and ecosystems

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BIS Research Support Since 2004

- Research support since 2004:
  - Number of projects funded: 116
  - Total investment by MOECC:
    - Approximately $10 million
  - Value of leveraged research:
    - Approximately $20 million in matching funds and in-kind support
  - Products of BIS-Supported Research to-date**:**
    - Over 100 Scientific Publications
    - Over 285 Scientific Presentations
    - At least13 Master's Degrees
    - At least 3 Doctoral Degrees

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Research Projects Funded in 2013-15

Project Title	Principal Investigator & Institution	Priority Areas Addressed
Chromium speciation in environmental samples - Ring of Fire	Vassili Karanassios University of Waterloo	Risk Assessment & Risk Management
A fluidic platform for multiple pathogen detection in water	Pouya Rezai York University	Testing Methods – Water
Artificial stream experiments to inform phosphorus management in Great Lakes Tributaries	Adam Yates University of Western	Water Quality – Great Lakes
Developing a universal instrument for fast screening and analysis of unknowns	Tadeusz Gorecki University of Waterloo	Testing Methods - Ring of Fire
Assessing seasonal patterns of the retention of nutrients in the nearshore of Lake Ontario.	Mathew Wells University of Toronto	Water Quality – Great Lakes
Children's exposure to critical air pollution due to drop-off programs at school	Pavlos Kanaroglou McMaster University	Air - Air Zone Management/ Mobile Sources-Transportation
Assessment of contaminants and ecosystem change in aquatic systems within the 'Ring of Fire' prior to resource extraction: Have natural contaminant levels been affected by recent warming?	John P. Smol Queen's University	Risk Assessment & Risk Management

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Research Projects Funded in 2013-15 cont'd.

Project Title	Principal Investigator & Institution	Priority Areas Addressed
Development of a rapid screening method for multiple enteric viruses in Ontario drinking and source waters	Marc Habash University of Guelph	Testing Methods – Water
Use of anaerobic digestion to reduce greenhouse nutrient discharges to Lake Erie	Rob Nicol University of Guelph	Water Quality – Great Lakes
Health impacts of roadside air pollution: controlled human exposures to particulate matter and ozone	Frances Silverman St Michael's Hospital	Air - Air Zone Management/ Mobile Sources- Transportation
The location and timing matter: Assessing water quantity effects of agricultural management practices under climate change and adaptation options	Wanhong Yang University of Guelph	Water Quality – Great Lakes
Hydrothermal Torrefaction/ Carbonization (HTC): an innovative process for biomass conversion to biochar for bioproduct applications	Animesh Dutta University of Guelph	Air – Local Air Quality and Climate Change - Greenhouse Gas Reduction
Weathering of rocks from the Ring of Fire: understanding the release and mobilization of CR- and V	Michael Schindler Laurentian University	Testing Methods - Ring of Fire

Climate Change Research Funded By BIS 2004-2014

Project Title	Principal Investigator & Institution	Funding Year
Climate Effects on Vertical Structure in Lakes and Implications for Food Web Interactions	Shelley Arnott Queen's University	FY 2006-2007
Determining the role of climate on recent changes in algal communities and water quality in reference lakes from the Experimental Lake Area, Northwestern Ontario.	Brian Cumming Queen's University	FY 2007-2008
Climate and nutrients: Using long-term data to explore the role of climatic variability on carbon, nitrogen and phosphorus retention by lakes.	Peter Dillon Trent University	FY 2007-2008
Predicting nutrient delivery by agricultural streams in the Lake Simcoe catchments: linking nutrient retention, nutrient saturation and climate change	Peter Dillon Trent University	FY 2007-2008
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Climate Change Research Funded By BIS 2004-2014, cont'd.

Project Title	Principal Investigator & Institution	Funding Year
Assessing long-term effects of climatic and environmental changes on water quality in the Lake of the Woods (Ontario) using diatoms and other environmental proxies.	John Smol Queen's University	FY 2007-2008
Impacts of climate change on water quality and hydrodynamics in Ontario lakes.	Leon Boegman Queen's University	FY 2007-2008
Scenario Studies Using A Regional Climate Model To Assess Potential Impacts On Gaseous And Particulate Air Quality	John McConnell York University	FY 2007-2008
The Location and Timing Matter: Assessing water quantity effects of agricultural management practices under climate change and adaptation options	Wanhong Yang University of Guelph	FY 2013-2014 ***In progress***
Assessment of Contaminants and Ecosystem Change in Aquatic Systems within the 'Ring of Fire' Prior to Resource Extraction: Have Natural Contaminant Levels been Affected by Recent Warming?	John Smol Queen's University	FY 2013-2014 ***In progress***

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Best in Science Program for FY 2015-16

- The Ministry is proposing to issue a call for BIS grant applications early next fiscal year
- Currently the Directors' Committee for Science is developing an updated list of Research Priorities for the 2015-2016 BIS call for proposals.
- The 2015-2016 research priorities and the call for proposal are subject to approval by SMC

Ontario

DYNAMICALLY DOWNSCALED CLIMATE CHANGE PROJECTIONS FOR ONTARIO AND THE GREAT LAKES BASIN

Best in Science, MOECC, November 27, 2014

Richard Peltier, Physics, U Toronto

UNIVERSITY OF TORONTO

PROGRAMME OBJECTIVES

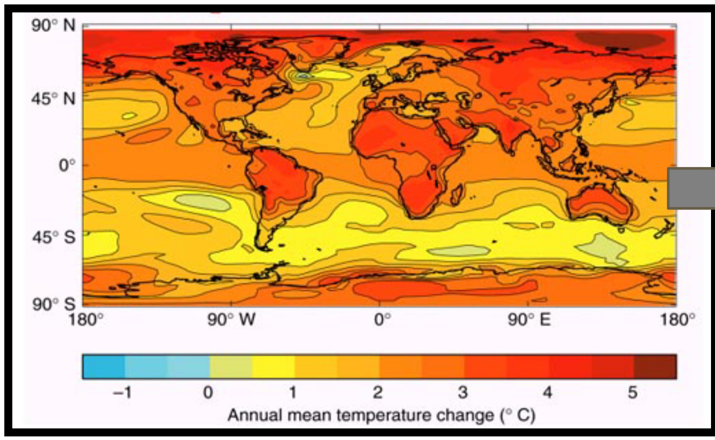
Provide climate change projections for Ontario and the Great Lakes Basin with an emphasis on the uncertainties concerning

- Future changes in extreme weather events (floods, droughts, heat waves, wind storms)
- Future changes in localized regions, eg. the Grand River Watershed of Southern Ontario

We are especially interested in employing simulations of future climate to drive a detailed model of the surface and subsurface hydrology of individual regions in order to address the question of water resource availability impacts due to climate change

Dynamical Downscaling

A2/RCP8.5 business as usual trace gas scenario



CCSM3: temperature change in 2050 relative to the 1950-1980 average

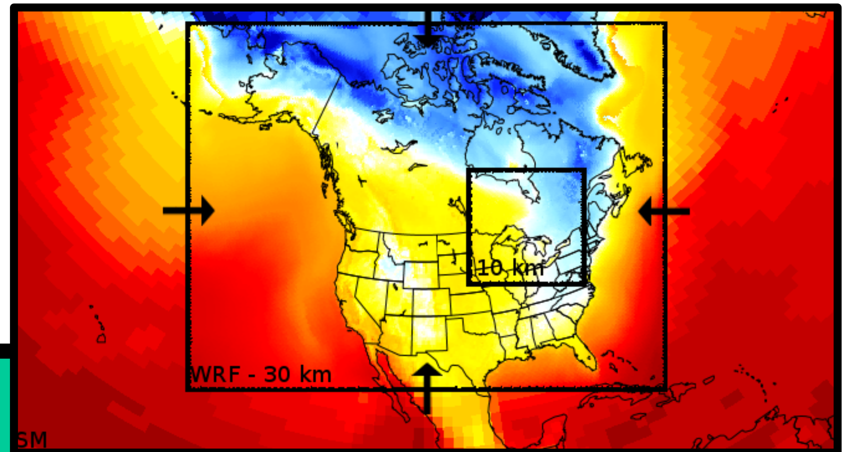
Lake effect snow storm in Buffalo, NY

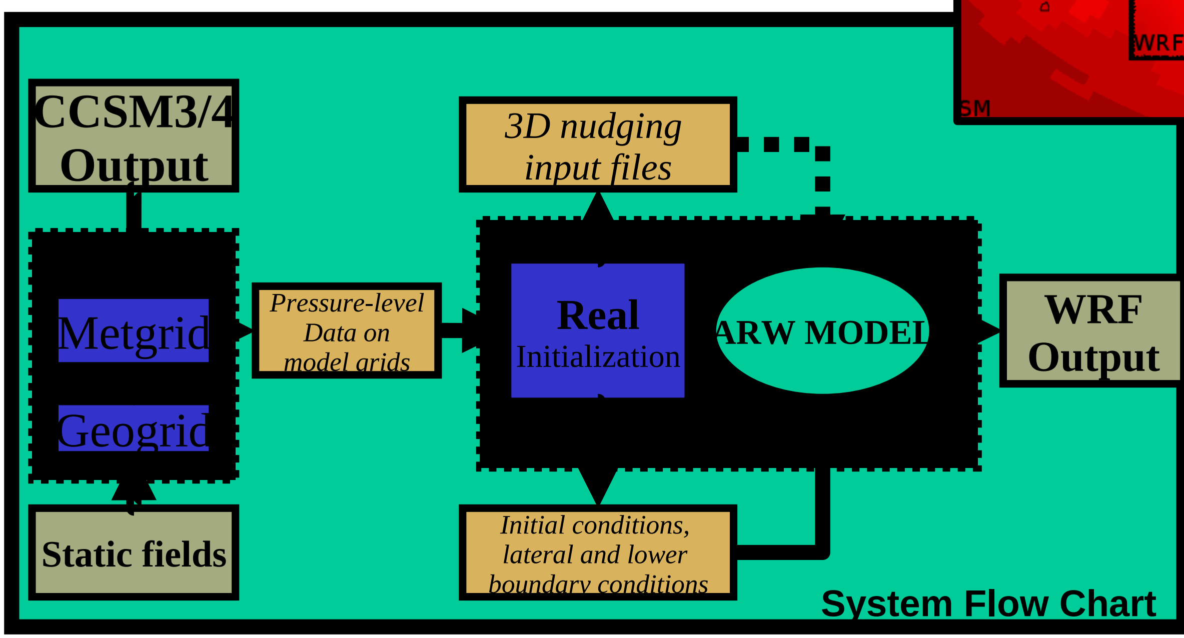
Estimate of climate change on global scales

Future projections of climate change must be resolved at the regional level if they are to be policy relevant

Methodology

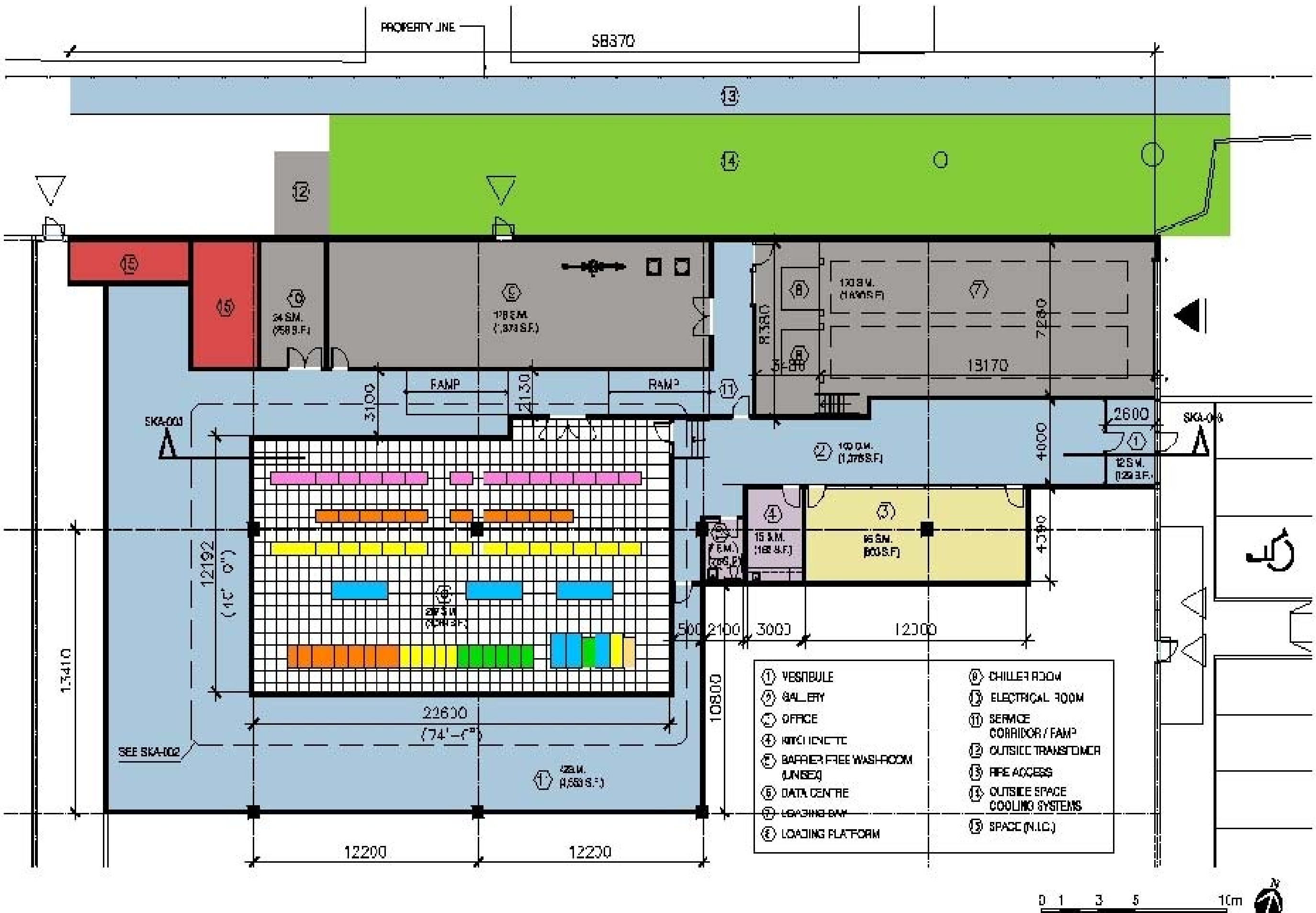
- Regional model (WRF) driven by GCM output (CCSM3/4, 1.5°) at 6h intervals
- 2 nested domains: *- North America (30km)*
  - Ontario (10km)





SciNet

All analyses are being performed on 10 nodes of the IBM Power 6 parallel HPC platform



2008 MARCH 25

UNIVERSITY OF TORONTO

SciNet HPC Centre

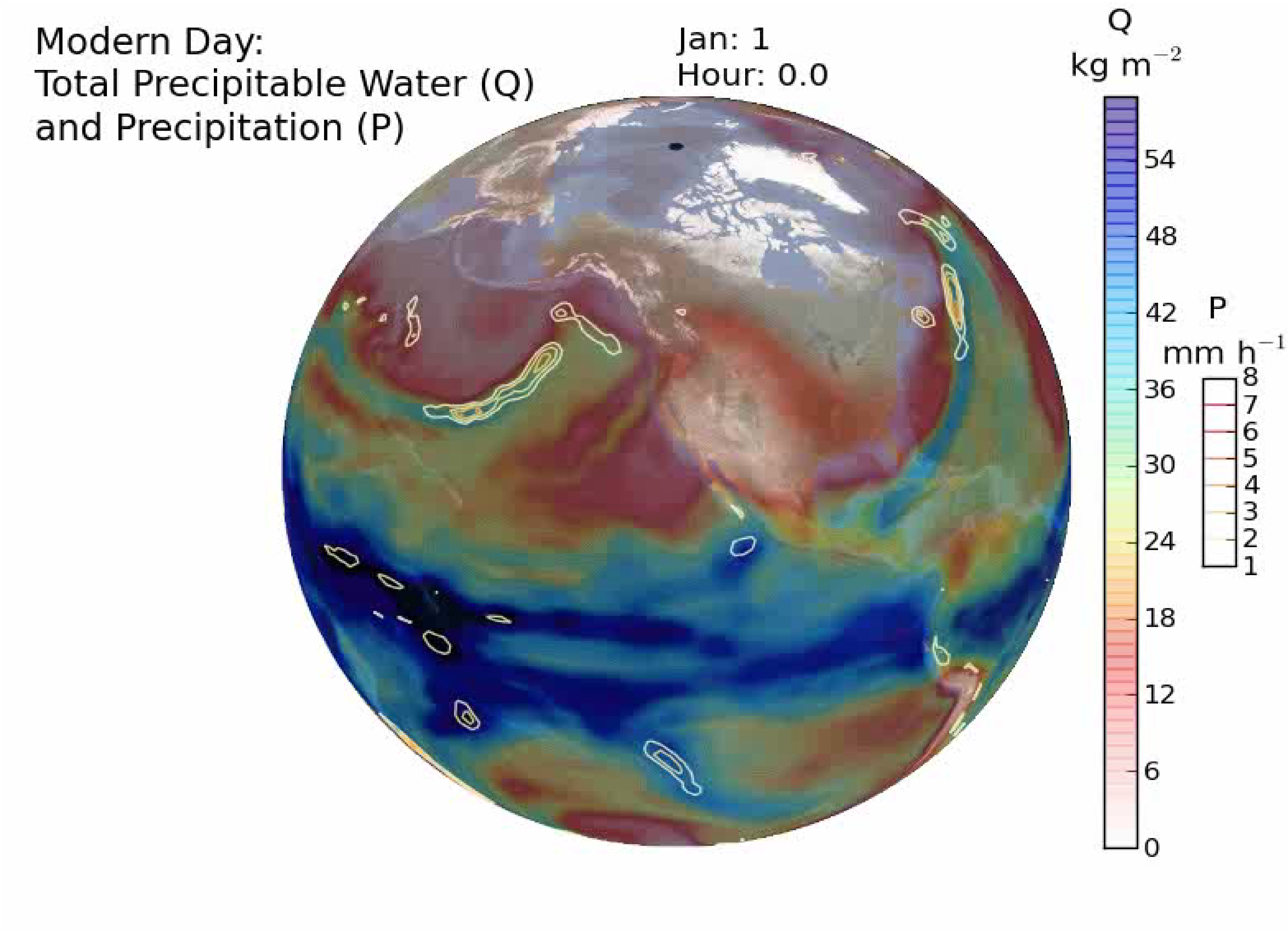
7700 KEELE STREET, CONCORD

FLOOR PLAN

ASKD-001

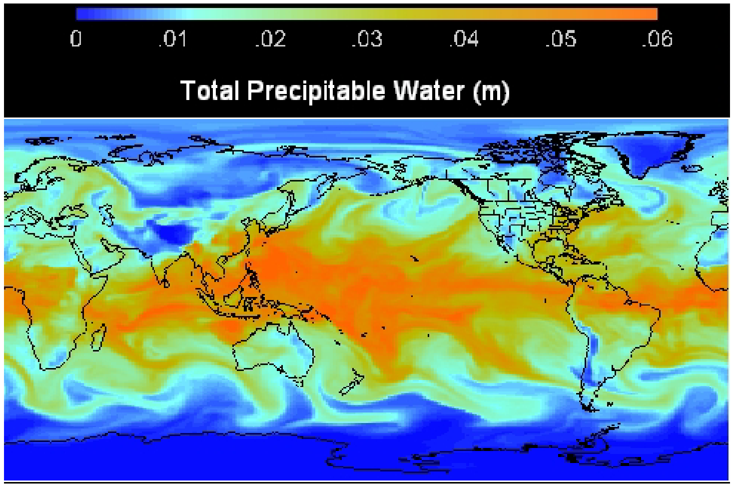
The Global Model

The Community Earth System Model 1 (CESM1)



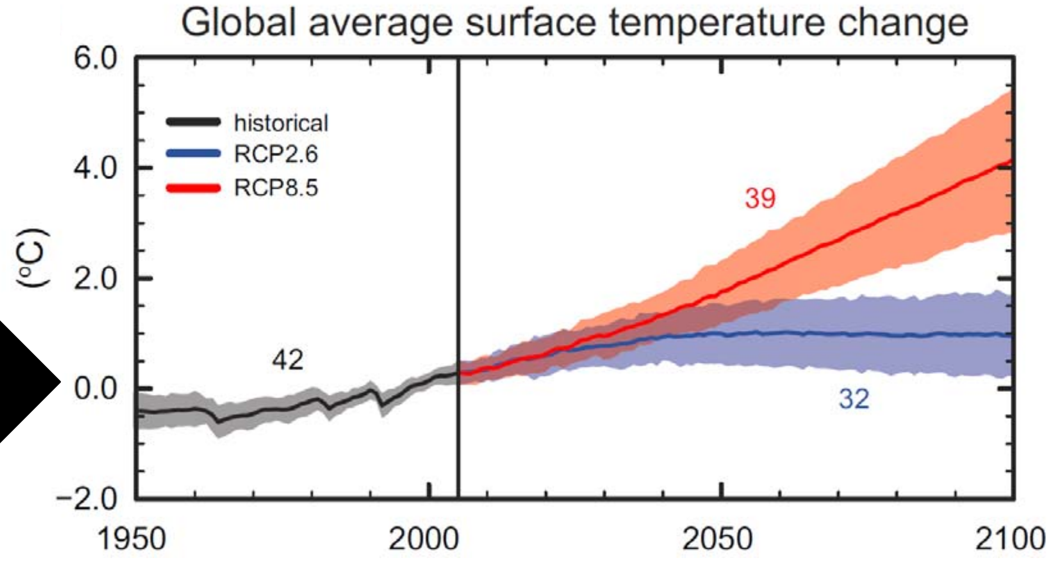
DYNAMICALLY DOWNSCALED CLIMATE CHANGE PROJECTIONS: WHAT DOES THAT MEAN ?

Global Climate Model (GCM) used for climate change projections on global scale



100 kms

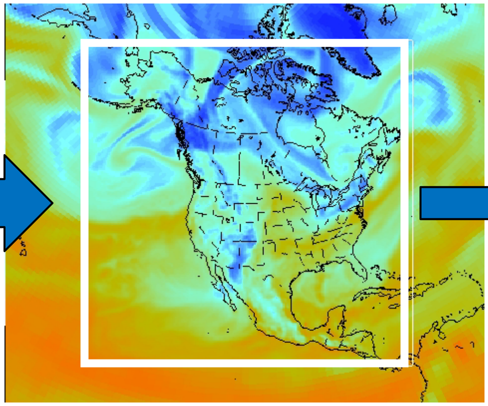
IPCC – AR5 summary for policymakers (2013)



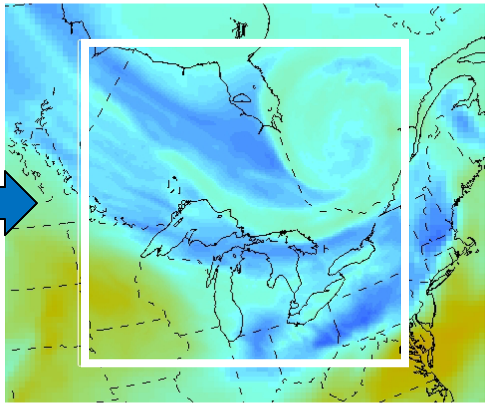
Regional Climate Model (RCM) driven by GCM for responses to climate change at regional and local levels

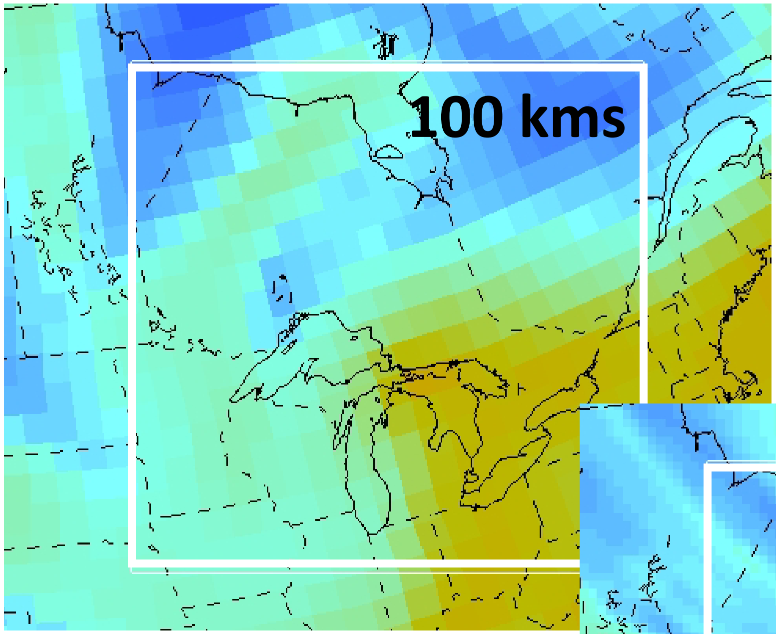
Weblink to Dynamical Downscaling Movie

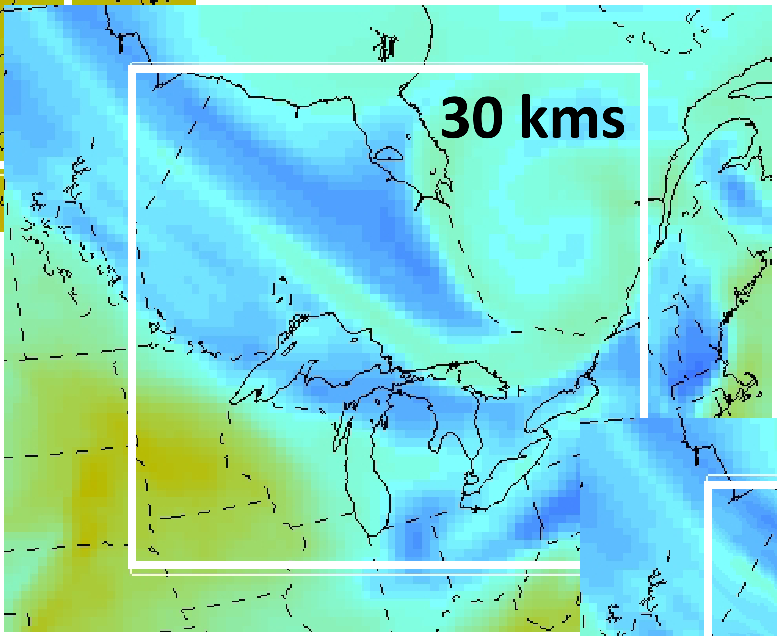
30 kms

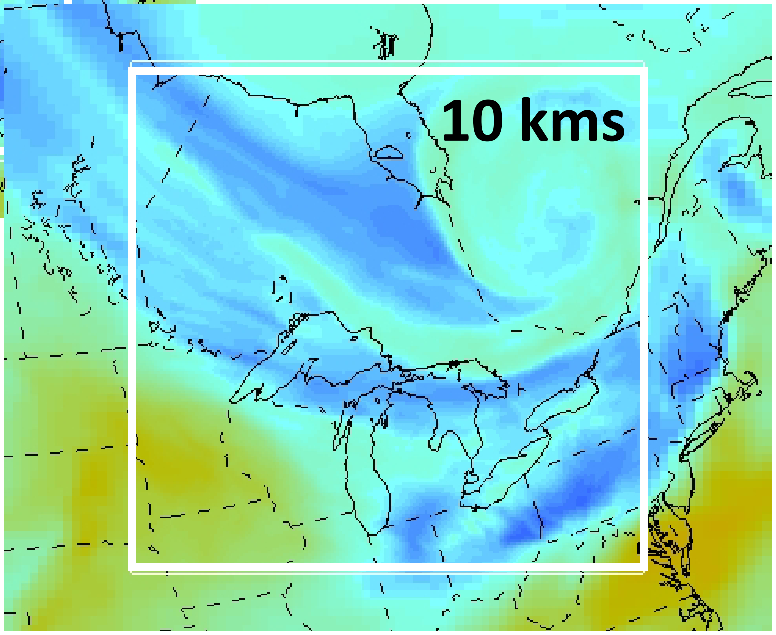


10 kms

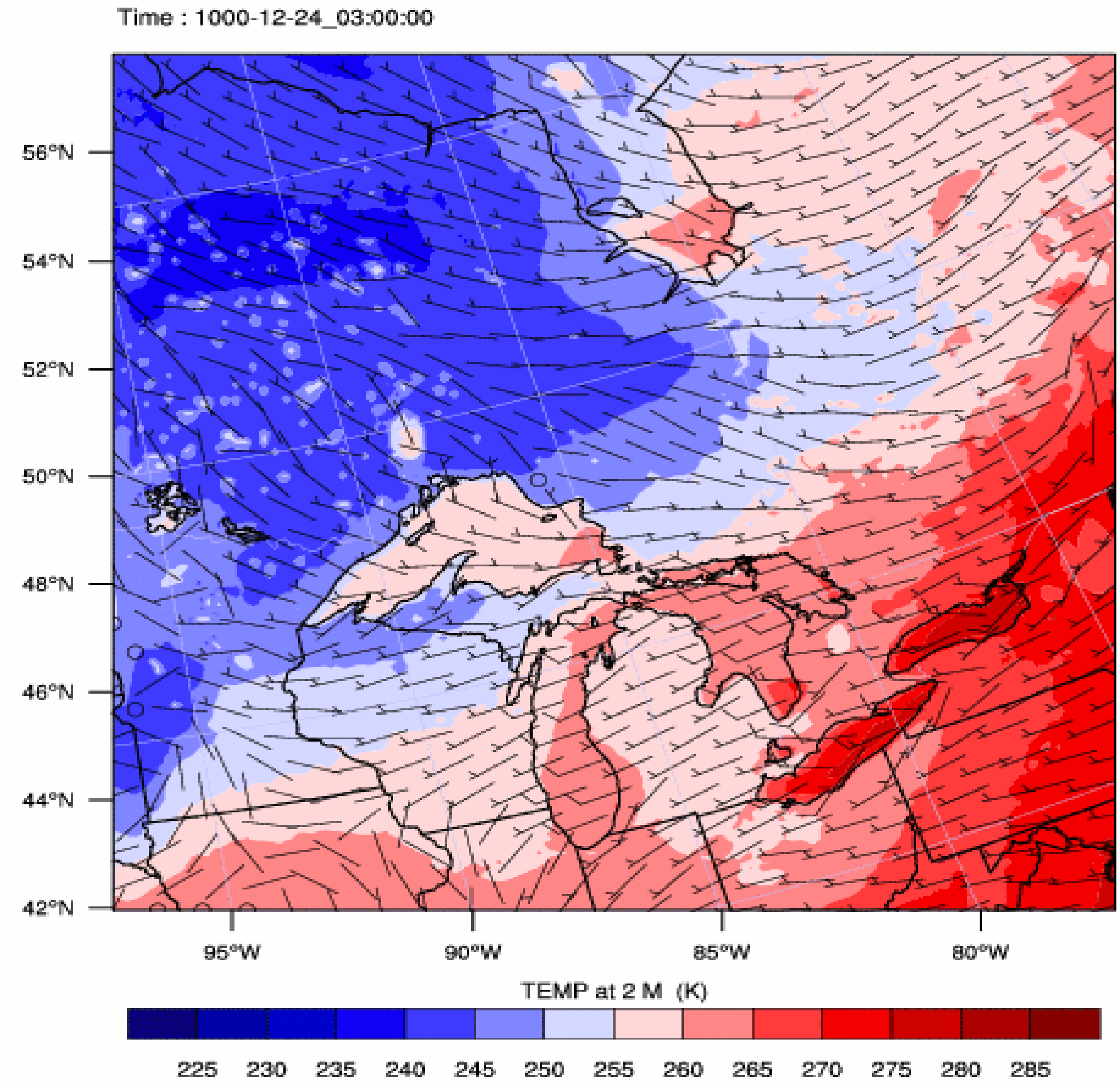








[*Weblink to hourly precipitation Movie*]



Time : 1000-12-24_03:00:00
56°N
54°N
52°N
50°N
48°N
46°N
44°N
42°N
95°W
90°W
85°W
80°W
TEMP at 2 M (K)
225
230
235
240
245
250
255
260
265
270
275
280
285

Representation of Lake Influence

WRF does not include an explicit accounting of lake influencebut we may run a modern model of lake evolution either off-line or on line to properly represent this

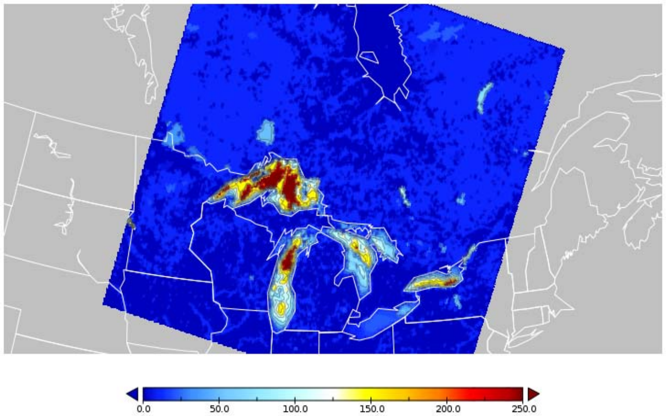
•Freshwater lake model **Flake** *[Mirovov (2008)]*

-1D lake model intended as a lake parameterisation scheme for atmospheric models

-two-layer parametric representation of temperature, heat and kinetic energy budgets (mixed-layer + thermocline)

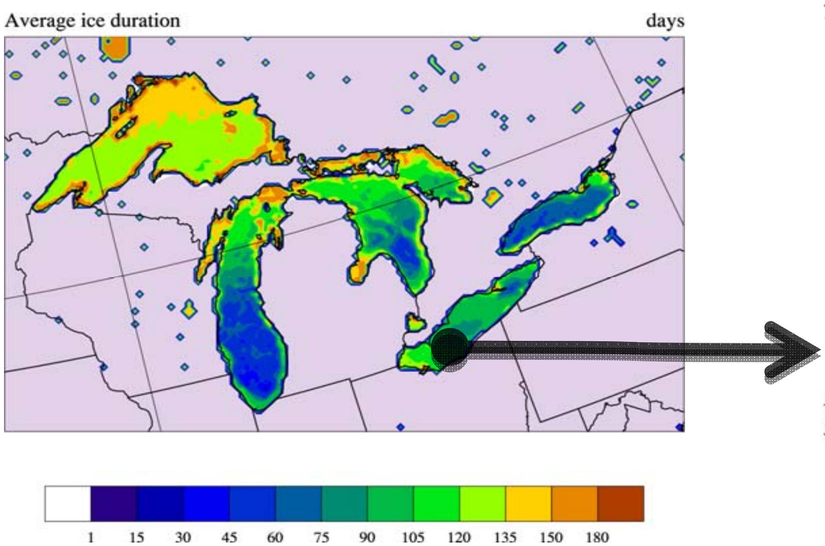
-Atmospheric forcing: T2, P, Q, SW, LW, U10, V10, snow fall rate

•Lake bathymetries are required:
Global data set from *[Kourzena (2009)]*



Representation of lake influence

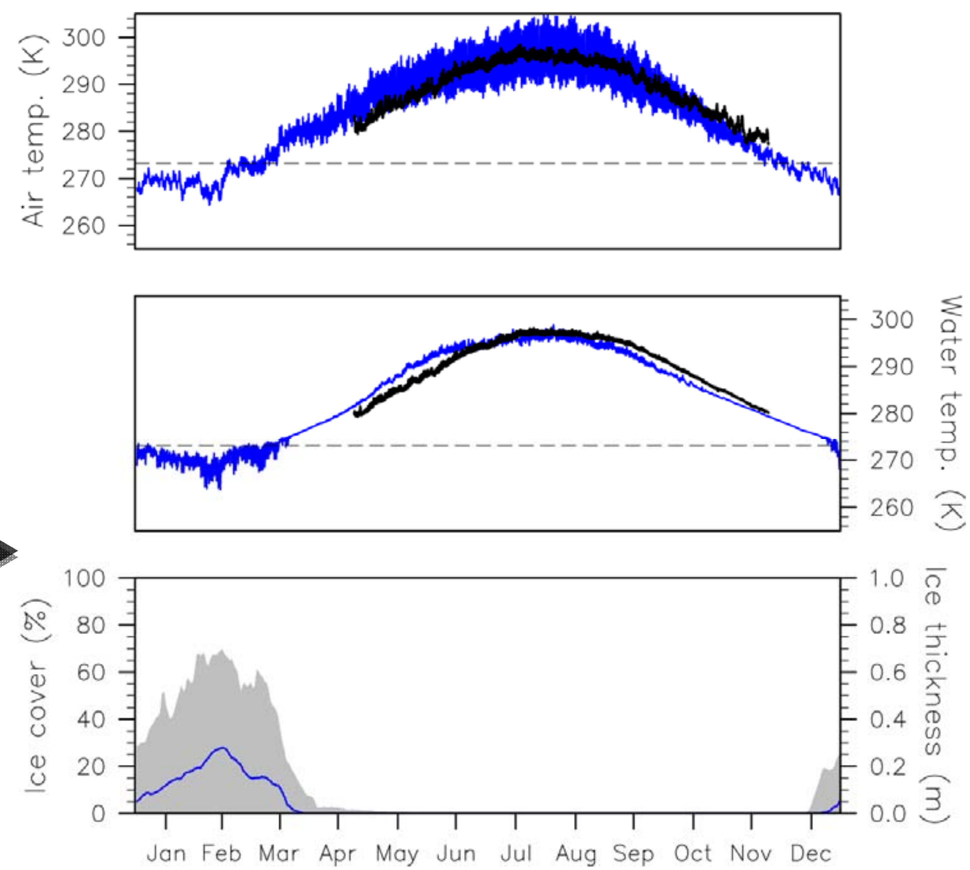
- **CCSM3-Flake Simulations:**



Average ice duration (1979-2001)

From Gula and Peltier, Journal of Climate, vol. 25, 7723-7742, 2012.

Lake Irie (depth = 12m)



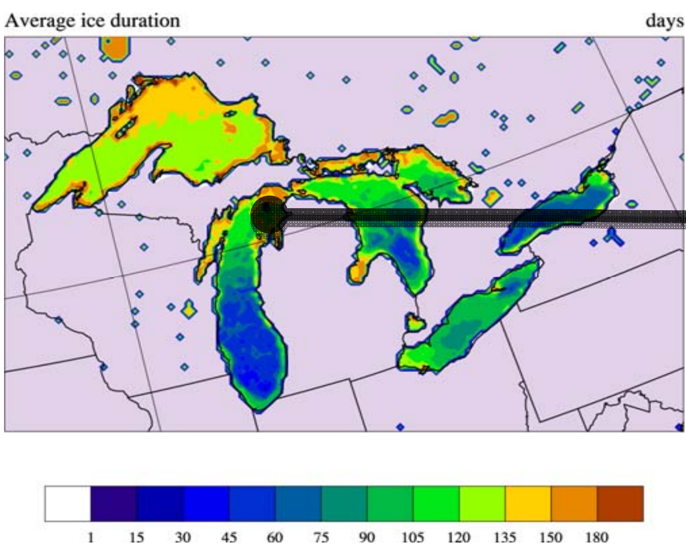
Blue = FLake/CCSM3 simulations

Black = Measurements from NDBC Buoy stations

Gray = Ice observations from GLERL

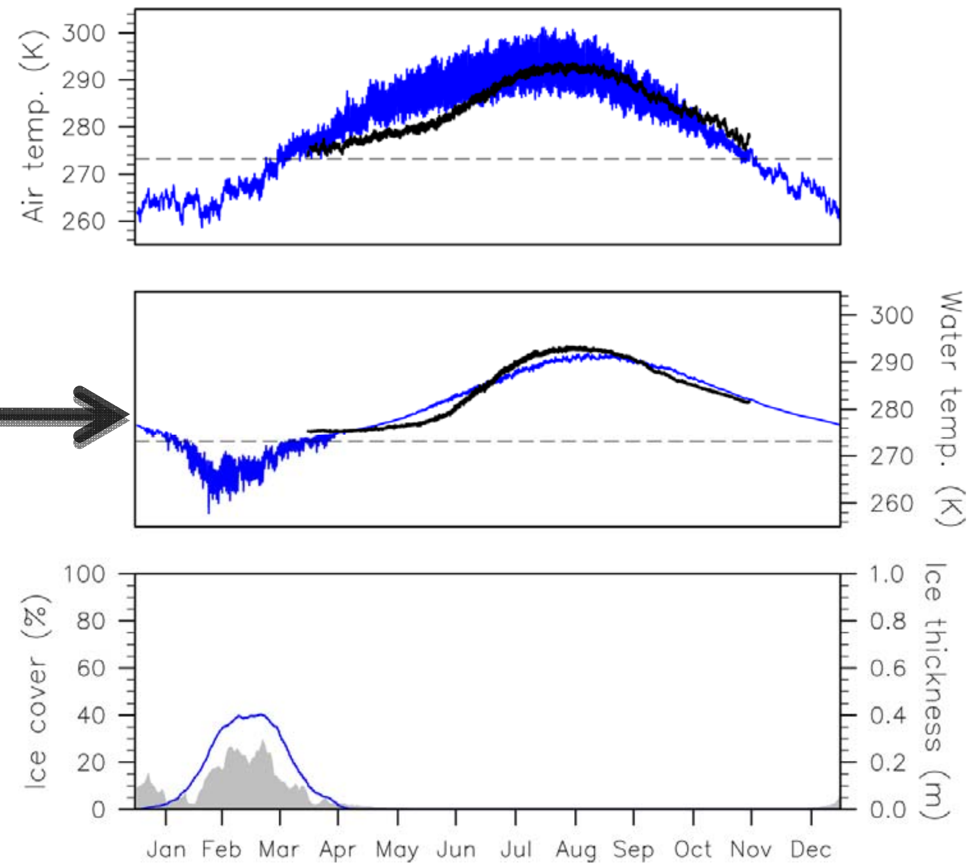
Representation of lake influence

- **CCSM-Flake Simulations:**



Average ice duration (1979-2001)

Lake Michigan (depth = 180m)

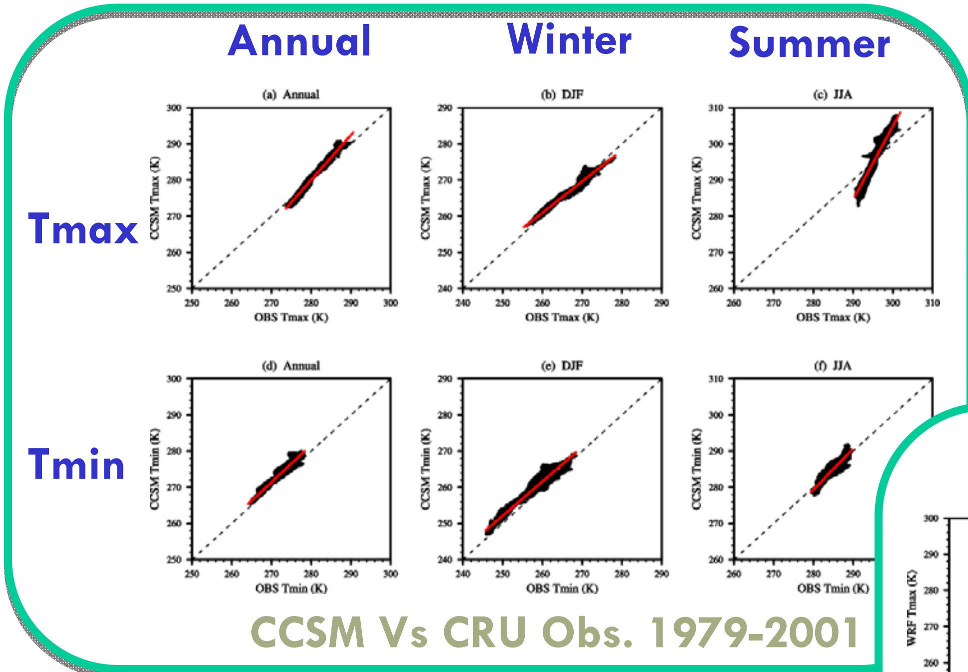


Blue = FLake/CCSM simulations

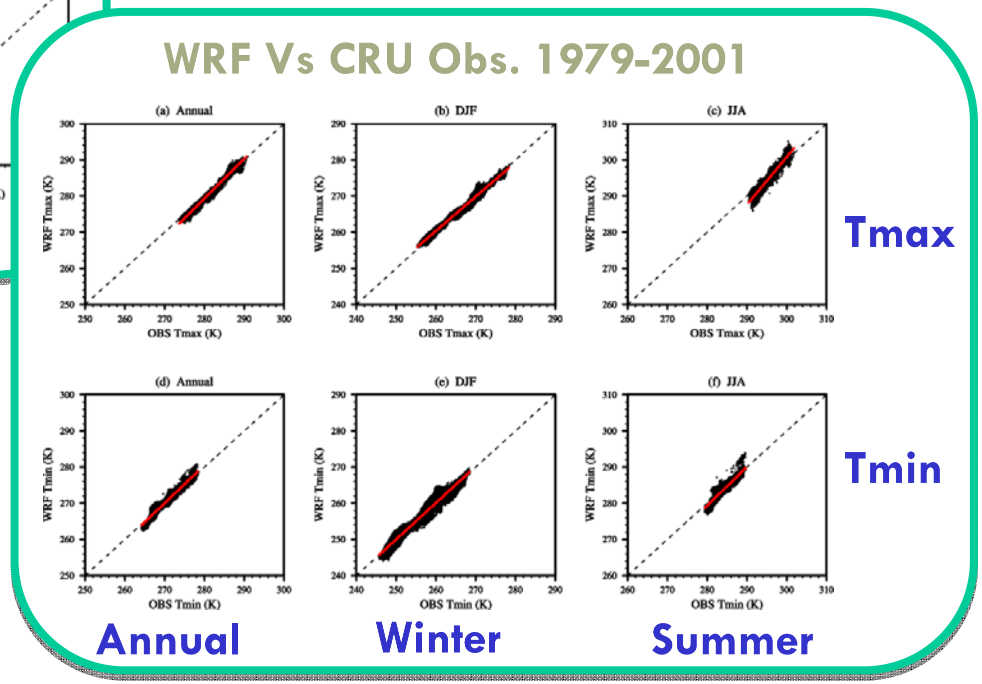
Black = Measurements from NDBC Buoy stations

Gray = Ice observations from GLERL

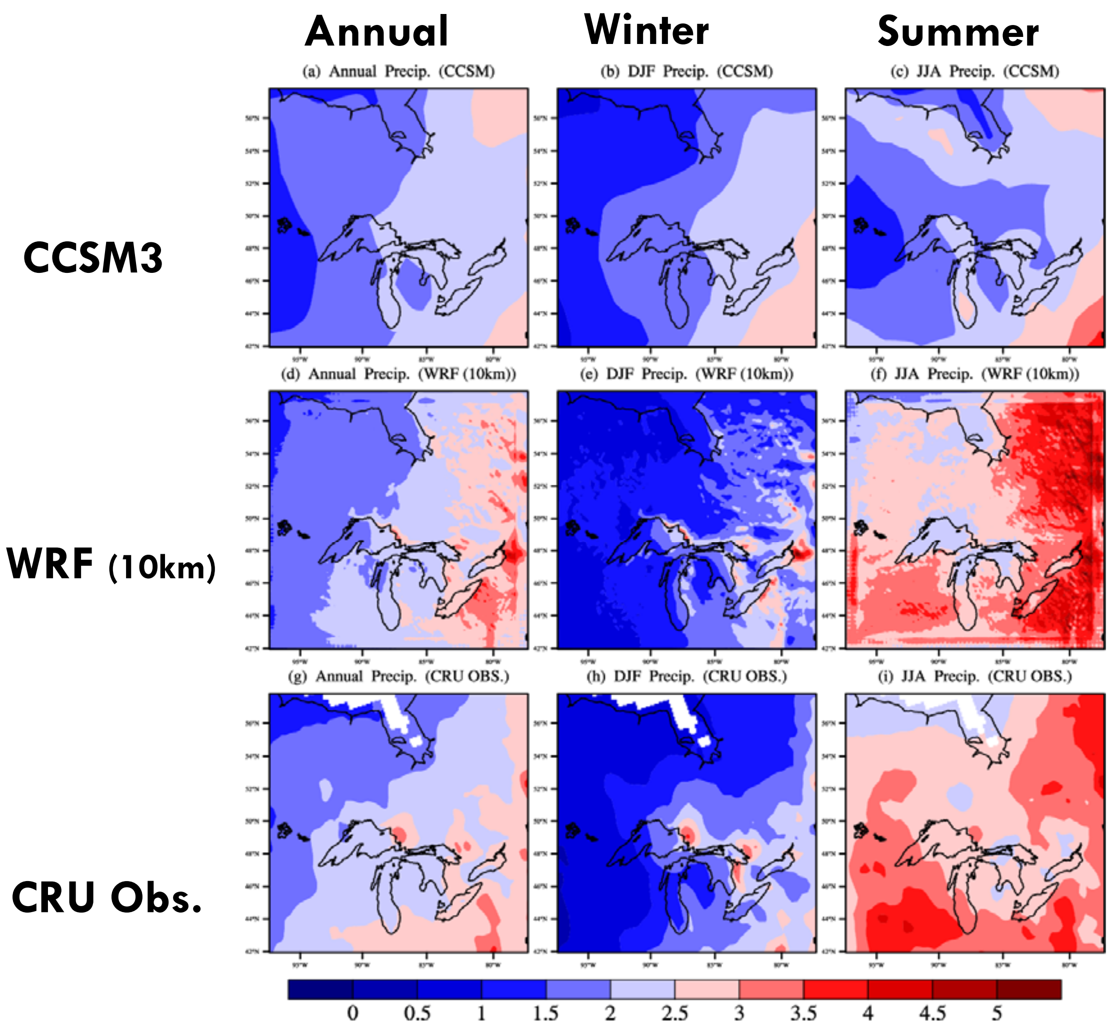
Historical period - Validation



- **Comparison of WRF downscaled results (10 km) over Ontario with Climate Research Unit (CRU)-University of East Anglia observational data for the 1979-2001 instrumental period**



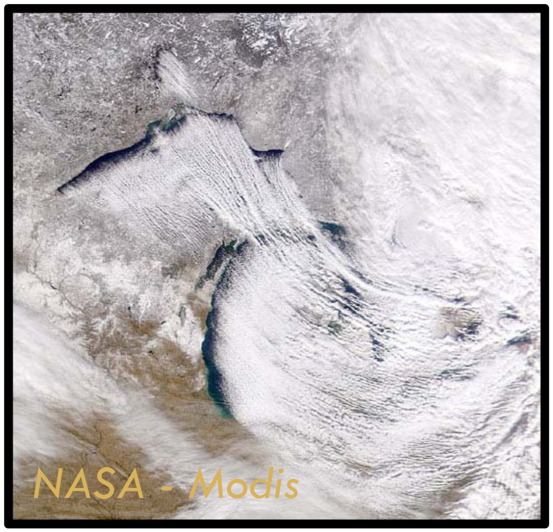
Historical period – Validation

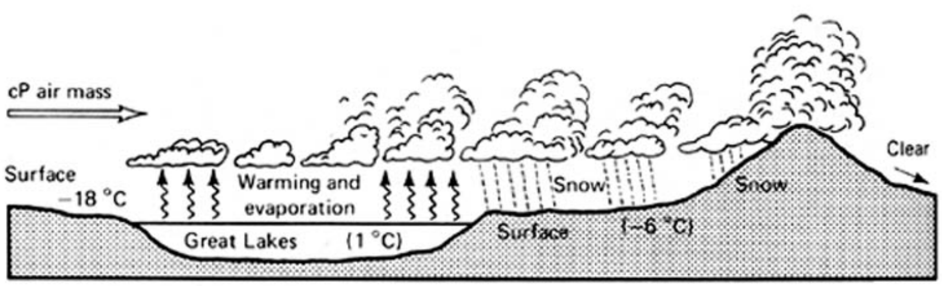


- **Annual mean precipitation (mm/day) for 1979-2001**

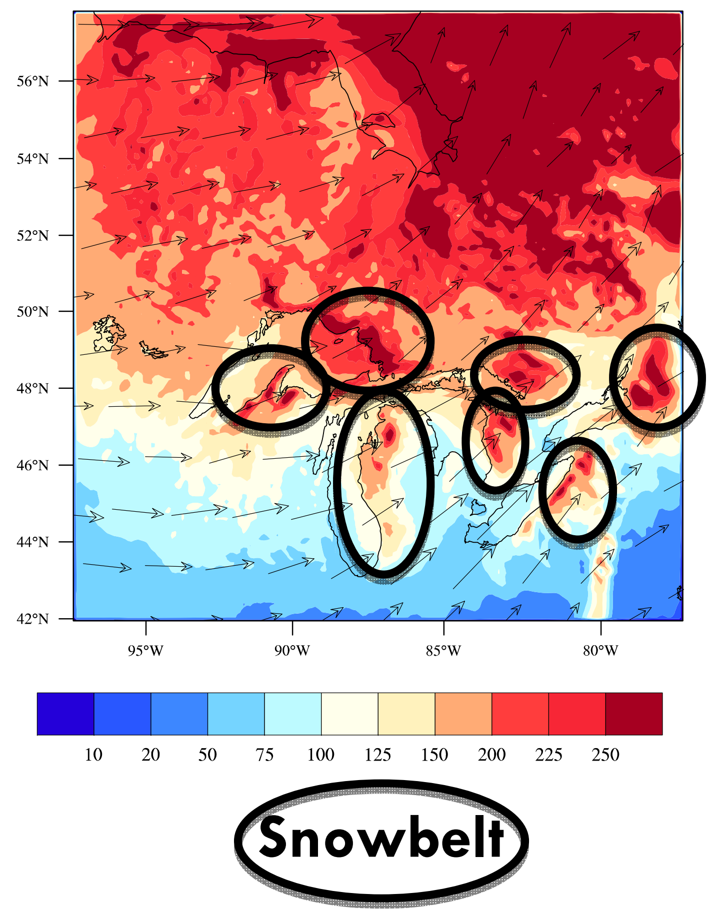
Historical period - Validation

- **Lake-effect snow:**



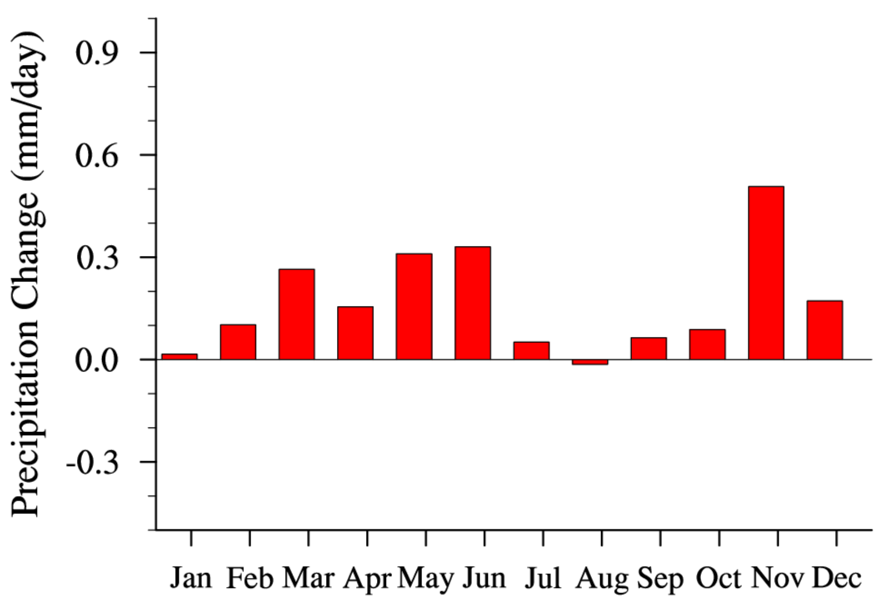


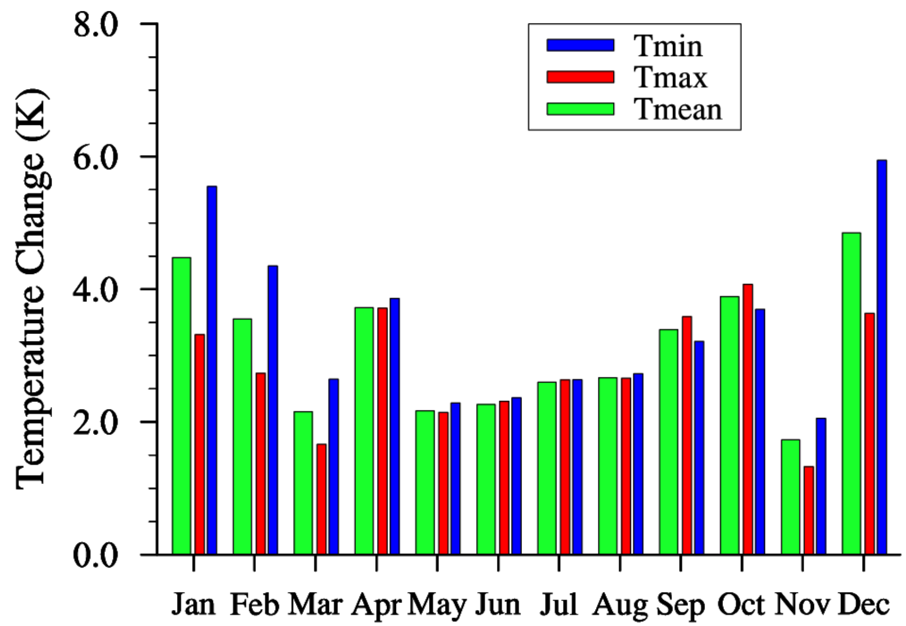
Mean annual snowfall (1979-2001)



Future scenario for Ontario

Changes for 2050-2060 relative to 1979-2001over Ontario:



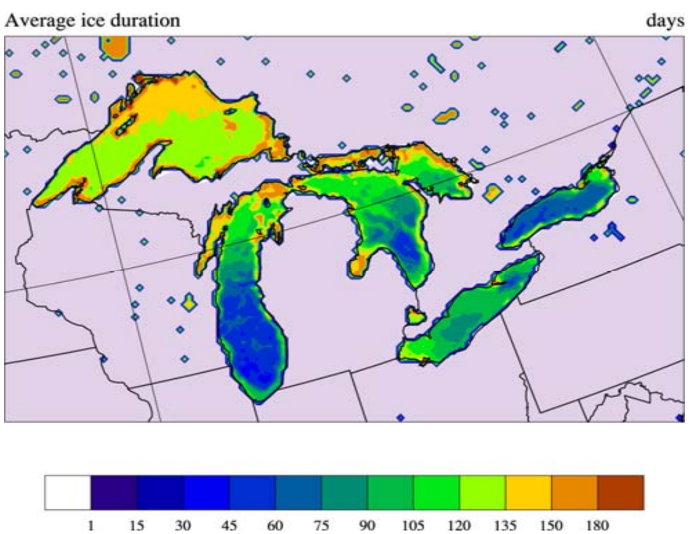


WRF (Flake)

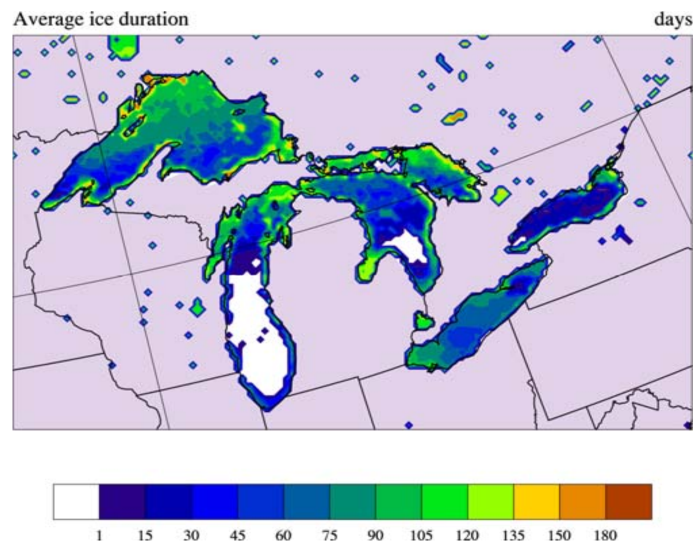
Future scenario for the lakes

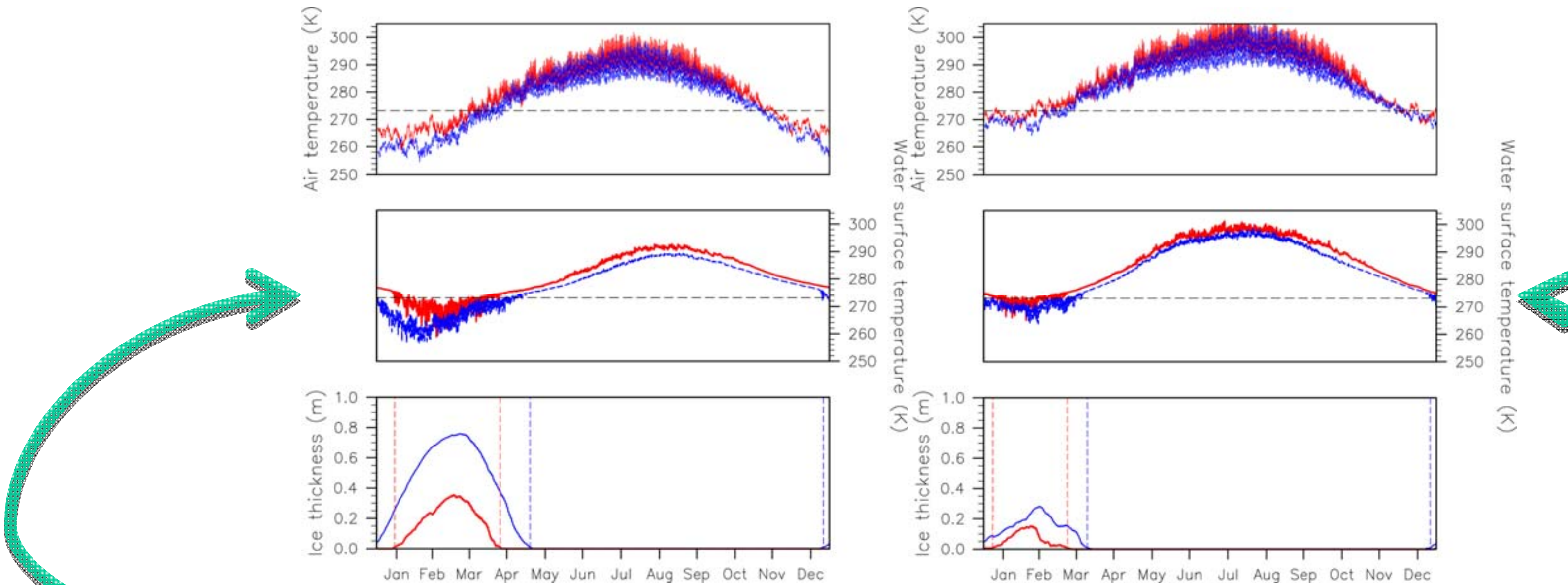
- **CCSM-Flake Simulations:** *Scenario SRES A2*

Average ice duration (1979-2001)



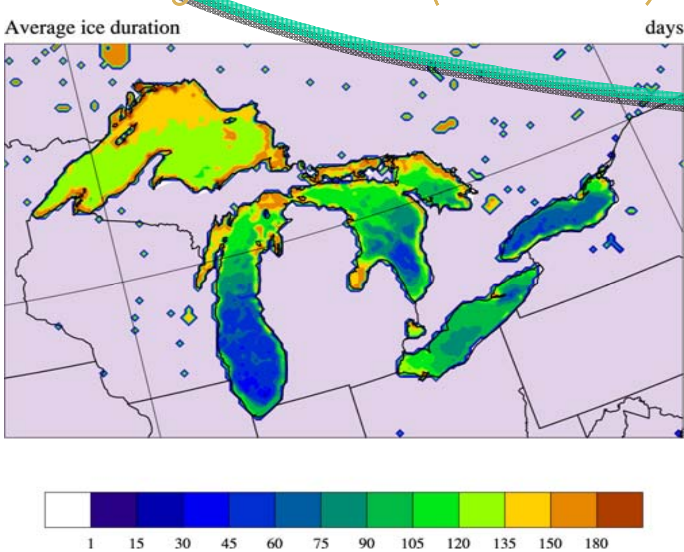
Average ice duration (2050-2060)

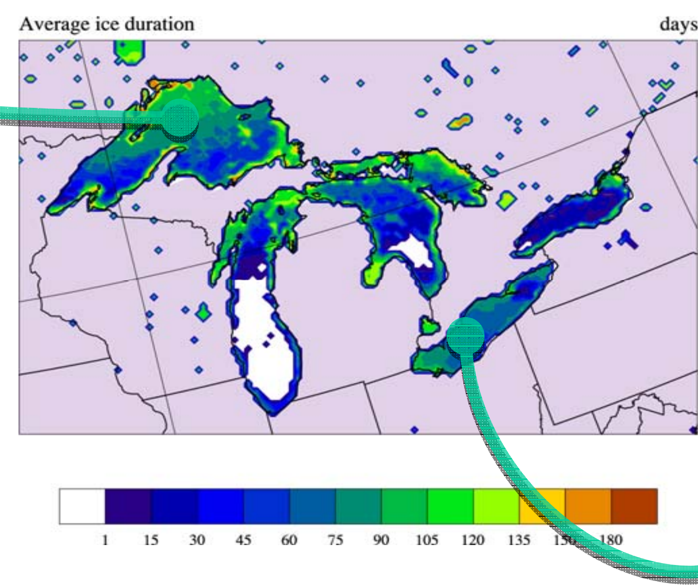




Average ice duration (1979-2001)

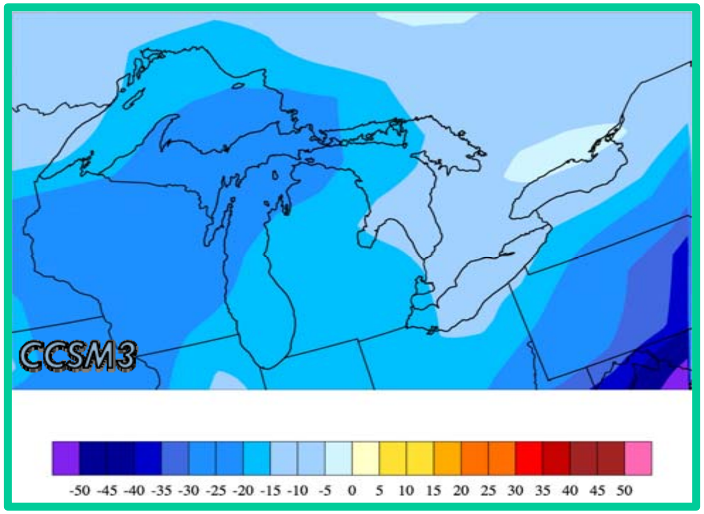
Average ice duration (2050-2060)

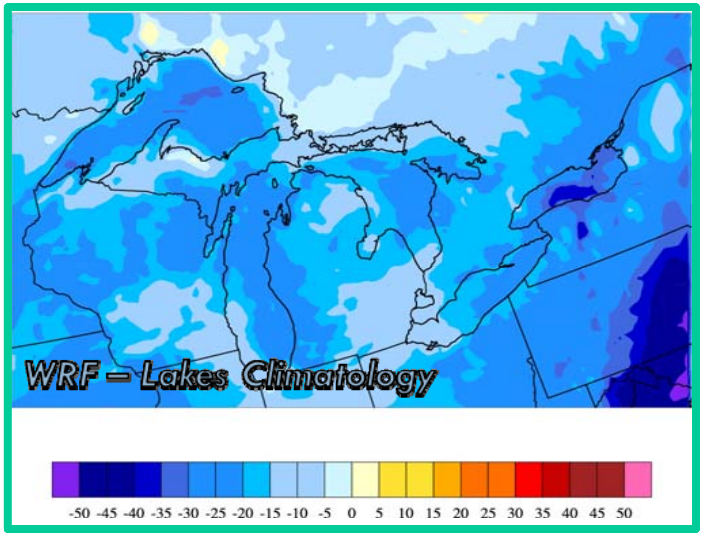


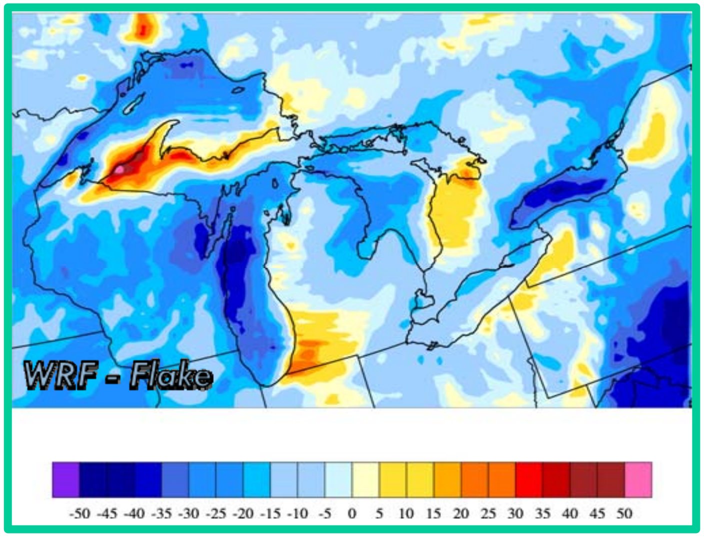


Future scenario for Ontario

Changes in mean annual snowfall (%) for 2050-2060 relative to 1979-2001

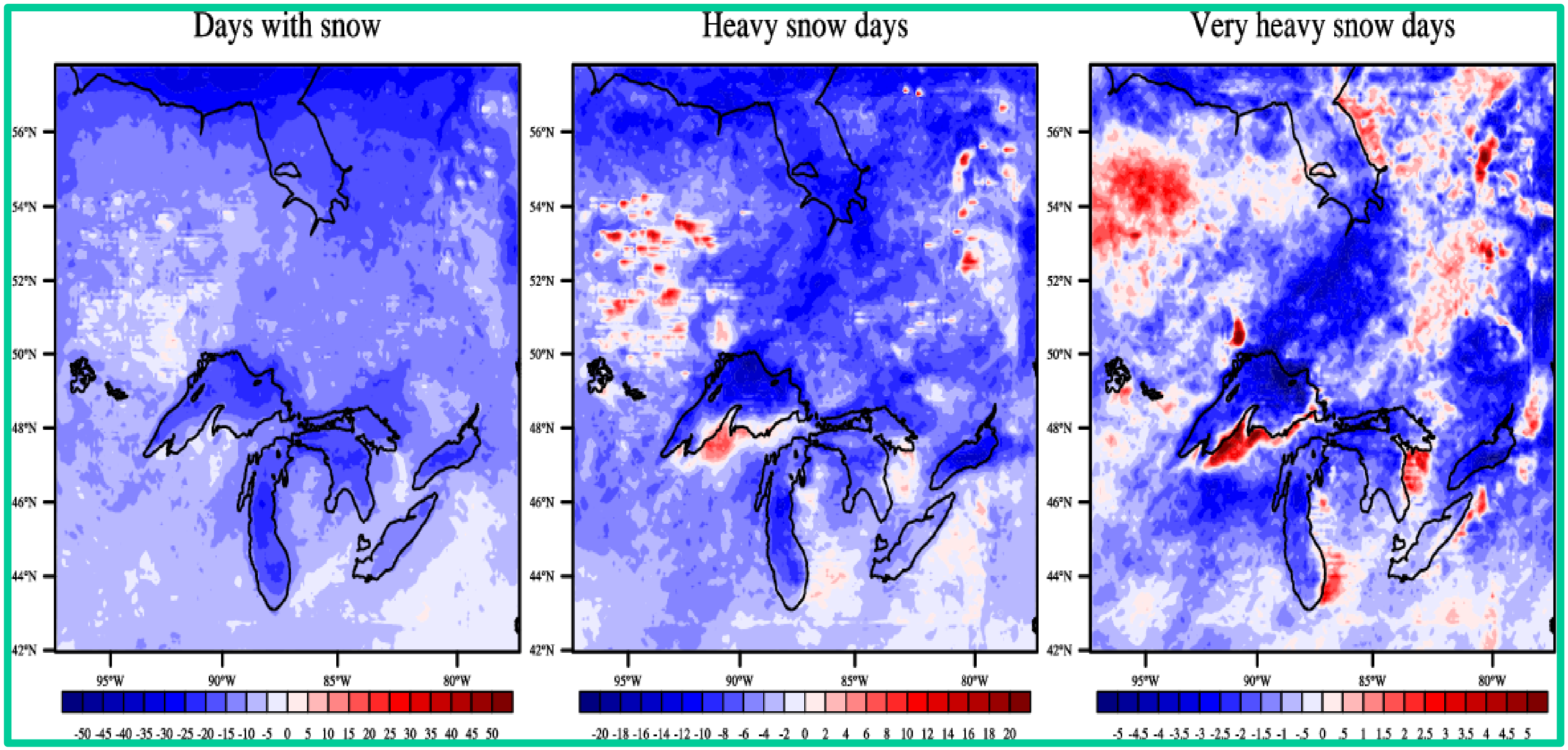






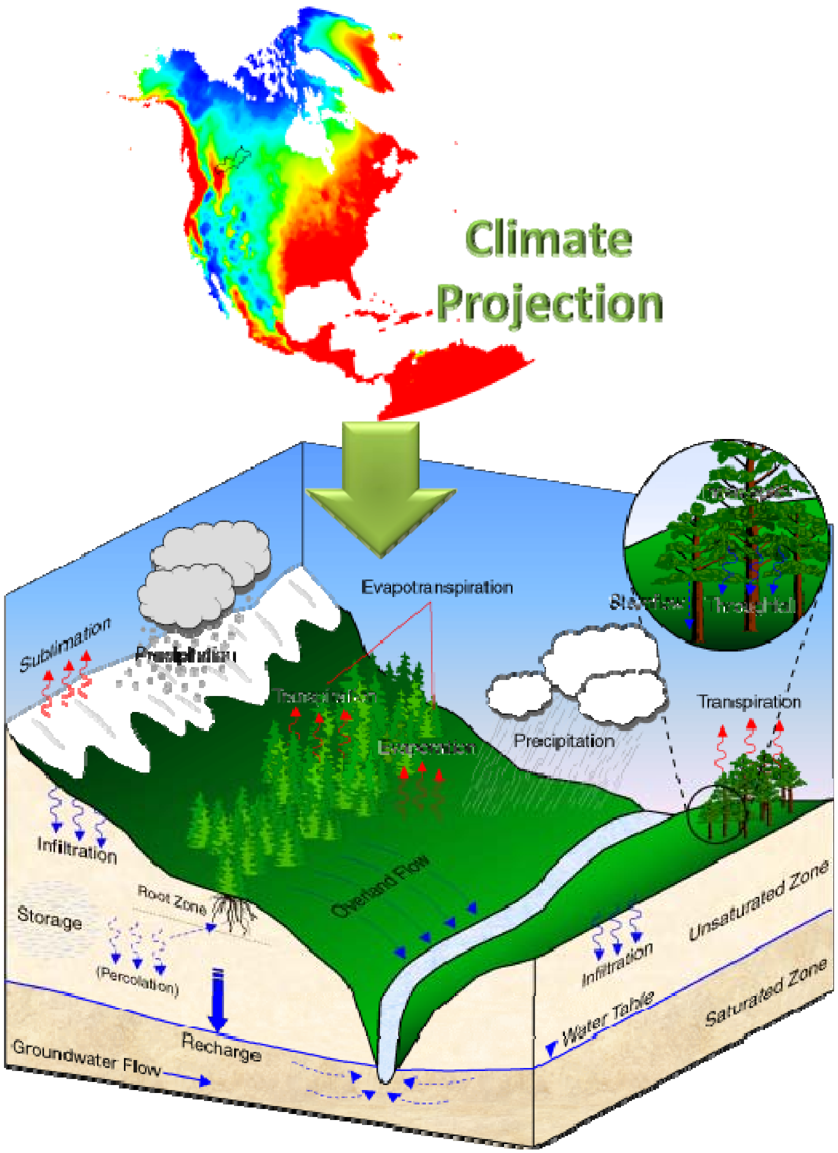
Future scenario for Ontario

Changes in number of days with snow for
2050-2060 relative to 1979-2001:



WRF - Flake

Background – What is HydroGeoSphere



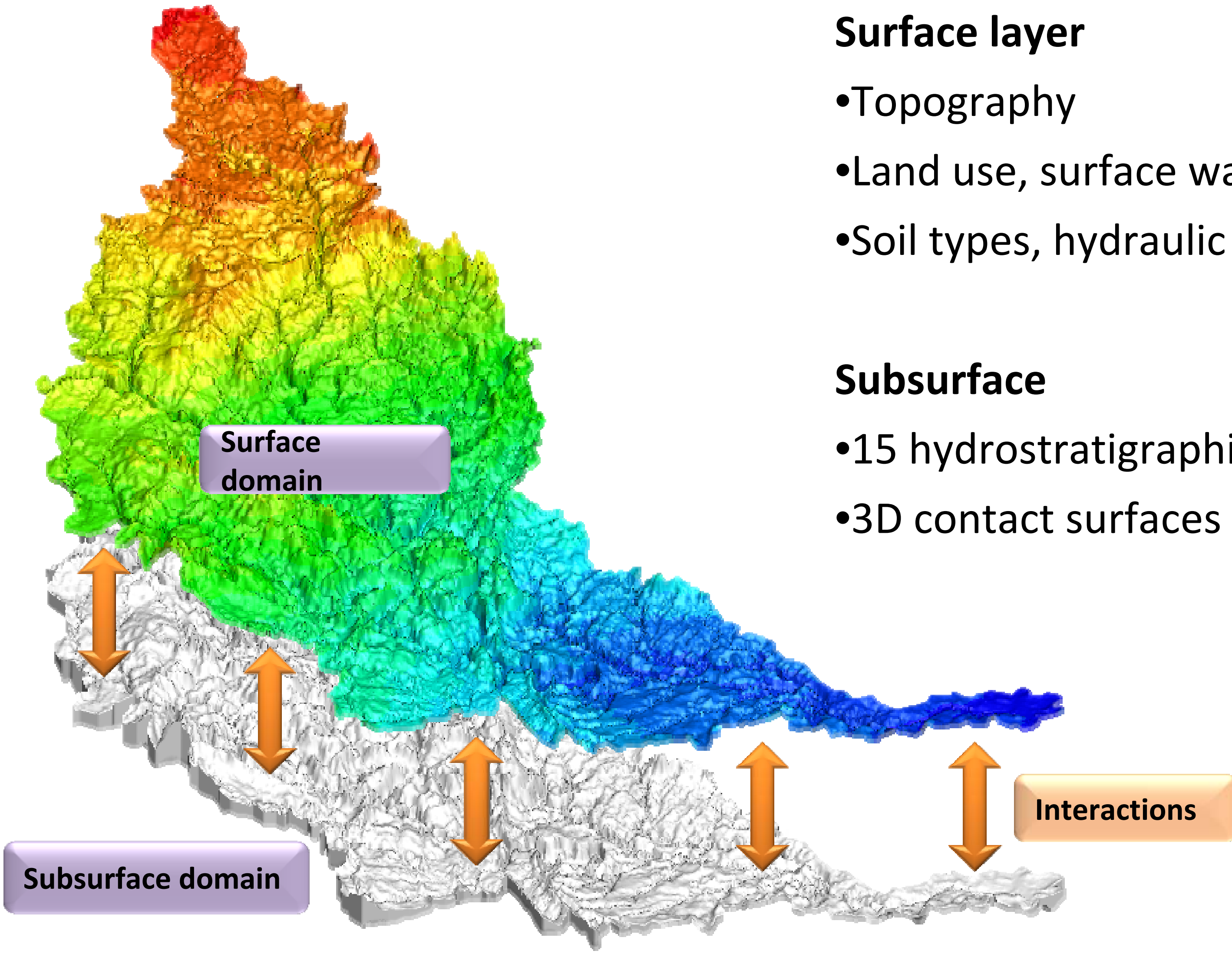
HydroGeoSphere is a three-dimensional control-volume finite element simulator which is designed to simulate the entire terrestrial portion of the hydrologic cycle.

Grand River Watershed Background

- 7000 km^2
- Population of ~900,000
- Intensive Agriculture
  - 93% rural/agricultural land use
  - 290,000 head of cattle
  - 500,000 thousand swine
  - 8.8 million poultry
- 900 mm of precipitation/year
- Heavy Dependence on Groundwater for Municipal Water Supply
- Heavily Instrumented
- Long Term Records

(Image courtesy of Grand River Conservation Authority)

Model Construction



Surface layer

•Topography

•Land use, surface water channels

•Soil types, hydraulic characteristics

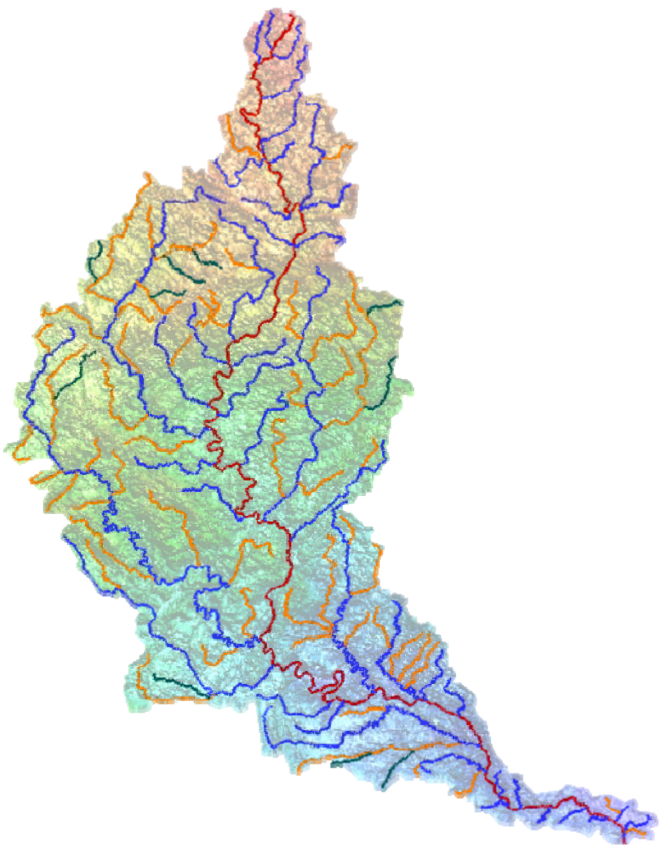
Subsurface

•15 hydrostratigraphic units

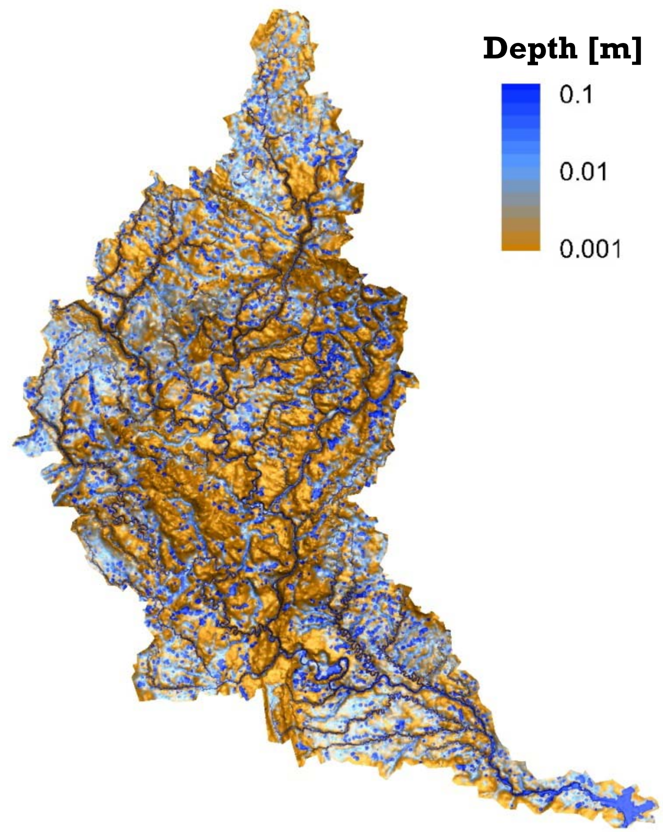
•3D contact surfaces

Steady-State Simulations: Historic Averages

Observed vs. Simulated Surface Drainage Network



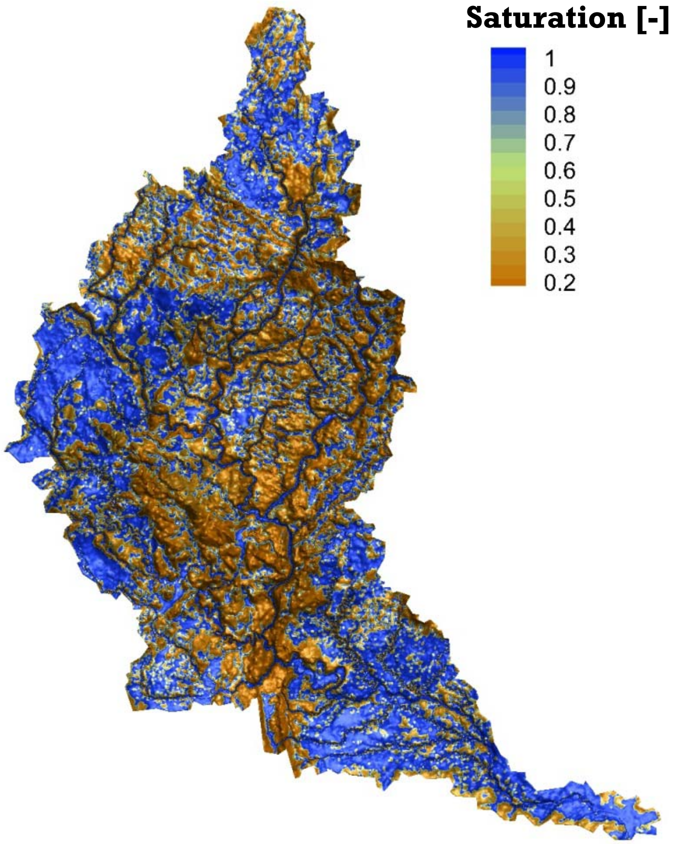
Observed Drainage Network



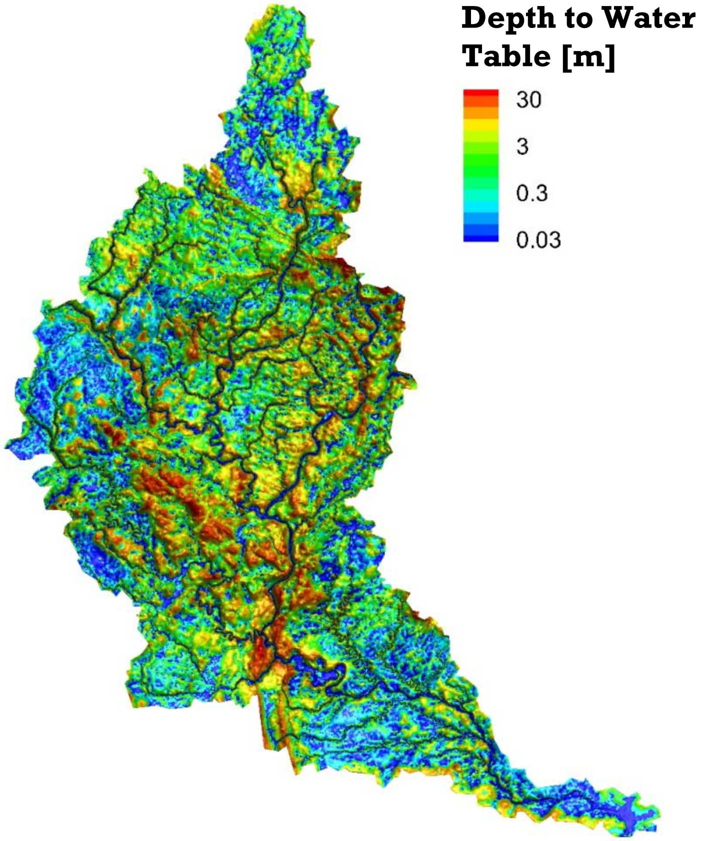
Simulated Surface Water Depth

Steady-State Simulations: Historic Averages

Subsurface Saturation and Depth to GW Table Distributions



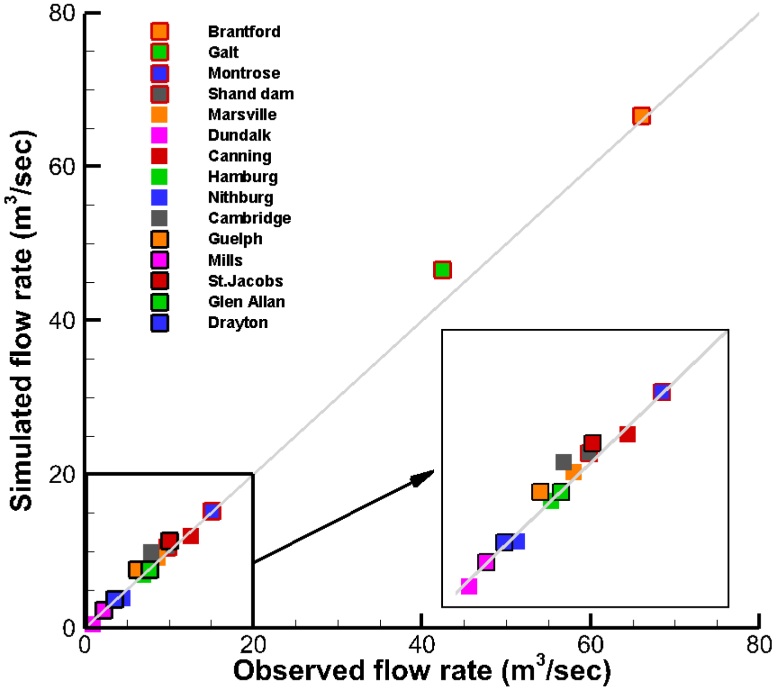
Soil Saturation



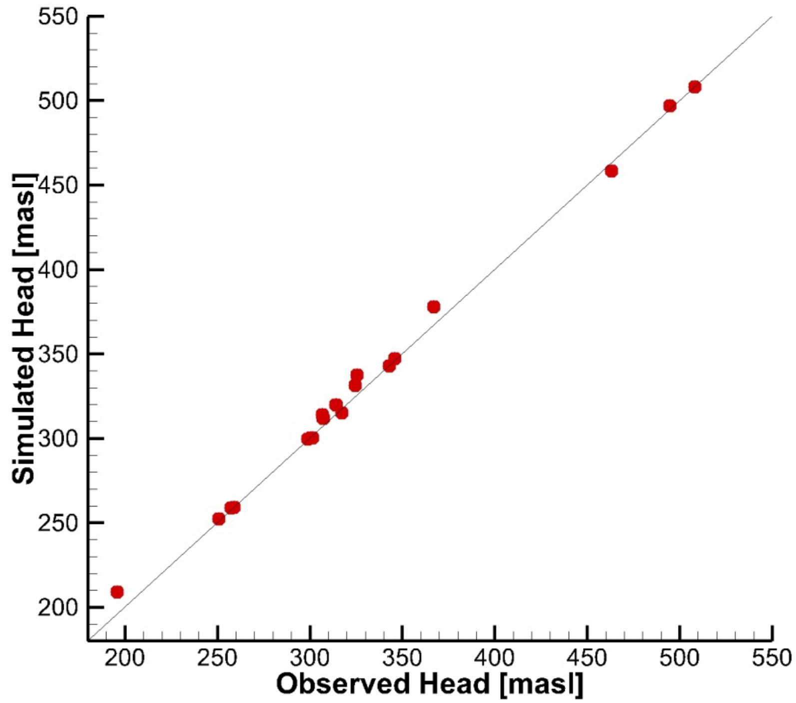
Depth to GW Table

Steady-State Simulations: Historic Averages

Observed vs. Simulated: Stream Flow and GW Head



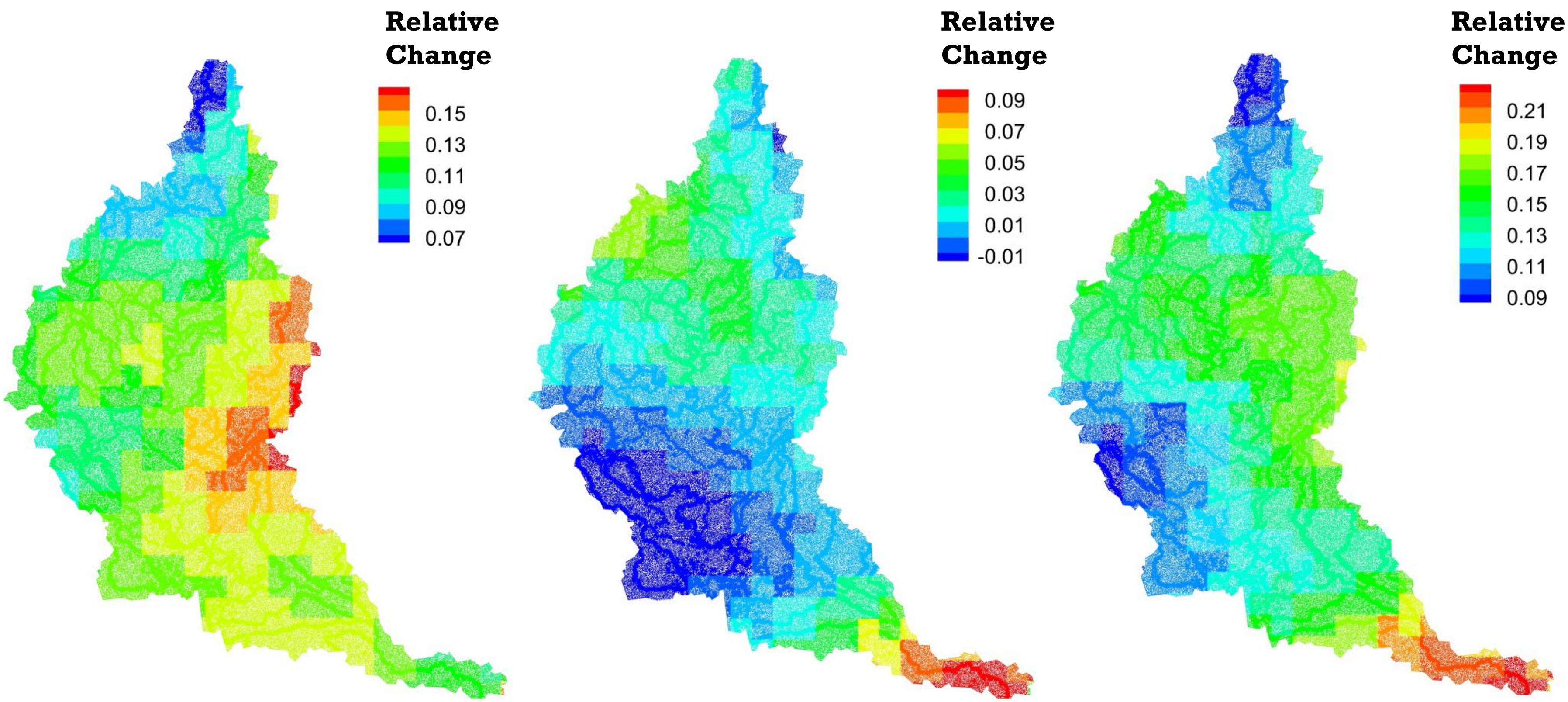
Observed vs. Simulated Stream Flow



Observed vs. Simulated GW Head

Climate Projection: Precipitation

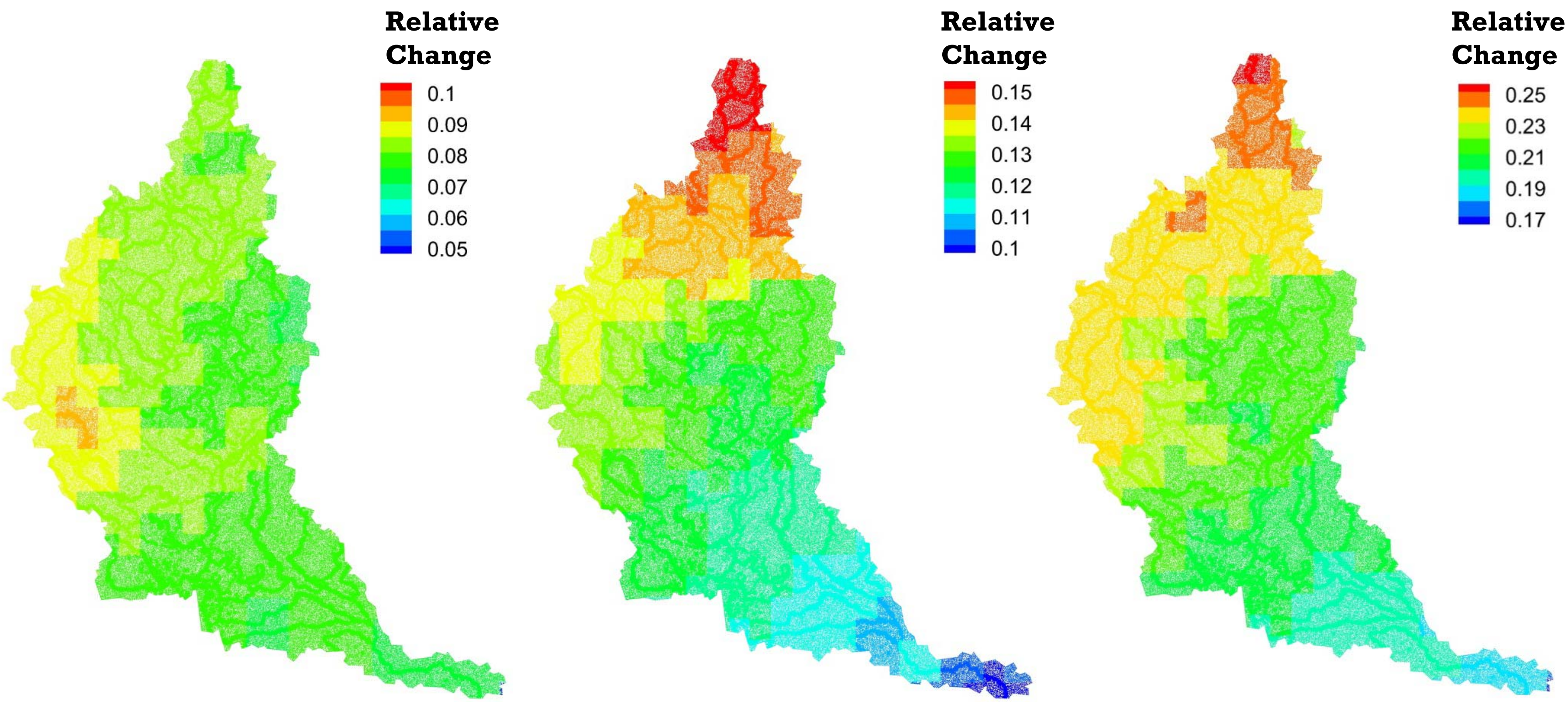
Changes in Annual Total Precipitation:
12 % Increase by Mid-Century; 14 % Increase by End-Century



Historic to Mid-Century **Mid- to End-Century** **Historic to End-Century**

Climate Projection: Potential Evapotranspiration

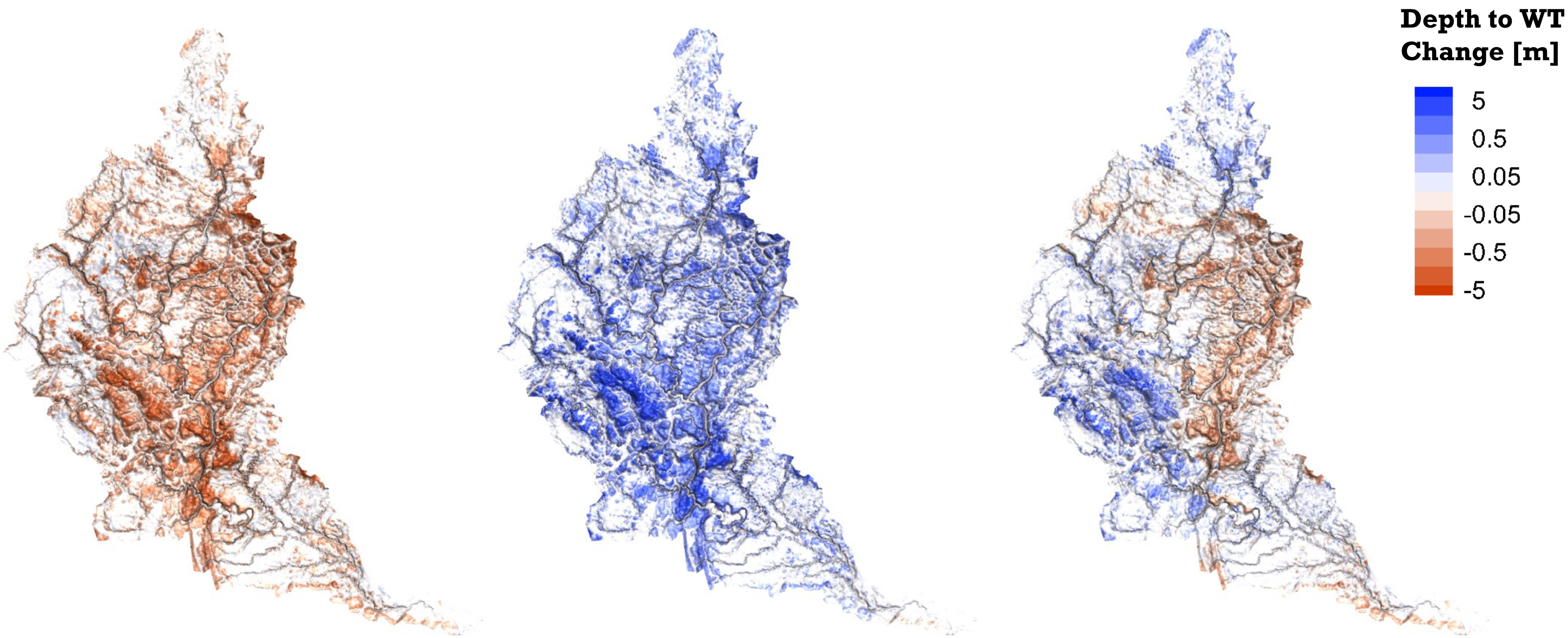
Changes in Annual Total Potential Evapotranspiration:
8 % Increase by Mid-Century; 22 % Increase by End-Century



Historic to Mid-Century **Mid- to End-Century** **Historic to End-Century**

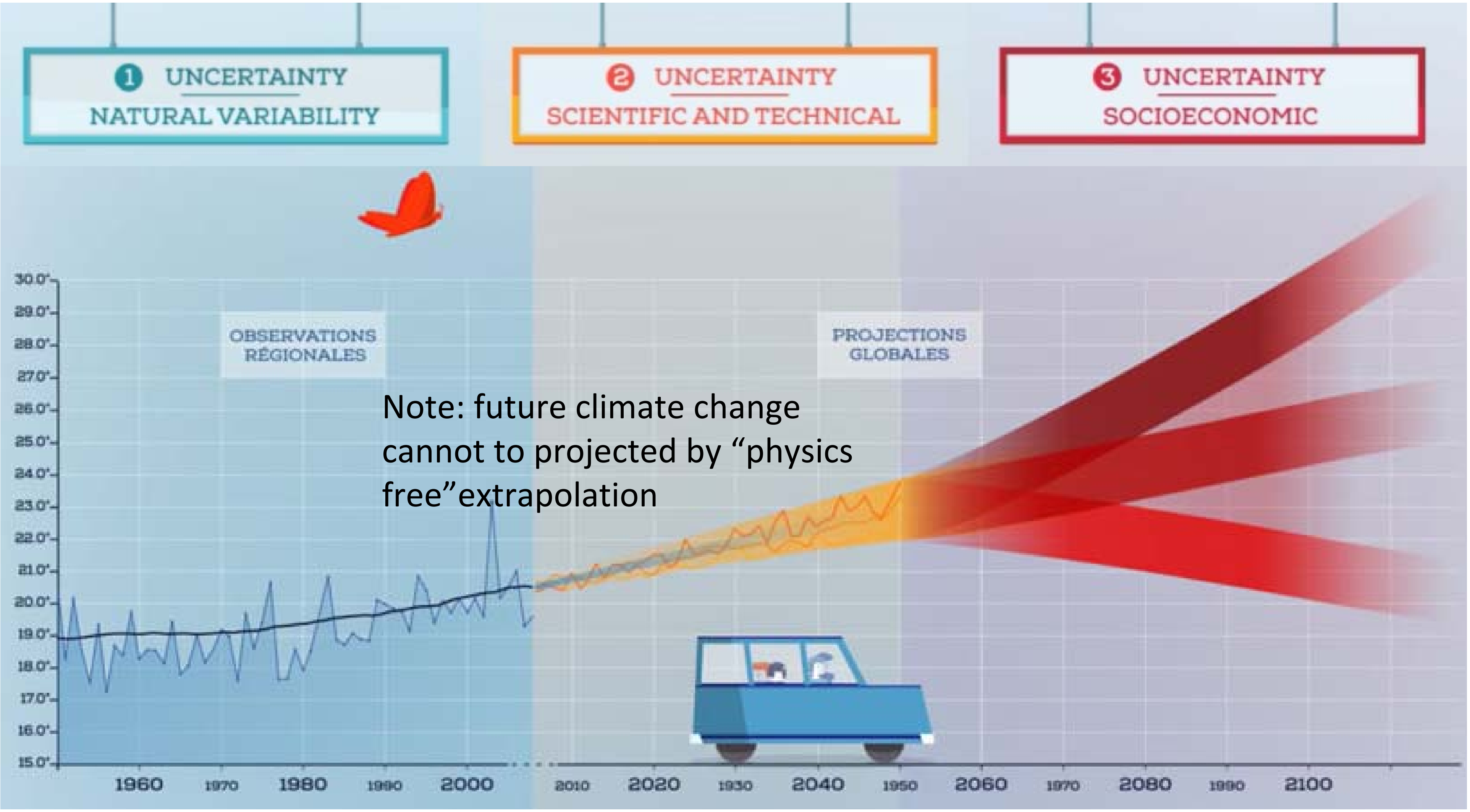
Projection: Average Subsurface Conditions

Changes in Steady-State Depth to Water Table



Historic to Mid-Century **Mid- to End-Century** **Historic to End-Century**

UNCERTAINTIES IN CLIMATE CHANGE PROJECTIONS:
or the reasons to employ the Blue Gene/Q



Note: future climate change cannot to projected by "physics free"extrapolation

[Weblink to multiple simulation Movie]

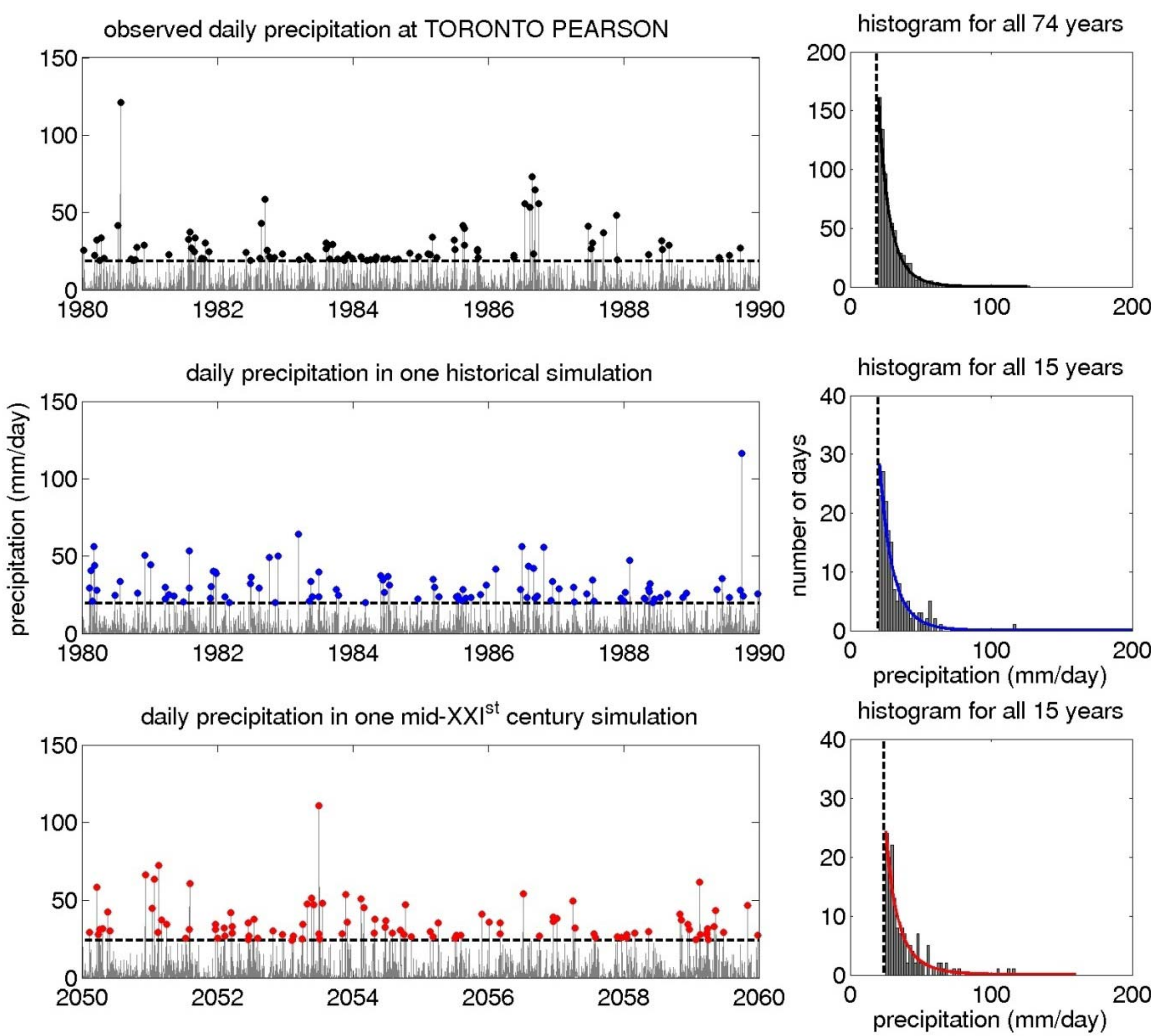
CLIMATE IS THE STATISTICS OF THE WEATHER
Extreme Value Analysis of daily precipitation

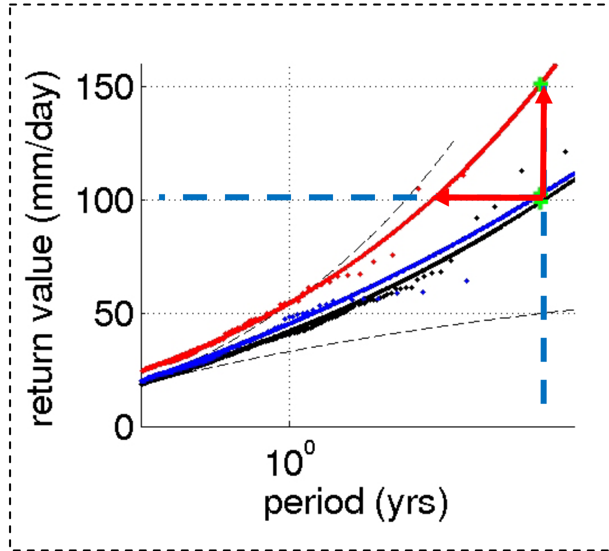
From d'Orgeville, Petier Et al, JGR-Atmospheres, In press, 2014.

Daily precipitation timeseries

Tail distribution

Return value for a given period of time





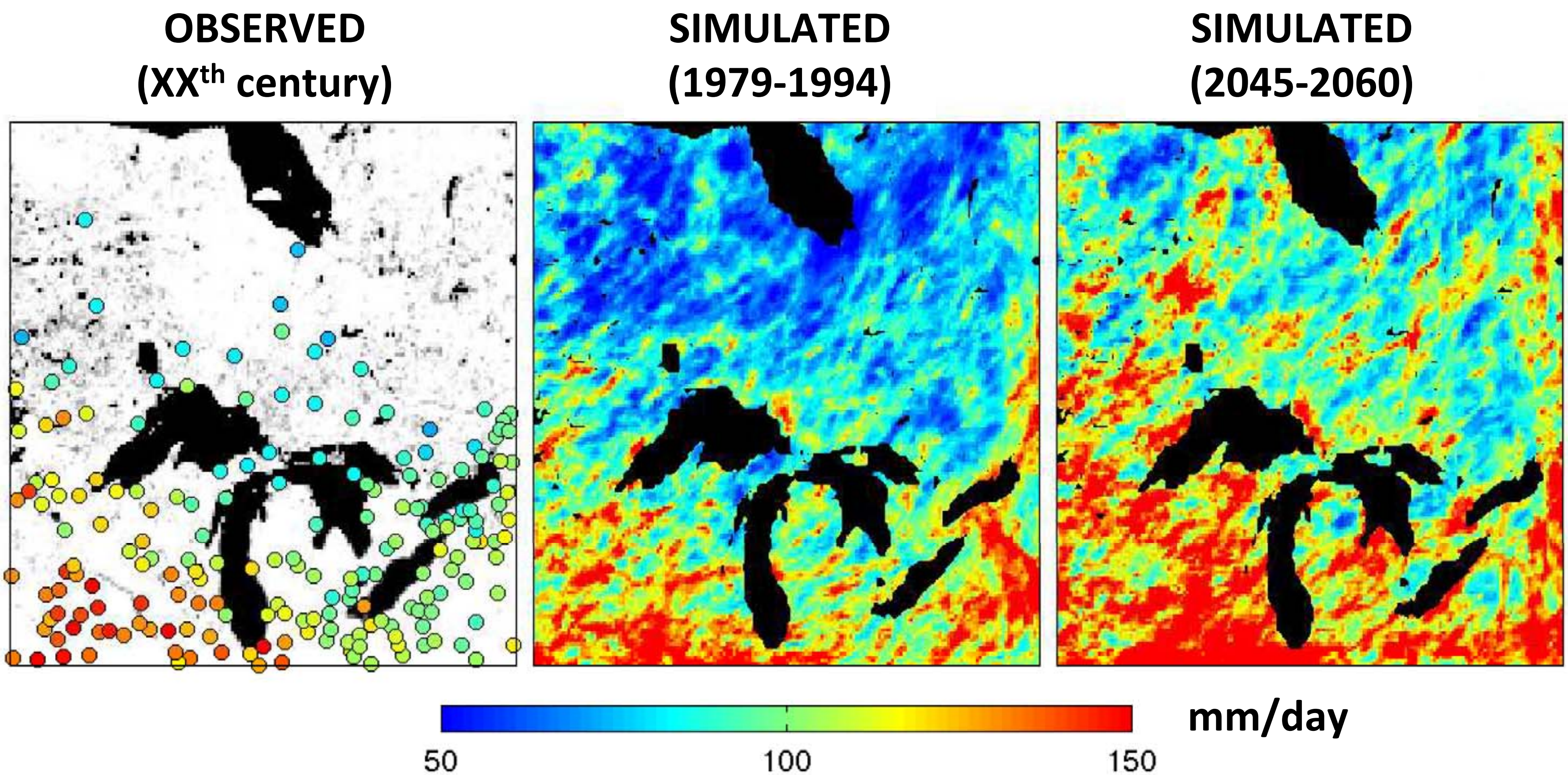
50 yr event ↔100mm/day

50 yr event ↔ 102mm/day

50 yr event ↔ 151mm/day
20 yr event ↔ 102mm/day

but large uncertainties for one location and one simulation only

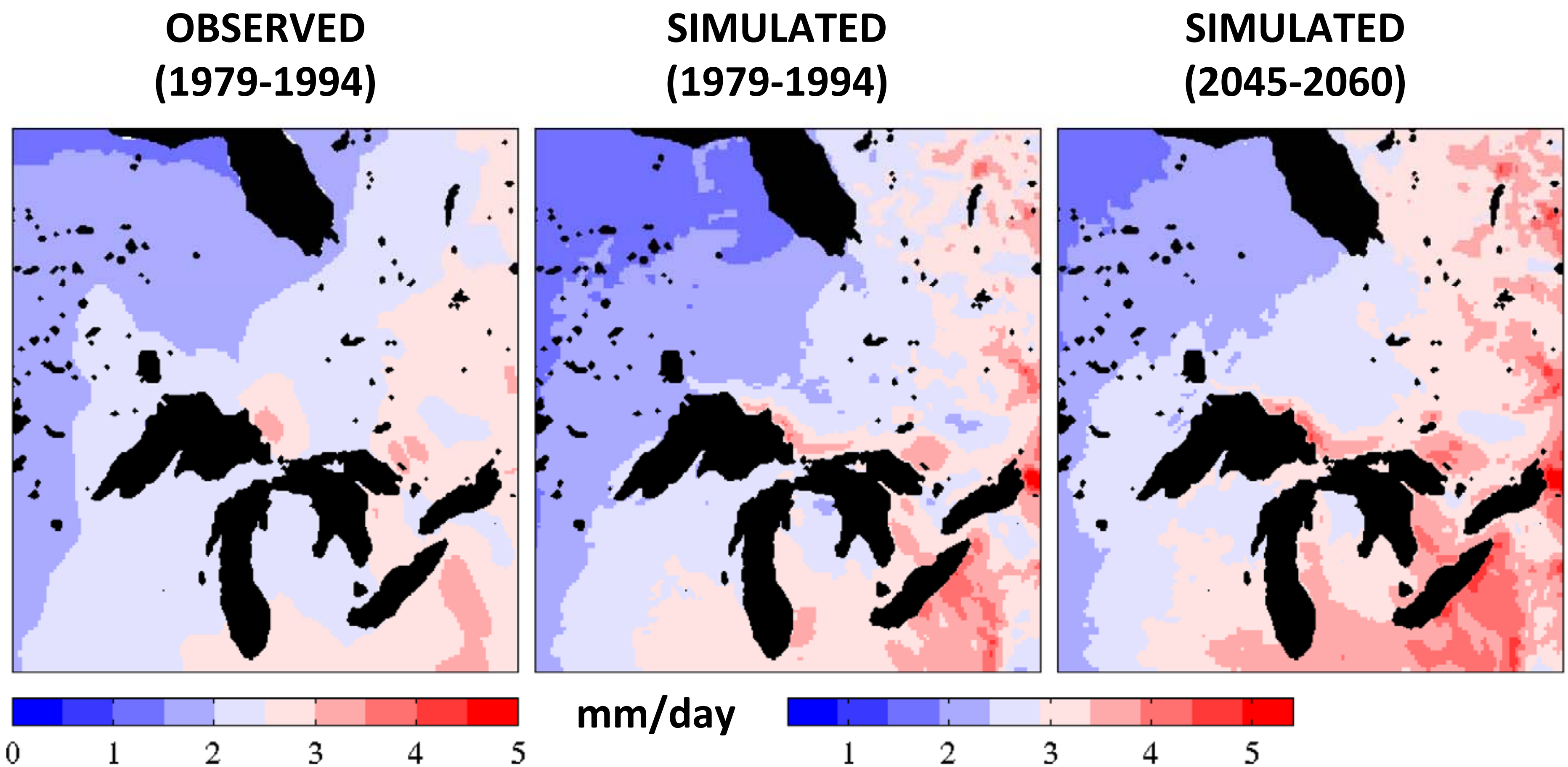
FUTURE PRECIPITATION CHANGES: Extremes



Precipitation amplitudes of 50 year events increase by 14 to 29% by mid-century

⇔ Current 50 year events will occur more frequently every 25 to 15 year period

FUTURE PRECIPITATION CHANGES: Annual averages



Average precipitation increase 13 to 19% by mid-century
Increase in extremes larger than increase of averages
➔ Precipitation increases are becoming more extreme

Summary

- The dynamical downscaling methodology is able to provide robust estimates of future climate change at the regional scale which are useful for environmental policy development
- Robustness is achieved by employing ensembles of climate change projections that enable the construction of a probabilistic estimate of the expected change at a given future epoch in a given region
- The methodology requires the application of significant computational resources on the fastest computer systems available
- The Ontario government funded SciNet facility has been employed to demonstrate proof of concept in the application of this methodology to increasing understanding of the environmental future of the province.
- We need to develop an in province technical capability to take full advantage of the existing facility and the upgrade to come in order to provide climate data services for the purpose of provincial policy development.

HIGH RESOLUTION PROBABILISTIC PROJECTIONS OVER ONTARIO THROUGH COMBINED DOWNSCALING TECHNIQUES USING ALL AVAILABLE IPCC GCM AND NARCCAP RCM RESULTS

ZIWANG DENG[1], XIN QIU[1,2] AND HUAIPING ZHU[1]

1. LAMPS, YORK UNIVERSITY

2. NOVUS ENVIRONMENTAL INC.

NOVEMBER 27, 2014

ACKNOWLEDGEMENT

This project is funded by the Ministry of Environment and Climate Change (MOECC).

Special thanks to

Dr. John Liu of MOECC for his constant scientific guidance;

Dr. Xuebin Zhang of Environment Canada for his scientific advices, and

Other members of LAMPS and Novus for technical assistance.

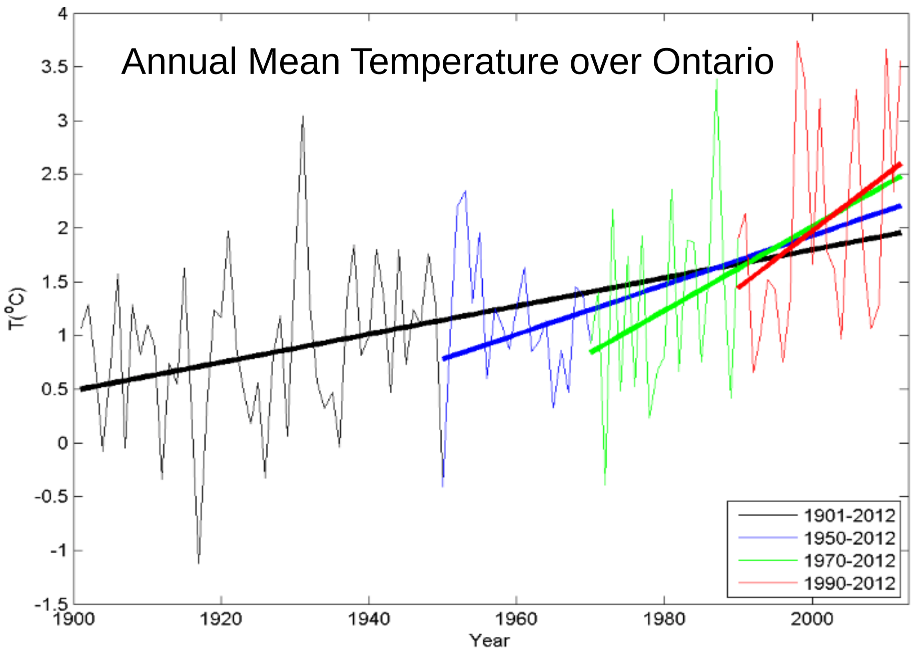
Steven Chen, Xiaolan Zhou, Longbin Chen, Don Yu
Neal Madras, Rick Bello, Kaz Higuchi, Fuquan Yang

OUTLINE

- **Motivation**
- **Methodology**
- **Validation**
- **Projected future climate in Ontario**
- **Data dissemination – public data portal**
- **Data application examples**
- **Future work**

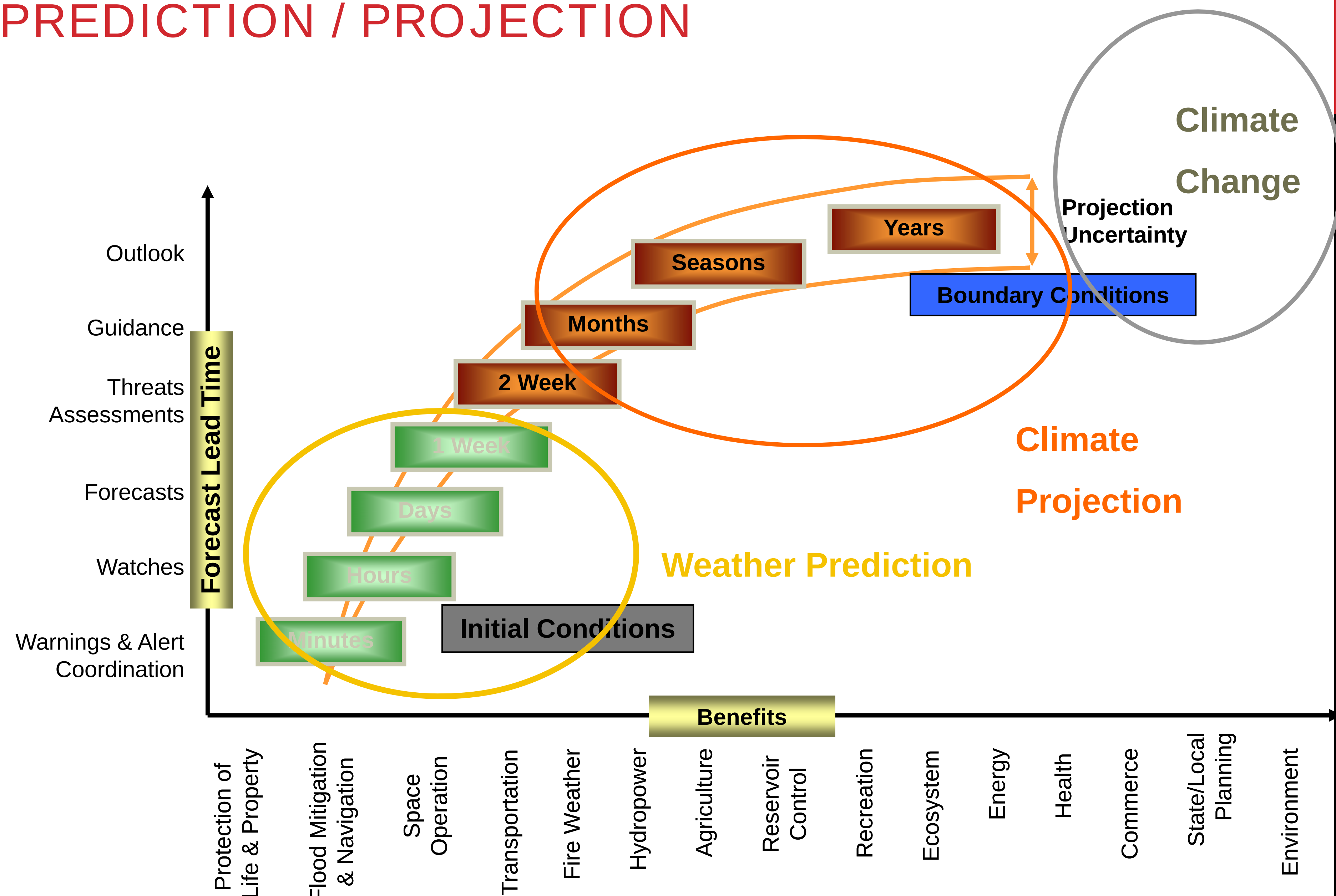
MOTIVATION

- **Global changes**
- **Canadian Nation-wide changes**
- **In Ontario, changes too.**



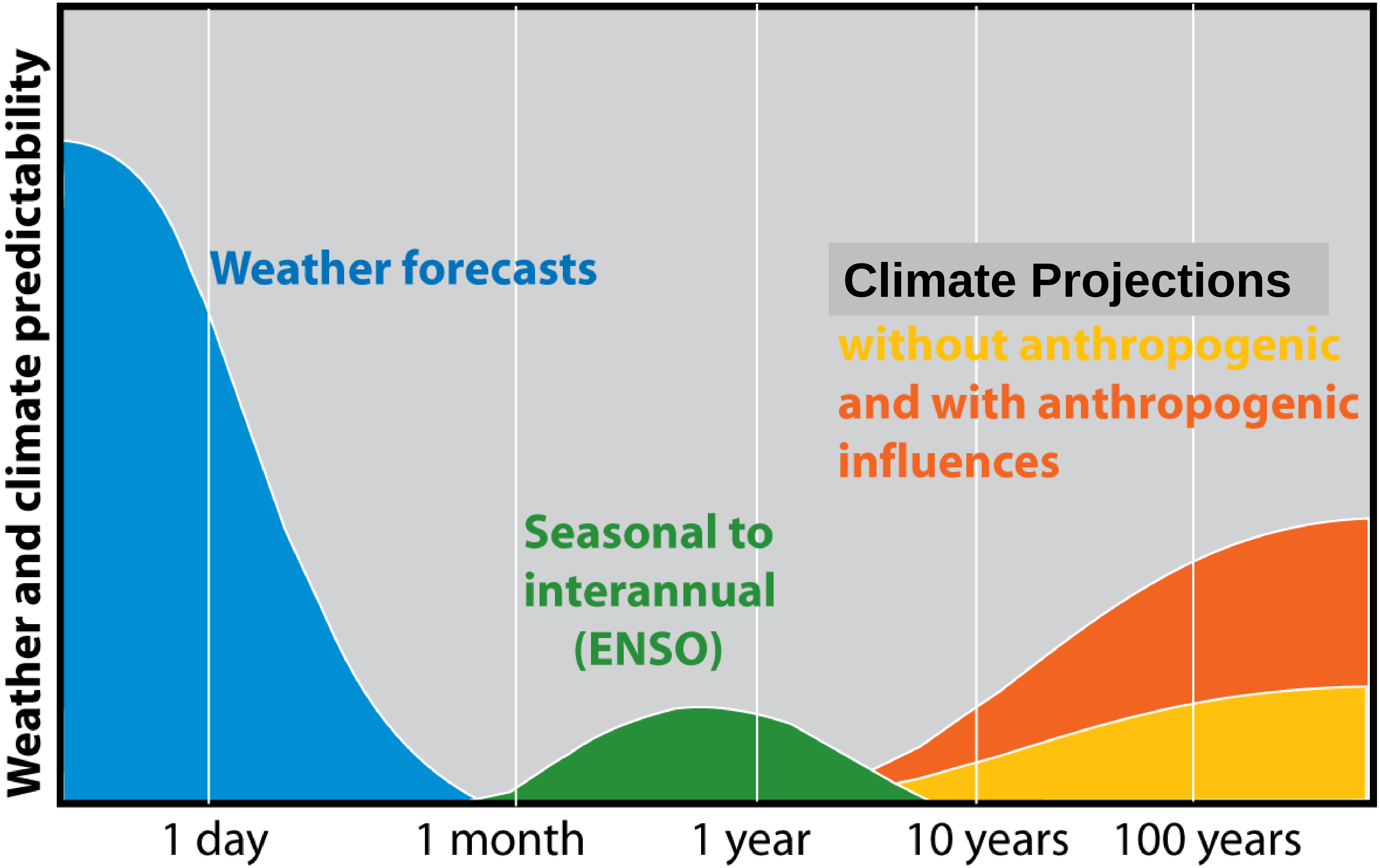
Observed change in annual mean temperature in Ontario.

EXPECTED: SEAMLESS SUITE OF FORECASTS/ PREDICTION / PROJECTION



Credited: Lawrence Buja, 2013

REALITY: PREDICTABILITY OF WEATHER AND CLIMATE

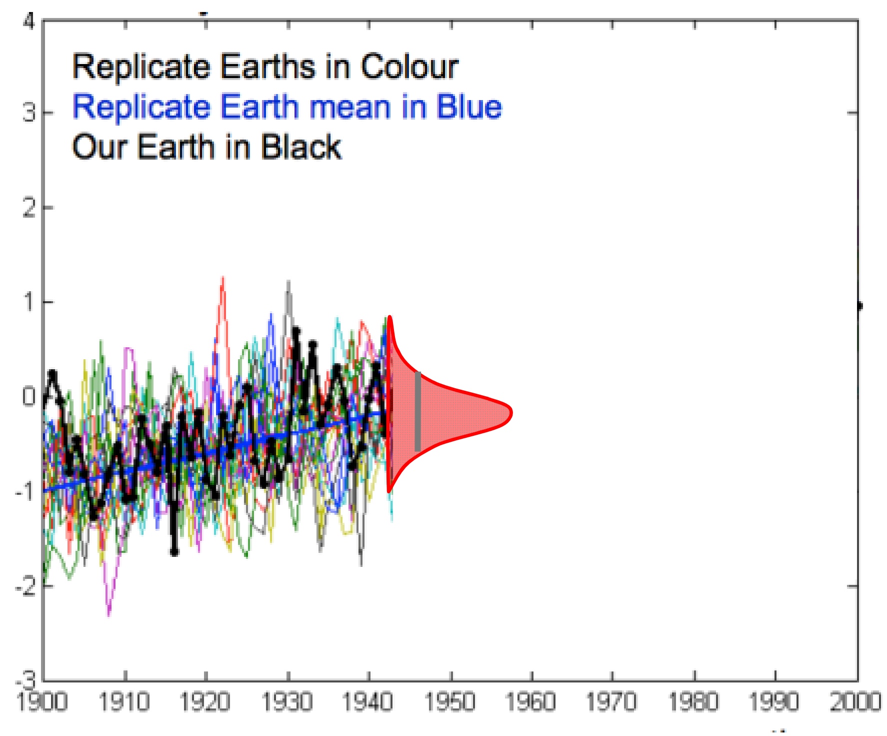


Credited: Lawrence Buja, 2013

WE USED MANY MODELS TO REFINE CLIMATE INFO TO REGIONAL / LOCALE SCALE

1. Can we narrow the uncertainty range by considering only models that reproduce observations relatively well? (Difficult.)

2. IPCC recommended that we should use multiple models to address uncertainties (Yes)

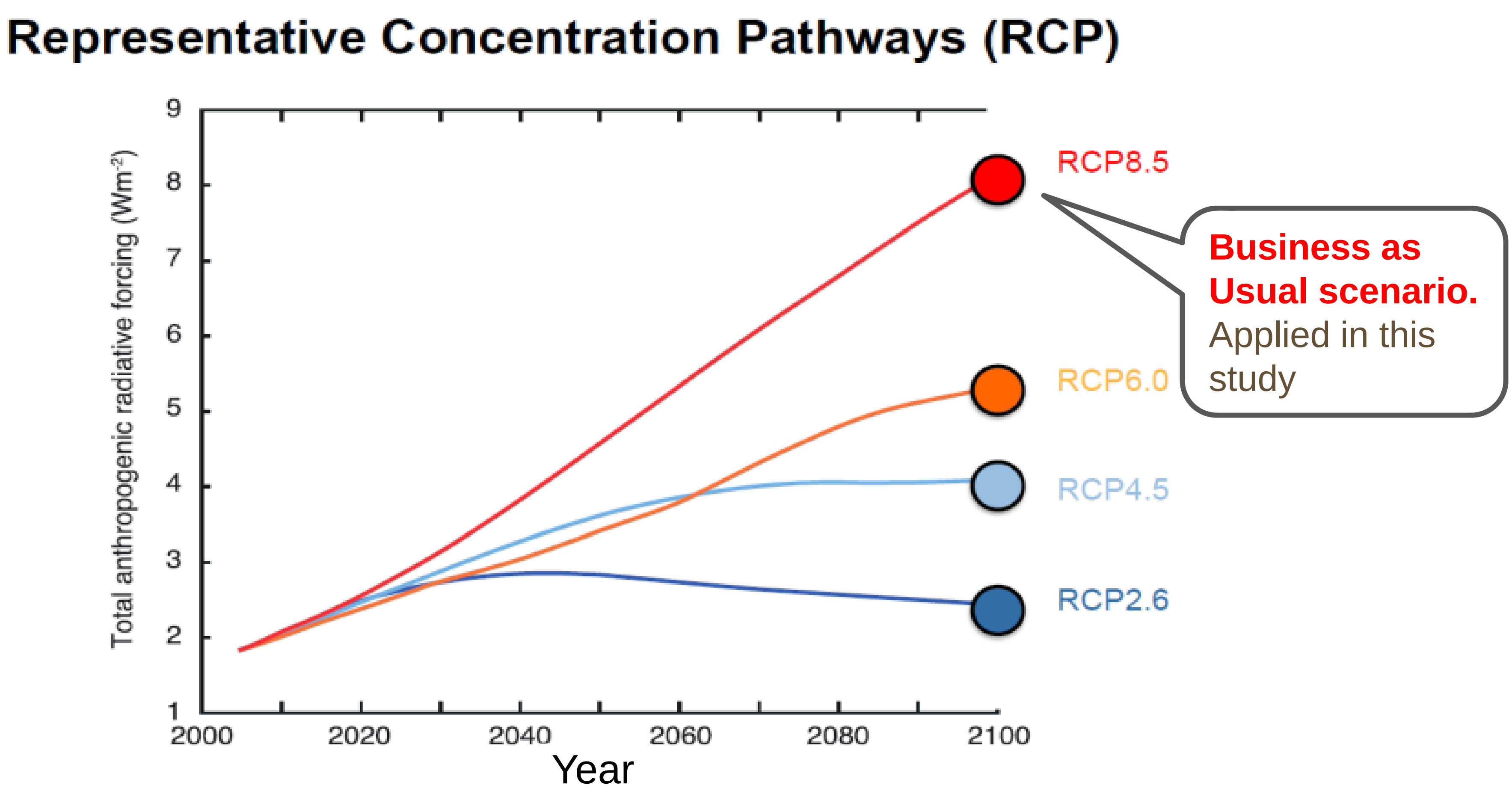


(C. H. Bishop and G. Abramowitz, 2013)

OUR APPROACH:

Using All Available IPCC GCM and NARCCAP RCM Results for Probabilistic Downscaling

IPCC AR5 EMISSION SCENARIOS



IPCC AR5 GCMS USED IN THIS STUDY

ACCESS1.0	**CSIRO-Mk3.6.0**	**IPSL-CM5A-MR**
ACCESS1.3	**EC-EARTH**	**IPSL-CM5B-LR**
BCC-CSM1.1	**FGOALS-g2**	**MIROC-ESM**
BCC-CSM1.1-m	**GFDL-CM3**	**MIROC-ESM**
BNU-ESM	**GFDL-ESM2G**	**MIROC-ESM-CHEM**
CanESM2	**GFDL-ESM2M**	**MIROC5**
CCSM4	**GISS-E2-H**	**MPI-ESM-MR**
CESM1(BGC)	**GISS-E2-R**	**MPI-ESM-LR**
CESM1(CAM5)	**HadGEM2-AO**	**MRI-CGCM3**
CMCC-CESM	**HadGEM2-CC**	**MRI-ESM1**
CMCC-CM	**HadGEM2-ES**	**NorESM1-M**
CMCC-CMS	**INM-CM4**	Total 37 Models
CNRM-CM5	**IPSL-CM5A-LR**	

Plus:

Climate Forecast System Reanalysis (CFSR, ~30km X 30km grids)

METHODOLOGY

1. Downscaling
2. Bias correction
3. Mean and extreme indices calculation

STEP 1 DOWNSCALING

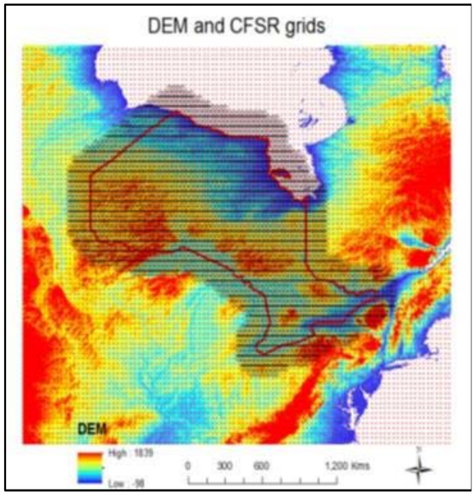
Kalman filter like downscaling method:

$$X^a = X^c + K\Delta X$$
$$\Delta X = X^m - HX^C$$

X^a – downscaled variable (temperature, precipitation) on CFSR grid (~ 32km)
X^c –climatology from 30-year CFSR data(annual cycle: 365 days for each variable)
ΔX –Variable anomaly relative to the climatology X^c
K –Kalman gain, which projects the GCM anomaly to CFSR grid
X^m –GCM projection
H –interplator which interpolates CFSR climatology to each GCM grid

$$K = PH^T\,(HPH^T + R)^{-1}$$
$$P = X^{c\prime}X^{c\prime T}$$

$X^{c\prime}$ is anomaly matrix (2440x150) from 30-year (1981-2010)of CFSR data

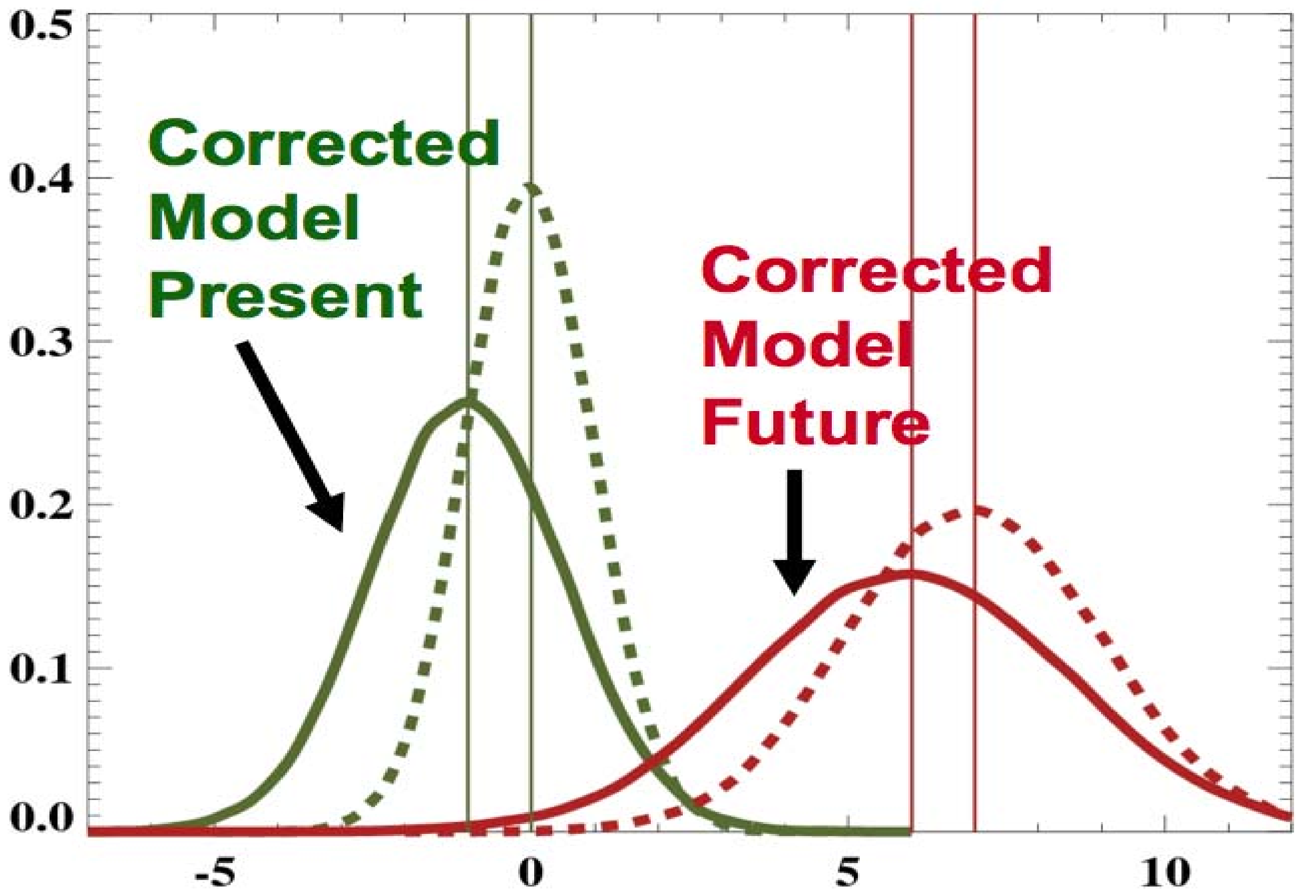


References;
- Dumedah G. and Coulibaly, P. 2012 and 2013;
- Karspeck, A. R., *et al.* 2013;
- J.R. Porto de Carvalho *et al.* 2011;
- Monache, D. L., *et, al*. 2011;
- Renwick, J.A., *et al.*, 2009

This method can downscale GCM anomaly to CFSR grid based on the dynamical relationship between different CFSR grids,
but can not correct bias → Step 2

STEP 2: BIAS CORRECTION

Bias correction using local intensity scaling (LOCI): e.g.,



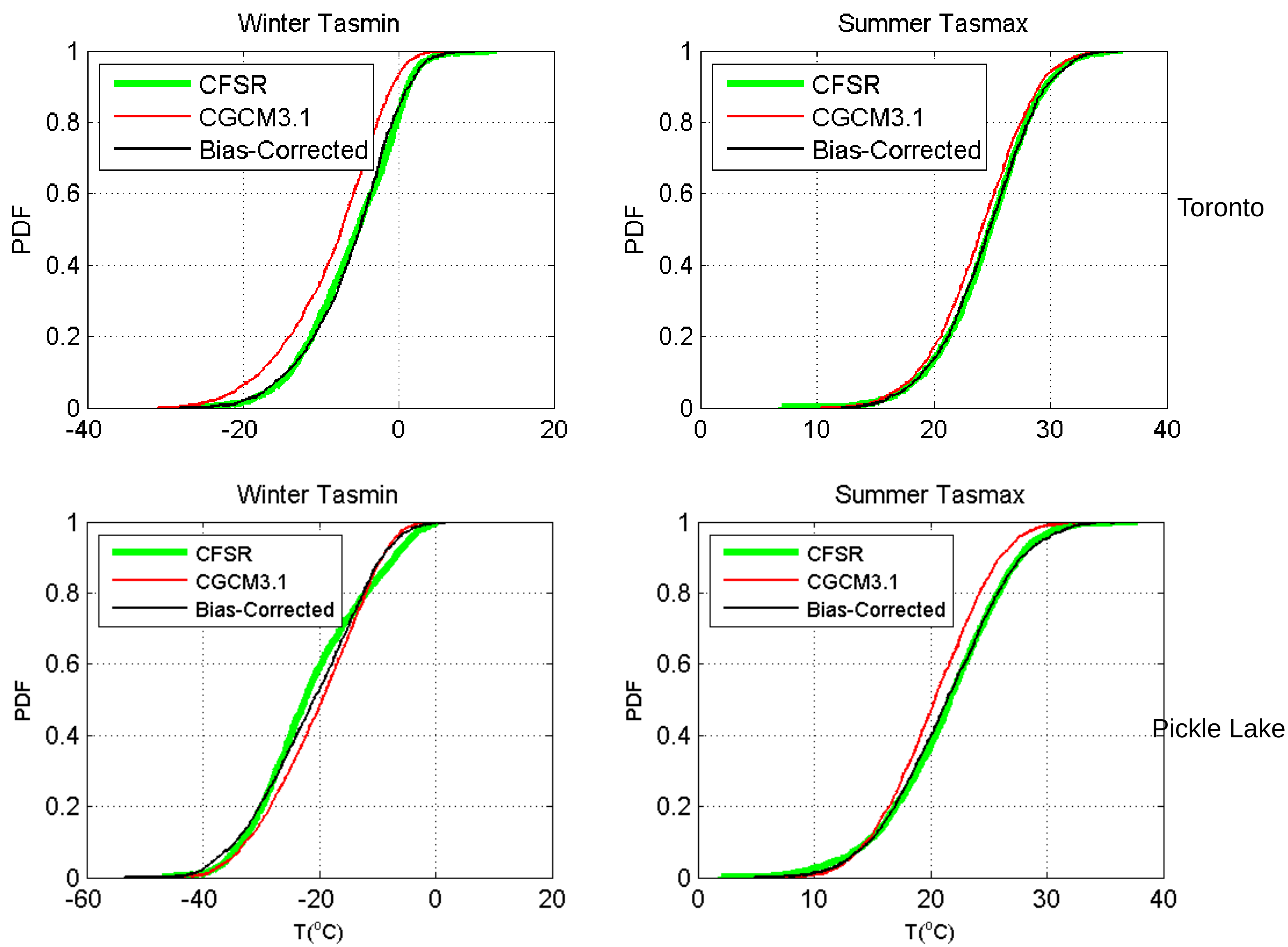
Probability Density Functions

STEP 3: 27 MEAN AND EXTREME INDICES CALCULATION

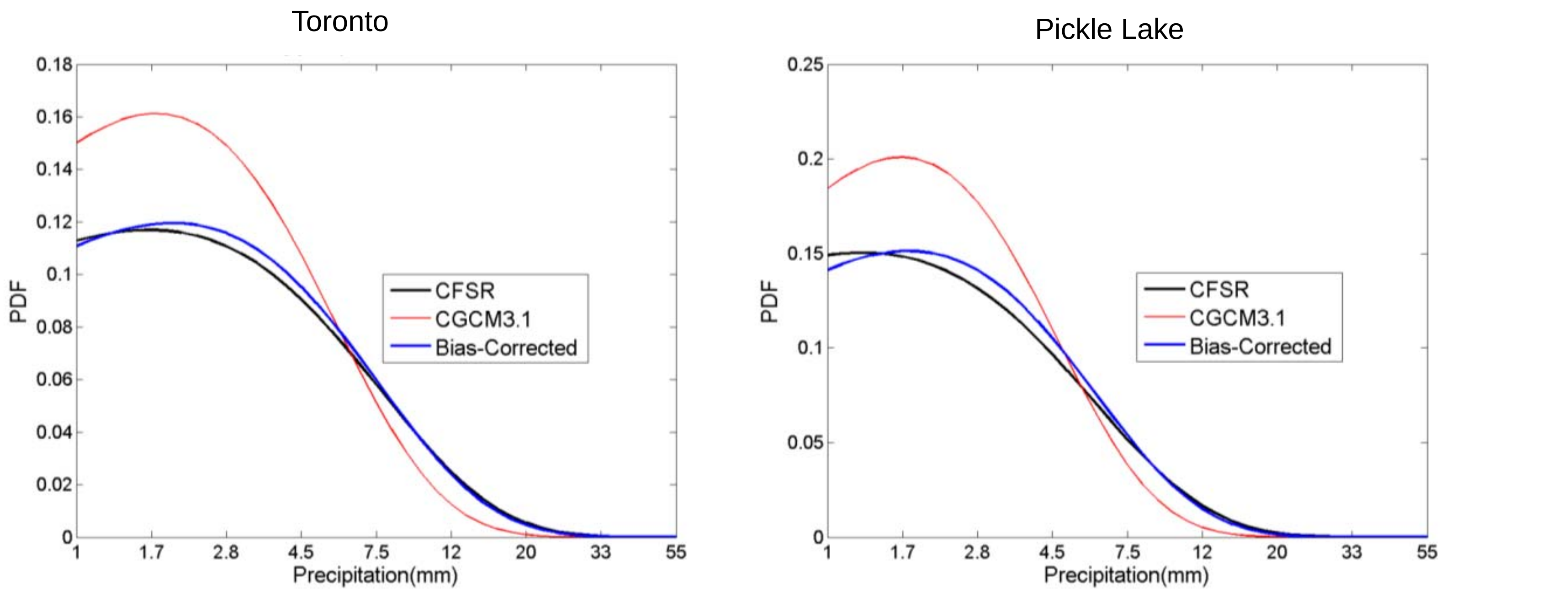
Examples of Indices

Extreme Index	Name	Definition
Tn10p	cold nights	count of days where TN < 10th percentile
TX10p	cold days	count of days where TX < 10^{th} percentile
TN90p	warm nights	count of days where TN > 90^{th} percentile
TX90p	warm days	count of days where TX > 90^{th} percentile
HWDI	Heat Wave Duration Index	Days, Times, Strength
RX1day	maximum one-day precip	highest precipitation in one-day
SU	Summer day	Daily maximum temperature > 25 degC
SDII	simple daily intensity index	mean precipitation on a wet day
R1mm	Wet days	days where RR ≥1mm
R10mm	heavy precipitation days	count of days where RR ≥ 10 mm
R20mm	very heavy precipitation days	count of days where RR ≥ 20 mm
CDD	consecutive dry days	maximum length of dry spell (RR < 1 mm)
CWD	consecutive wet days	maximum length of wet spell (RR ≥ 1 mm)
R95p	Very wet days	Precipitation due to very wet days (> 95th percentile)
R99p	Extreme wet days	Extreme wet days (> 99th percentile)
PRCTOT	Total wet day precipitation	total precipitation above 1.0mm

VALIDATION (DAILY MAX/MIN TEMP)



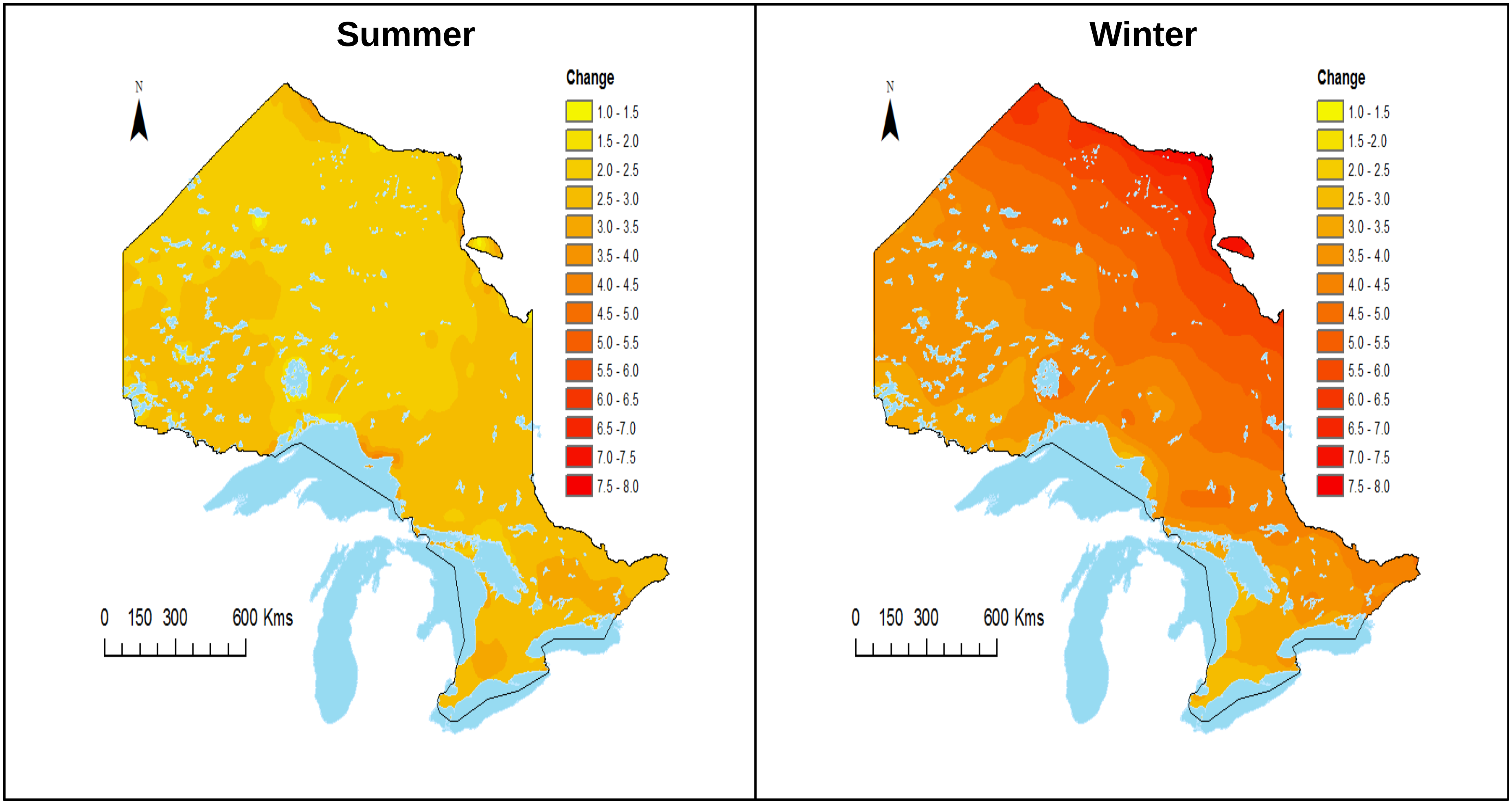
VALIDATION (WET-DAY PRECIPITATION)



Wet-Day Precip from Toronto and Pickle Lake.

- GCM Models are too dry (underestimate precipitation)
- Bias corrected results are much closer to the reality based on CFSR data.

Projected Changes in Summer and Winter Mean Temperatures(ºC) by 2050s compared with 1981-2010

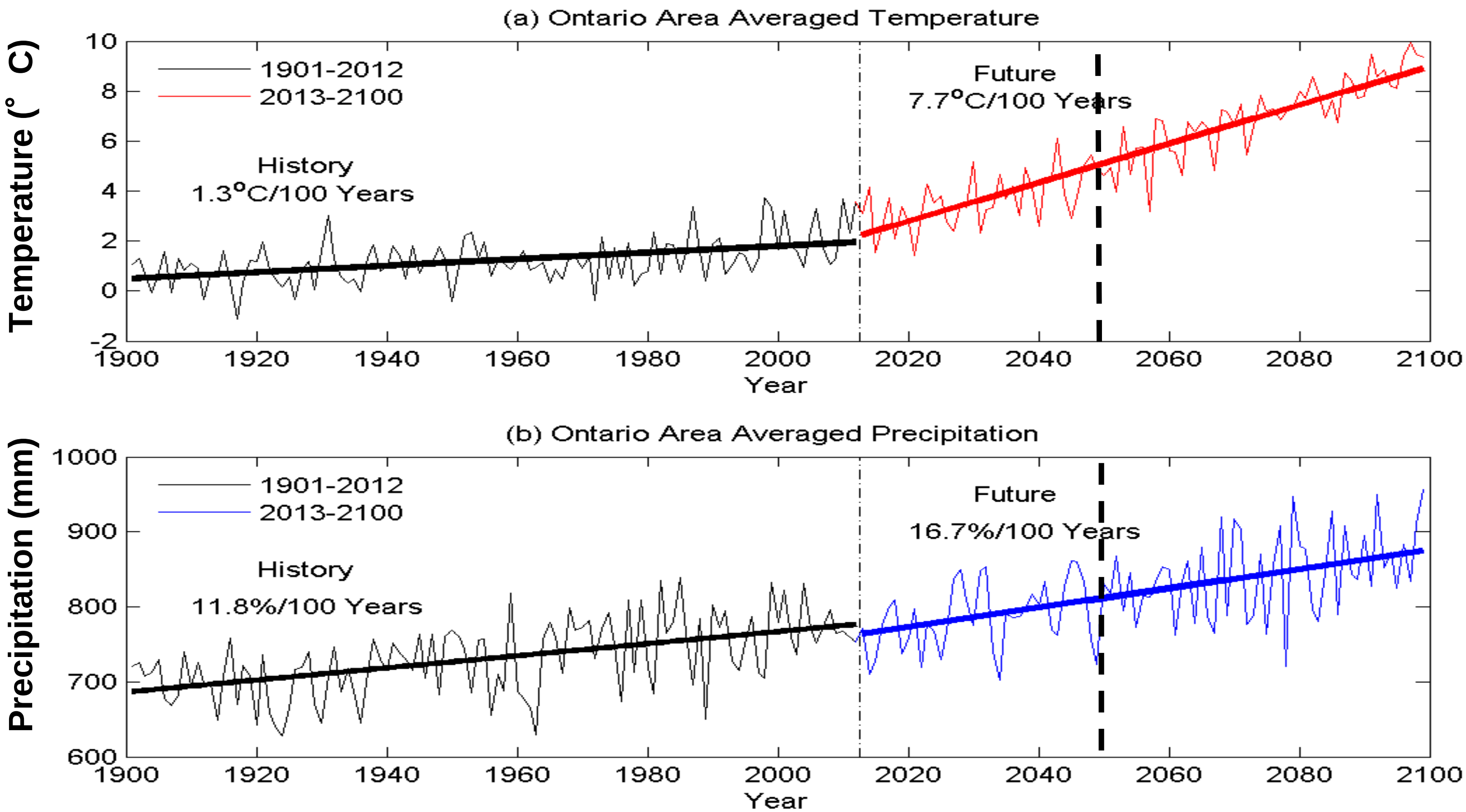


1 Preliminary results from MOECC funded York University project, under the IPCC AR5 **RCP8.5** business as usual projections.

2 2050s is defined as 2041-2070; all changes are calculated as the differences between the 2041-2070 and the averages of the end of last century, 1990s (1981-2010).

CLIMATE TRENDS IN ONTARIO

FROM THE OBSERVED PAST TO THE PROJECTED FUTURE

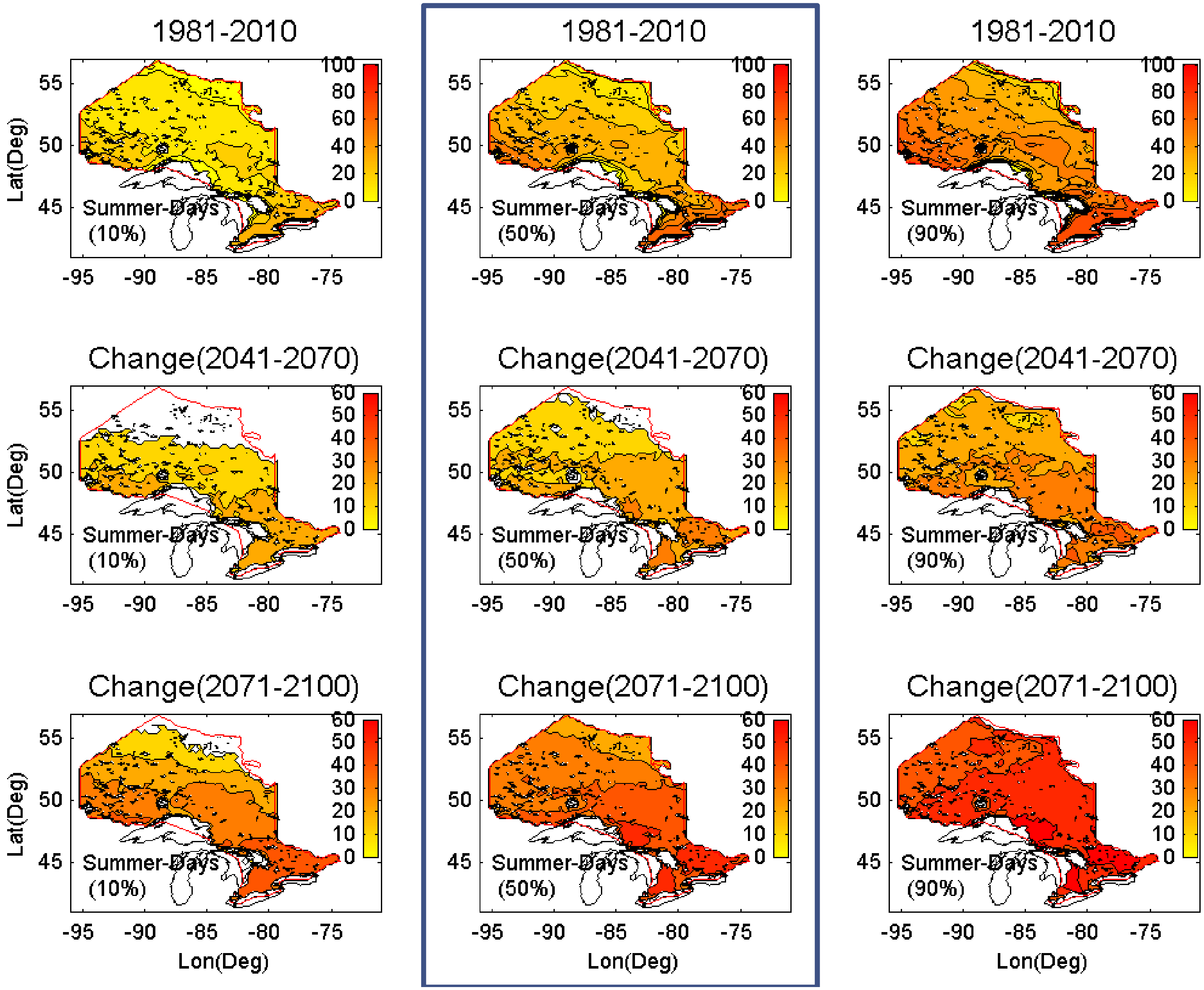


* 1901-2012 period is based on observed data http://badc.nerc.ac.uk/view/badc.nerc.ac.uk__ATOM__dataent_12562237733328276.

** 2013-2100 period is based on preliminary results from MOECC funded York University project, based on IPCC AR5 RCP8.5 business as usual projections.

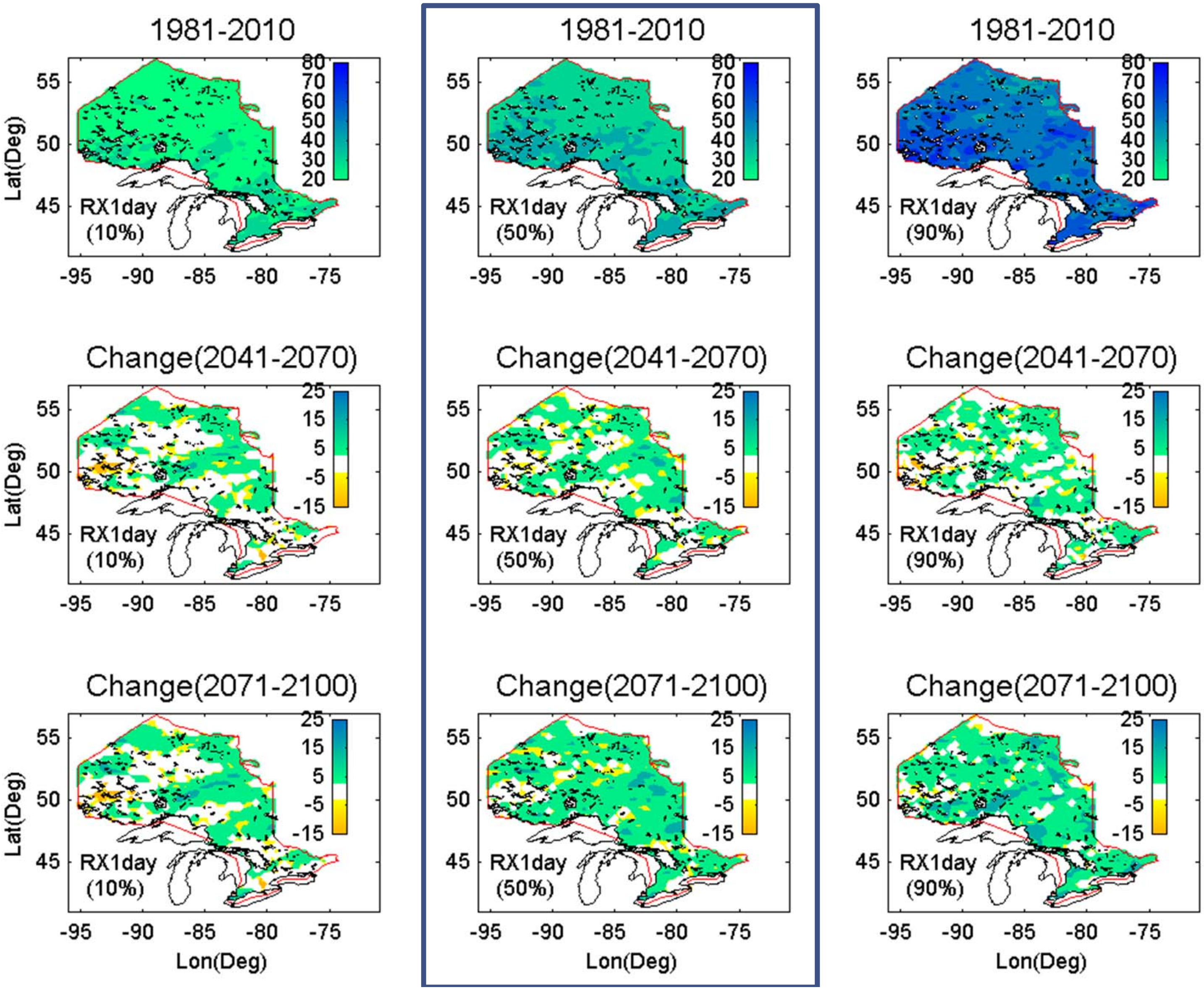
PROBABILISTIC ANALYSIS (1)

Summer Day (when Tmax > 25 deg C)



PROBABILISTIC ANALYSIS (2)

RX1day (Maximum 1-day Precip)



SUMMARY: PROJECTED CHANGES IN ONTARIO BY 2050S (UNDER RCP8.5)

- **Average Climate Indicators**
  - **Temperature very likely to increase significantly**
    - o Annual: by ~3.6 [1.3~6.9]° C
    - o Winter: by ~5.3 [0.9~11.2]° C
    - o Summer: by ~2.4 [-0.6~6.0] ° C
  - **Cooling degree day (CDD)** increases by ~177 [6 ~ 459]° C or ~167%
  - **Frost Days** decrease by ~31 [-38 ~ 12] days or 19%
  - **Precipitation likely to increase** (low confidence)
    - o Annual: by ~11 [-13~34]%
    - o Winter: by ~16 [-23~67]%
    - o Summer: by ~12 [-37~65]%

- **Extreme Climate Indicators**
  - **Temperature-related**
    - o Warm-days increase ~59 [10~126] days or 164%
    - o Warm-nights increase ~70 [23~139] nights or 194%
    - o Maximum single heat wave duration increase ~16 [1~50] days or 200%
  - **Precipitation –related** (low confidence)
    - o Heavy precipitation days (>10mm/day) increase ~4 [-6~13] days or 17%
    - o Very heavy precipitation days (>20mm/day) increase ~2 [-3~6] days or 33%
    - o Very wet days (>95 percentile) increase ~2 [-3~8] days or 25%

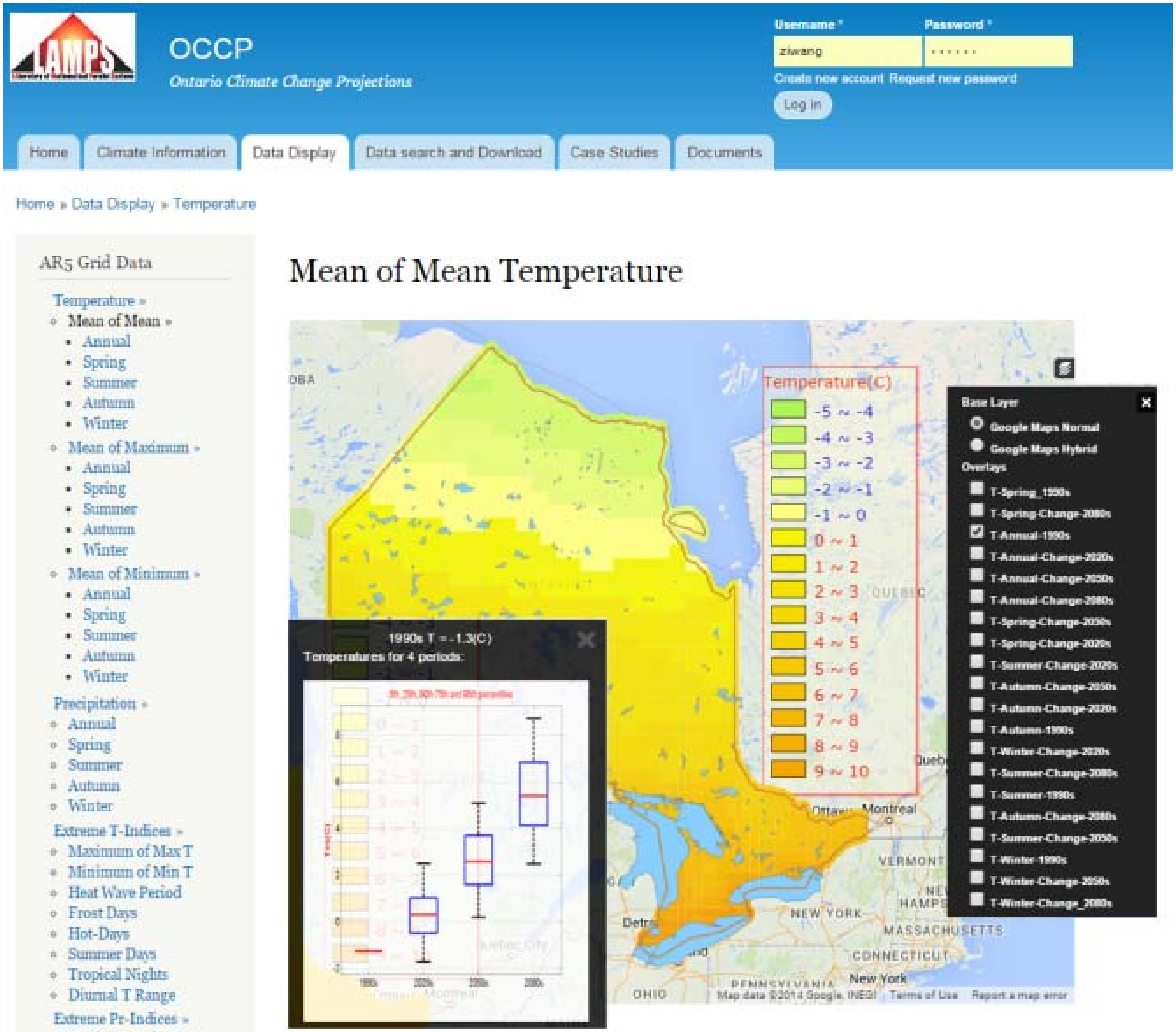
PUBLICATIONS RESULTED FROM THE MOECC-FUNDED PROJECTS

- **Presentations**

1. Deng, Z., X. Qiu, N. Madras, and H. Zhu, **2014**: Trend in frequency of extreme precipitation events over Ontario from ensembles of multiple GCMs and RCMs, 2014 Congress of the Canadian Meteorological and Oceanographic Society (CMOS), Rimouski QC, June 1-5, 2014. 21.
2. Liu, Y., H. Zhu, J. Chen, Z. Deng, and L. Chen, **2014**: Assessing Potential Impacts of Climate Change on Mosquito Abundance Associated with West Nile Virus Risks in Ontario, 2014 CMS Winter Meeting - Canadian Mathematical Society, Hamilton. Dec. 6-7, 2014
3. Deng, Z., and H. Zhu, **2014**: Trend in frequency of extreme precipitation events over Ontario from ensembles of multiple GCMs and RCMs, the 2nd Annual Symposium of the Ontario Climate Consortium, University of Western Ontario, London, Ontario, Canada, May 13, 2014.
4. Qiu, X., **2013**: Practice in Climate Change Downscaling, Meteorology, Emissions and Chemistry. Seminar, Western University of Ontario, London, Canada
5. Qiu, X., J. Wang, L. Chen, D. Yu, and H. Zhu, **2011**: Climate Change Downscaling and Probabilistic Analysis". 2011 CMS Winter Meeting, Toronto, Canada, December 10-12, 2011
6. Yu, D. and A. Abdelrazec, **2013**: High Resolution Probabilistic Climate Projections over Ontario, SHARCNET Research Day, University of Guelph.
7. Deng, Z., **2013**: Probabilistic Projections of Extreme Precipitation over Ontario, Conference of High Performance Computing of Southern Ontario Smart Computing Innovation Platform (SOSCIP), Ontario Centre of Excellent. November 11, 2013

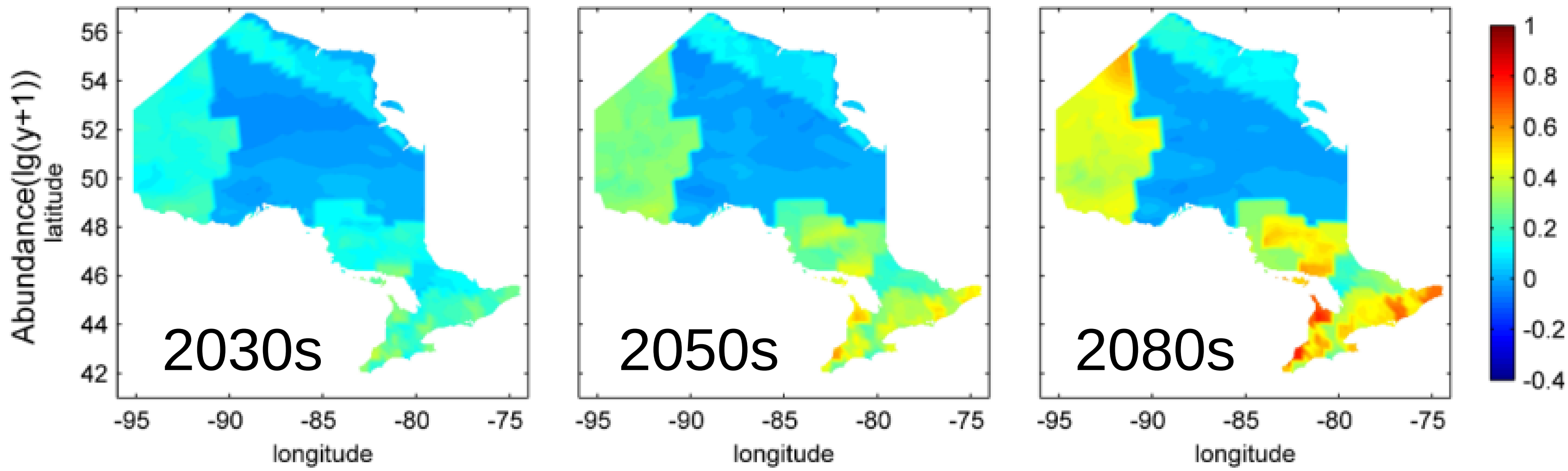
- **Two papers** in final group review will be submitted for journal publication in 2014

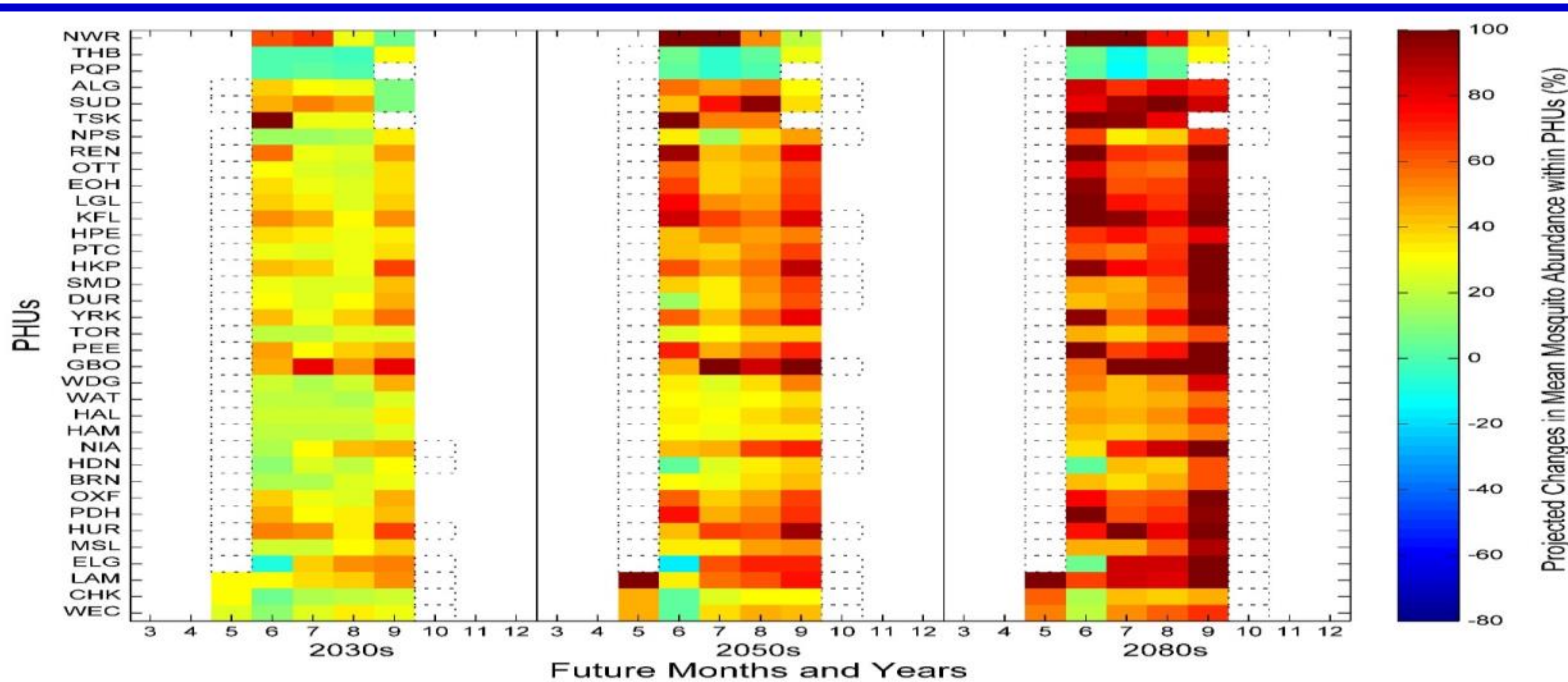
MAKE THE DATA PUBLICALLY AVAILABLE (1)



OUR DATA WAS USED FOR HEALTH RISKS ASSESSMENT

PROJECTED MOSQUITO ABUNDANCE CHANGES OVER ONTARIO





OUR DATA IS BEING USED IN AN AGRICULTURE PRODUCTION AND RURAL RESILIENCE STUDY

ONTARIO CLIMATE CONSORTIUM

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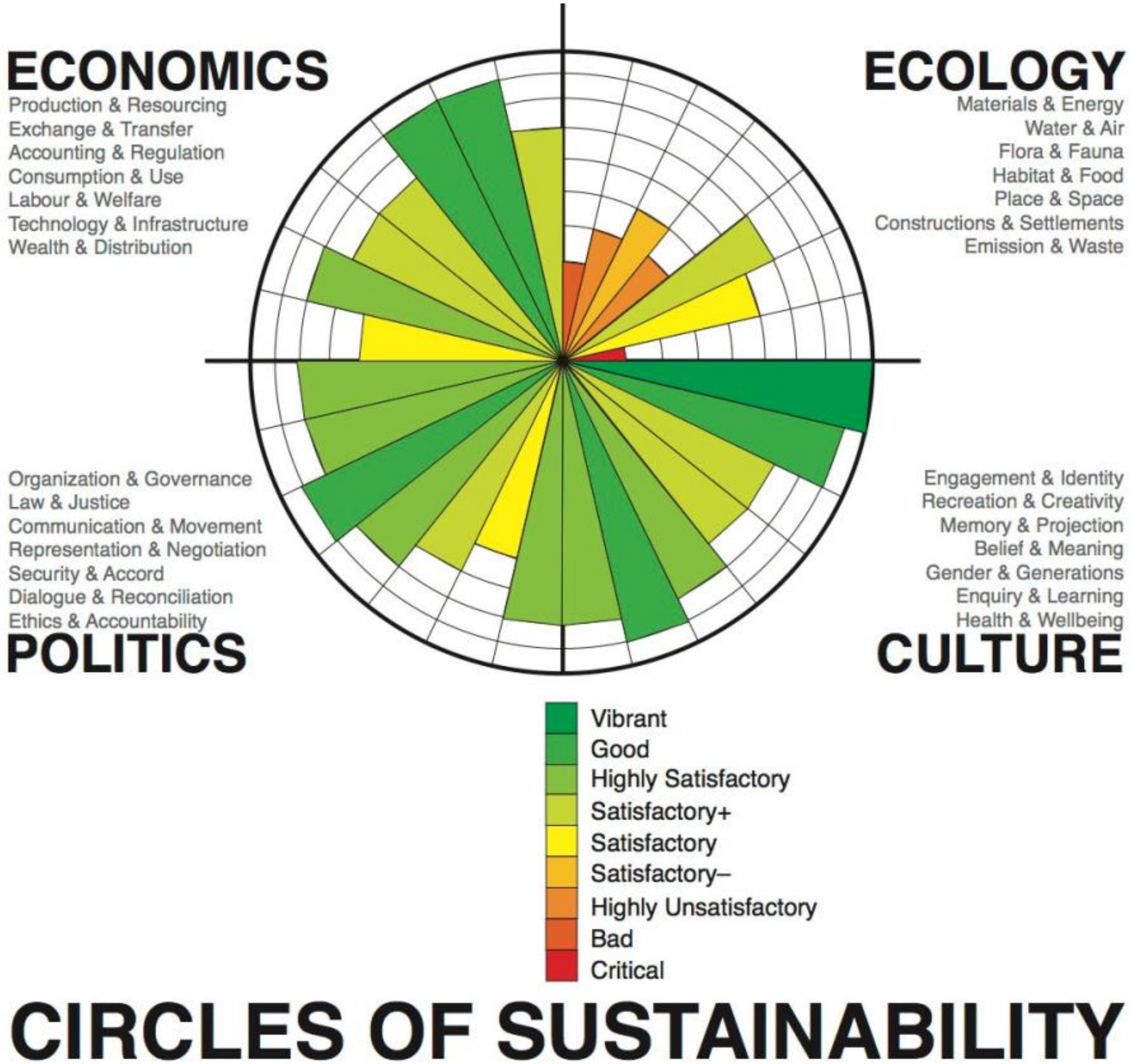
The Identification and Validation of Extreme Weather Indicators for Agricultural Production and Rural Resilience in Ontario

Project Partners

York University | International Institute for Sustainable Development | Carleton University | Agriculture and Agri-Food Canada

OUR DATA IS ALSO PLANNED IN SMART CITY DESIGN

THE WCCD/GCI PROJECT



Novus is working on development of Global City Index (GCI) by applying MOECC output in Ontario for The World Council on City Data (WCCD) and ISO 37120.

FUTURE WORK

- **Complete the current project on updating the projections with the latest AR5 results**
- **Finalize the Data Portal for more effective data dissemination to better serve climate change impact and adaptation assessment in Ontario**
- **Further explore possibility to downscale the monthly average variables to 1km resolution over Ontario in support of adaptation and impact assessment at community scales.**
- **More papers will be submitted for publication**

Thank You!

High Resolution Probabilistic Climate Projections over Ontario through UK PRECIS Model and SCADS Technique

Gordon Huang and Xander Wang

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University of Regina

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Email: huangg@uregina.ca

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IEESC

Institute for Energy, Environment and Sustainable Communities

University of Regina

University of Regina

Contents

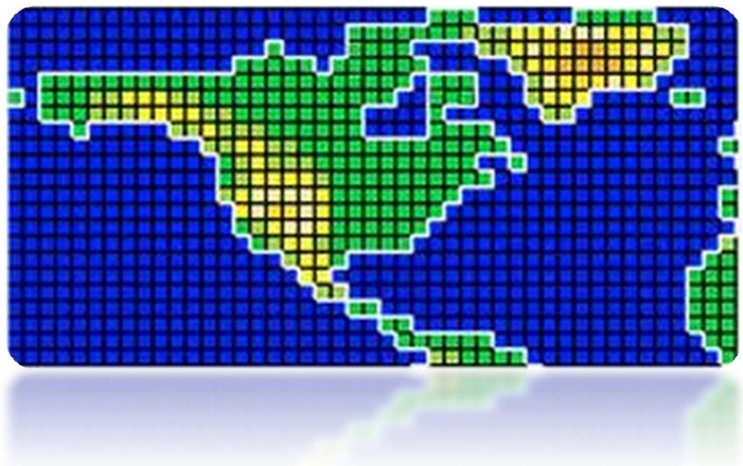
- Introduction
- Combined Dynamical-Statistical Downscaling
- Probabilistic Projections
- Projected IDF Curves
- Ontario Climate Change Data Portal
- Q & A

1 Introduction

Necessity of Regional Climate Modeling

- **GCM projections lack regional details**

  due to coarse spatial resolution



- **Impact analysts need regional details**

  to assess vulnerability and possible adaptation strategies

Modeling Capacity at U of R

- **Regional Models & Statistical Tools**
  - PRECIS (UK Met Office Hadley Centre)
  - RegCM (US NCAR and Italian Int'l Centre for Theoretical Physics)
  - WRF (US National Center for Atmospheric Research)
  - SCADS (IEESC, U of R, http://env.uregina.ca/sca)
- **High Performance Computing Cluster**

Sun Cluster

Dell Cluster

Workstation

Server

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Projects Funded by MOECC

- Regional Climate Modelling over Ontario Using UK PRECIS (25 km x 25 m), 2009-2010
  - Website: http://env.uregina.ca/moe/rcm
- Regional Climate Modelling over Ontario Using UK PRECIS (10 km x 10 km), 2011
  - Website: http://env.uregina.ca/moe/ds
- High-Resolution (25 km x 25 km) Probabilistic Climate Change Projections over Ontario, 2012
  - Website: http://env.uregina.ca/moe
- Developing Future Projected IDF Curves and a Public Climate Change Data Portal for the Province of Ontario, 2013
  - Website: http://ontarioccdp.ca

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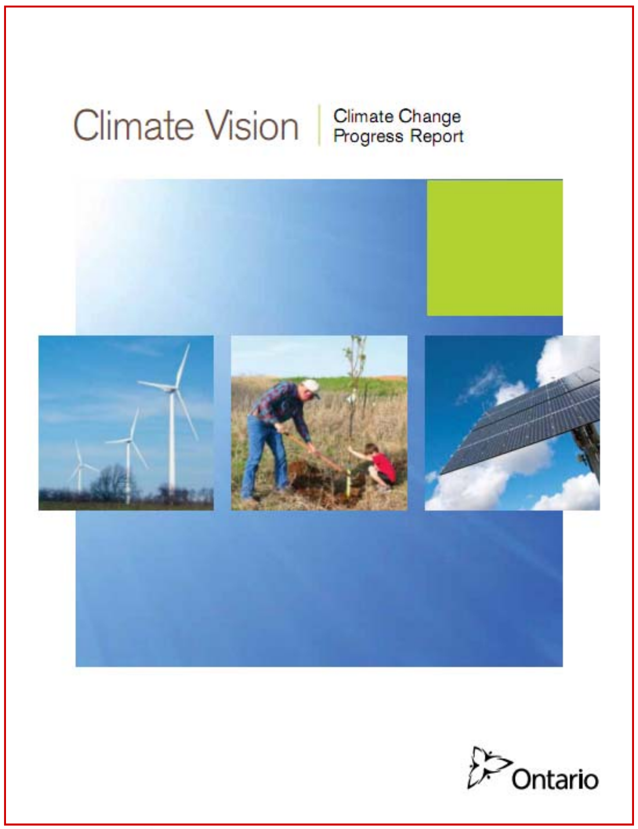
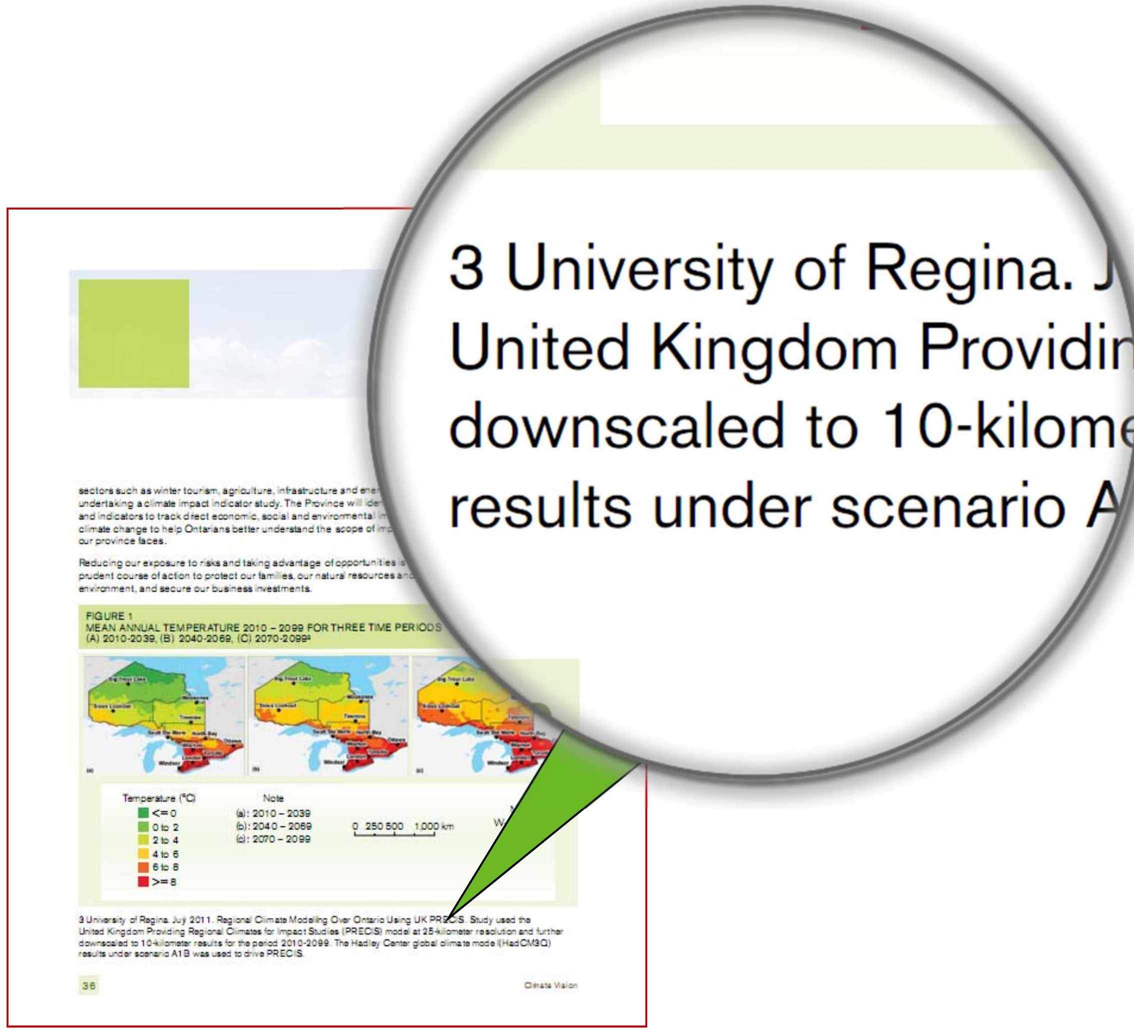
Results Published in the Climate Change Progress Report by MOECC





Peer-Reviewed Publications

- Wang, Xiuquan, et al. 2014: High-Resolution Probabilistic Projections of Temperature Changes over Ontario, Canada. **Journal of Climate**, 27, 5259-5284.
- Wang, Xiuquan, et al. 2014: High-resolution temperature and precipitation projections over Ontario, Canada: a coupled dynamical-statistical approach. **Quarterly Journal of the Royal Meteorological Society**. doi:10.1002/qj.2421.
- Wang, Xiuquan, et al. 2014: Projected increases in near-surface air temperature over Ontario, Canada: a regional climate modeling approach. **Climate Dynamics**. doi:10.1007/s00382-014-2387-y
- Wang, Xiuquan, et al. 2014: Projected increases in intensity and frequency of rainfall extremes through a regional climate modeling approach. **Journal of Geophysical Research: Atmospheres**. doi:10.1002/2014JD022564
- Wang, Shuo, et al. 2014: Comparison of interpolation methods for estimating spatial distribution of precipitation in Ontario, Canada. **International Journal of Climatology**. doi:10.1002/joc.3941.
- Wang, Xiuquan, et al. 2013: A stepwise cluster analysis approach for downscaled climate projection–A Canadian case study. **Environmental Modelling & Software**, 49, 141-151.

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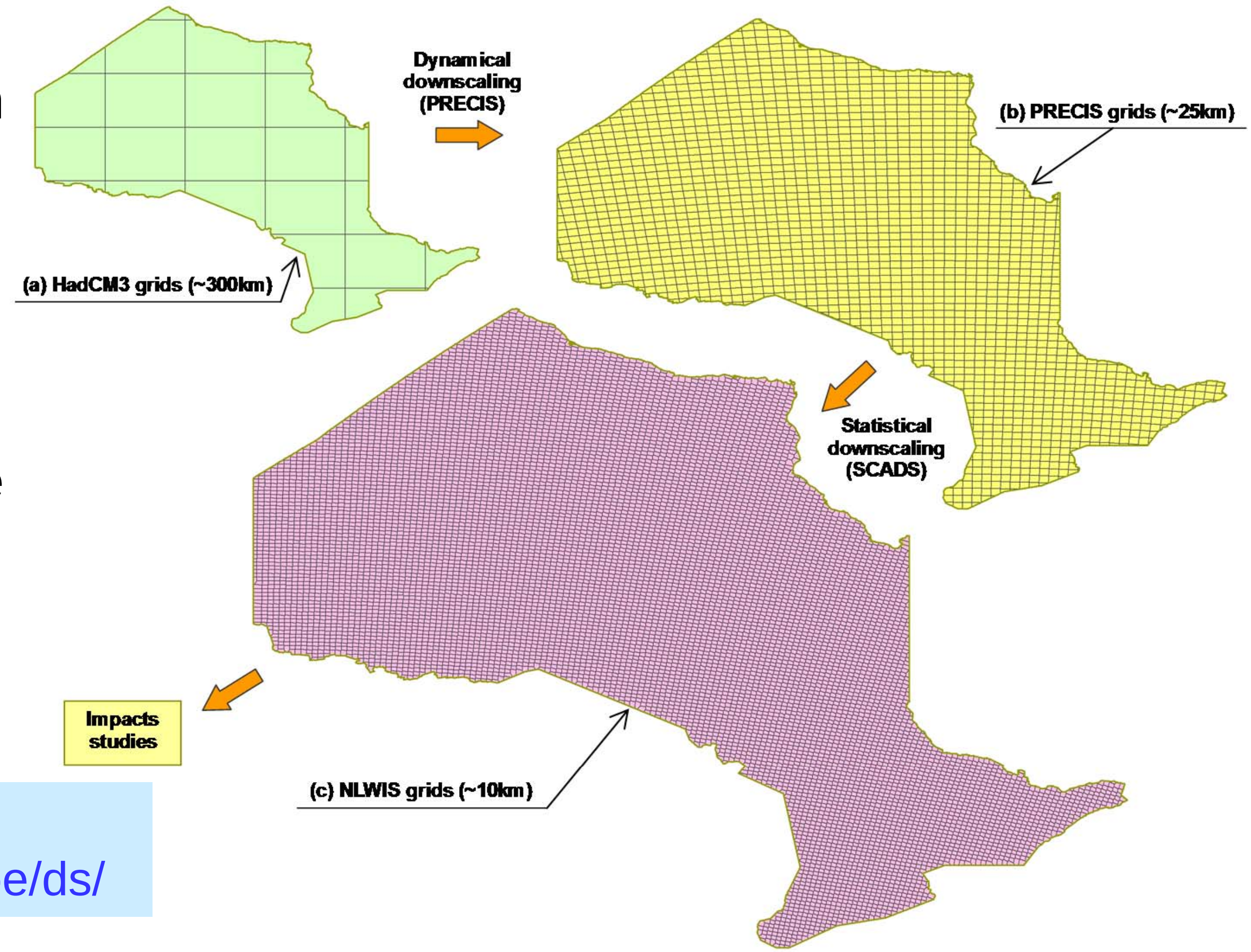
2 Combined Dynamical-Statistical Downscaling

10-km Climate Projections

A dynamical-statistical downscaling approach is developed:

- PRECIS RCM
- SCADS

➔ construct 10-km high resolution climate projections for Ontario



Results available at:
http://env.uregina.ca/moe/ds/

NLWIS: National Land and Water Information Service(NLWIS), Agriculture and Agri-Food, Canada.

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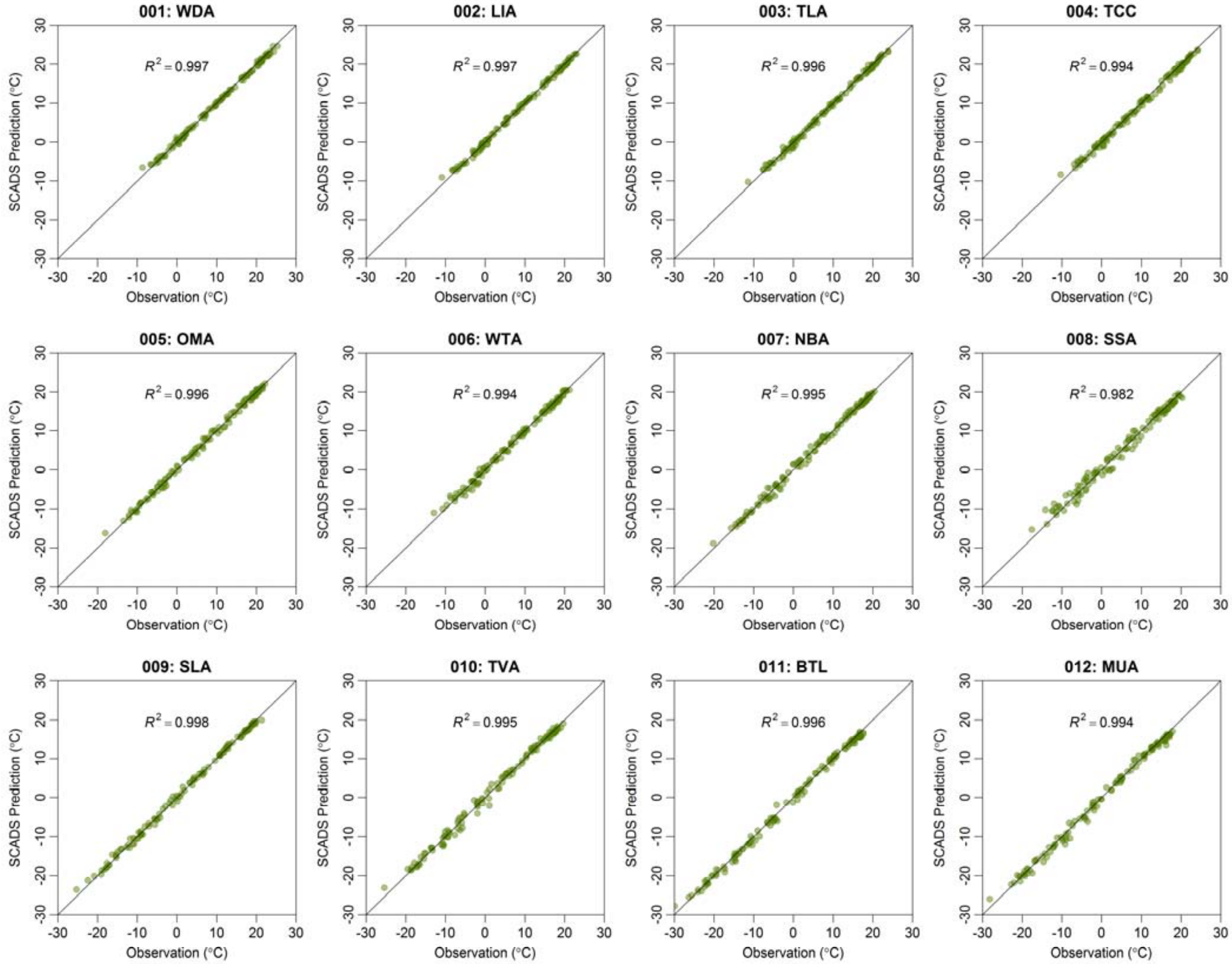
Validation … for 1960-1990



Validation at 12 weather stations:
monthly mean temperature (Wang et al, 2014)

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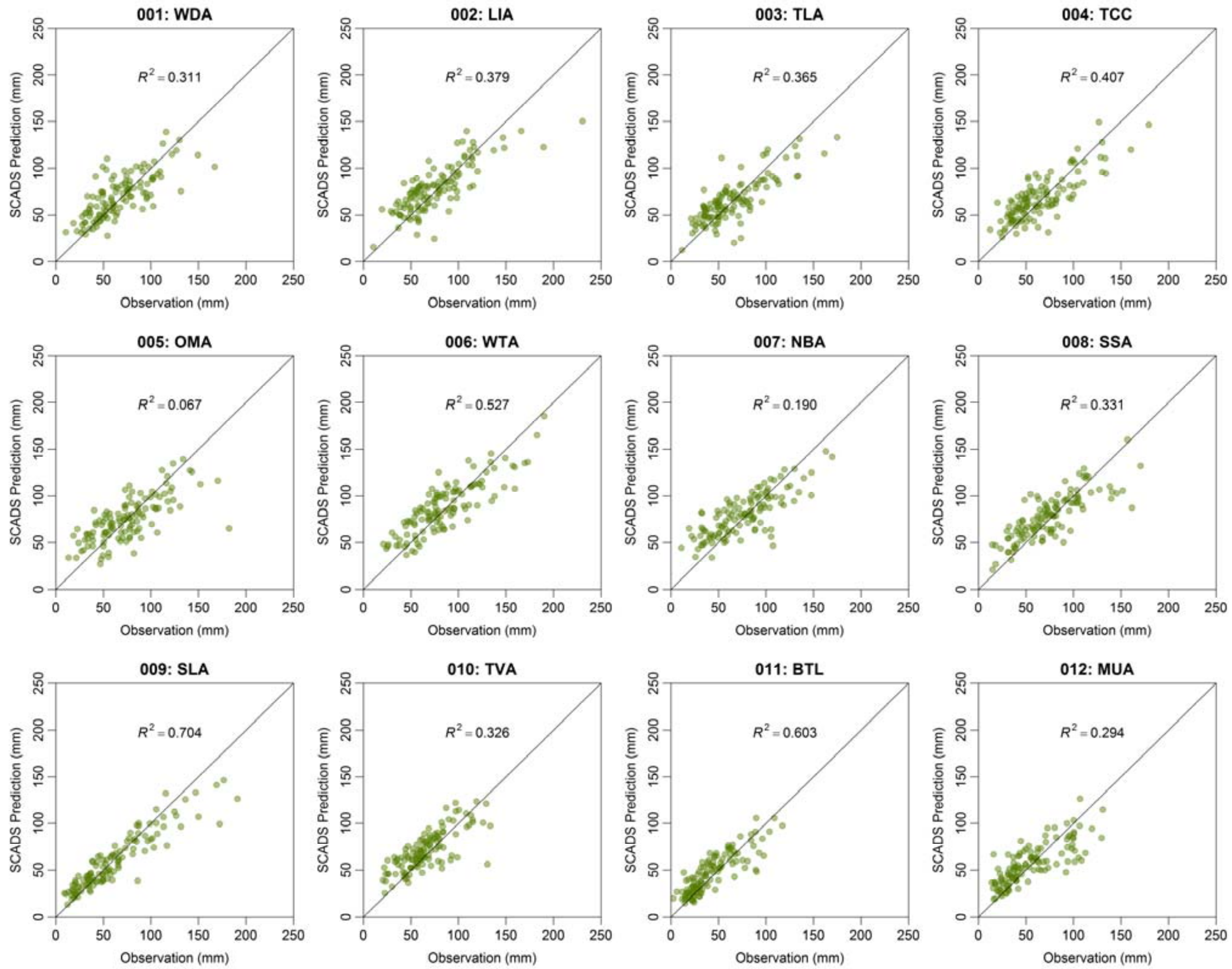
Validation … for 1960-1990



Validation at 12 weather stations:
monthly total precipitation (Wang et al, 2014)

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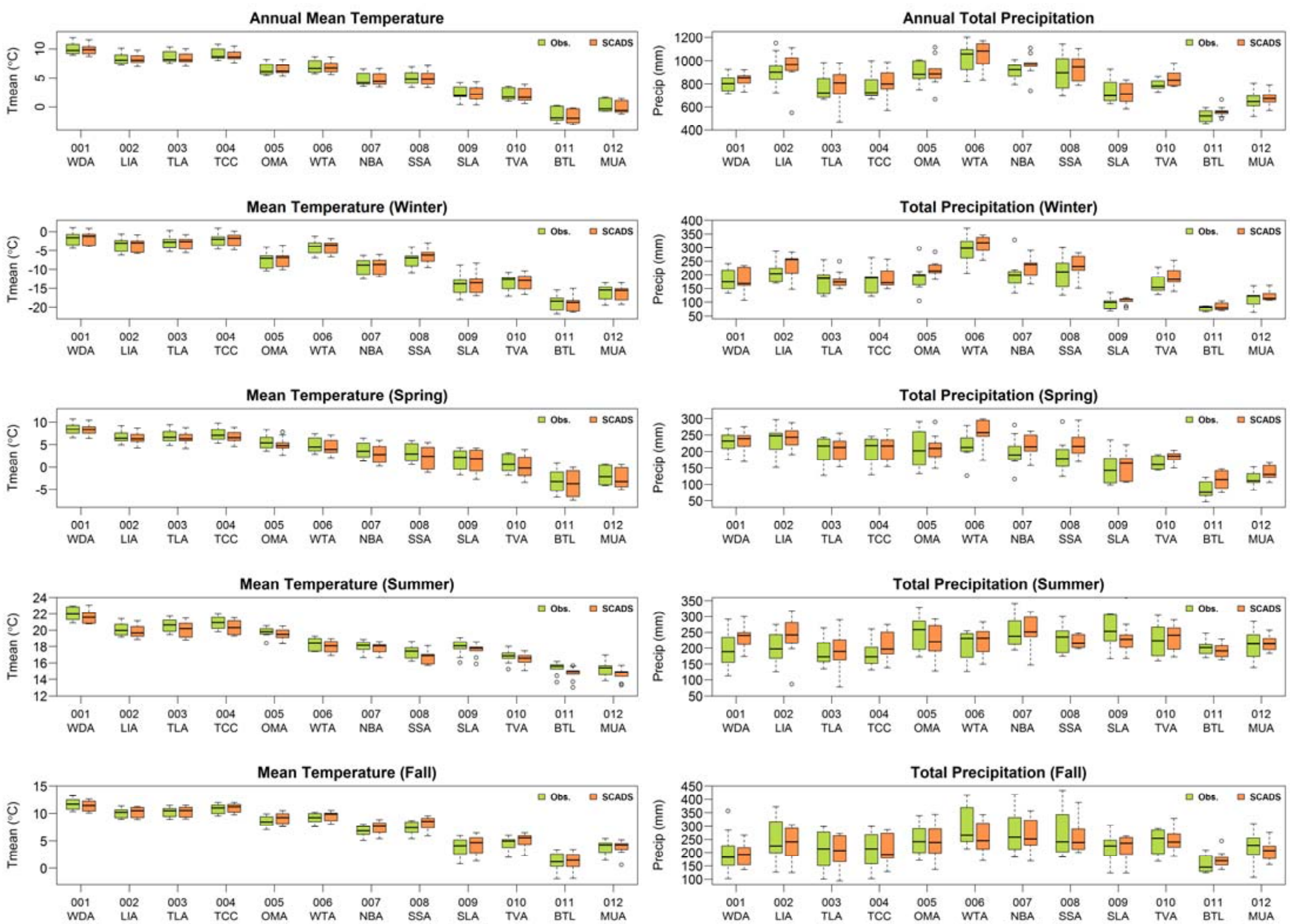
Validation … for 1960-1990



Validation at 12 weather stations:
annual & seasonal mean T and total P (Wang et al, 2014)

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Validation … for 1960-1990

Our validation results show:

The coupled approach …

- Good in reproducing mean **T**
- Less satisfactory for **P** (due to its high spatial variability and nonlinear nature)
- Spatial patterns of **P** are well captured

Use the coupled approach …

project future climate over Ontario at 10-km resolution

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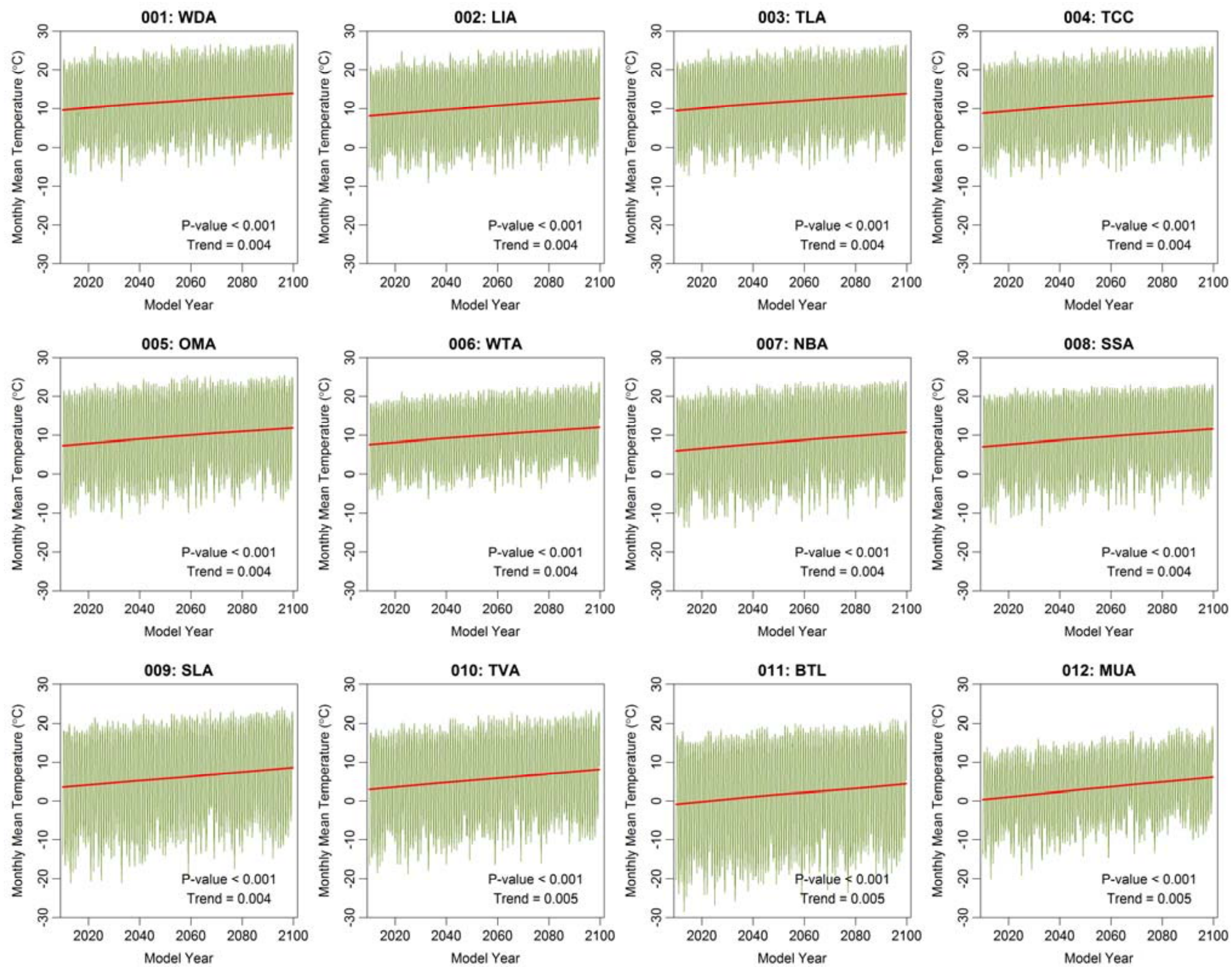
Projection … Trends for 2010-2099



Trends of projected monthly mean T
at 12 weather stations **(Wang et al, 2014)**

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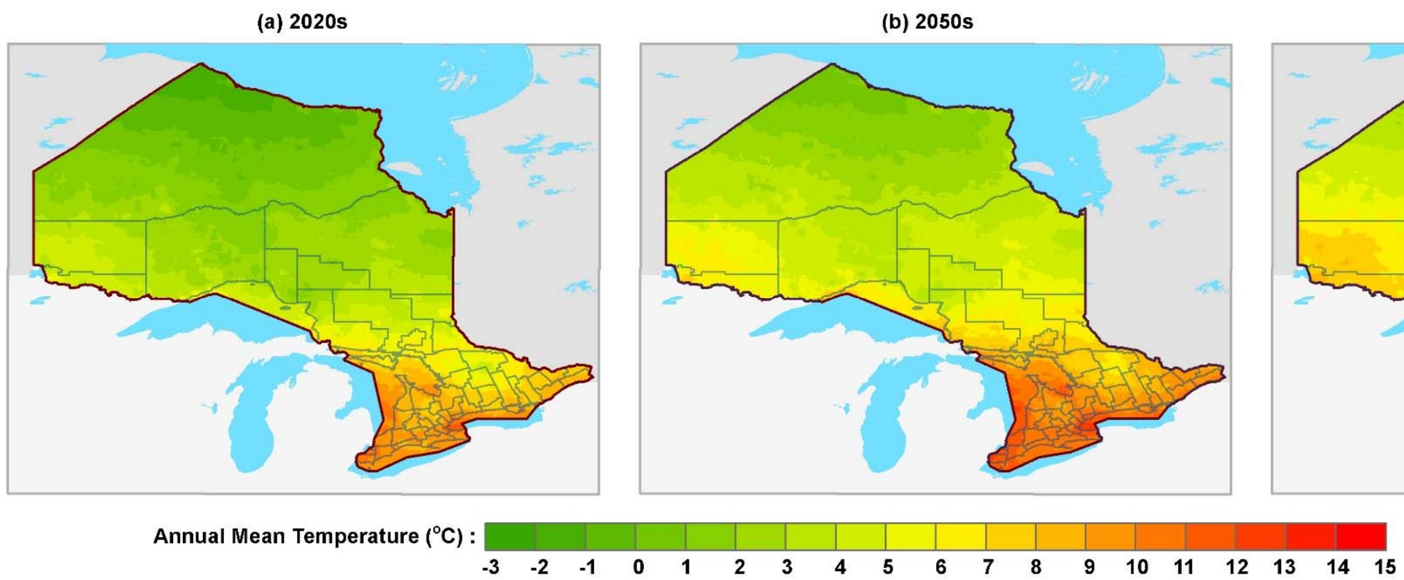
Projections … for 2020s, 2050s, 2080s



High-resolution projections of
annual mean T (Wang et al, 2014)

Projection … Trends of Future Climate

Our analyses reveal:

(1) Significant warming trend throughout this century for the entire Province

(2) Significant spatial variability in amount of P

(3) No significant change in spatial pattern of P

NOTE: More findings can be found in the paper of Wang et al. (2014, Quarterly Journal of the Royal Meteorological Society)

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3 Probabilistic Projections

High-Resolution PRECIS Ensemble

PRECIS modeling ➔ regional climate ensemble simulations over Ontario

driven by boundary conditions of a 5-member HadCM3-based perturbed-physics ensemble:

- HadCM3Q0
- HadCM3Q3
- HadCM3Q10
- HadCM3Q13
- HadCM3Q15

In order to explore uncertainties associated with climate projections

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Bayesian Hierarchical Model

PRECIS ensemble simulations

➔ are synthesized through a Bayesian hierarchical model

➔ Purpose: develop probabilistic projections of future T (given uncertain inputs for RCM)

Posterior distributions of uncertain parameters

➔ are obtained through a Gibbs-based Markov chain Monte Carlo implementation

$$x_i = m + h_i$$

$$y_i = n + x_i + b(x_i - m)$$

$$p(m|x_o, x_1, \ldots, x_N, y_1, \ldots, y_N) \propto N\left(\frac{\sum_{i=1}^{N}\left[l_i x_i - qbl_i(y_i - n - bx_i)\right] + l_0 x_0}{l_0 + \sum_{i=1}^{N} l_i(1+qb^2)}, \left[l_0 + \sum_{i=1}^{N} l_i(1+qb^2)\right]^{-1} \right)$$

$$p(n|x_o, x_1, \ldots, x_N, y_1, \ldots, y_N) \propto N\left(\frac{\sum_{i=1}^{N} l_i \left(y_i - b(x_i - m)\right)}{\sum_{i=1}^{N} l_i}, \left(q\sum_{i=1}^{N} l_i\right)^{-1} \right)$$

NOTE: Assumptions on the non-informative priors of all unknown parameters and the derivation of their posteriors can be found in the paper of Wang et al. (2014, Journal of Climate)

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Projection … Temperature at Major Cities

No.	City name	T_{mean} (°C, 50 %)			T_{max} (°C, 50 %)			T_{min} (°C, 50 %)		
		2030s	2050s	2080s	2030s	2050s	2080s	2030s	2050s	2080s
1	Toronto	10.9	12.3	13.7	15.3	16.8	18.2	6.6	7.9	9.2
2	Ottawa	8.4	9.9	11.4	13.8	15.4	16.8	3.2	4.6	6.2
3	London	10.2	11.6	13.1	15.1	16.6	18.2	5.4	6.6	8.0
4	Windsor	12.1	13.5	15.0	16.6	18.0	19.6	7.6	8.9	10.3
5	Kingston	9.8	11.3	12.6	14.3	15.9	17.2	5.3	6.7	8.2
6	Thunder Bay	4.7	5.9	7.6	10.5	11.9	13.7	−0.9	0.5	1.9
7	Sault Ste. Marie	6.2	7.4	9.1	11.6	13.0	14.5	0.9	1.9	3.9
8	Timmins	4.1	5.7	7.4	10.4	11.9	13.6	−2.1	−0.6	1.3
9	Owen Sound	9.0	10.3	11.7	13.7	15.2	16.8	4.3	5.4	6.6
10	Sudbury	6.5	7.9	9.3	12.1	13.5	15.0	0.9	2.3	4.0
11	Kenora	4.8	6.2	7.8	10.5	11.8	13.7	−0.8	0.6	2.0
12	Marathon	3.8	5.0	7.1	9.1	10.5	12.1	−1.0	0.3	2.4
13	Moose Factory	2.0	3.8	6.1	8.0	9.8	12.1	−4.0	−2.2	0.0
14	Sandy Lake	1.6	3.1	4.6	7.0	8.5	10.1	−3.7	−2.3	−1.0
15	Fort Hope	1.6	2.8	4.6	7.6	9.0	10.6	−4.3	−2.8	−0.8
16	Kitchenuhmaykoosib	0.0	1.5	3.0	5.3	6.8	8.3	−5.7	−3.7	−1.8
17	Fort Severn	−1.6	0.4	3.0	3.2	5.2	7.7	−6.5	−4.8	−2.4

Projected Tmean, Tmax, Tmin for major cities
at 50% probability level (for 2030s, 2050s, and 2080s)

NOTE: Tmax and Tmin indicate **30-yr average daily maximum and minimum temperature**, respectively. The temperature values in the above table are bias-corrected, please refer to Wang et al. (2014, Climate Dynamics) for more details.

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Projection … Temperature over Ontario

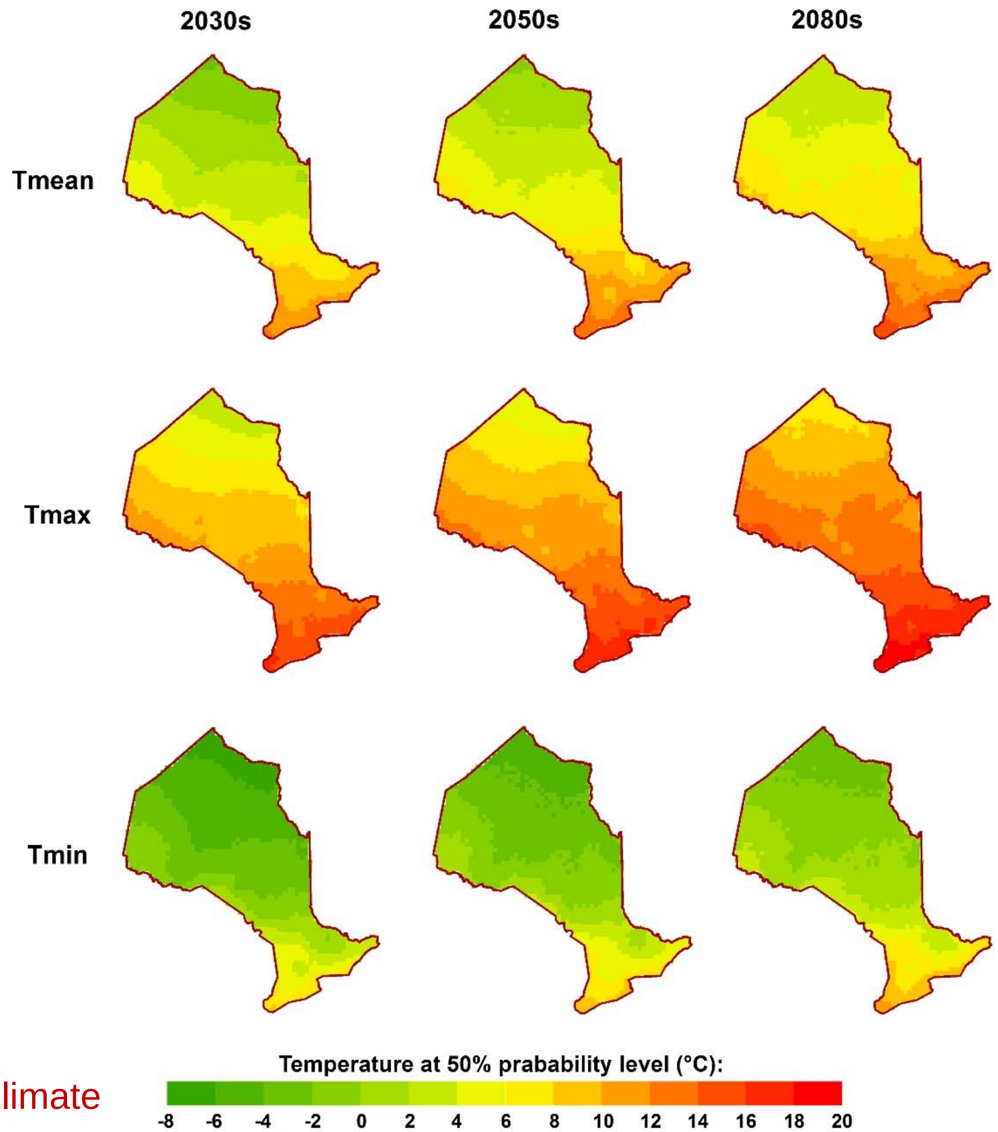
The most likely Tmean in next decades (i.e., 2050s) would be:

- [0, 4] ℃ in northern Ontario,
- [4, 8] ℃ in the middle,
- [8, 14] ℃ in the south,

Tmean may keep rising by ~2 ℃ per 30-year period.

Continuous warming till the **end** of this century …

- Tmin in the north may reach **2 ℃**
- Tmax in the south may reach **16 ℃**



Refer to Wang et al. (2014, Climate Dynamics) for more details.

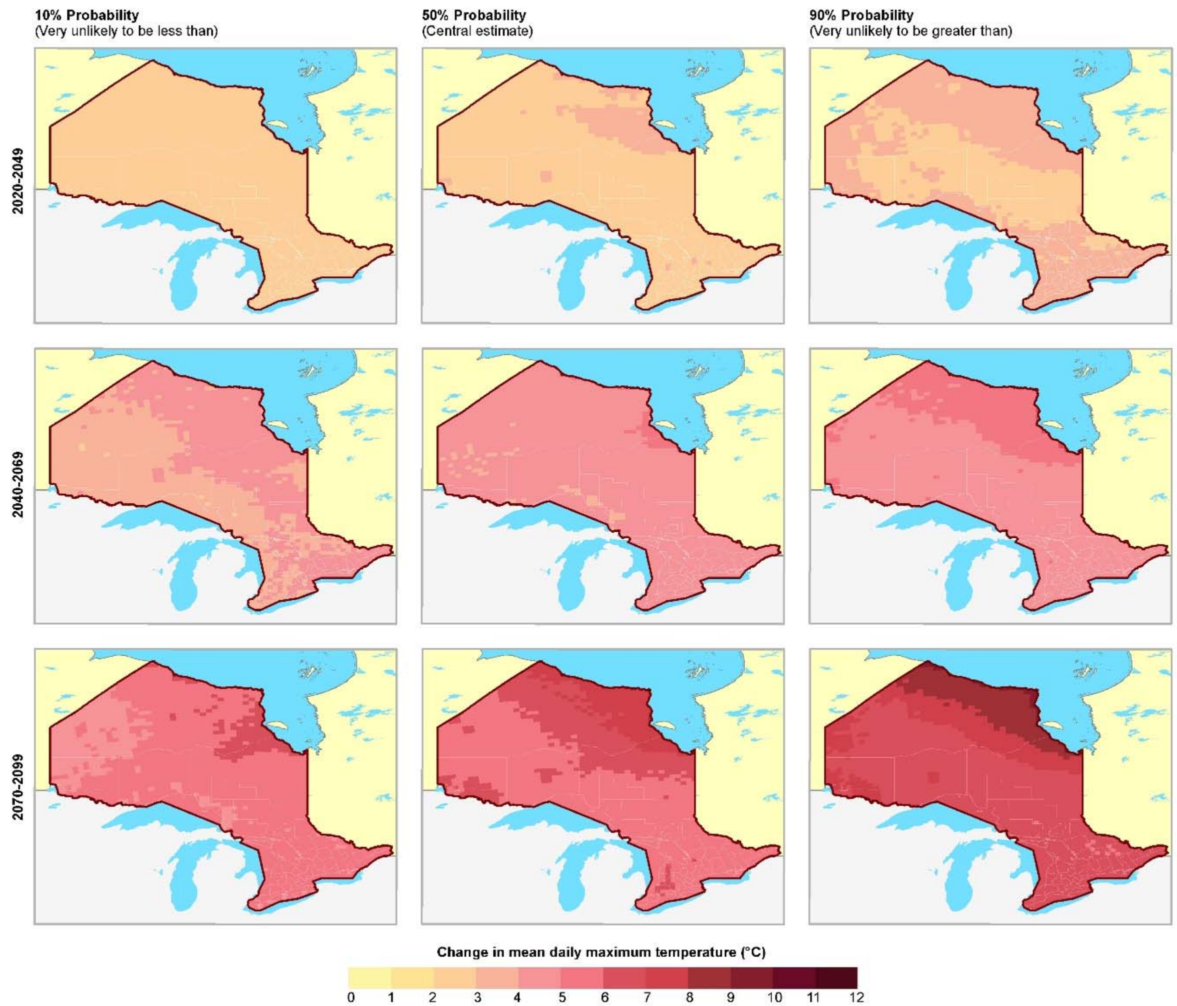
Change … Possible Warming over Ontario

Probabilistic projections of Tmean reveal:

Ontarians are very likely to suffer a **change** of Tmean (30-yr-average daily mean temperature):

➔ by at least **2 ℃** in the forthcoming decades

➔ by at most **10 ℃** to the end of this century



NOTE: We used the IPCC descriptive terms: "very unlikely to be less than", "central estimate", and "very unlikely to be greater than" to interpret our results. Refer to Wang et al. (2014, Journal of Climate) for more details.

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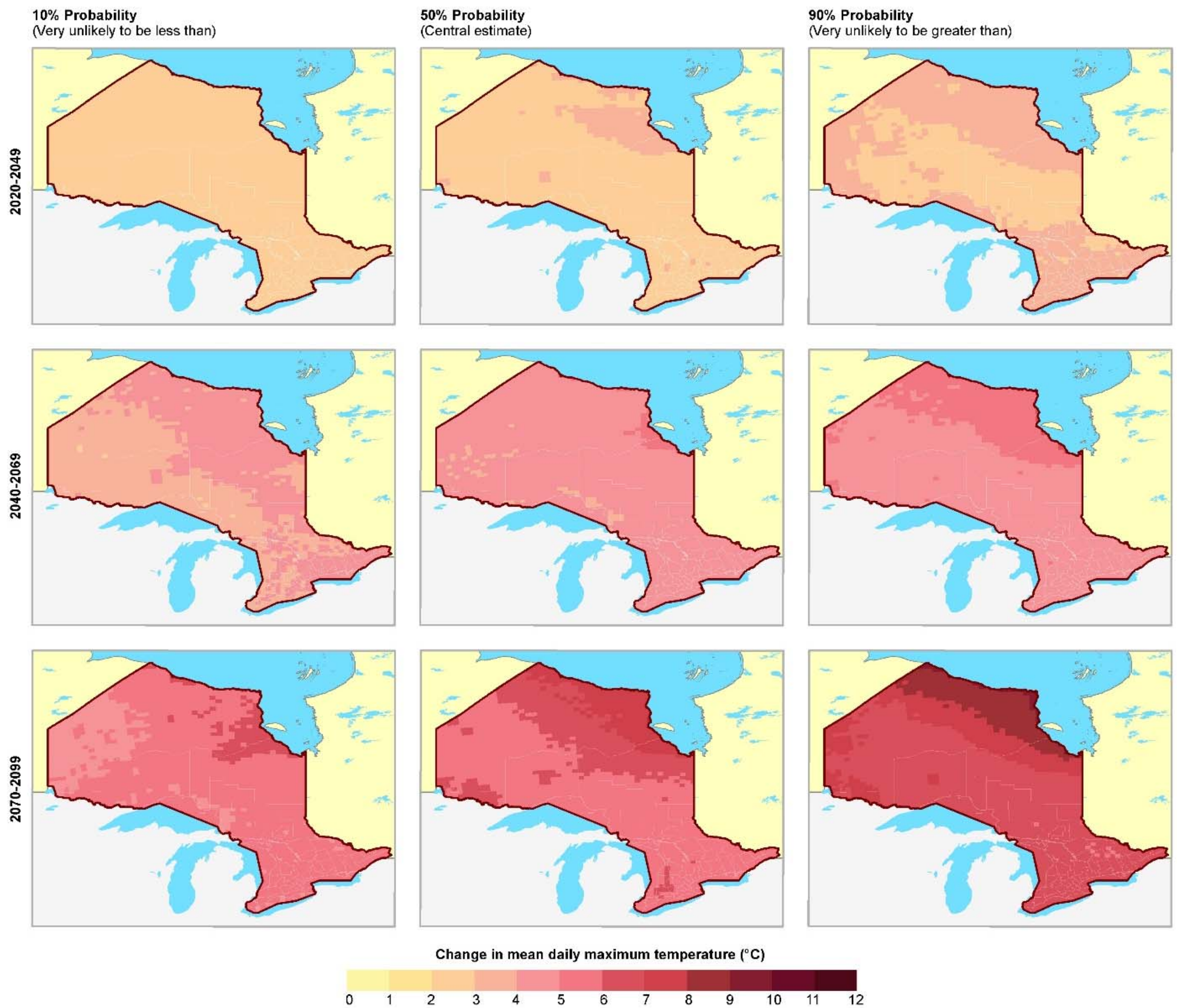
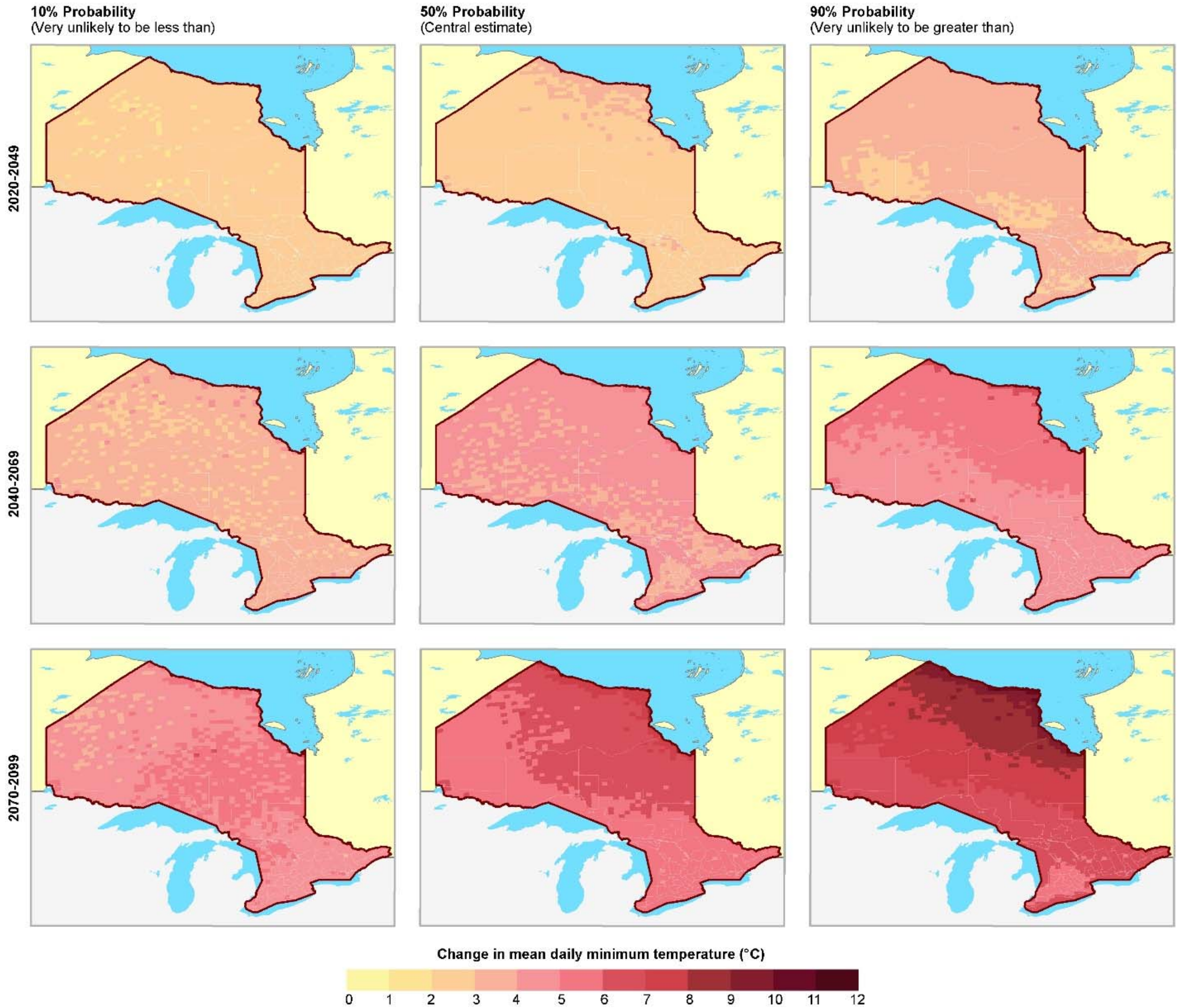
Change … 30-yr-average daily max temperature (Tmax)



Wang et al. (2014, Journal of Climate)

Change … 30-yr-average daily min temperature (Tmin)



Wang et al. (2014, Journal of Climate)

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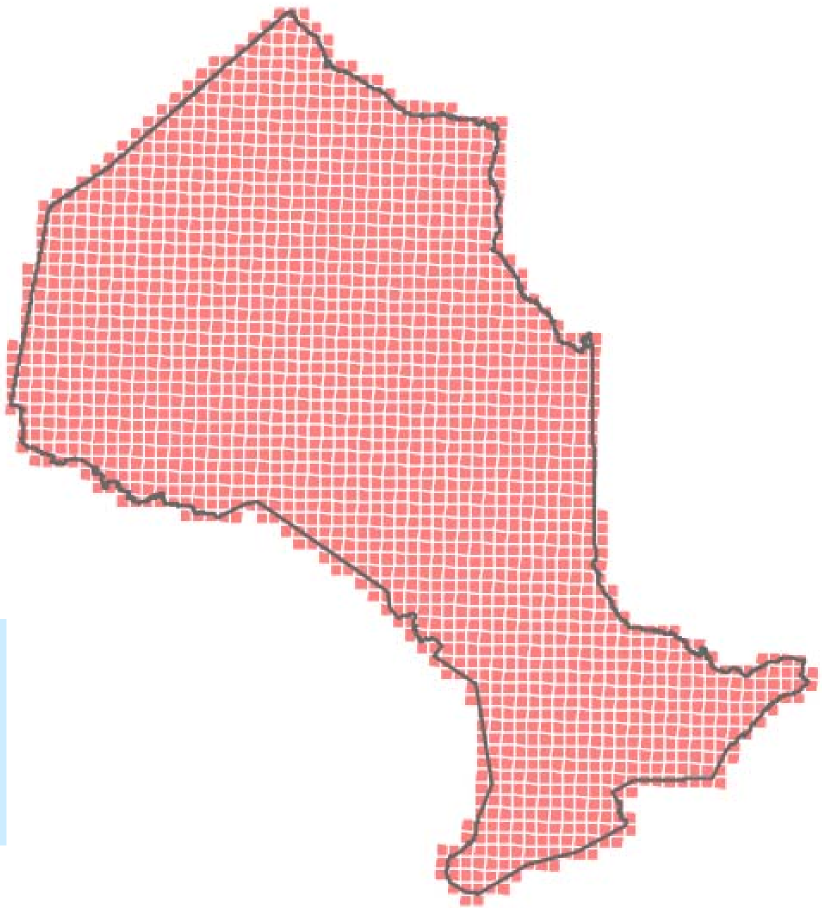
4 Projected IDF Curves

IDF Projection over Ontario

Based on PRECIS ensemble simulations …

➔ projected IDF curves of **almost 2000 grid cells** across Ontario (under current and future climate forcing conditions)



Changes in rainfall intensities in 2030s, 2050s, 2080s (relative to 1960-1990)

NOTE: We follow the guides by Environment Canada, Canadian Standards Association, and Ministry of Transportation of Ontario to develop IDF curves, please refer to Wang et al. (2014, Journal of Geophysical Research - Atmospheres) for more details.

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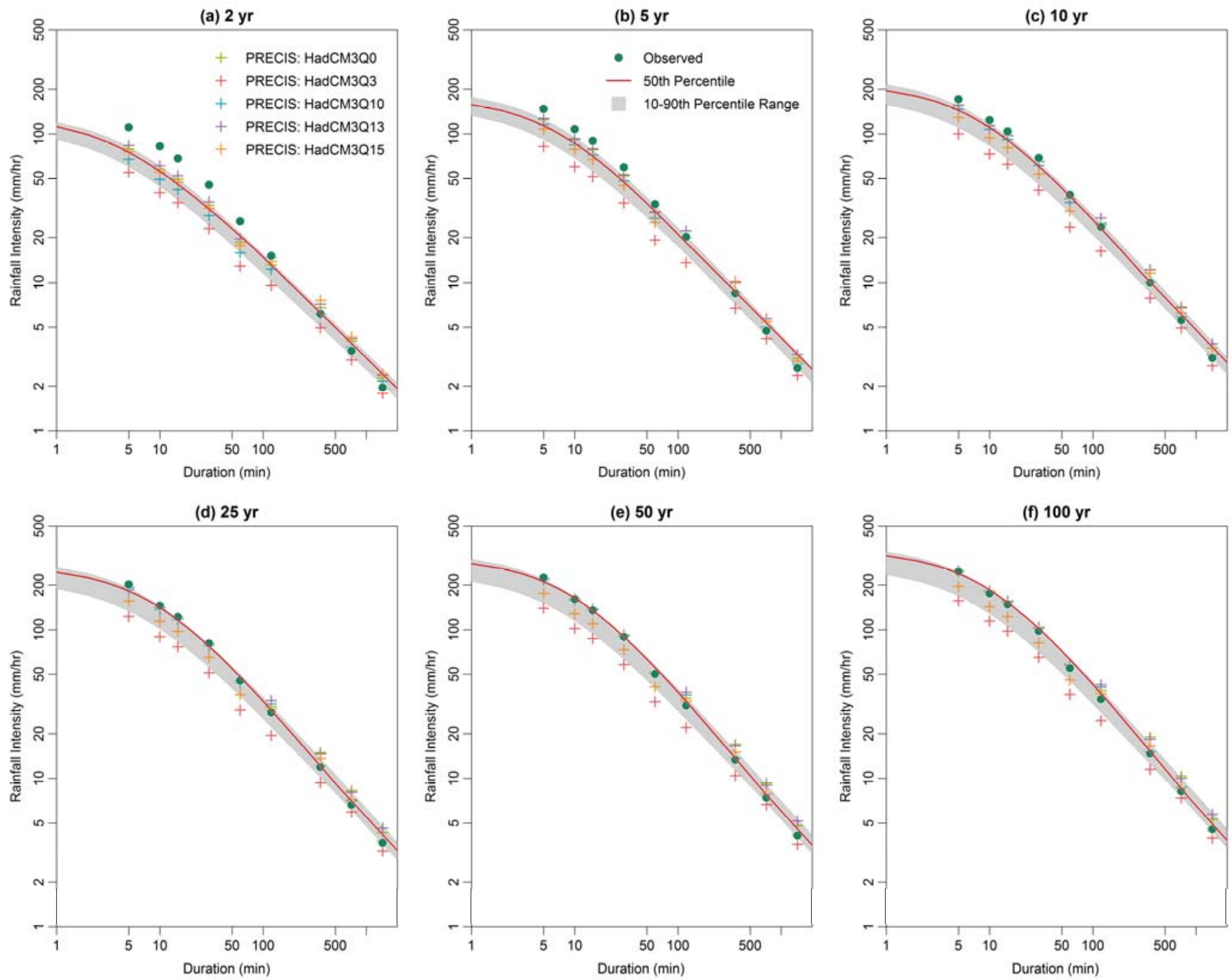
Validation … for City of Toronto



Validation of rainfall intensity
in 1960-1990 (Wang et al. 2014)

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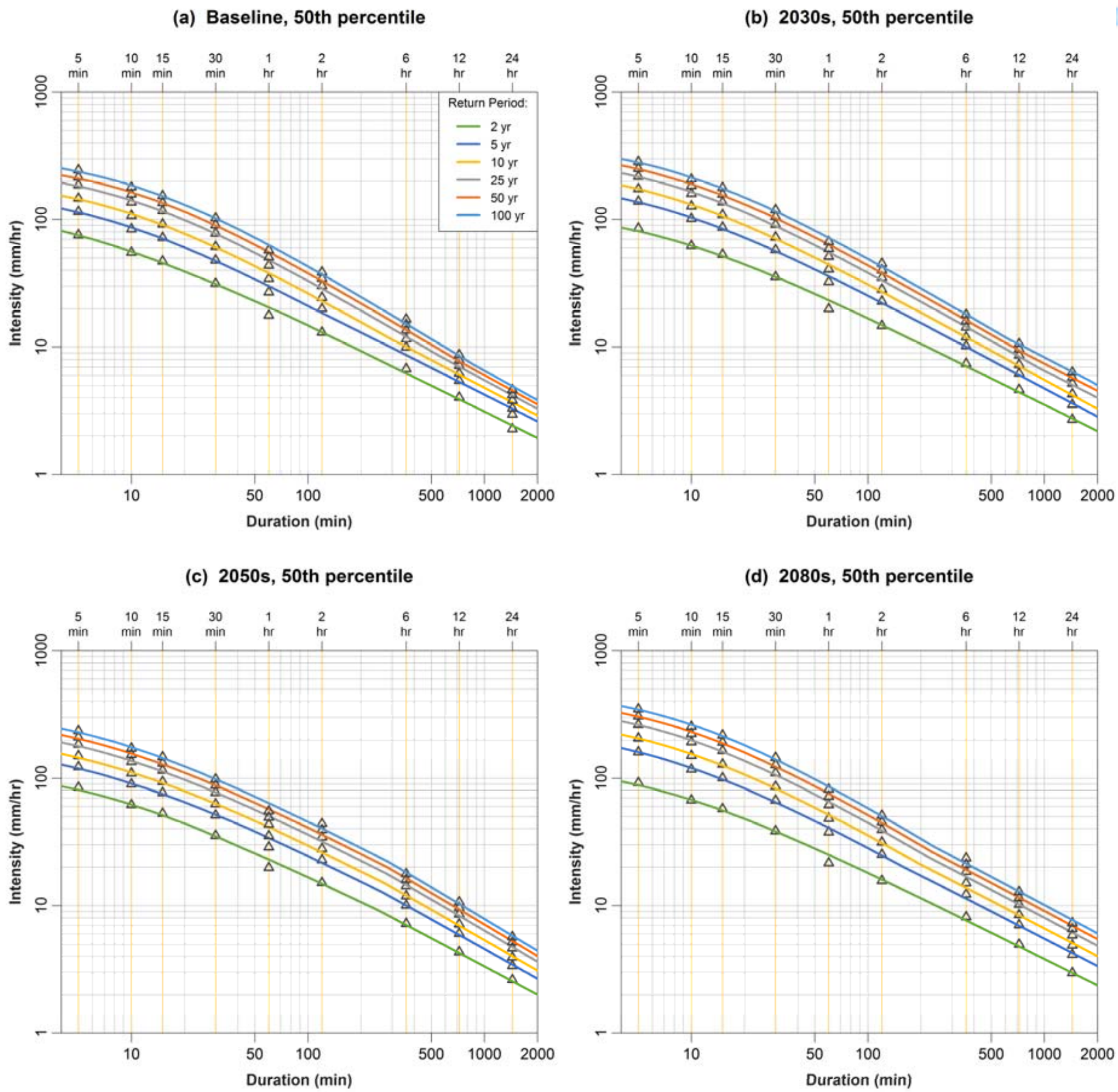
Projection … IDF Curves for City of Toronto

1960-1990

2030s



2050s

2080s

Wang et al. (2014, Journal of Geophysical Research - Atmospheres)

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Projection … Changes of IDF Curves in Future Years

City of Toronto

Duration

Return Period		5 min	10 min	15 min	30 min	1 hr	2 hr	6 hr	12 hr	24 hr
2 yr	2030s:	-0.2%	5.9%	8.7%	11.9%	13.2%	13.2%	11.7%	9.8%	9.1%
	2050s:	13.4%	14.8%	15.2%	14.9%	15.2%	17.6%	18.5%	17.5%	12.4%
	2080s:	18.3%	23.1%	25.4%	28.1%	29.3%	29.4%	28.4%	27.5%	26.6%
5 yr	2030s:	8.7%	12.7%	14.3%	15.8%	15.5%	14.1%	10.7%	11.7%	15.6%
	2050s:	18.1%	18.4%	17.7%	16.0%	13.7%	11.0%	13.2%	16.5%	19.6%
	2080s:	35.4%	36.9%	37.6%	36.6%	35.1%	36.6%	39.0%	38.7%	38.3%
10 yr	2030s:	12.8%	15.2%	16.4%	17.0%	16.2%	14.3%	10.3%	15.6%	16.1%
	2050s:	20.0%	19.4%	18.7%	16.9%	14.4%	11.4%	12.2%	16.3%	20.5%
	2080s:	41.4%	40.4%	39.1%	37.1%	39.5%	42.0%	42.8%	43.2%	43.5%
25 yr	2030s:	14.9%	15.9%	16.4%	17.0%	16.7%	14.3%	11.1%	15.0%	14.3%
	2050s:	20.9%	20.3%	19.6%	17.6%	14.9%	11.7%	11.3%	15.8%	20.8%
	2080s:	43.7%	41.1%	39.6%	40.8%	44.1%	45.1%	46.2%	46.9%	47.8%
50 yr	2030s:	15.9%	15.5%	16.1%	16.6%	16.6%	14.4%	11.9%	14.5%	13.6%
	2050s:	21.0%	20.7%	20.0%	18.2%	15.4%	11.9%	10.9%	15.8%	20.8%
	2080s:	44.3%	41.5%	39.9%	43.3%	46.3%	46.8%	48.1%	49.1%	49.9%
100 yr	2030s:	16.5%	15.8%	15.8%	16.3%	16.3%	14.4%	12.6%	13.8%	12.8%
	2050s:	21.4%	21.0%	20.4%	18.4%	15.5%	12.0%	10.6%	15.7%	21.3%
	2080s:	44.4%	41.7%	41.2%	45.2%	47.7%	48.2%	49.6%	50.7%	51.7%

Change at 50th percentile: -5 0 5 10 15 20 25 30 35 40 45 50 55 60 (%)

Wang et al. (2014, Journal of Geophysical Research - Atmospheres)

Projection … Increase in Rainfall Intensity

Results for City of Toronto suggest:

Intensities of rainfall extreme events (in various durations with different return periods) ➔ are likely to increase over time:

- [11, 22]% in 2050s
- [25, 50]% in 2080s

For entire Province:

Severe storms with high flooding risk (i.e., 50-yr and 100-yr events) ➔ are likely to increase:

- [7 to 18]% in 2050s
- [19 to 43]% in 2080s

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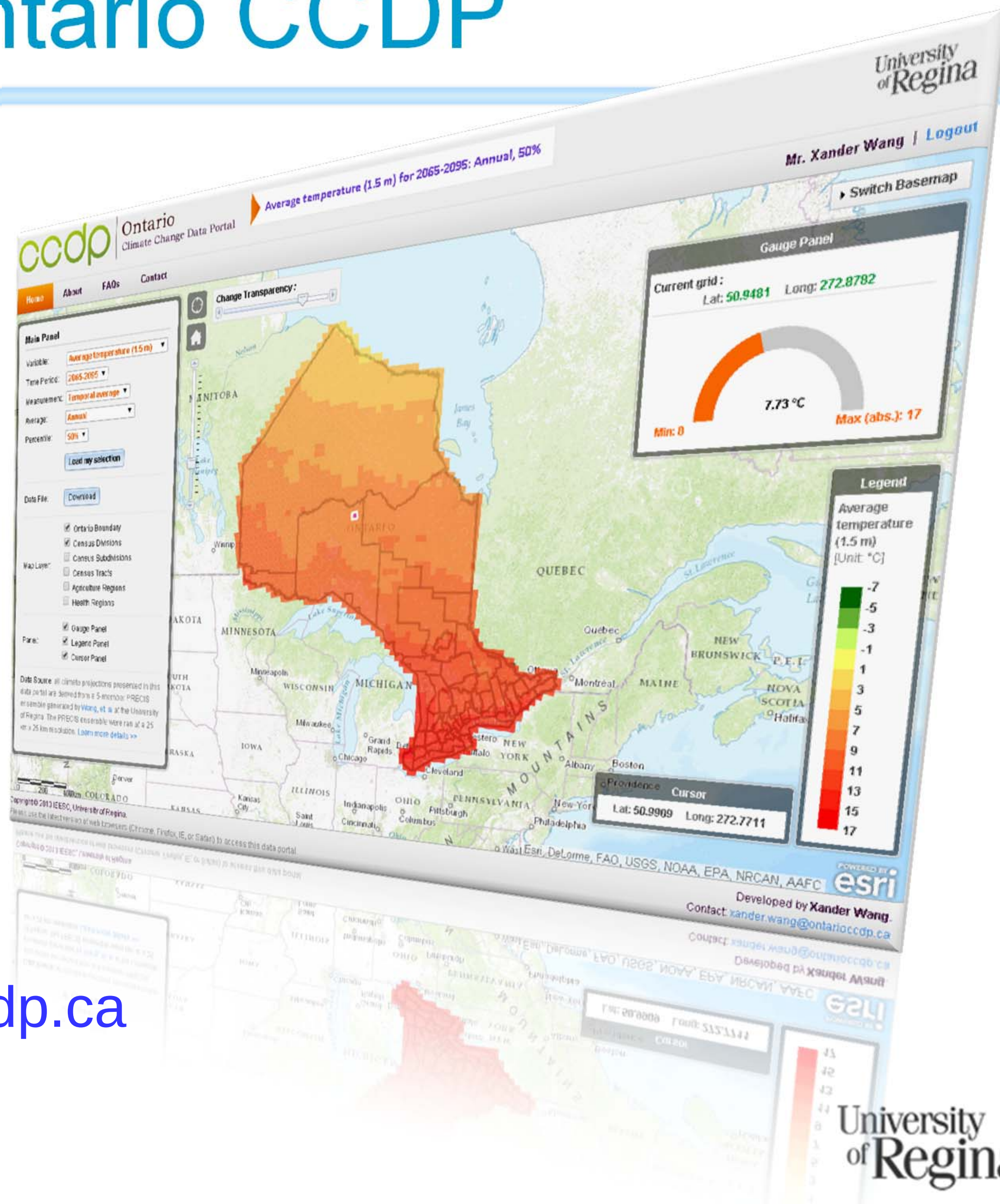
5 Ontario Climate Change Data Portal

Ontario CCDP

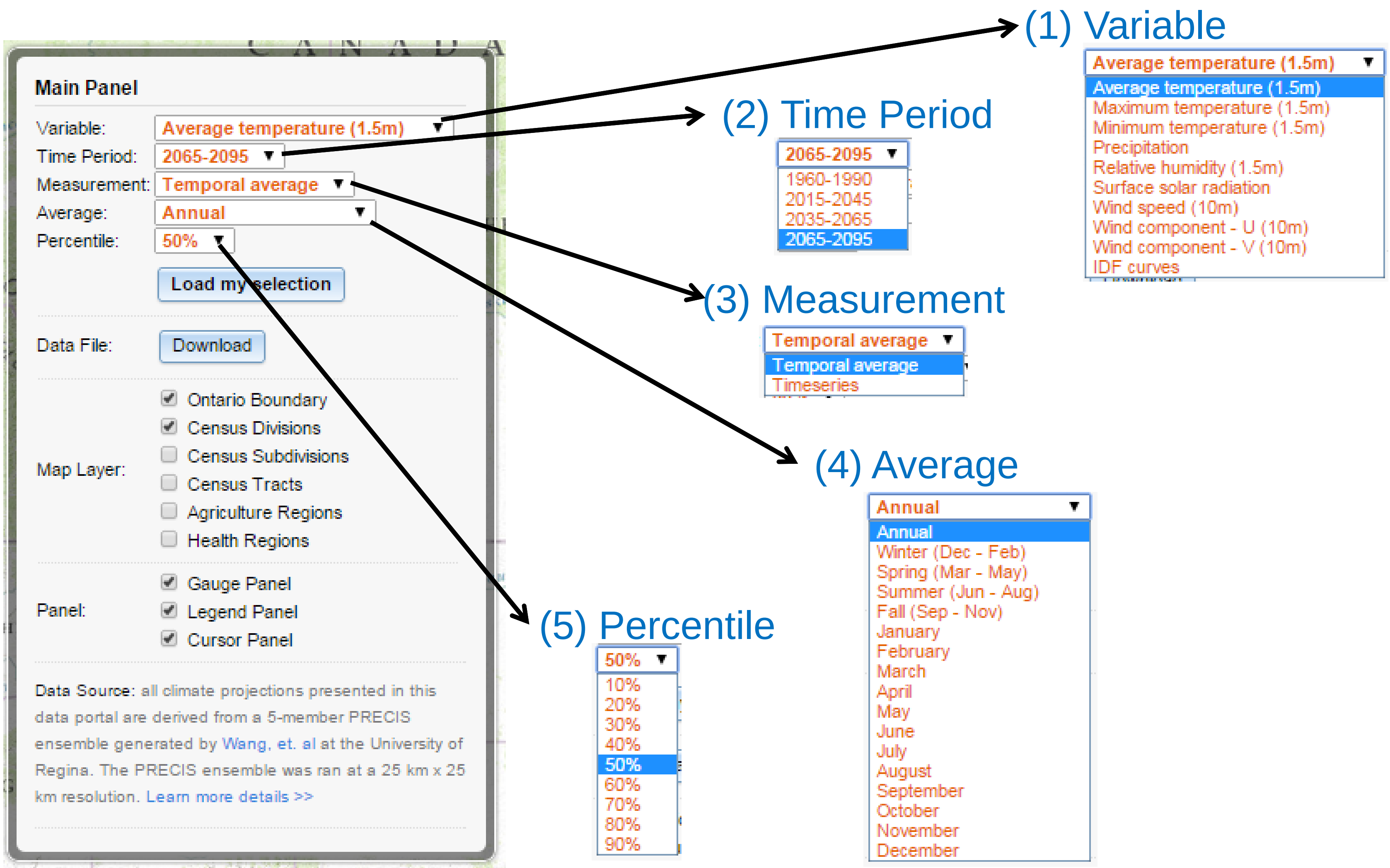
Ontario Climate Change Data Portal (CCDP) was launched in early 2014

➔ to ensure easy access to refined high-resolution regional climate data.



Available at:
http://ontarioccdp.ca

Downloading Data from Main Panel



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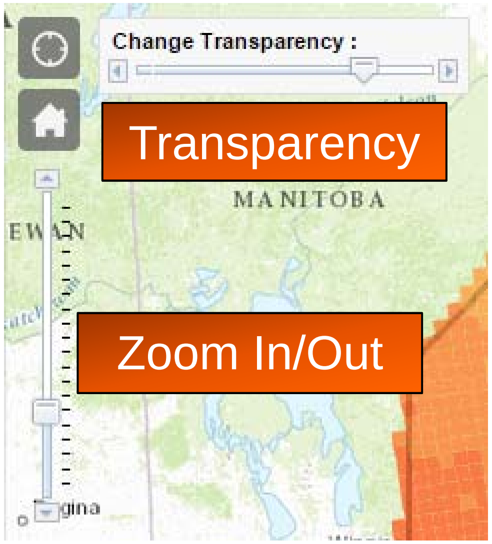
Auxiliary Functions

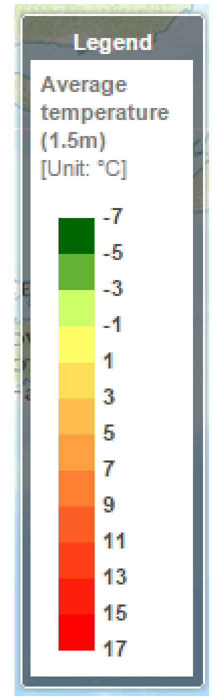
Transparency

Zoom In/Out

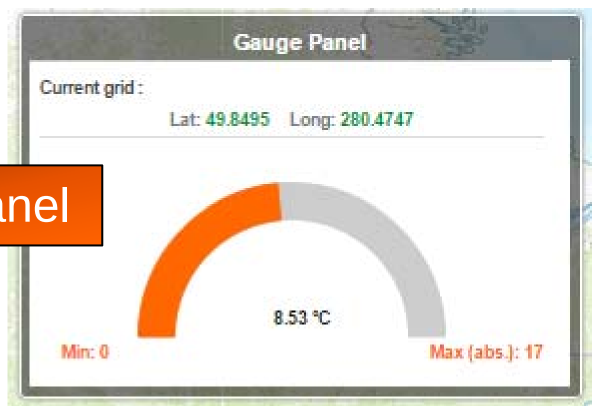


Basemap

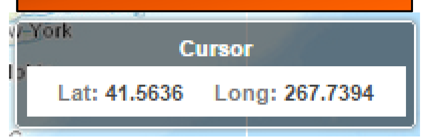
Legend



Gauge Panel



Cursor Locator



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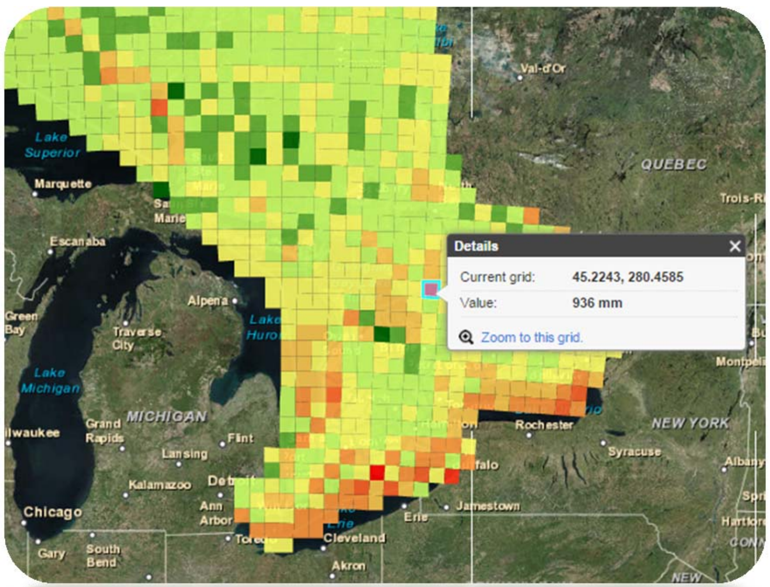
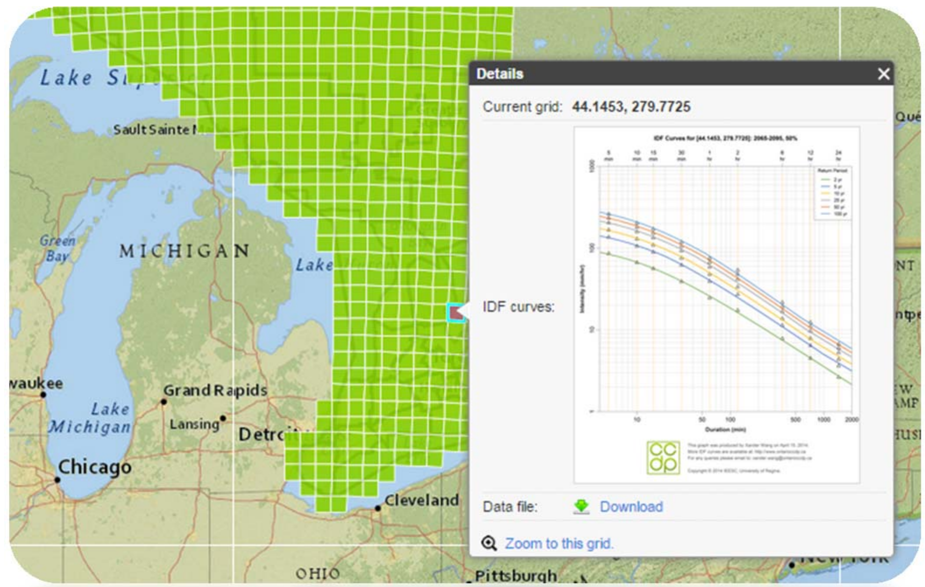
Supporting Impact Assessment

Ontario CCDP …

- **provide** more than 1,200 gridded maps …
- **Inform** spatial patterns of T and P
- **4 Terabytes** of data (of time series with daily and hourly time steps)
- **Projected** IDF curves in future (at almost 2000 grid cells)





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Usage Statistics

Since its initial launch in January 2014, Ontario CCDP **(as of Nov 26, 2014)**

- has received about **15,000** downloading requests
- from over **60** registered users (academia, municipal and provincial agencies, non-government agencies, private sectors)

RWTH Aachen University (Germany)

University of Michigan (USA)

OCCIAR

City of London

QPC Consulting

SENES Consultants

University of Guelph

Dillon Consulting

University of Waterloo

Queen's University

Town of Oakville

York University

Green Analytics

Trent University

University of Toronto

Western University

YPDT-CAMC

OMAFRA

City of Waterloo

MMM Group

Great Lakes and St. Lawrence Cities Initiative

Ontario Climate Consortium

Ontario Ministry of Agriculture and Food

Muskoka Watershed Council

Drainage Investment Group

Ministry of Transportation of Ontario

Town of BWG / Municipal Services Board

S.F. Pope Sustainability Consulting

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Thank you very much

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Institute for Energy, Environment and Sustainable Communities

6 Bayesian Model Formulation

Step 1. Likelihoods

1) Likelihoods for existing data x_0, x_i, y_i:

$$x_0 \sim N(\mu, \lambda_0^{-1}) = \frac{\sqrt{\lambda_0}}{\sqrt{2\pi}} \exp\left[-\frac{\lambda_0 (x_0 - \mu)^2}{2}\right]$$

$$x_i \sim N(\mu, \lambda_i^{-1}) = \frac{\sqrt{\lambda_i}}{\sqrt{2\pi}} \exp\left[-\frac{\lambda_i (x_i - \mu)^2}{2}\right]$$

$$y_i \sim N[\nu + \beta(x_i - \mu), (\theta\lambda_i)^{-1}] = \frac{\sqrt{\theta\lambda_i}}{\sqrt{2\pi}} \exp\left\{-\frac{\theta\lambda_i [y_i - \nu - \beta(x_i - \mu)]^2}{2}\right\}$$

Step 2. Prior Distributions

2) Prior distributions for parameters μ, ν, β, θ, λ_0, λ_1, $\ldots$, λ_N:

Assume uniform prior densities on the real line for μ and ν, uniform prior distribution on $[-1, 1]$ for β, respectively. For the remaining parameters, we assume gamma distributions as follows:

$$\lambda_0 \sim \text{Gamma}(m,n) = \frac{n^m}{\Gamma(m)} \lambda_0^{m-1} e^{-n\lambda_0}$$

$$\lambda_i \sim \text{Gamma}(a,b) = \frac{b^a}{\Gamma(a)} \lambda_i^{a-1} e^{-b\lambda_i}, \quad i = 1, \ldots, N$$

$$\theta \sim \text{Gamma}(c,d) = \frac{d^c}{\Gamma(c)} \theta^{c-1} e^{-d\theta}$$

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Step 3. Posterior Distribution

3) Posterior is given by, up to a normalizing constant

$$p(\Theta \mid D) = p(\mu, \nu, \beta, \theta, \lambda_0, \lambda_1, \ldots, \lambda_N | x_0, x_1, \ldots, x_N, y_1, \ldots, y_N)$$

$$\propto p(\mu) \cdot p(\nu) \cdot p(\beta) \cdot p(\theta) \cdot p(\lambda_0) \cdot \prod_{i=1}^{N} p(\lambda_i) \cdot p(x_0|\mu, \lambda_0) \cdot \prod_{i=1}^{N} p(x_i|\mu, \lambda_i) \cdot \prod_{i=1}^{N} p(y_i|\upsilon, \theta, \lambda_i, \beta, x_i, \mu)$$

$$\propto \prod_{i=1}^{N} \left[\lambda_i^{a-1} e^{-b\lambda_i} \cdot \lambda_i \sqrt{\theta} \exp\left(-\frac{\lambda_i}{2} \{(x_i - \mu)^2 + \theta[y_i - \nu - \beta(x_i - \mu)]^2\} \right) \right]$$

$$\cdot \theta^{c-1} e^{-d\theta} \cdot \lambda_0^{m-1} e^{-n\lambda_0} \cdot \sqrt{\lambda_0} \exp\left[-\frac{\lambda_0}{2} (x_0 - \mu)^2 \right]$$

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Step 4. Full Conditional Distributions

Thus, we can obtain full conditional distributions for each parameter by ignoring all terms that are constant with respect to the parameter:

Full conditional for θ:

$$p(\theta \mid \mu, \nu, \beta, \lambda_0, \lambda_1, \ldots, \lambda_N, x_0, x_1, \ldots, x_N, y_1, \ldots, y_N)$$

$$\propto \prod_{i=1}^{N} \left[\sqrt{\theta} \exp\left\{ -\frac{1}{2} \theta \lambda_i [y_i - \nu - \beta(x_i - \mu)]^2 \right\} \right] \theta^{c-1} e^{-d\theta}$$

$$\propto \theta^{(c+N/2)-1} \exp\left(-\theta \left\{ d + \frac{1}{2} \sum_{i=1}^{N} \lambda_i [y_i - \nu - \beta(x_i - \mu)]^2 \right\} \right)$$

$$\propto \text{Gamma}\left\{ c + \frac{N}{2}, d + \frac{1}{2} \sum_{i=1}^{N} \lambda_i [y_i - \nu - \beta(x_i - \mu)]^2 \right\}$$

Step 4. Full Conditional Distributions

Full conditional for β:

$$p(\beta \mid \mu, \nu, \theta, \lambda_0, \lambda_1, \ldots, \lambda_N, x_0, x_1, \ldots, x_N, y_1, \ldots, y_N)$$

$$\propto \prod_{i=1}^{N} \exp\left\{-\frac{1}{2}\theta\lambda_i[y_i - \nu - \beta(x_i - \mu)]^2\right\}$$

$$\propto \exp\left\{-\frac{1}{2}\theta\left[\beta^2 \sum_{i=1}^{N} \lambda_i(x_i - \mu)^2 - 2\beta \sum_{i=1}^{N} \lambda_i(y_i - \nu)(x_i - \mu)\right]\right\}$$

$$\propto \exp\left\{-\frac{1}{2}\theta \sum_{i=1}^{N} \lambda_i(x_i - \mu)^2 \left[\beta - \frac{\sum_{i=1}^{N} \lambda_i(y_i - \nu)(x_i - \mu)}{\sum_{i=1}^{N} \lambda_i(x_i - \mu)^2}\right]^2\right\}$$

$$\propto N\left\{\frac{\sum_{i=1}^{N} \lambda_i(y_i - \nu)(x_i - \mu)}{\sum_{i=1}^{N} \lambda_i(x_i - \mu)^2}, \left[\theta \sum_{i=1}^{N} \lambda_i(x_i - \mu)^2\right]^{-1}\right\}$$

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Step 4. Full Conditional Distributions

Full conditional for λ_0:

$$p(\lambda_0 \mid \mu, \nu, \beta, \theta, \lambda_1, \ldots, \lambda_N, x_0, x_1, \ldots, x_N, y_1, \ldots, y_N)$$

$$\propto (\lambda_0^{m-1} e^{-n\lambda_0}) \sqrt{\lambda_0} \exp\left[-\frac{\lambda_0}{2}(x_0 - \mu)^2\right]$$

$$\propto \lambda_0^{(m+1/2)-1} \exp\left\{-\lambda_0\left[n + \frac{1}{2}(x_0 - \mu)^2\right]\right\}$$

$$\propto \text{Gamma}\left[m + \frac{1}{2}, n + \frac{1}{2}(x_0 - \mu)^2\right]$$

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Step 4. Full Conditional Distributions

Full conditional for λ_i, $i = 1, \ldots, N$:

$$p(\lambda_i \mid \mu, \nu, \beta, \theta, \lambda_0, \lambda_1, \ldots, \lambda_{i-1}, \lambda_{i+1}, \ldots, \lambda_N, x_0, x_1, \ldots, x_N, y_1, \ldots, y_N)$$

$$\propto (\lambda_i^{a-1} e^{-b\lambda_i}) \lambda_i \sqrt{\theta} \exp\left(-\frac{\lambda_i}{2} \{ (x_i - \mu)^2 + \theta [y_i - \nu - \beta(x_i - \mu)]^2 \} \right)$$

$$\propto \lambda_i^{(a+1)-1} \exp\left[-\lambda_i \left(b + \frac{1}{2} \{ (x_i - \mu)^2 + \theta [y_i - \nu - \beta(x_i - \mu)]^2 \} \right) \right]$$

$$\propto \text{Gamma}\left(a + 1, b + \frac{1}{2} \{ (x_i - \mu)^2 + \theta [y_i - \nu - \beta(x_i - \mu)]^2 \} \right)$$

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Step 4. Full Conditional Distributions

Full conditional for μ:

$$p(\mu \mid \nu, \beta, \theta, \lambda_0, \lambda_1, \ldots, \lambda_N, x_0, x_1, \ldots, x_N, y_1, \ldots, y_N)$$

$$\propto \prod_{i=1}^{N} \left[\exp\left(-\frac{\lambda_i}{2} \{ (x_i - \mu)^2 + \theta [y_i - \nu - \beta(x_i - \mu)]^2 \} \right) \right] \exp\left[-\frac{\lambda_0}{2} (x_0 - \mu)^2 \right]$$

$$\propto \exp\left[\sum_{i=1}^{N} \left(-\frac{\lambda_i}{2} \{ (x_i - \mu)^2 + \theta [y_i - \nu - \beta(x_i - \mu)]^2 \} \right) - \frac{\lambda_0}{2} (x_0 - \mu)^2 \right]$$

$$\propto \exp\left[-\frac{1}{2} \left(\left[\lambda_0 + \sum_{i=1}^{N} \lambda_i (1 + \theta\beta^2) \right] \mu^2 - 2\mu \left\{ \sum_{i=1}^{N} [\lambda_i x_i - \theta\beta\lambda_i (y_i - \nu - \beta x_i)] + \lambda_0 x_0 \right\} \right) \right]$$

$$\propto \exp\left(-\frac{1}{2} \left[\lambda_0 + \sum_{i=1}^{N} \lambda_i (1 + \theta\beta^2) \right] \left\{ \mu - \frac{\sum_{i=1}^{N} [\lambda_i x_i - \theta\beta\lambda_i (y_i - \nu - \beta x_i)] + \lambda_0 x_0}{\lambda_0 + \sum_{i=1}^{N} \lambda_i (1 + \theta\beta^2)} \right\}^2 \right)$$

$$\propto N \left\{ \frac{\sum_{i=1}^{N} [\lambda_i x_i - \theta\beta\lambda_i (y_i - \nu - \beta x_i)] + \lambda_0 x_0}{\lambda_0 + \sum_{i=1}^{N} \lambda_i (1 + \theta\beta^2)}, \left[\lambda_0 + \sum_{i=1}^{N} \lambda_i (1 + \theta\beta^2) \right]^{-1} \right\}$$

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Step 4. Full Conditional Distributions

Full conditional for ν:

$$p(\nu \mid \mu, \beta, \theta, \lambda_0, \lambda_1, \ldots, \lambda_N, x_0, x_1, \ldots, x_N, y_1, \ldots, y_N)$$

$$\propto \prod_{i=1}^{N} \exp\left(-\frac{1}{2}\theta\lambda_i\{\nu - [y_i - \beta(x_i - \mu)]\}^2\right)$$

$$\propto \exp\left(-\frac{1}{2}\theta \sum_{i=1}^{N} \lambda_i\{\nu - [y_i - \beta(x_i - \mu)]\}^2\right)$$

$$\propto \exp\left(-\frac{1}{2}\theta\left\{\sum_{i=1}^{N} \lambda_i \nu^2 - 2\nu \sum_{i=1}^{N} \lambda_i [y_i - \beta(x_i - \mu)]\right\}\right)$$

$$\propto \exp\left(-\frac{1}{2}\left(\theta \sum_{i=1}^{N} \lambda_i\right)\left\{\nu - \frac{\sum_{i=1}^{N} \lambda_i [y_i - \beta(x_i - \mu)]}{\sum_{i=1}^{N} \lambda_i}\right\}^2\right)$$

$$\propto N\left\{\frac{\sum_{i=1}^{N} \lambda_i [y_i - \beta(x_i - \mu)]}{\sum_{i=1}^{N} \lambda_i}, \left(\theta \sum_{i=1}^{N} \lambda_i\right)^{-1}\right\}$$

7 Gibbs-Based MCMC Simulation

Step 1. First guess

Step 1. Pick a starting value for the Markov chain: $(\mu, \nu, \beta, \theta, \lambda_0, \lambda_1, \ldots, \lambda_N)$, say

$$\left(\frac{1}{N}\sum_{i=1}^{N} x_i, \frac{1}{N}\sum_{i=1}^{N} y_i, 0, 0.9, 0.9, 0.7, \ldots, 0.7\right).$$

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Step 2. Update each parameter in turn

(i) Sample a value of θ from its full conditional distribution: $p(\theta \mid \mu, \nu, \beta, \lambda_0, \lambda_1, \ldots, \lambda_N, x_0, x_1, \ldots, x_N, y_1, \ldots, y_N)$, using the most up-to-date values of all the remaining parameters.

(ii) Sample a value of β from its full conditional distribution: $p(\beta \mid \mu, \nu, \theta, \lambda_0, \lambda_1, \ldots, \lambda_N, x_0, x_1, \ldots, x_N, y_1, \ldots, y_N)$, using the most up-to-date values of all the remaining parameters.

(iii) Sample a value of λ_0 from its full conditional distribution: $p(\lambda_0 \mid \mu, \nu, \beta, \theta, \lambda_1, \ldots, \lambda_N, x_0, x_1, \ldots, x_N, y_1, \ldots, y_N)$, using the most up-to-date values of all the remaining parameters.

(iv) Sample a value of λ_i from its full conditional distribution: $p(\lambda_i \mid \mu, \nu, \beta, \theta, \lambda_0, \lambda_1, \ldots, \lambda_{i-1}, \lambda_{i+1}, \ldots, \lambda_N, x_0, x_1, \ldots, x_N, y_1, \ldots, y_N)$, using the most up-to-date values of all the remaining parameters. Repeat for $i = 1, 2, \ldots, N$.

(v) Sample a value of μ from its full conditional distribution: $p(\mu \mid \nu, \beta, \theta, \lambda_0, \lambda_1, \ldots, \lambda_N, x_0, x_1, \ldots, x_N, y_1, \ldots, y_N)$, using the most up-to-date values of all the remaining parameters.

(vi) Sample a value of ν from its full conditional distribution: $p(\nu \mid \mu, \beta, \theta, \lambda_0, \lambda_1, \ldots, \lambda_N, x_0, x_1, \ldots, x_N, y_1, \ldots, y_N)$, using the most up-to-date values of all the remaining parameters.

Step 3. Repeat Step 2 for M-1 times

We run the Gibbs sampling for a total of 260 000 iterations for all parameters at each 25-km grid specified by the PRECIS model. The first 10 000 iterations are treated as random drawings in the burn-in period during which the MCMC simulation forgets about the initial values for all parameters. After that, we save only one iteration result from every 50. Thus, we can get a total of 5000 values for each parameter, representing a sample from its posterior distribution.

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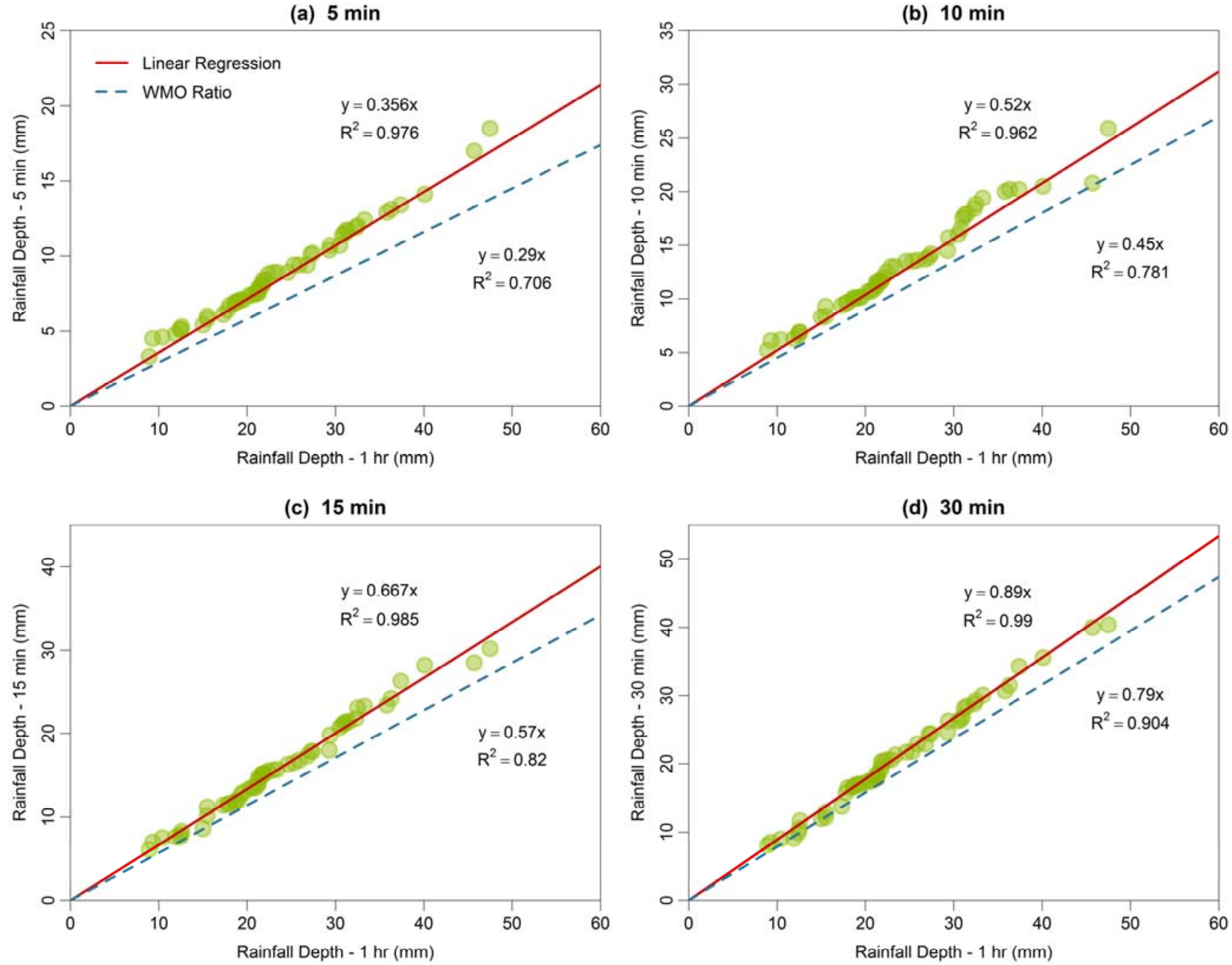
8 Others

Sub-hour precipitation extremes

Linear regression between sub-hour (5, 10, 15, and 30 min) extremes and 1-hour ones.



Wang et al. (2014, Journal of Geophysical Research - Atmospheres)

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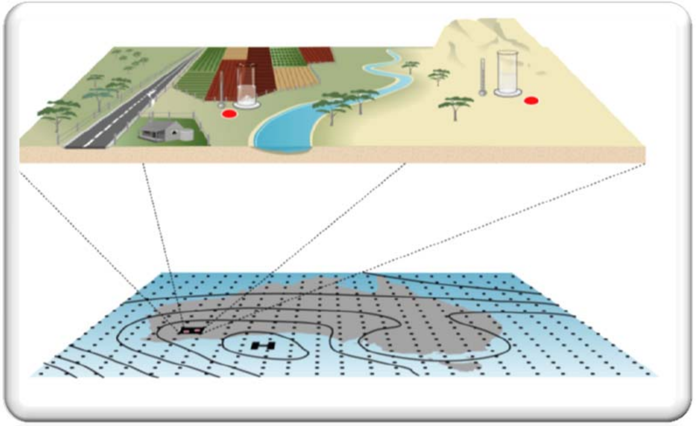
Necessity of Regional Climate Modeling

- Regionalization techniques are developed
  - to allow fine scale information to be derived from GCM output
  - to provide high-resolution climate projections under different emission scenarios
  - to drive impacts models (e.g. hydrologic and crop ones) and thus to assess the effects of climate change on local communities



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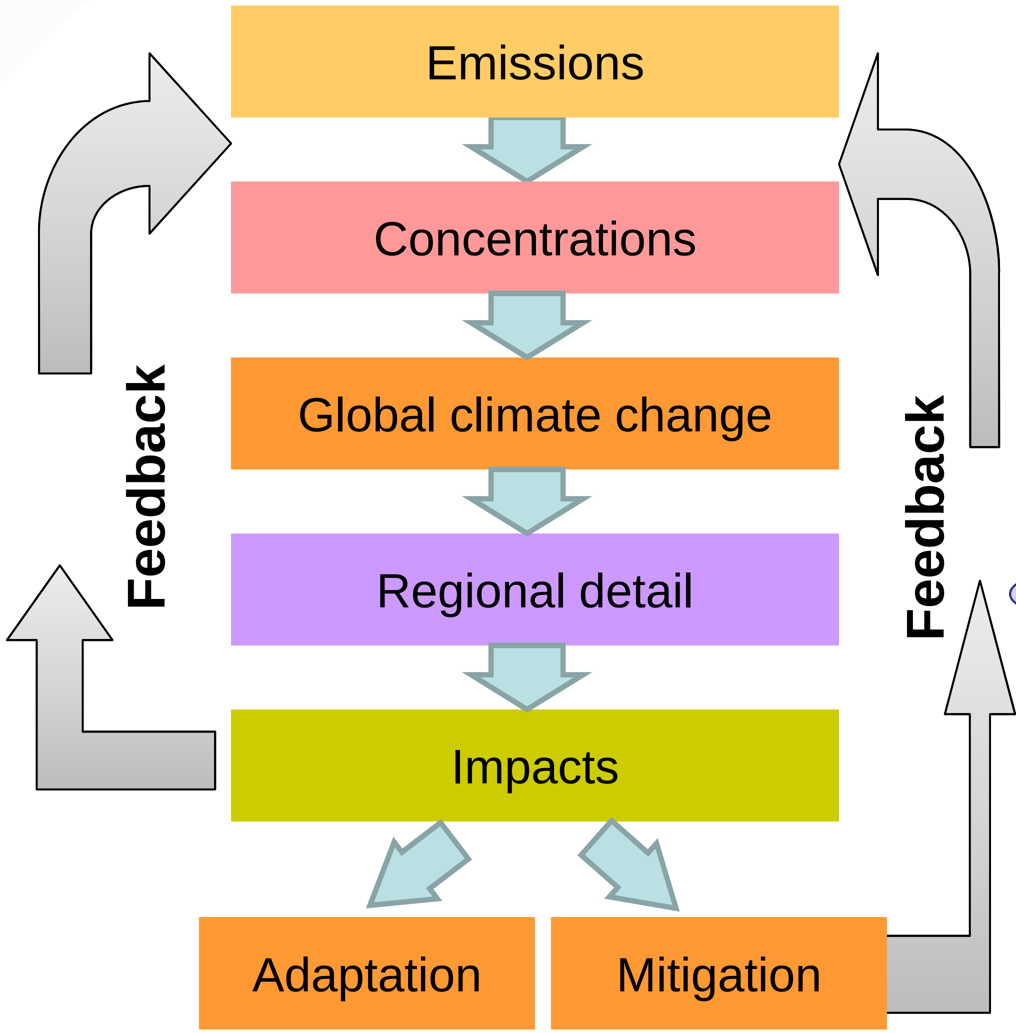
Flowchart of Impacts Studies



- ➔ Scenarios from population, energy, economics models
- ➔ Carbon cycle and chemistry models
- ➔ Coupled global climate models (temperature, rainfall, sea level, etc.)
- ➔ Regional climate models and downscaling techniques
- ➔ Impacts models

Our Focus

- ➔ Decision making

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Assessing Climate Change Impact on Carbon Cycles of Ontario's Far North (OFN) Ecosystems

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Nov 27-28, 2014

MOECC "Best in Science" 3rd Annual Symposium on Climate Change Modeling and Impact Assessment

Geography & Planning
UNIVERSITY OF TORONTO

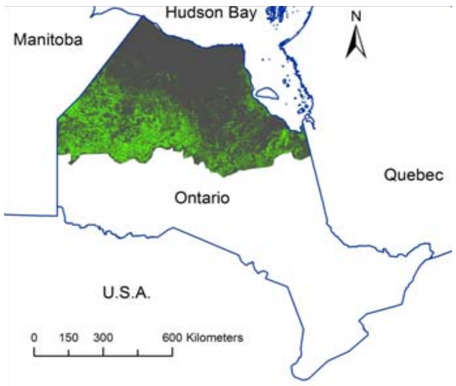
Ontario Ministry of Natural Resources and Forestry

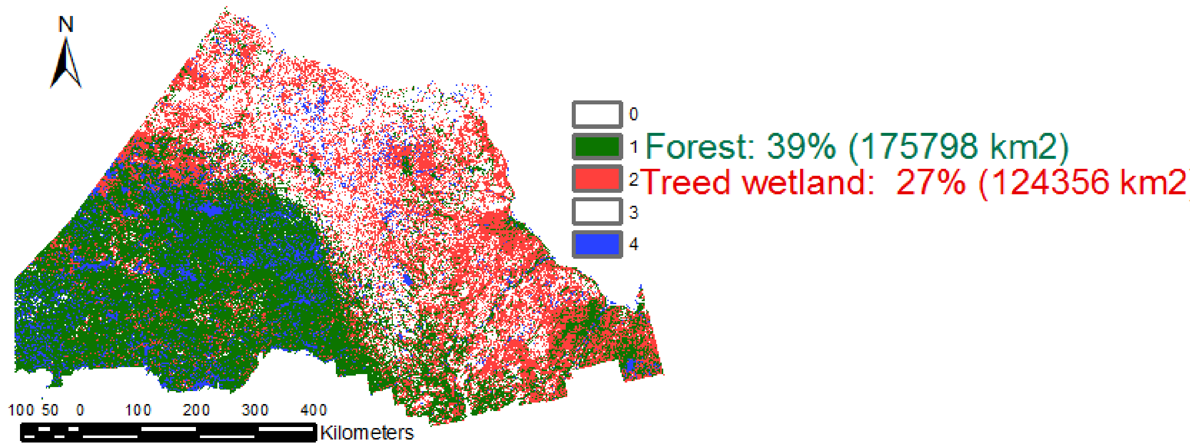
Ontario Ministry of the Environment and Climate Change

Overview

- OFN forests (MNRF)
  - ✓ To estimate the past, present, and future C stock and balance of OFN forests under the projected climate change
  - ✓ To study the relative contribution of CO_2 fertilization, forest age, climate and climate-induced fire on the future C dynamics of OFN forest
- OFN forests and treed wetlands (MOECC)
  - ✓ Application of 3D forest carbon (C) model to investigate the influence of hydrological processes on the C and water fluxes over the two 10 km × 10 km areas at 30 m resolution
  - ✓ Studying long-term C cycle from 1900 up to 2100 over the OFN forests and treed wetlands

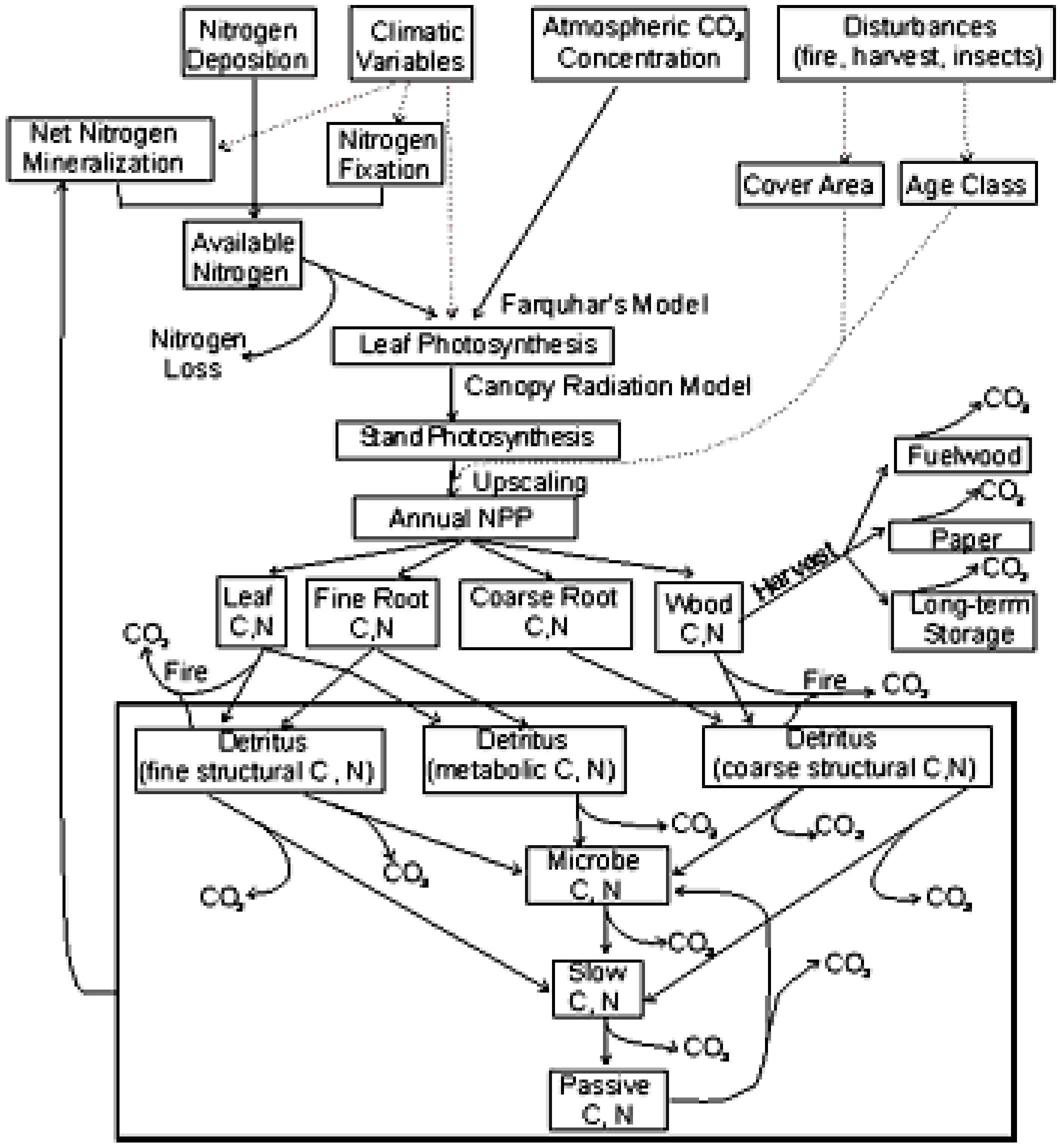
OFN forests and treed wetlands



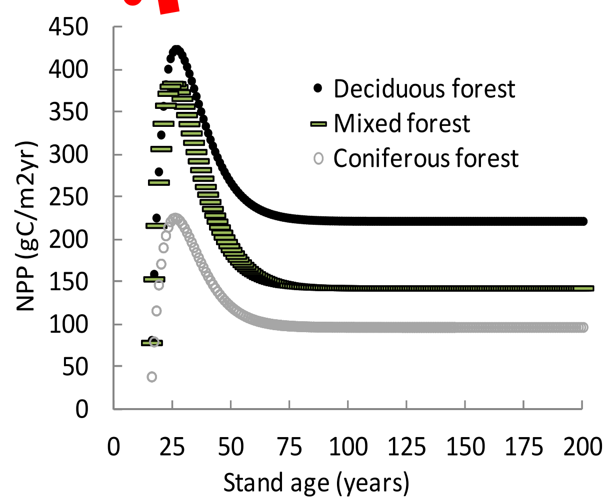


- The OFN represents 42% (453,788 km2) of Ontario's land mass
- OFN consists one of the world's largest remaining tracts of undisturbed natural boreal forest, the world's third largest area of wetland and the most southerly area of tundra
- OFN forest: characteristic of northern boreal forests with black spruce (dominant), white spruce, jack pine, trembling aspen, tamarack, white birch
- OFN forest is one of the least studied forest ecosystems in Canada
- The lowest aboveground biomass of any forested terrestrial ecozone in Canada
- Wetland ecosystems cover 50% of the area
- OFN non-forested bogs and fens store approximately 36 Gt C, is the largest peatland complex in North America

Integrated Terrestrial Ecosystem Carbon Model (InTEC)

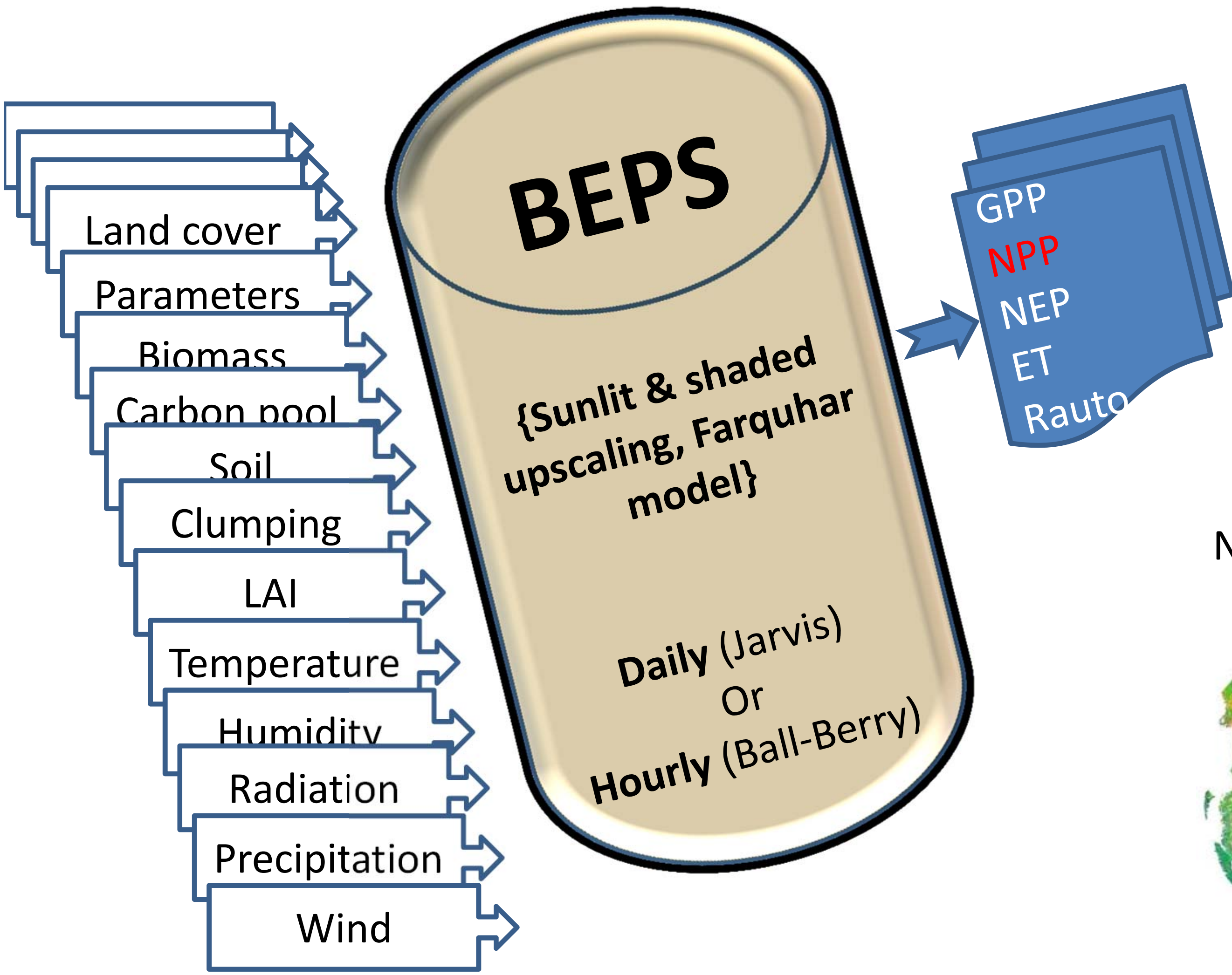


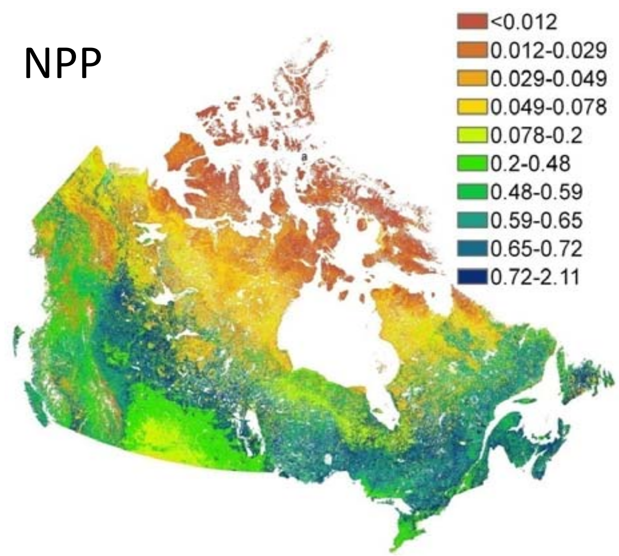
- Remote sensing: LAI, land cover, fire scars
- Forest age map
- Fire polygons
- T & precipitation
- Soil texture
- N deposition
- Soil C pools
- C simulation based on:
  - Farquhar
  - CENTURY
  - Townsend N mineralization
  - **NPP**-age curve



Chen et al. (2003), *Tellus*

Boreal ecosystem productivity simulator (BEPS)



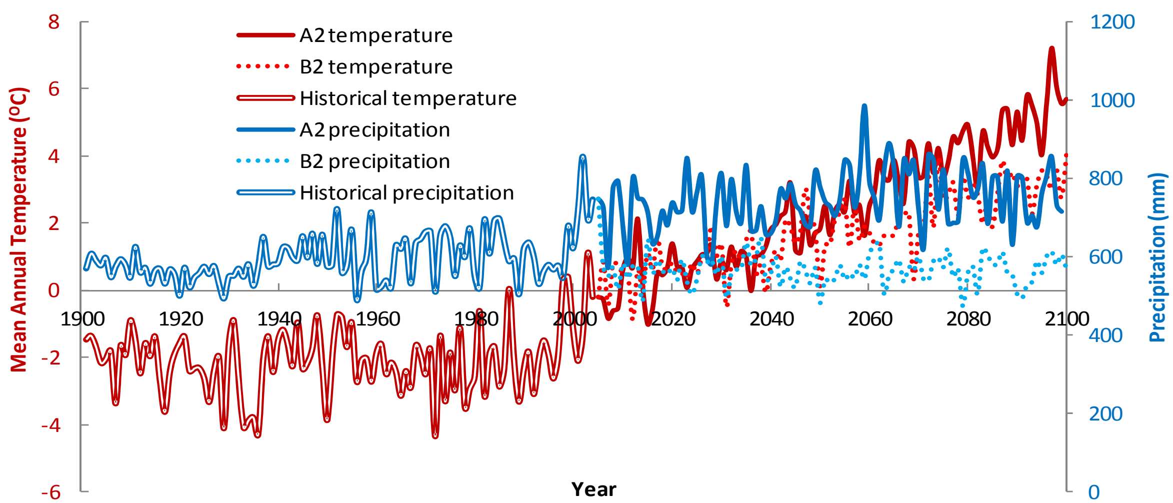


InTEC reference NPP is from BEPS estimate

Liu et al. 1997. RSE, Gonsamo et al. 2013. JGR

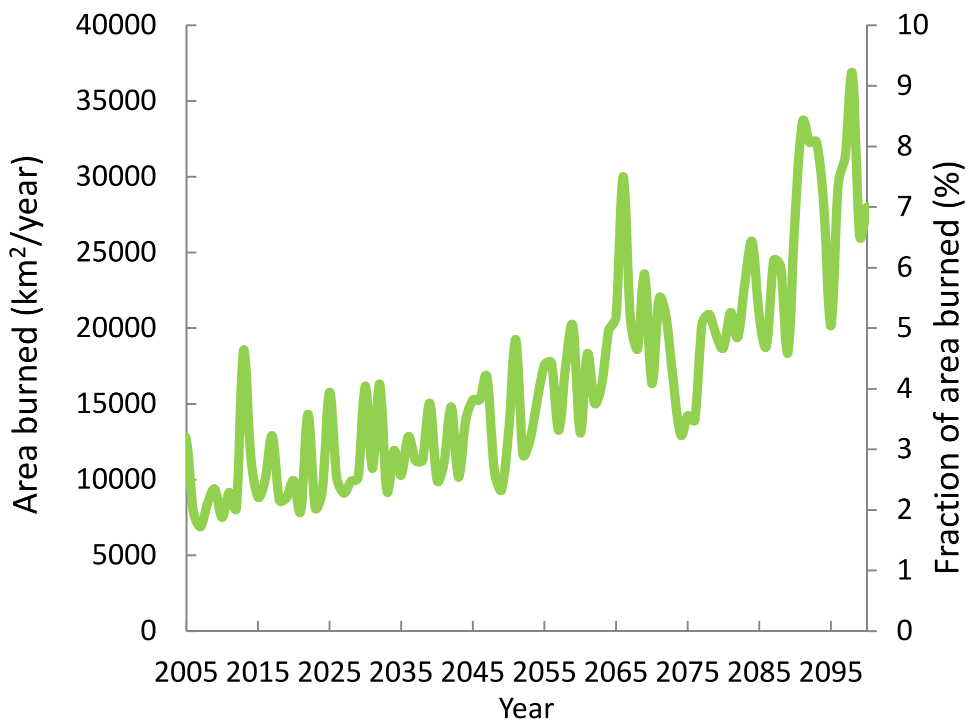
Data: Climate observations

- 1901–2004: U.K. Climate Research Unit (CRU), 0.5°
- 2005-2100: Canadian Coupled General Circulation Model (CGCM2), 3.75°
- Climate data were bi-linearly interpolated to 500 m resolution and adjusted to historic value
- A2 average temperature increases of 7.3°C and precipitation increases of about 20% from 1990 to 2100. B2 annual average temperature increases by 4.5°C and precipitation staying more or less the same from 1990 to 2100
- Seasonal variation in temperature causes greater warming during winter months for both scenarios



Data: Fire

- The historical fire disturbance data were compiled from the Canadian Large-Fire Data Base (LFDB) from 1961-1995 and remote sensing until 2004
- Projected A2 fire, 2005-2100 Canadian Fire Weather Index (CFWI)
- Minimum burnable age is 11 years [Ter-Mikaelian *et al.*, 2009]



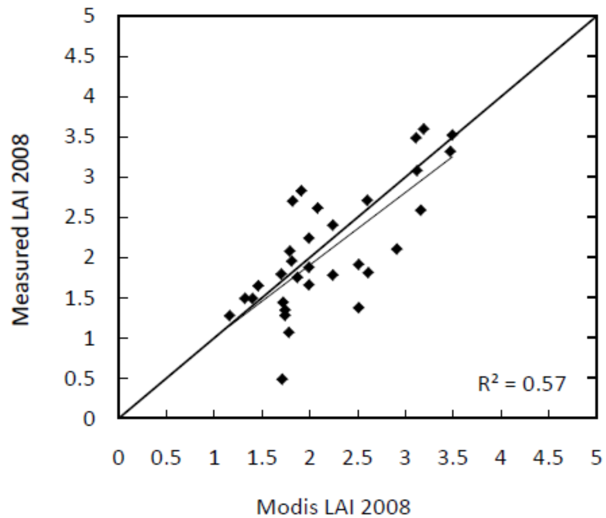
Data: Other

- InTEC model include spatial datasets of
  - ✓ Soil water, soil texture, drainage (SLC)
  - ✓ N deposition from Canadian Air and Precipitation Monitoring Network (CAPMN) and historical national greenhouse gas emissions
  - ✓ Digital Elevation Model (DEM)
  - ✓ MODIS land cover, leaf area index (LAI)
  - ✓ Forest stand age
  - ✓ Ground observations of forest structural parameters
  - ✓ Tree core measurements for developing NPP-age curve for each plant functional type

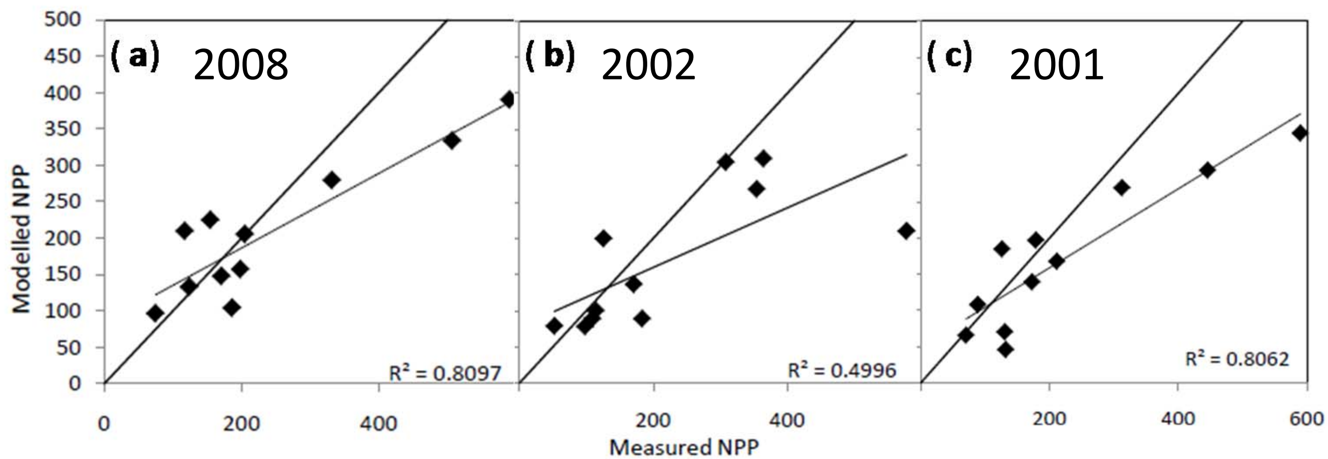
Model simulations

Simulation Name	Future Climate	Future CO_2 (ppmv) during 2005 to 2100	Future stand age and fire disturbance during 2005 to 2100
Control	CGCM2-control	371	Continuous age, no fire
A2 combined	CGCM2-A2	371 to 850	Continuous age, no fire
A2 climate	CGCM2-A2	371	Continuous age, no fire
A2 CO_2 fertilization	CGCM2-control	371 to 850	Continuous age, no fire
B2 combined	CGCM2-B2	371 to 600	Continuous age, no fire
B2 climate	CGCM2-B2	371	Continuous age, no fire
B2 CO_2 fertilization	CGCM2-control	371 to 600	Continuous age, no fire
A2 fire	CGCM2-A2	371 to 850	Age and area burned changes based on simulated fire disturbance using A2 climate

Results: reference LAI and NPP



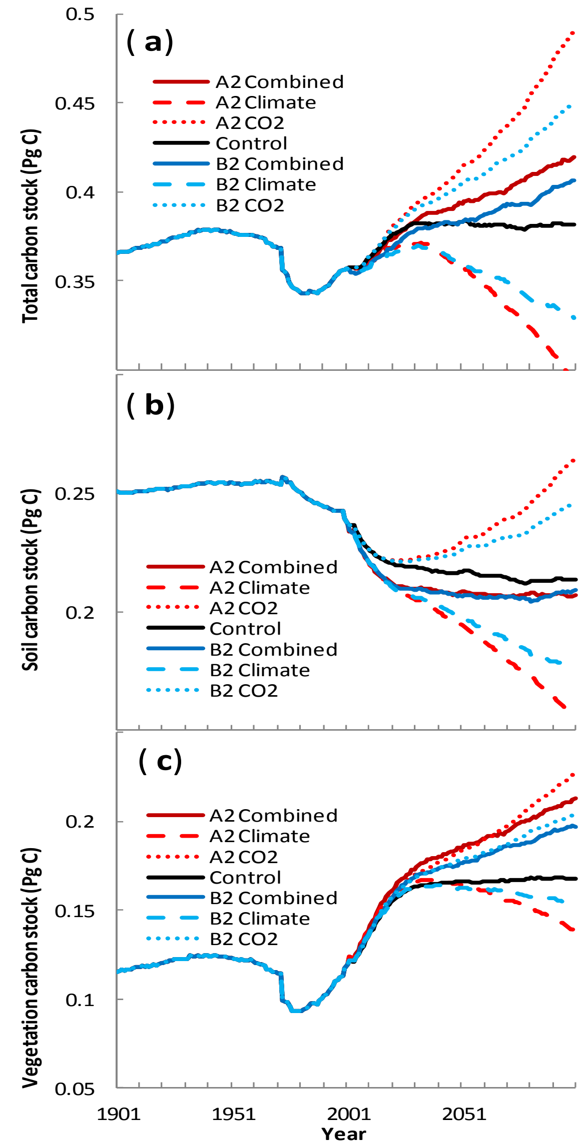
LAI increased with age and tree density. The highest LAI values were measured in mature black spruce and the lowest in lowland black spruce sites



Lower performance of BEPS for white birch with dense stocking

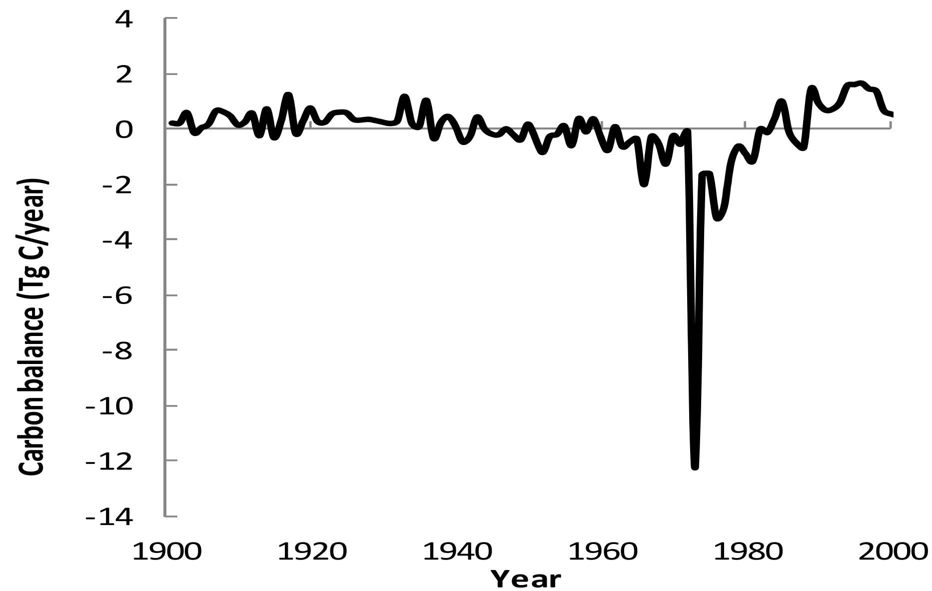
Results: effects of climate change and CO_2 on C storage

- Until year 2022, most of the OFN soil, vegetation and total C stocks are controlled by disturbance effects on age class composition due to historical fires in the early years of the second half of 20th century
- Forest C stocks decreased by 7% and vegetation C stocks by 19% during the 1970s due to the large areas affected by forest fires during the 1970s.
- CO_2 fertilization will increase C stocks
- Climate change alone will decrease C stocks
- Soil C stock will decrease in all scenarios except CO_2 fertilization alone



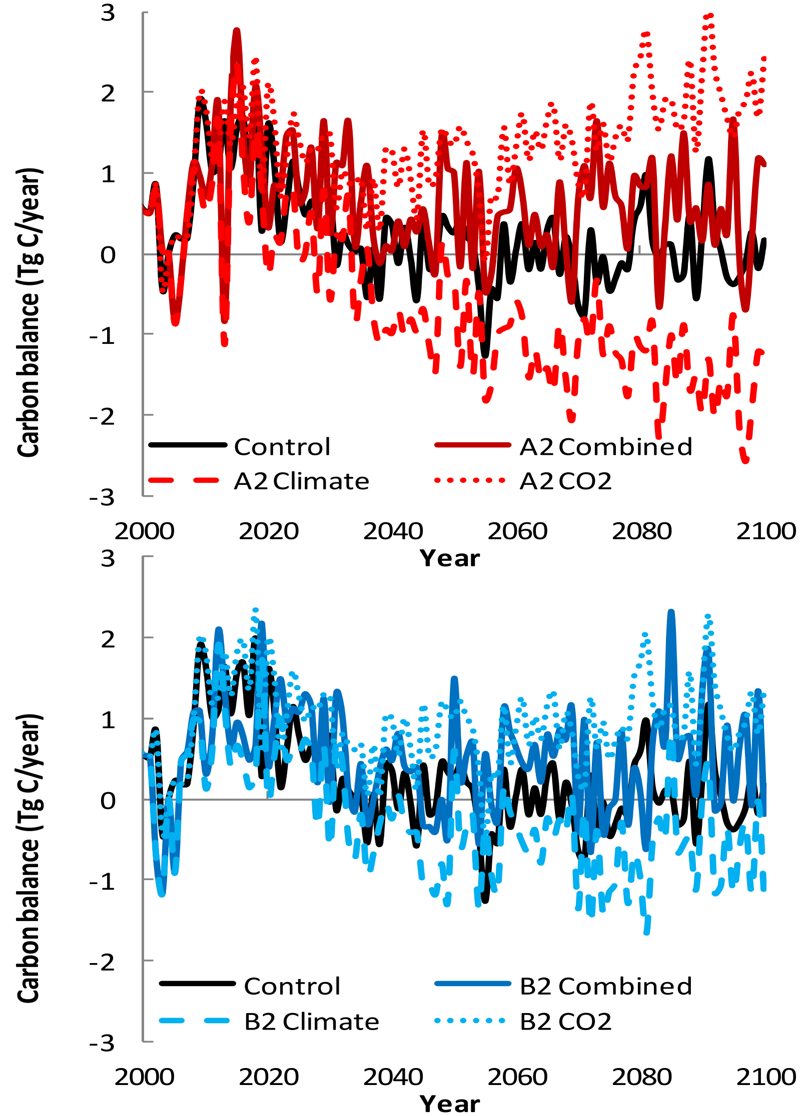
Results: Historical OFN forest C balance

- OFN forests were C neutral for much of the period between 1901 and mid-1950, mainly due to large areas of older forest with relatively few disturbances
- During the period 1955−1990, OFN was a large C source due to increased area affected by forest fires
- Disturbances in the most productive parts of the OFN during the 1970s created a younger cohort of stands which will have higher rates of C sequestration than older forests over a period of about 50 years post-fire



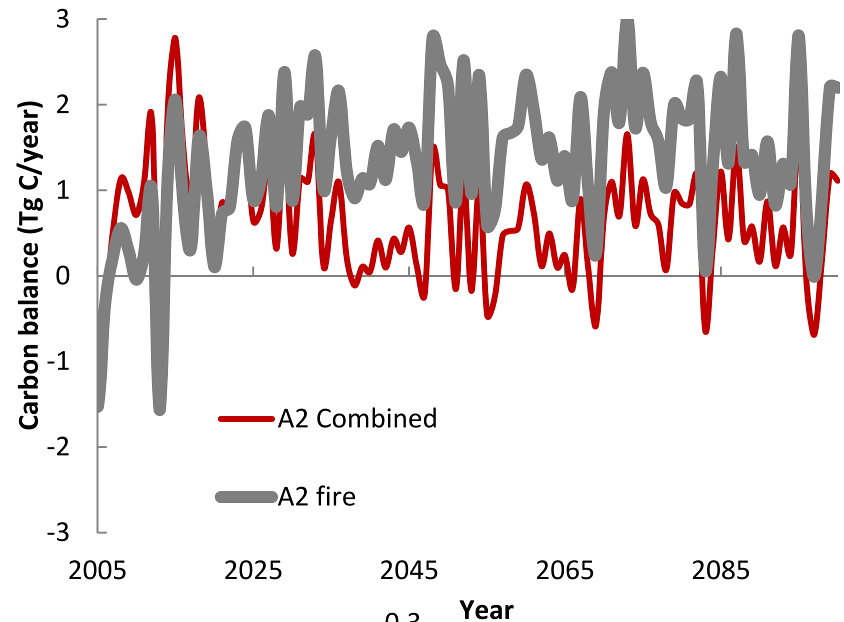
Results: effects of climate change and CO_2 on C balance

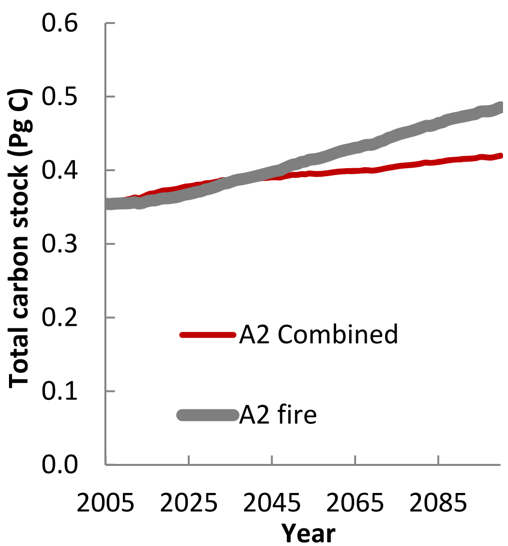
- Climate alone makes OFN forest C source
- The positive effect of increased atmospheric CO_2 offsets declining OFN forest productivity due to increasing stand age and heterotrophic respiration, making the OFN forest a 7.2 g C m^{-2} $yr^{-}1$ and a 5.7 g C m^{-2} yr^{-1} sink under the A2 and B2 combined simulations, over the 21st century

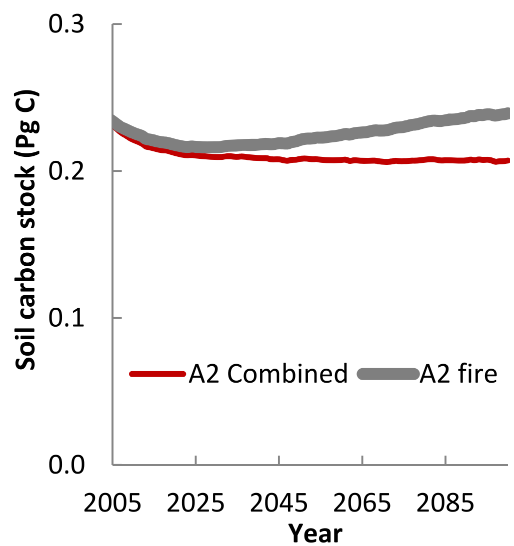


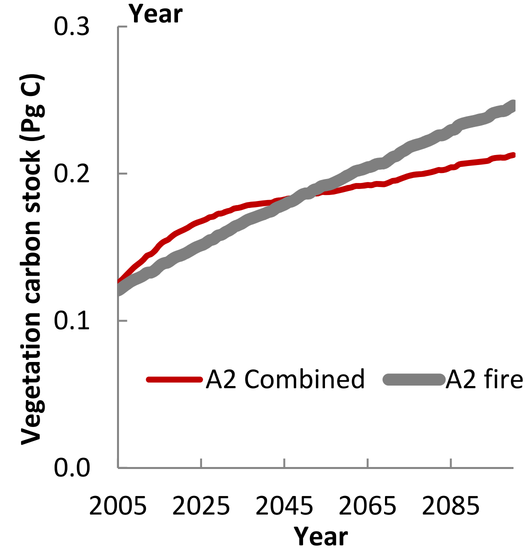
Results: effect of fire on C stock and balance

- ✓ C gains due to CO_2 fertilization on the re-growth of intermediate aged forests burned in past surpasses C losses due to small fires and young forest ecosystem respiration after the first quarter of 21st century
- ✓ Forest is the main control on C dynamics
- ✓ 100% roots, and 75% aboveground woody biomass are added to soil C pool (10% of the75% as a charcoal).
- ✓ Post fire C storage decomposes slowly
- ✓ C recovery under high CO_2 is faster than C loss by small and persistent wild fire
- ✓ More productive post-fire intermediate aged forests than those replaced by fire under high CO_2









Preliminary summary on OFN forest and climate change

- Historically (1901−1990), OFN forests were a small C source of -0.24 Tg yr^{-1}
- In recently years (1991−2004), OFN forests were a C sink of 0.96 Tg yr^{-1}
- The strong effect of CO_2 fertilization will make the OFN forest a C sink in the future (2005-2100)
- Our results indicate that climate change may produce a redistribution of the relative size of different forest C pools
- The simulations conducted in this study that include the effects of fire should be interpreted as a lower bound of possible global change induced disturbance effects
  - ✓ Insect and forest disease disturbances were not considered
  - ✓ Interactions between fire severity, insect, disease, soil thermal, and permafrost regimes were not considered
  - ✓ Dynamic fuel loading due to climate change was not considered
  - ✓ If fire seasons become longer, there is potential for the alteration of depth of burn (i.e. greater severity) due to the potential for drier conditions in the duff layer in addition to deeper thaw of the soil

OFN forests and treed wetlands (MOECC)

Assessing Climate Change Impact on Carbon Cycles in the Ontario's Far North Ecosystems

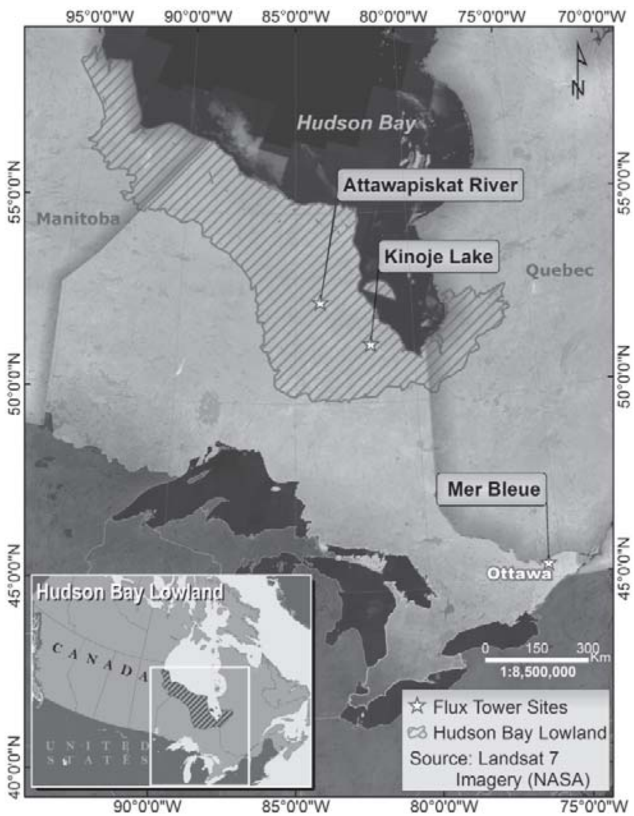
Application of the forest carbon models on treed bogs

Kinoje Lake bog

- Shrub bog, LAI= 0.35
- Tree density (<1 cm dbh) (stems/ha) =0
- Small tree density (>50cm height (stems/ha) =929
- Total above ground understory biomass (g m-2) =104.2
- Sphagnum covers 50–60%, lichens and sedges the remaining
- Stunted black spruce and ericaceous shrubs
- Peat depth from1.4 to 2.7 m

Attawapiskat River bog

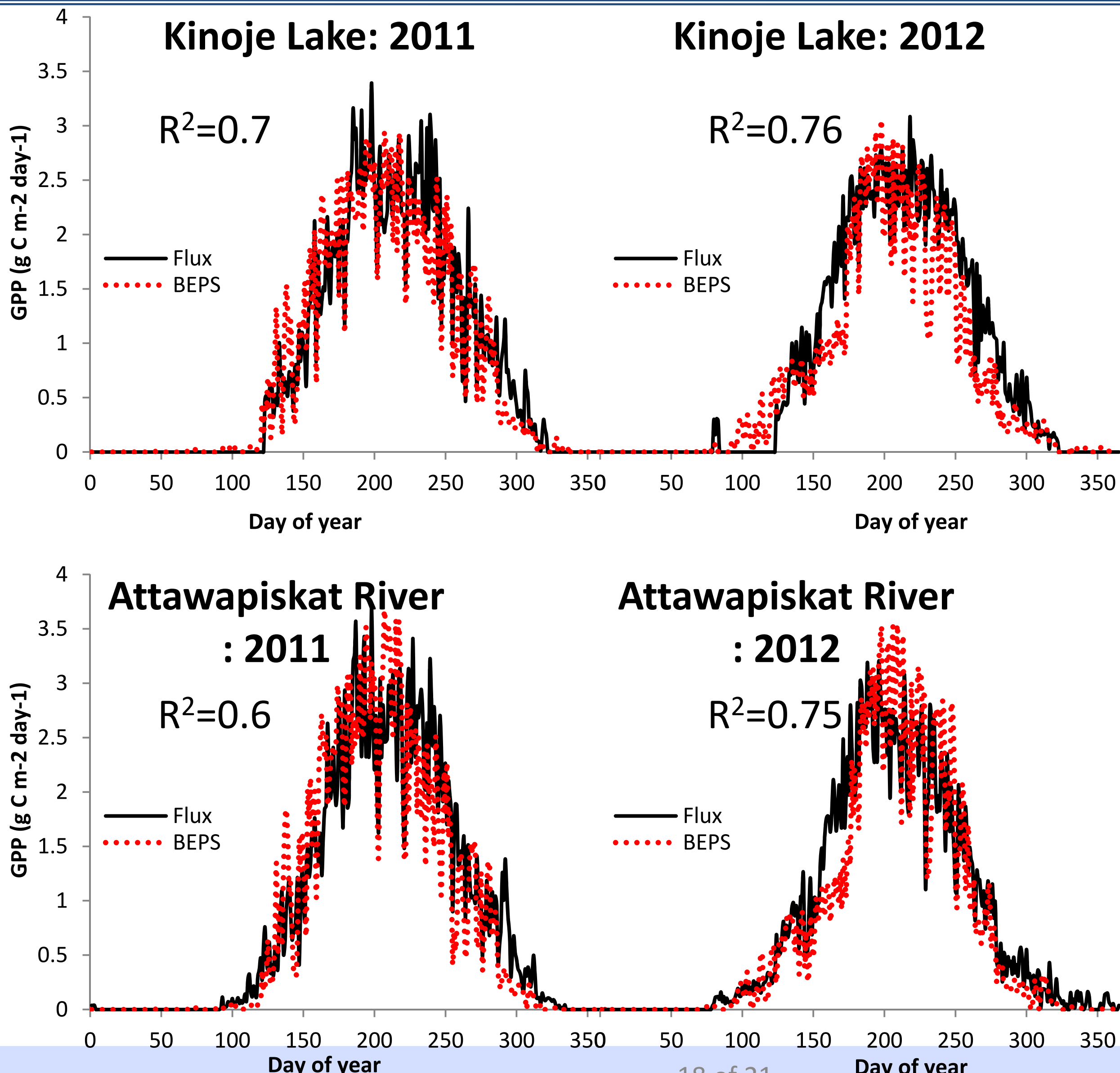
- Treed bog, LAI= 0.45
- Tree density (<1 cm dbh) (stems/ha) =446
- Small tree density (>50cm height (stems/ha) =1419
- Total above ground understory biomass (g m-2) =84
- Sphagnum covers 50% while lichesn account for the remaining
- Stunted black spruce and tamarack
- Peat depth > 2m



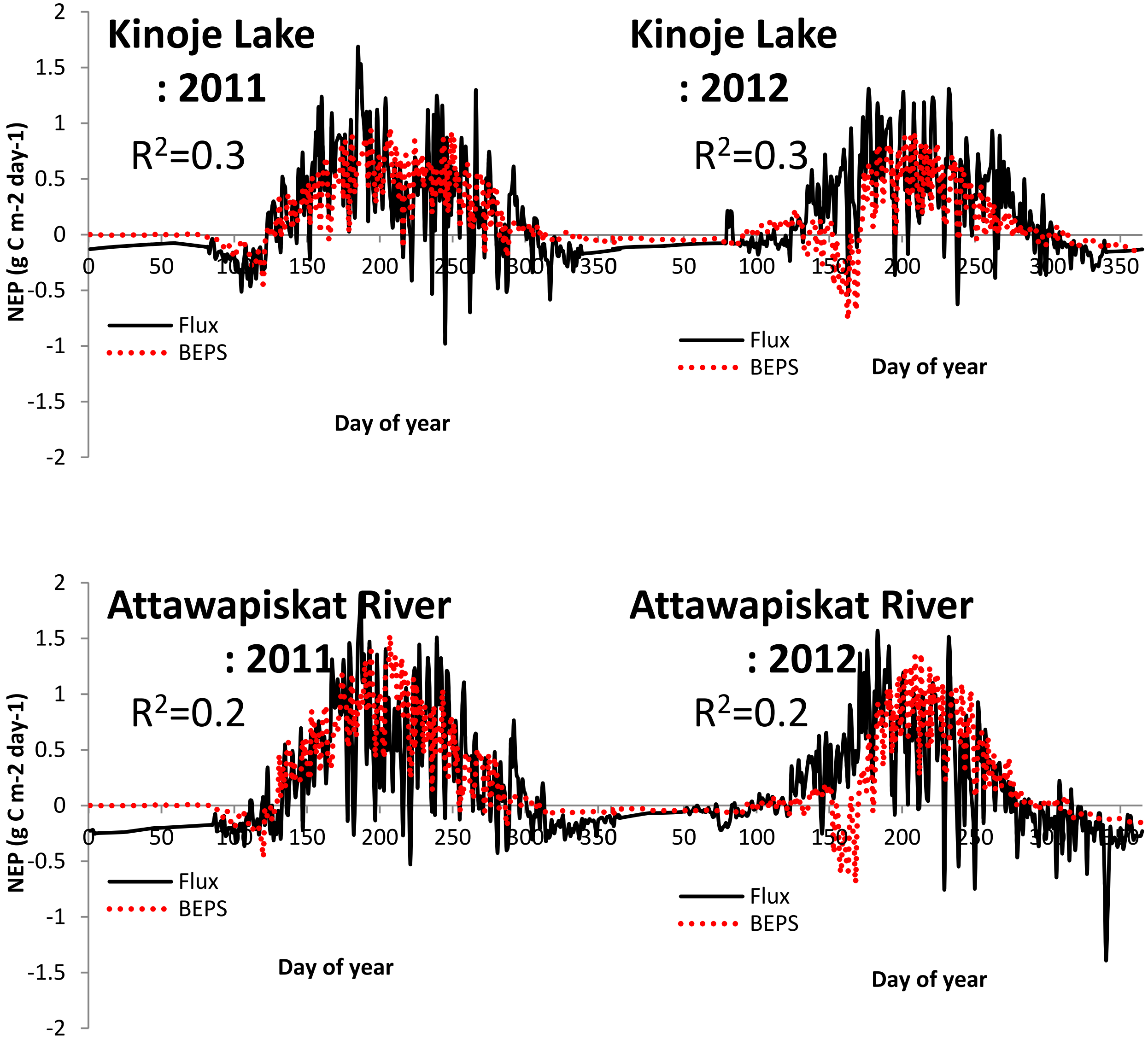
Elyn Humphreys, Nigel Roulet, Chris Charron

Humphreys et al. (2014). AAAR

Performance of BEPS for GPP on treed bogs



Performance of BEPS for NEP on treed bogs

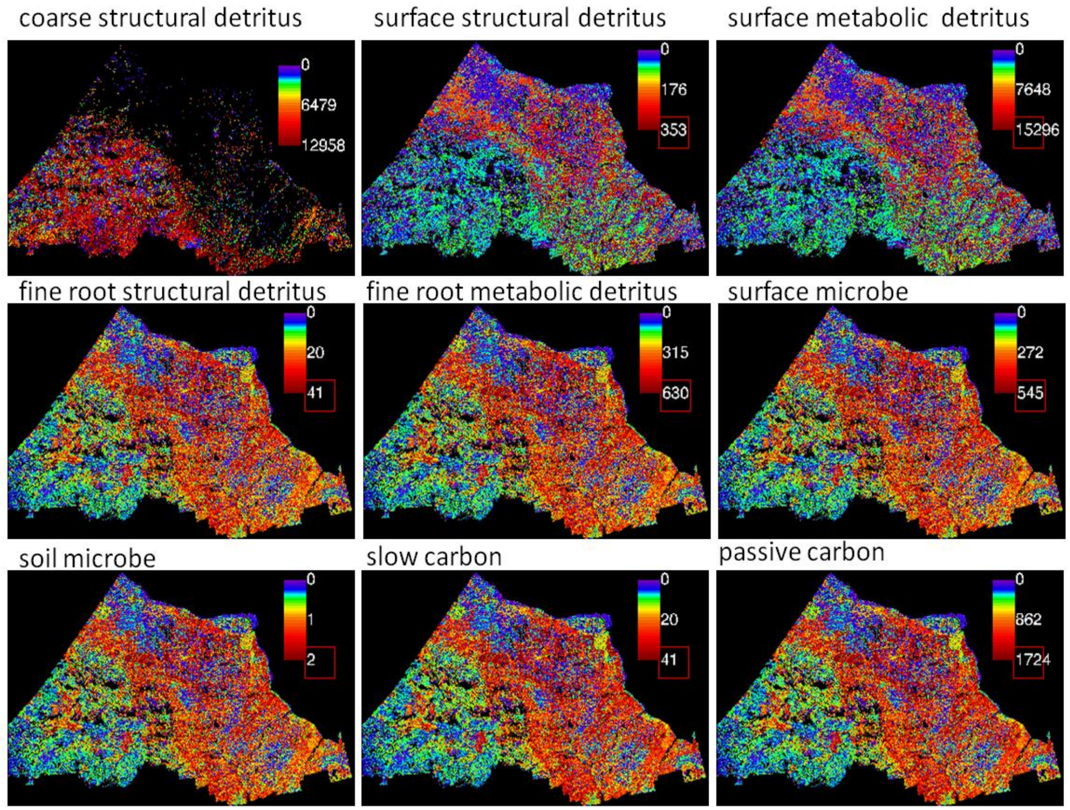


Progress of the ongoing work with MOECC

•To run Boreal Ecosystem Productivity Simulator (BEPS)-TerrainLab for the two 10 km × 10 km areas with consideration of the redistribution of water over the landscape under the influence topography

•To investigate the influence of lateral water flow on the C flux and hydrological regime (wet and dry area fractions) and the carbon sink and source distribution for the two 10 km × 10 km areas

•And eventually run the long-term carbon cycle model from 1900 up to 2100 over the Ontario's Far North

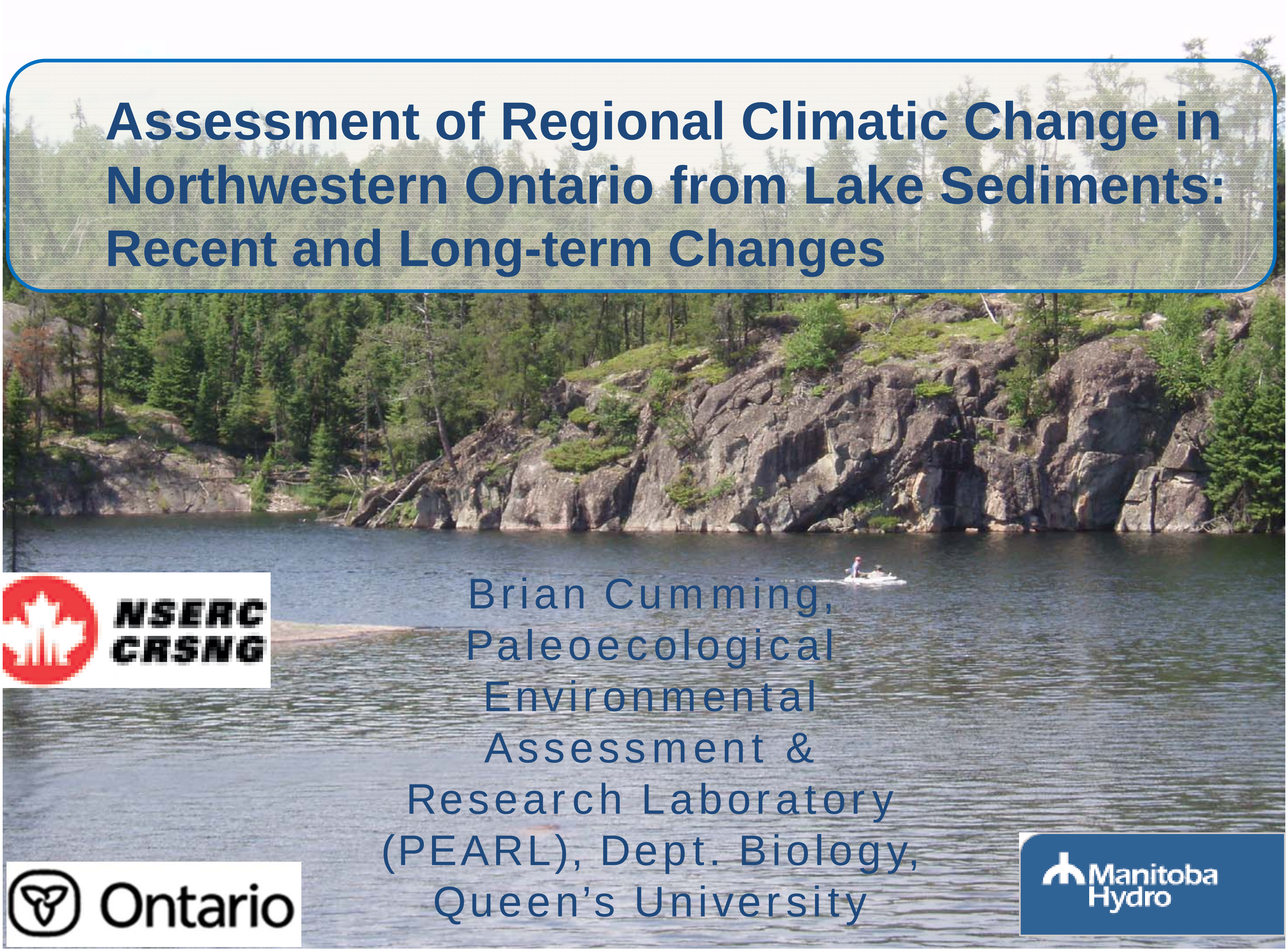


Financial supports

Ontario Ministry of Natural Resources and Forestry

Ontario Ministry of the Environment and Climate Change

Assessment of Regional Climatic Change in Northwestern Ontario from Lake Sediments: Recent and Long-term Changes



Brian Cumming,
Paleoecological Environmental Assessment & Research Laboratory (PEARL), Dept. Biology, Queen's University

Acknowledgements

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Donya Danesh (Ph.D. cand.)

Heather Haig (M.Sc.)
Melanie Kingsbury (M.Sc.)
Susan Ma (M.Sc.)
Shelley Wilkinson
Christina Clarke
Chris Lorenz
Erin MacMillan

Andrew Paterson; **Bill Girling**

Issue:

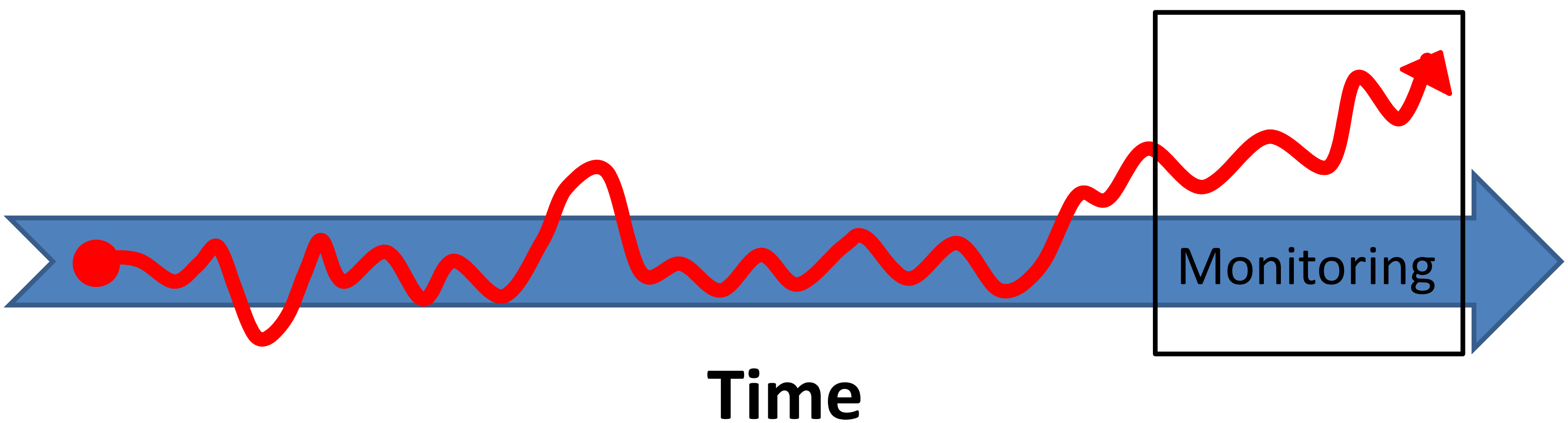
- **How have freshwater lakes in northwest Ontario changed in terms of water quantity and quality over centuries to millennia?**

Issue:

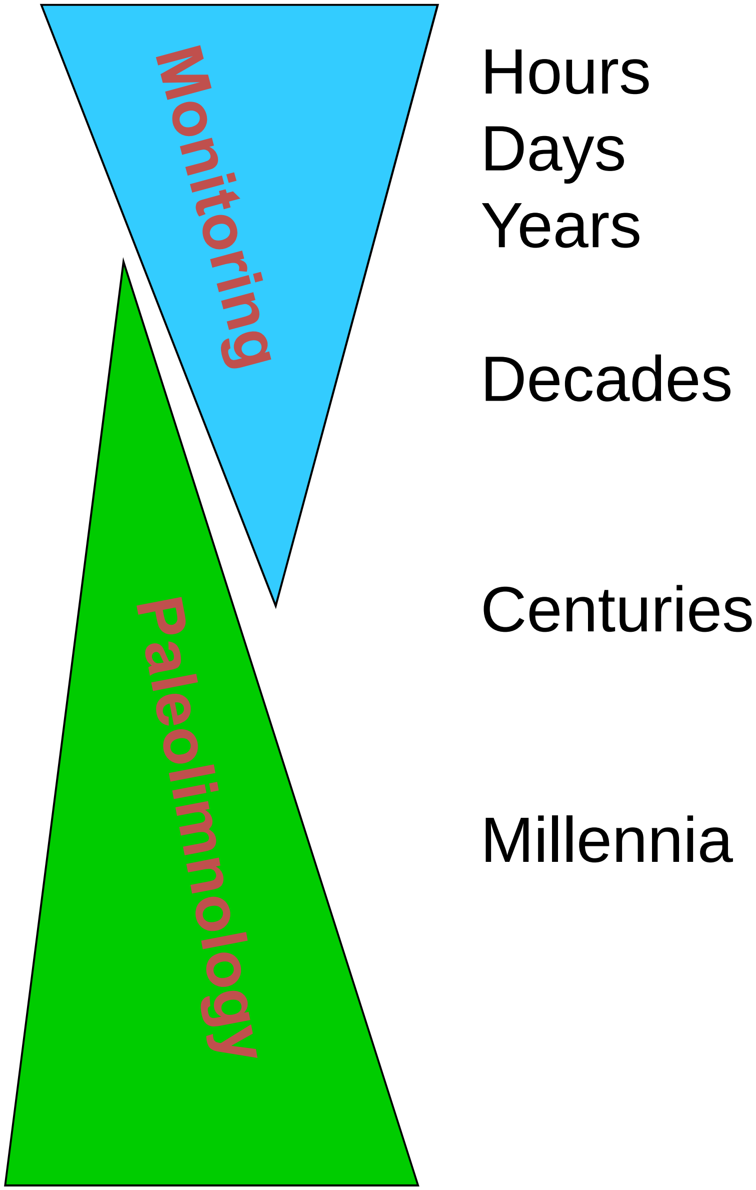
- How have freshwater lakes in northwest Ontario changed in terms of water quantity and quality over centuries to millennia?

Background:

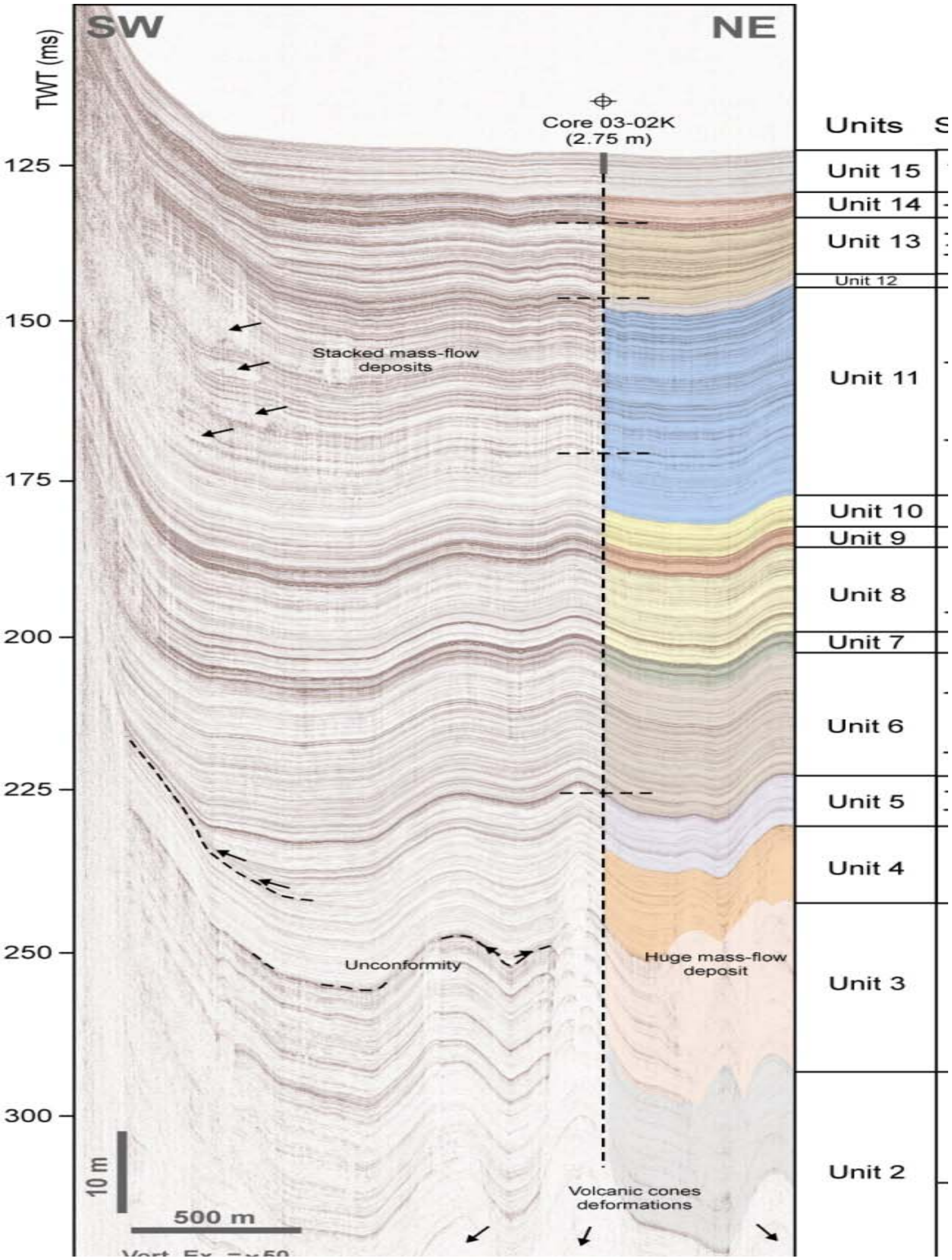
- **long-term data on the impact of climate change in many parts of Ontario, including the northwest, is sadly absent.**
- **Our information from sediment cores fills some of these gaps and provides information to evaluate the extent and magnitude of past changes of climate on aquatic and terrestrial systems, thereby informing both current risks and adaptation strategies.**



A Matter of Scale



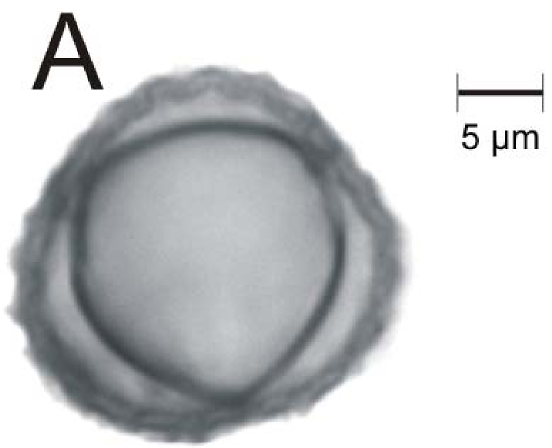
Adapted from Smol, 2002



Lake Challa (Verschuren and others)

Proxies of terrestrial environments: Pollen

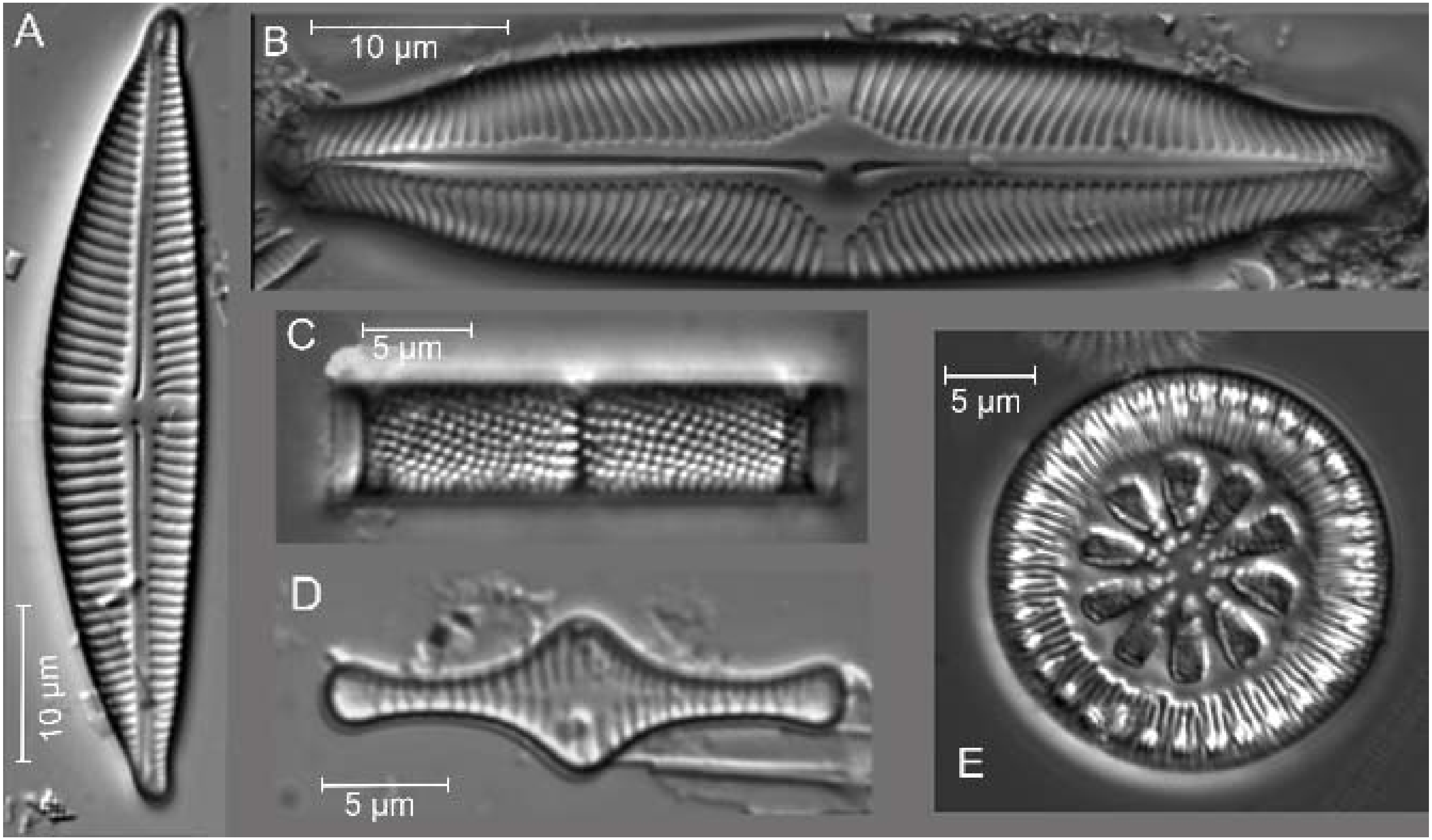
Ambrosia (ragweed)



Pinus (pine)

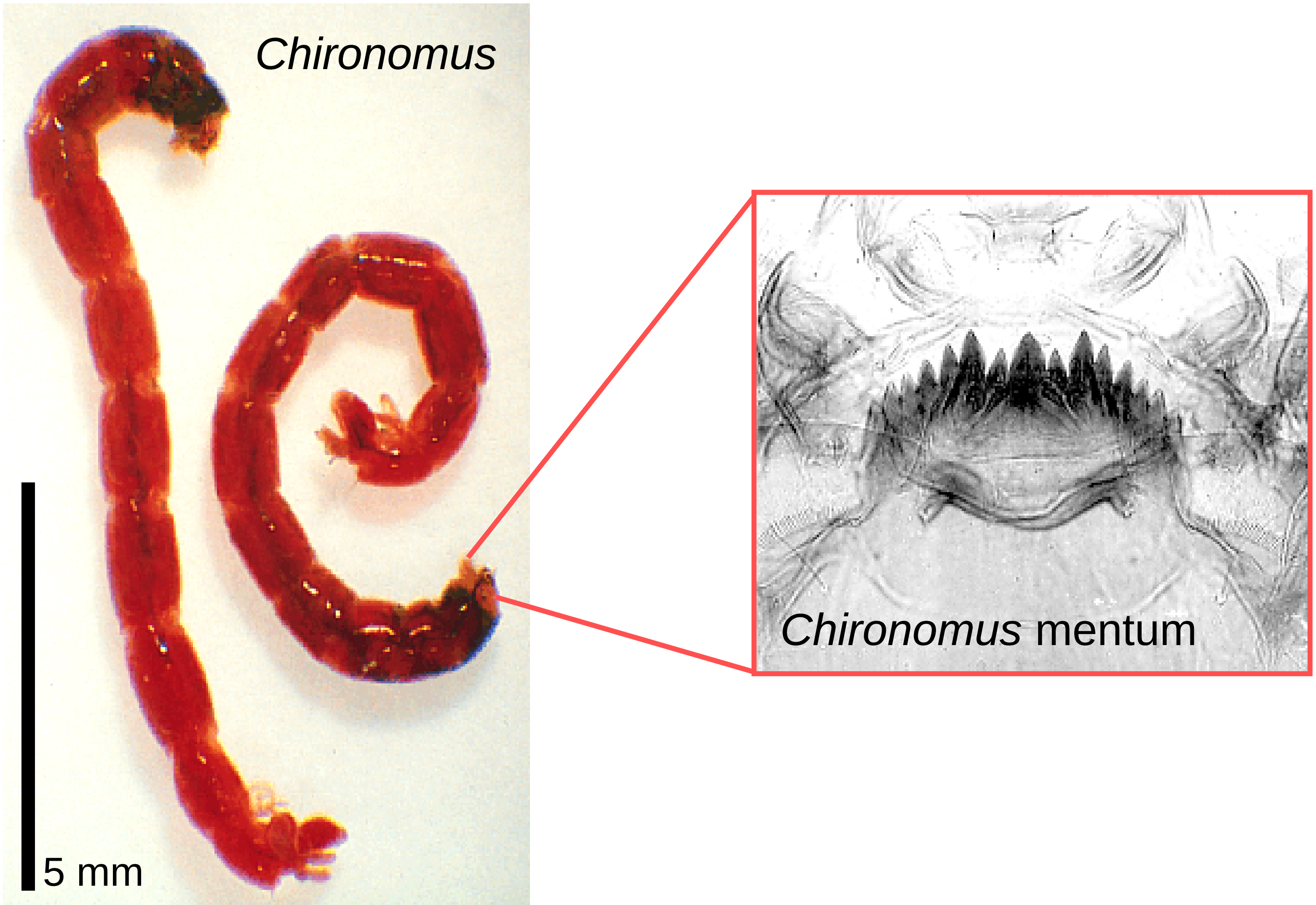
From Smol (2008)

Aquatic environment: Diatoms

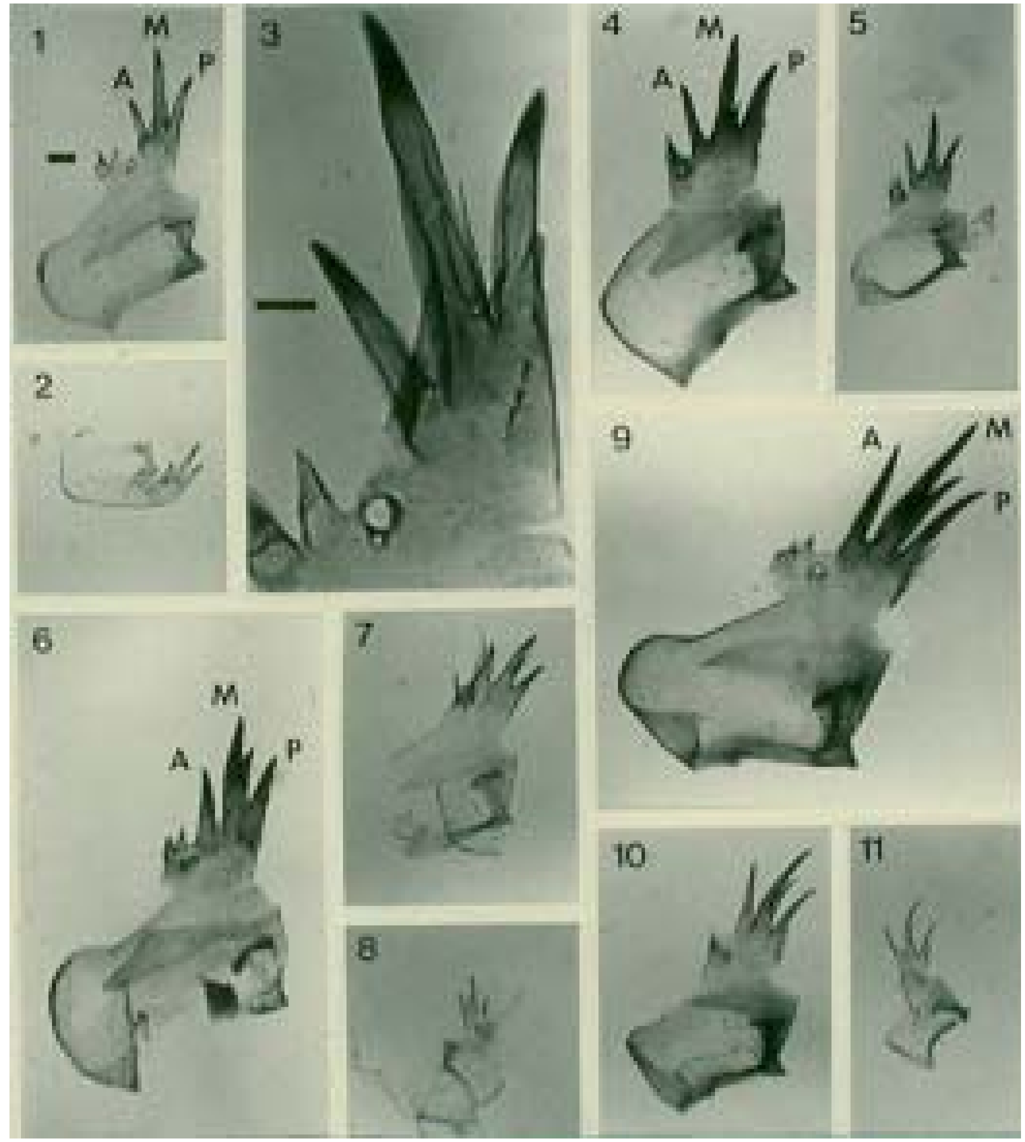


Photographs by K. Laird & B. Cumming; Figure 5.4 in Smol (2008)

Chironomids



Chaoborus

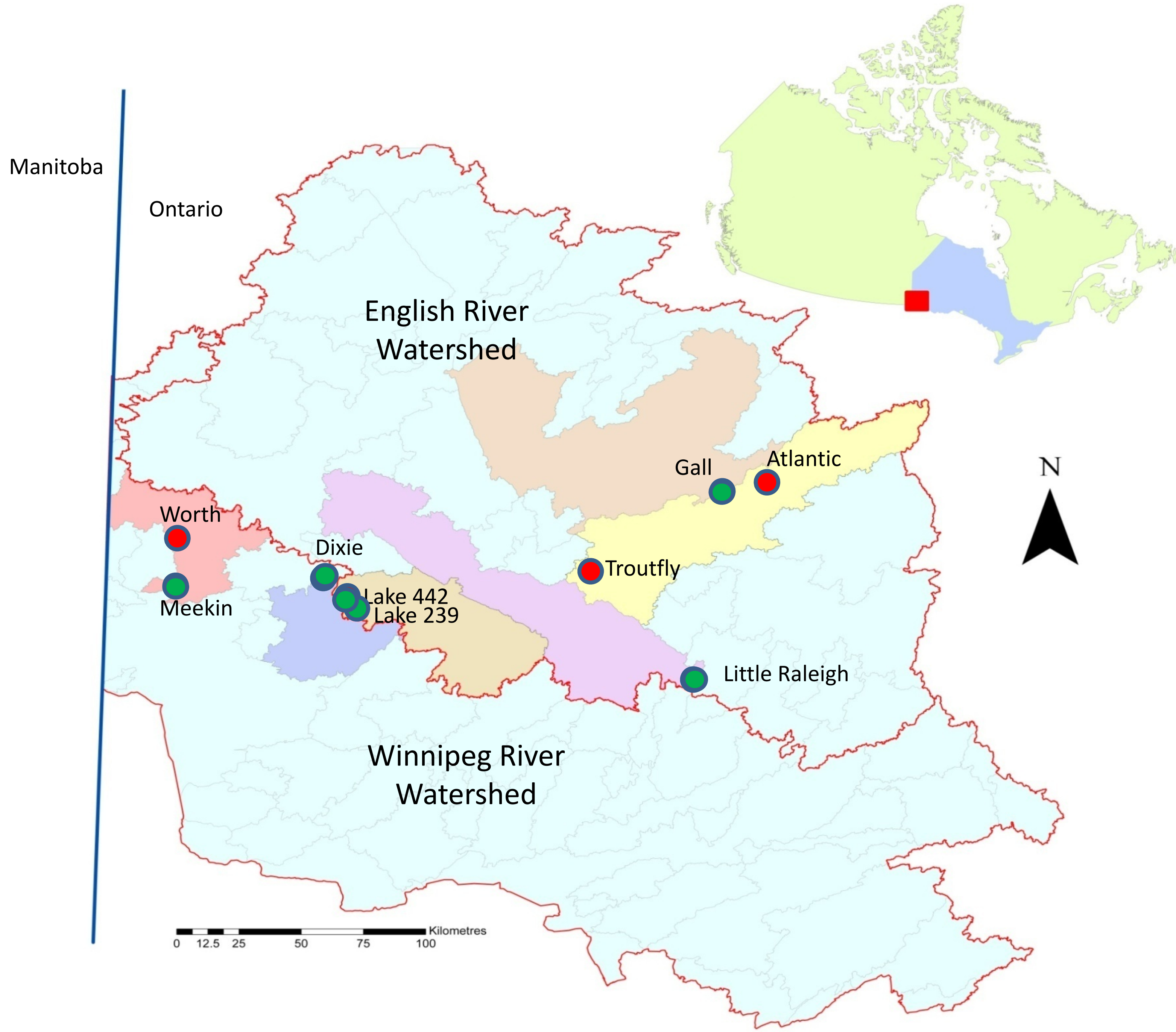


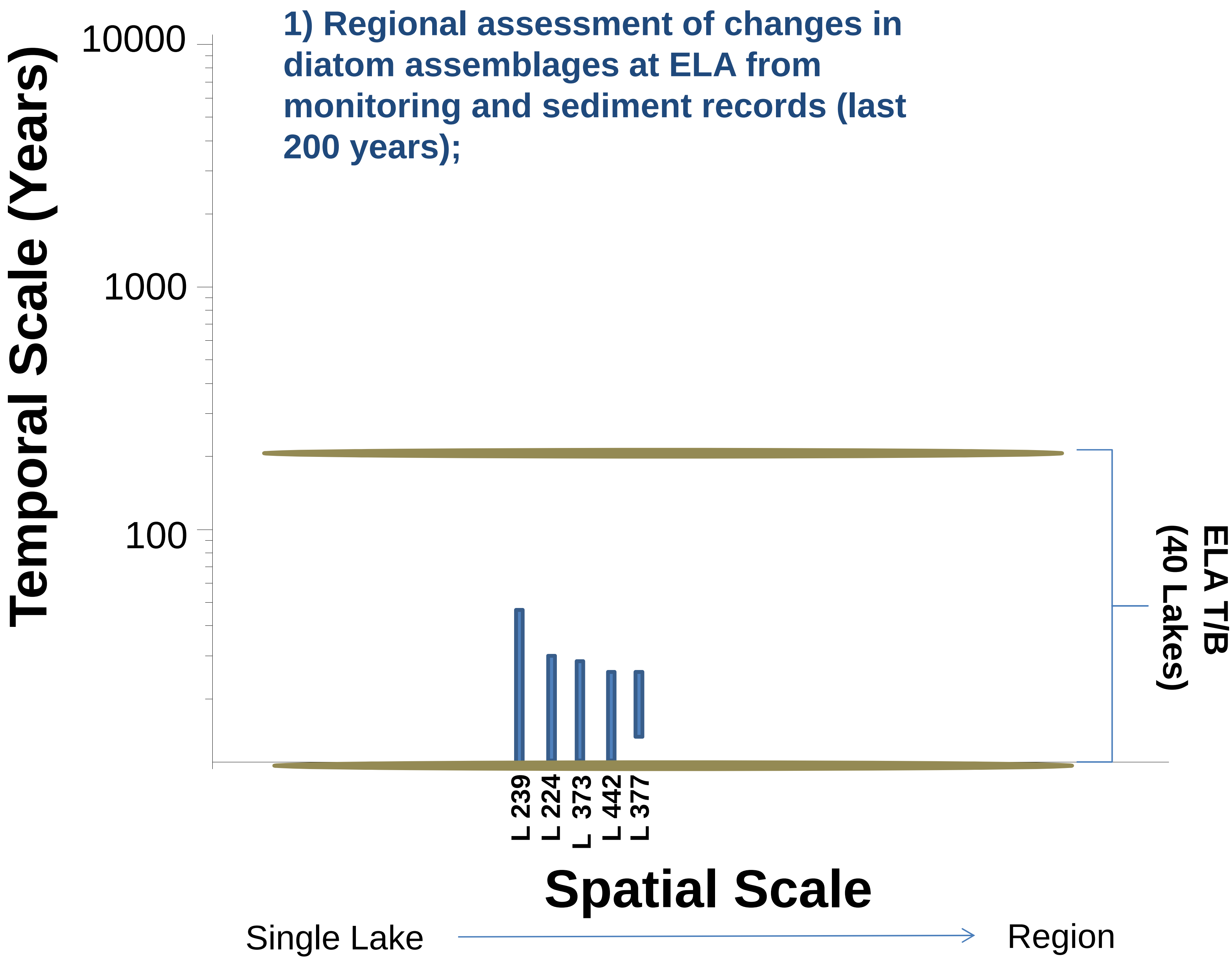
Chaoborus mandibles

From Uutala (1990)

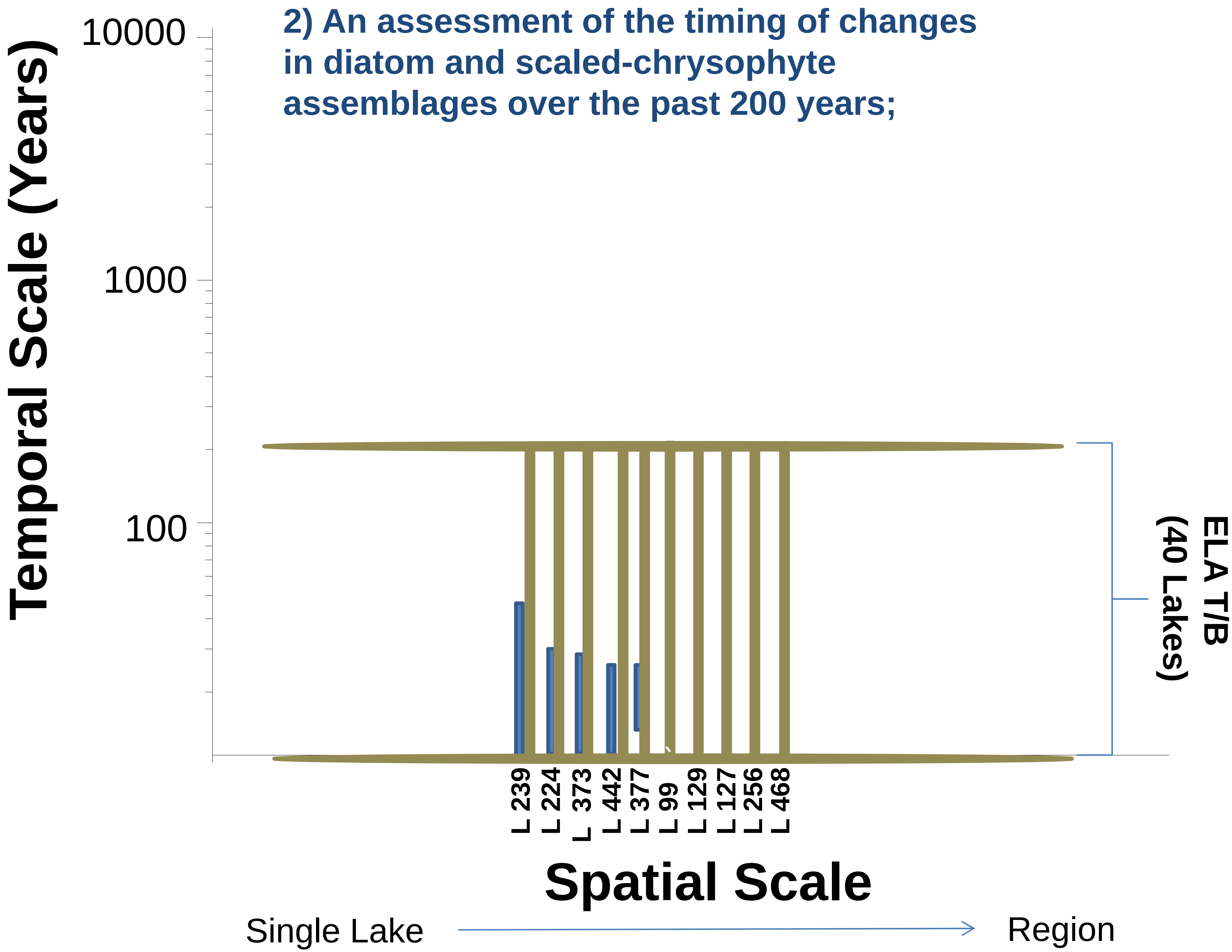
GOALS/OBJECTIVES:

- **Provide a summary of the temporal and spatial scales of environmental change in boreal lakes from northwest Ontario**

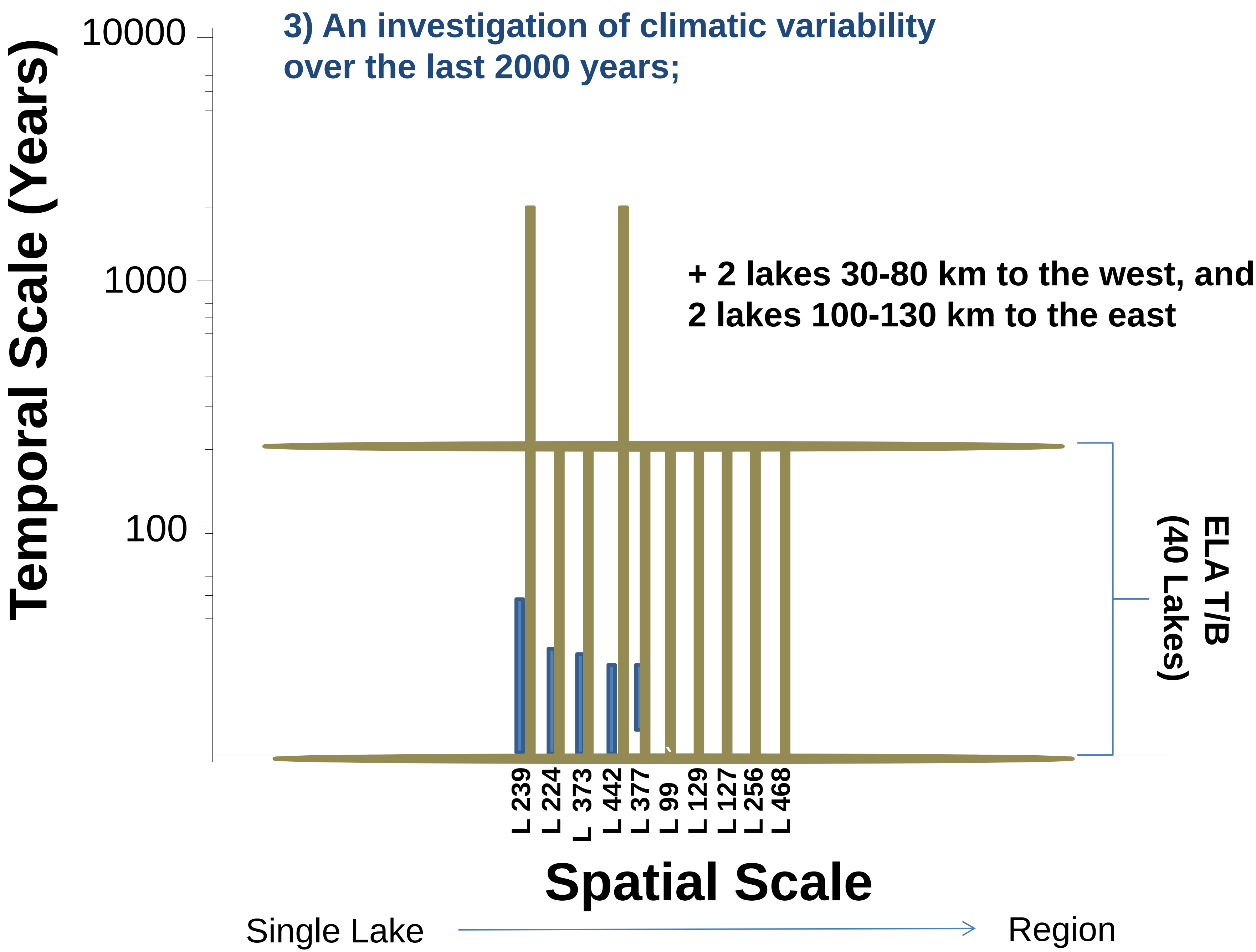

Manitoba
Ontario
English River Watershed
Winnipeg River Watershed
Gall
Atlantic
Worth
Dixie
Troutfly
Lake 442
Lake 239
Meekin
Little Raleigh
N
Kilometres
0 12.5 25 50 75 100



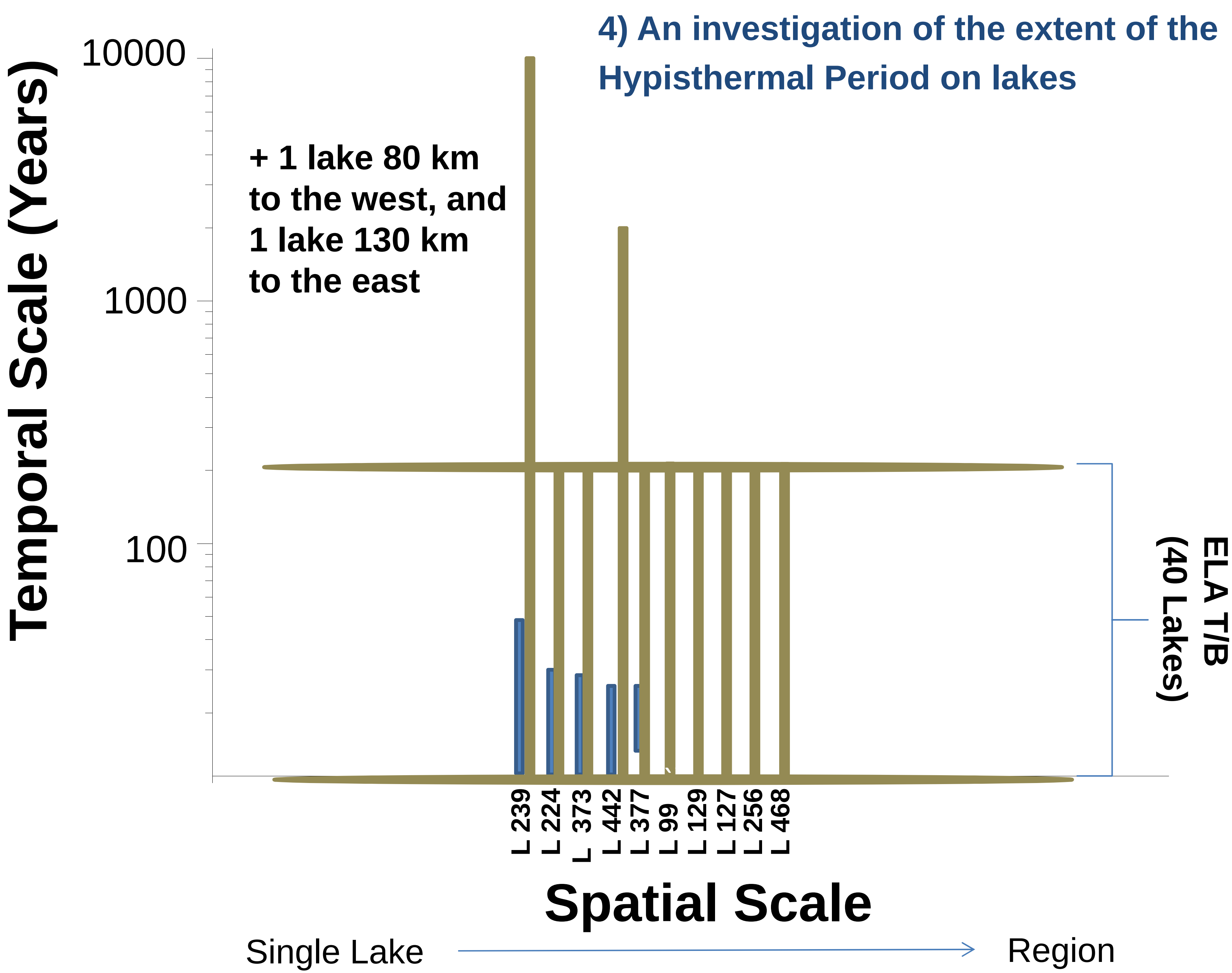
1) Regional assessment of changes in diatom assemblages at ELA from monitoring and sediment records (last 200 years);
Temporal Scale (Years)
10000
1000
100
L 239
L 224
L 373
L 442
L 377
ELA T/B
(40 Lakes)
Spatial Scale
Single Lake
Region



2) An assessment of the timing of changes in diatom and scaled-chrysophyte assemblages over the past 200 years;
Temporal Scale (Years)
10000
1000
100
L 239
L 224
L 373
L 442
L 377
L 99
L 129
L 127
L 256
L 468
ELA T/B (40 Lakes)
Spatial Scale
Single Lake
Region



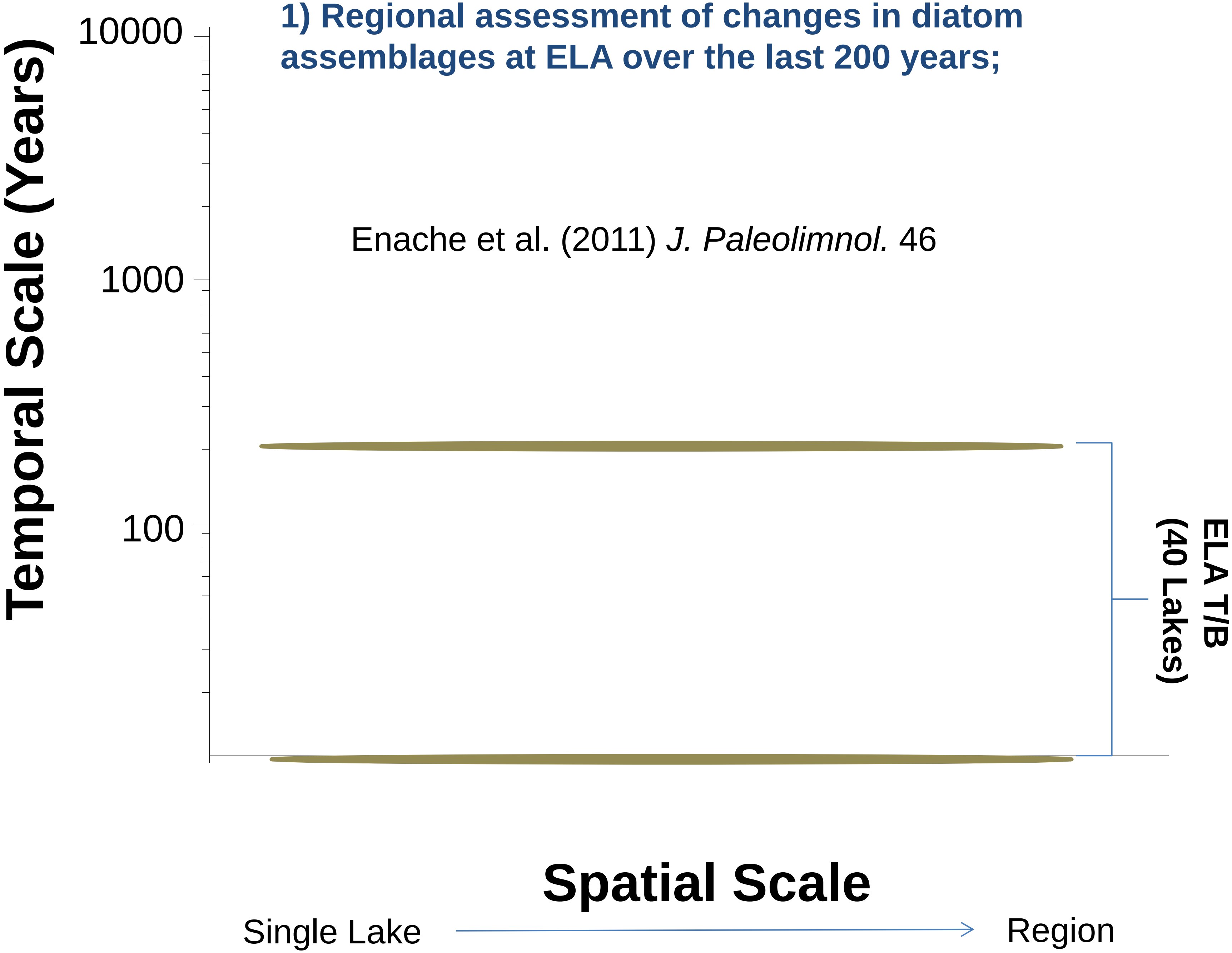
Temporal Scale (Years)
10000
1000
100
3) An investigation of climatic variability
over the last 2000 years;
+ 2 lakes 30-80 km to the west, and
2 lakes 100-130 km to the east
ELA T/B
(40 Lakes)
L 239
L 224
L 373
L 442
L 377
L 99
L 129
L 127
L 256
L 468
Spatial Scale
Single Lake
Region

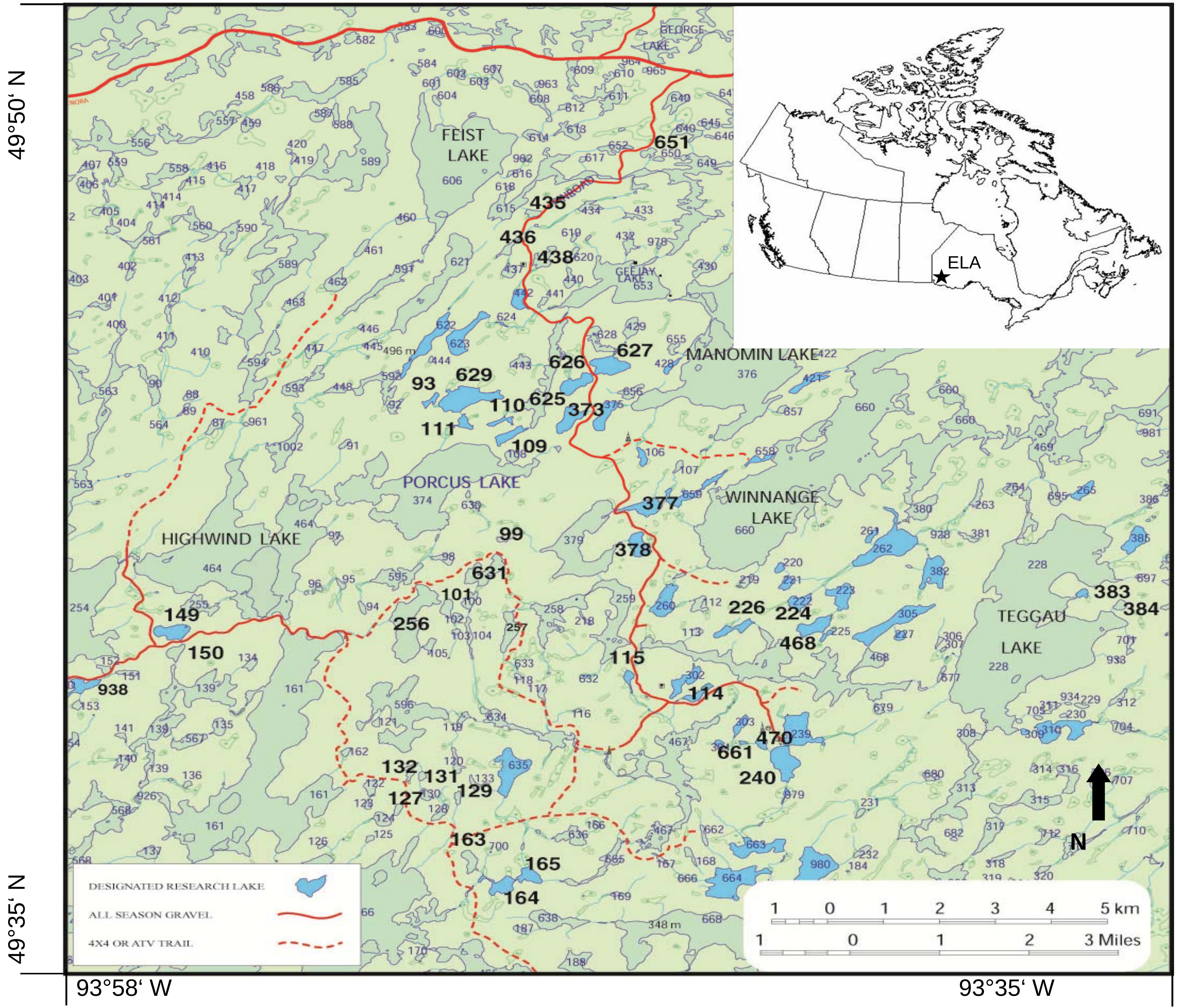


4) An investigation of the extent of the Hypisthermal Period on lakes
Temporal Scale (Years)
10000
1000
100
+ 1 lake 80 km to the west, and 1 lake 130 km to the east
ELA T/B (40 Lakes)
L 239
L 224
L 373
L 442
L 377
L 99
L 129
L 127
L 256
L 468
Spatial Scale
Single Lake
Region

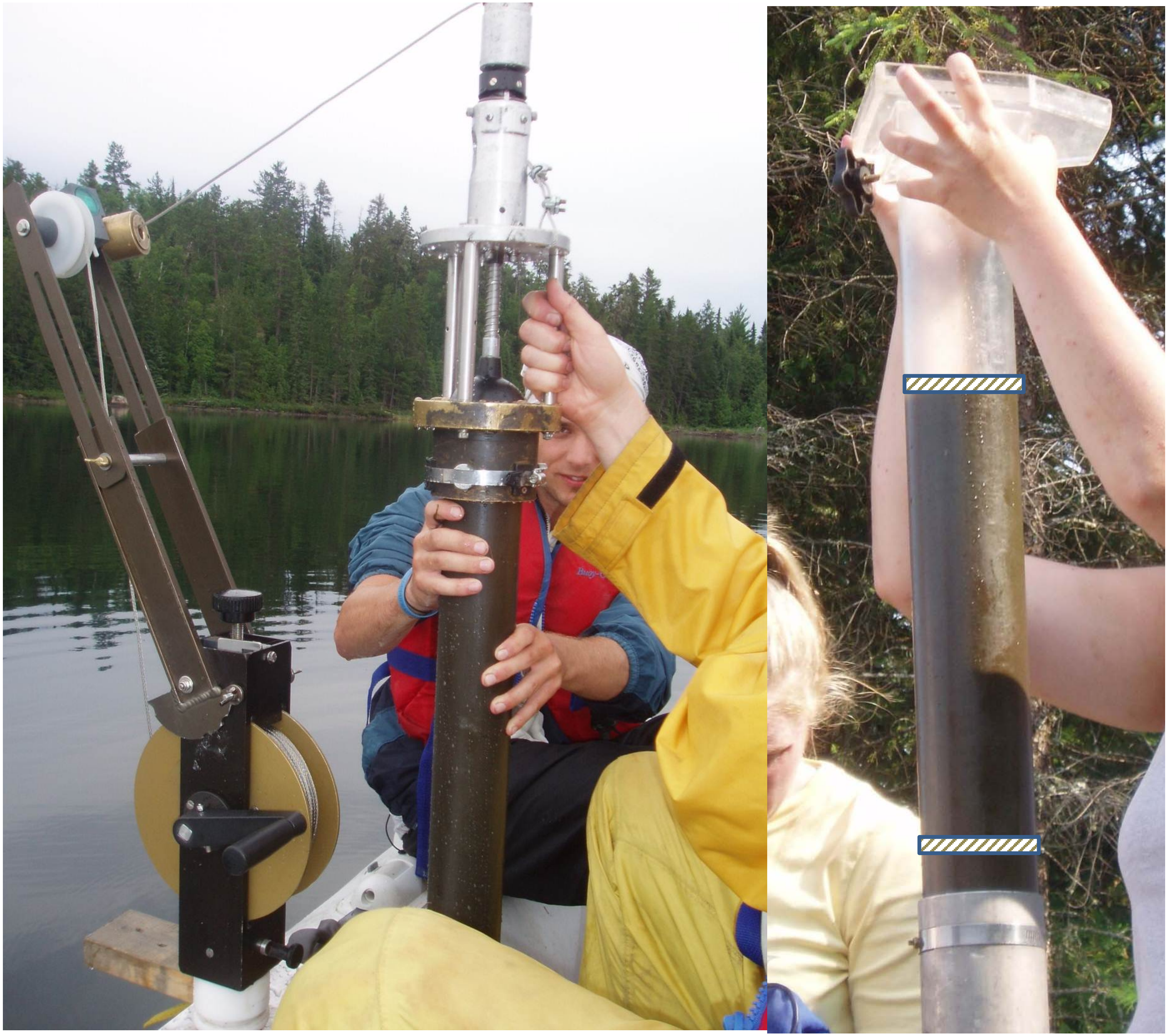
1) Regional assessment of changes in diatom assemblages at ELA over the last 200 years;

Enache et al. (2011) *J. Paleolimnol.* 46



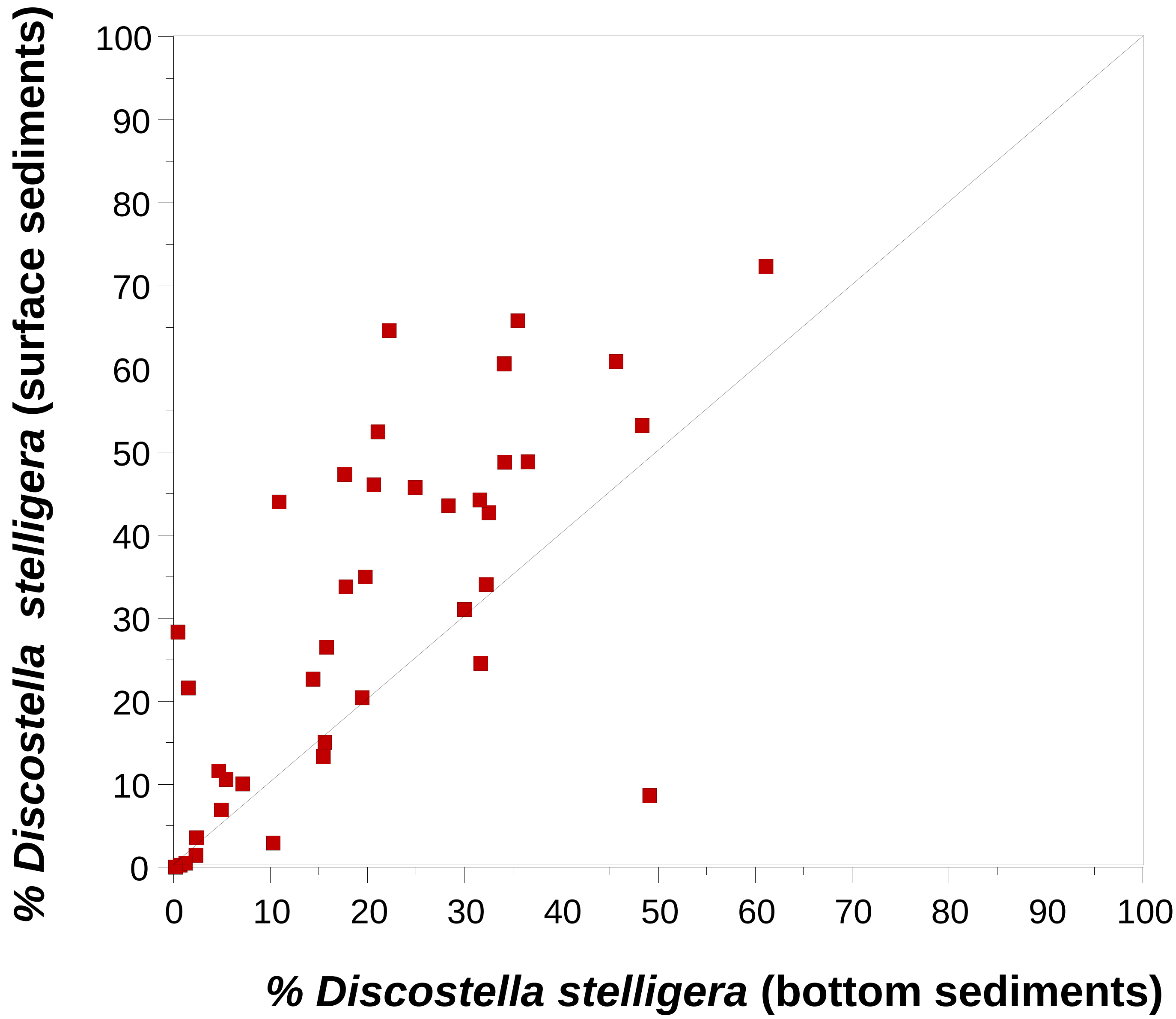


Enache et al. (2011) *J. Paleolimnol.* 46:1-15

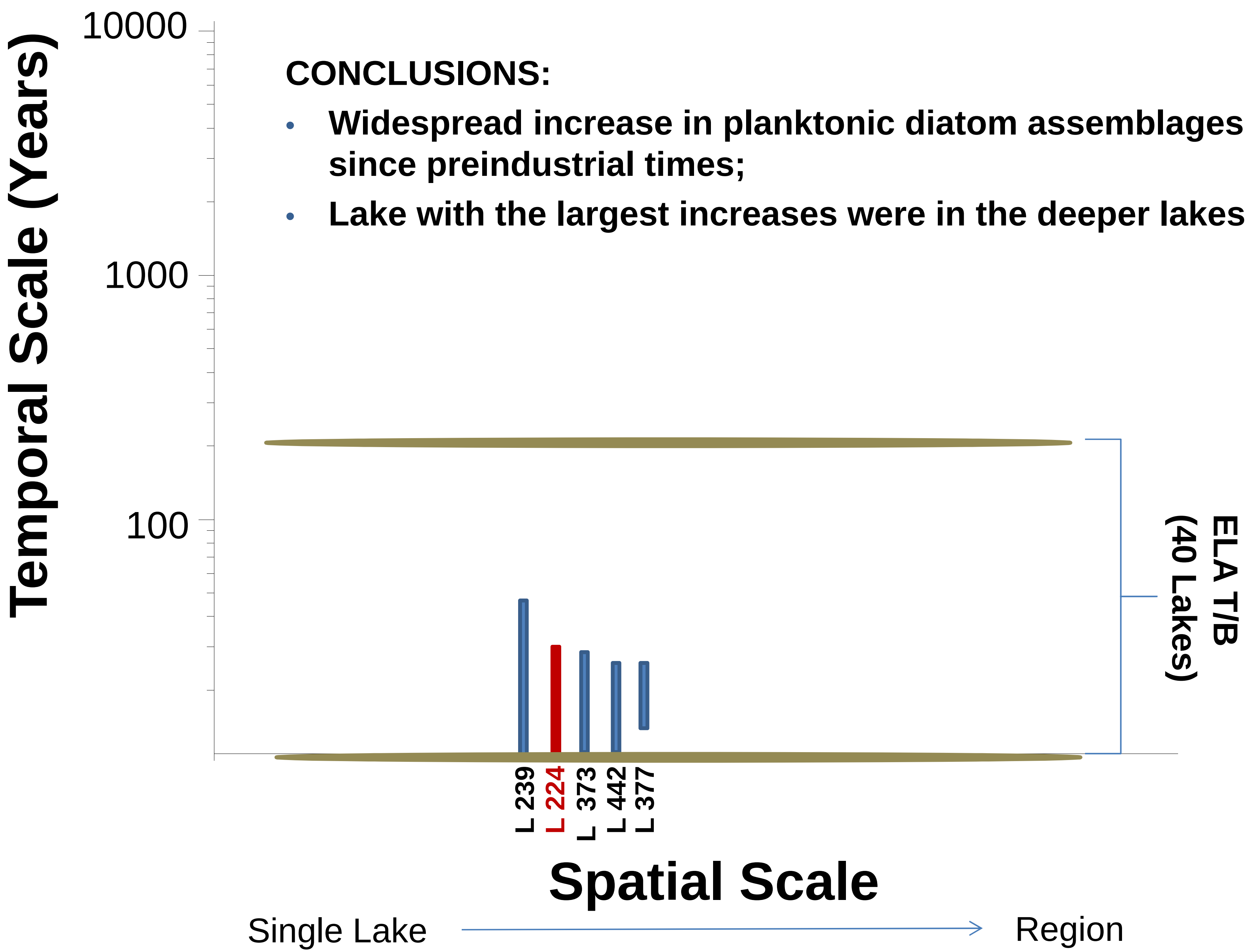


Top
(0-0.5 cm)

Bottom
(20-20.5 cm)

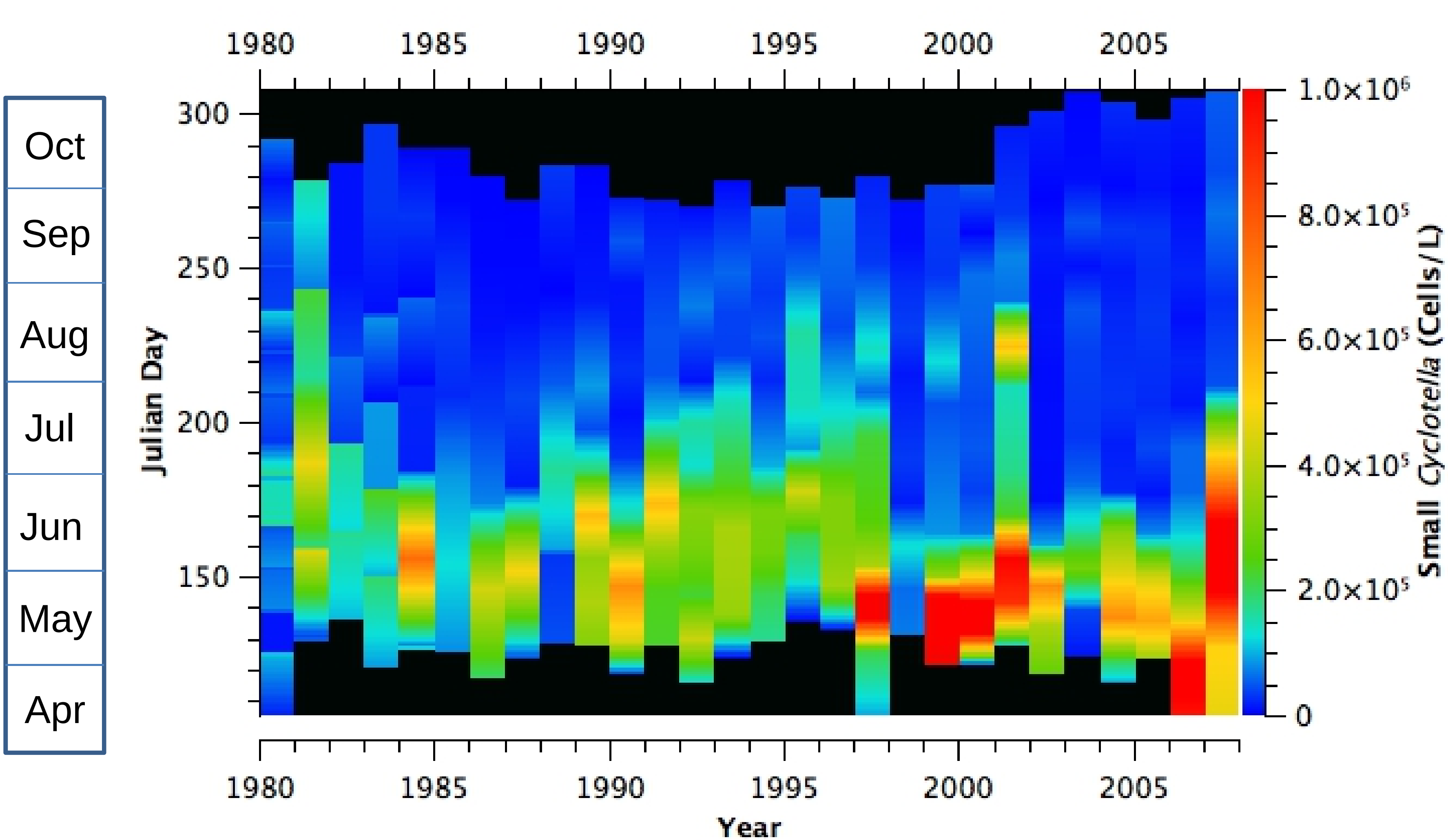


Enache et al. (2011) J. *Paleolimnol*. 46:1-15



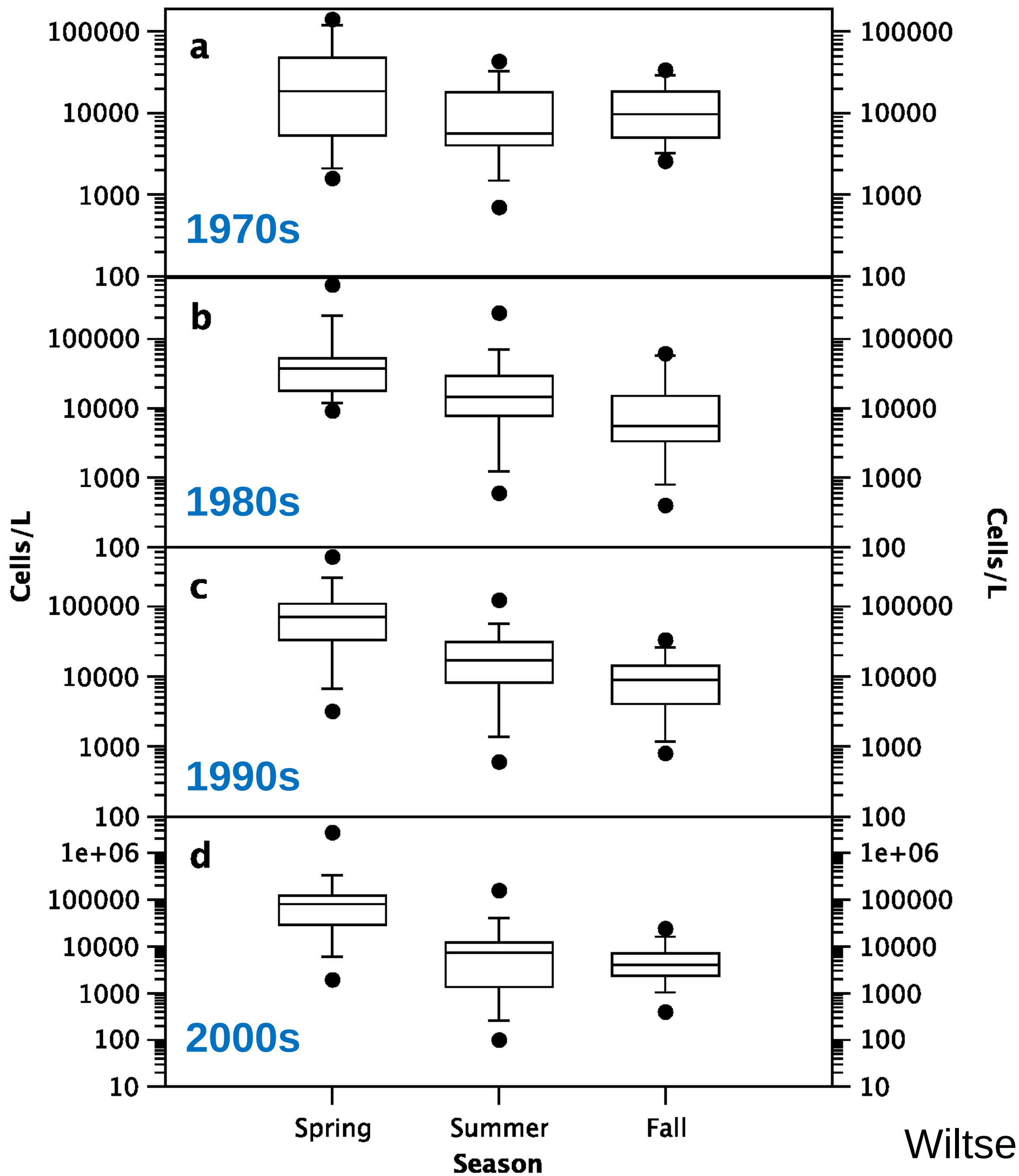
Temporal Scale (Years)
10000
1000
100
CONCLUSIONS:
• Widespread increase in planktonic diatom assemblages since preindustrial times;
• Lake with the largest increases were in the deeper lakes
ELA T/B
(40 Lakes)
L 239
L 224
L 373
L 442
L 377
Spatial Scale
Single Lake
Region

LAKE 224 – Small *Discostella* (biweekly monitoring data)

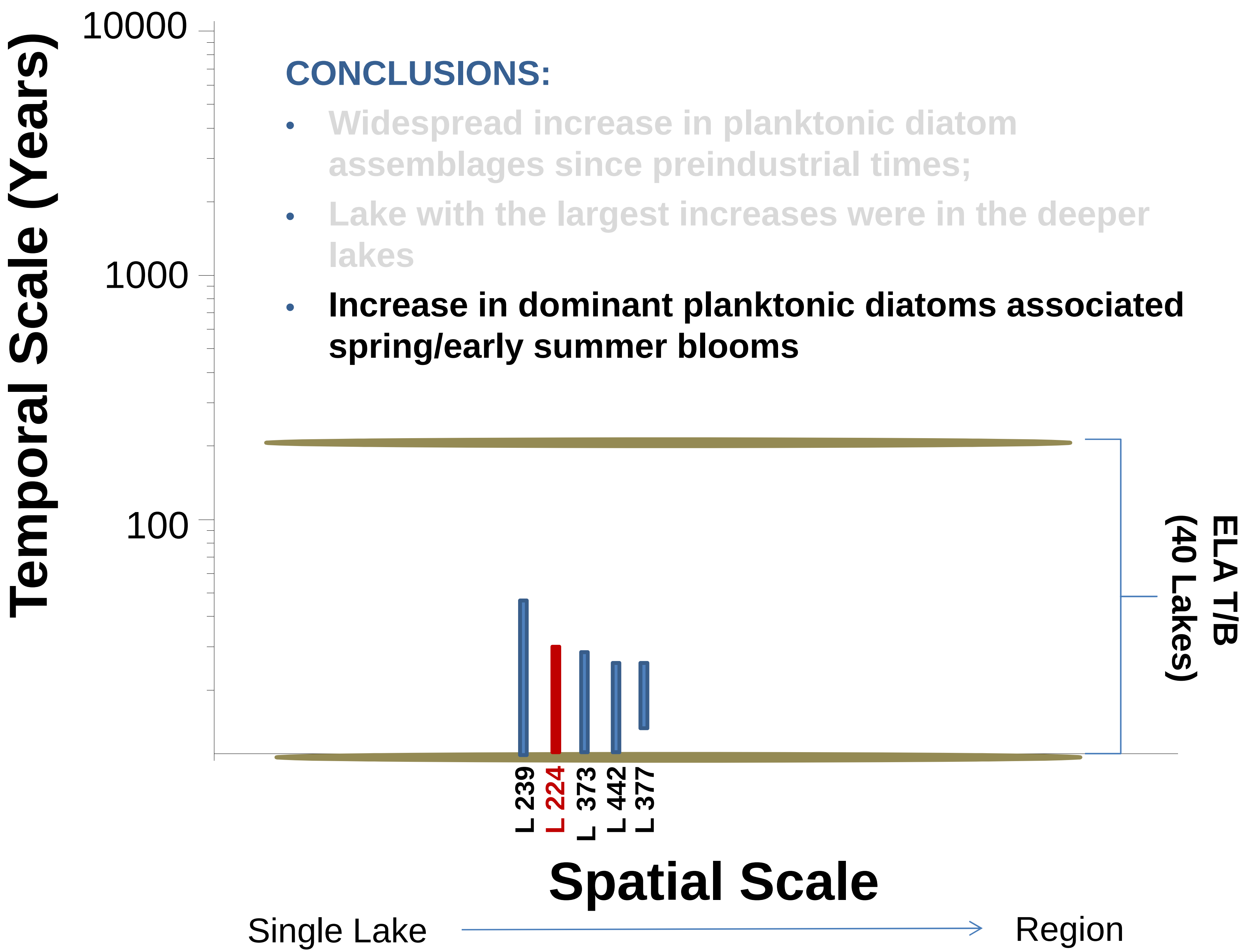


Wiltse (2014)

LAKE 224 – Small *Discostella*

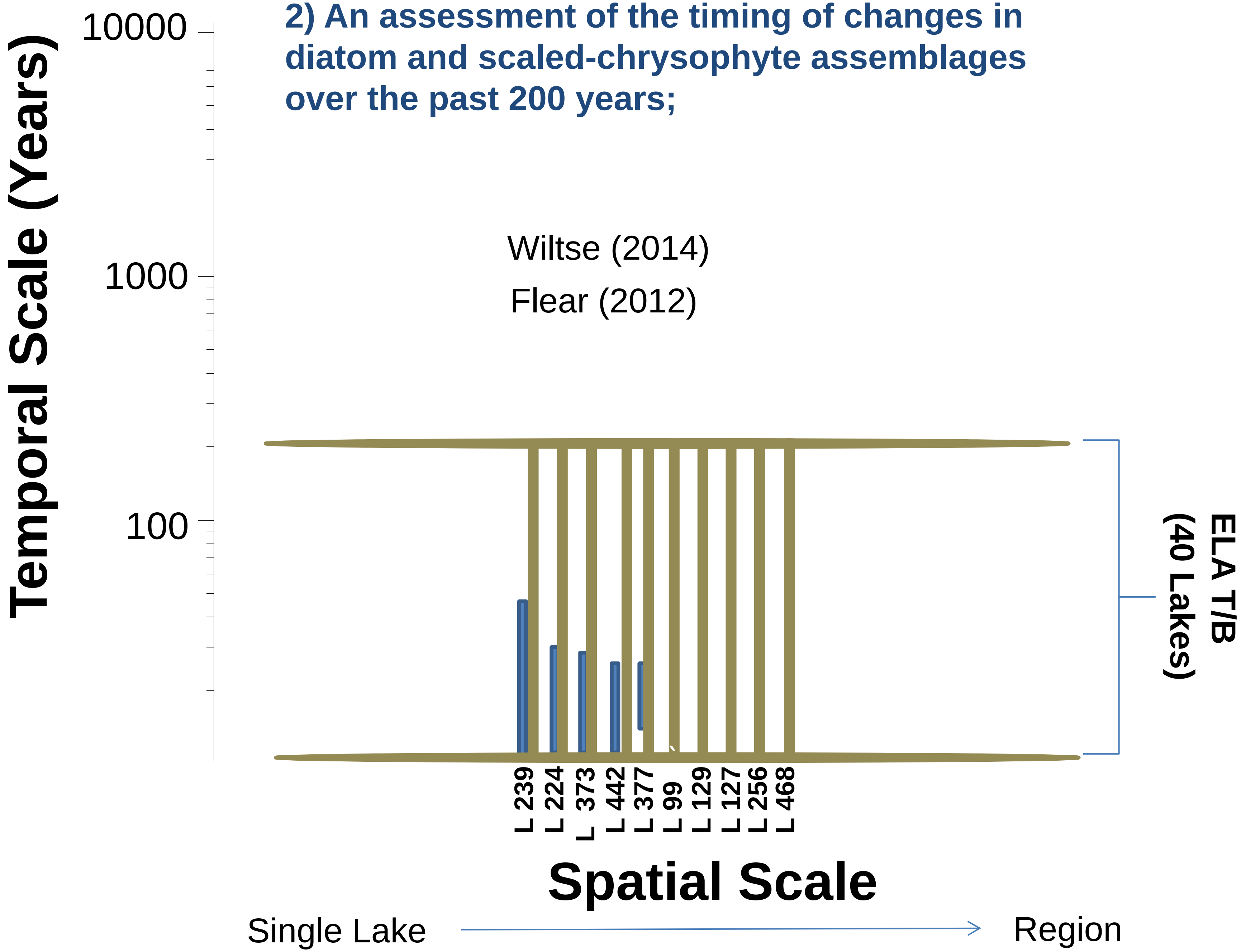


Wiltse (2014)

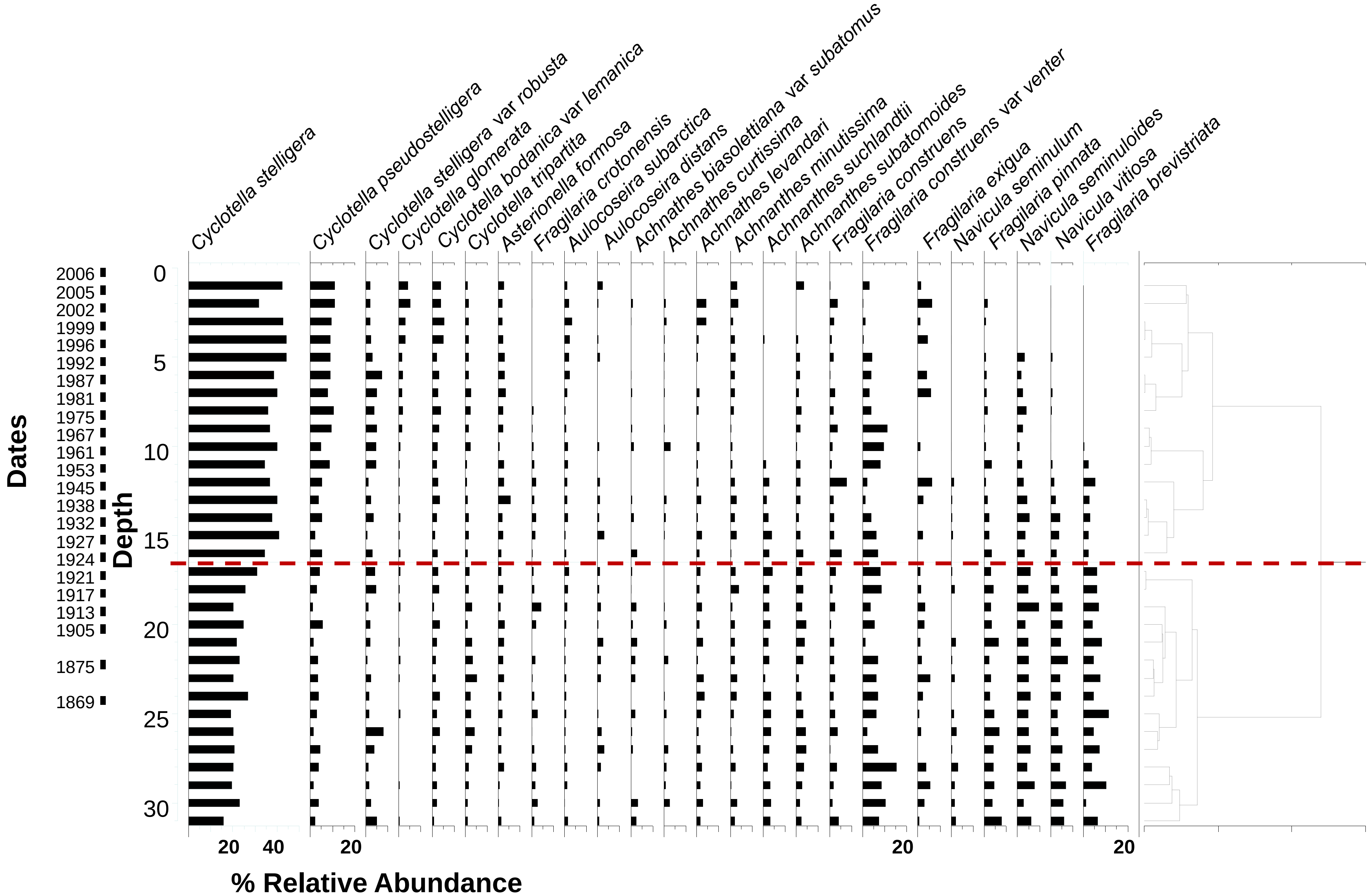


Temporal Scale (Years)
10000
1000
100
CONCLUSIONS:
• Widespread increase in planktonic diatom assemblages since preindustrial times;
• Lake with the largest increases were in the deeper lakes
• Increase in dominant planktonic diatoms associated spring/early summer blooms
ELA T/B
(40 Lakes)
L 239
L 224
L 373
L 442
L 377
Spatial Scale
Single Lake
Region

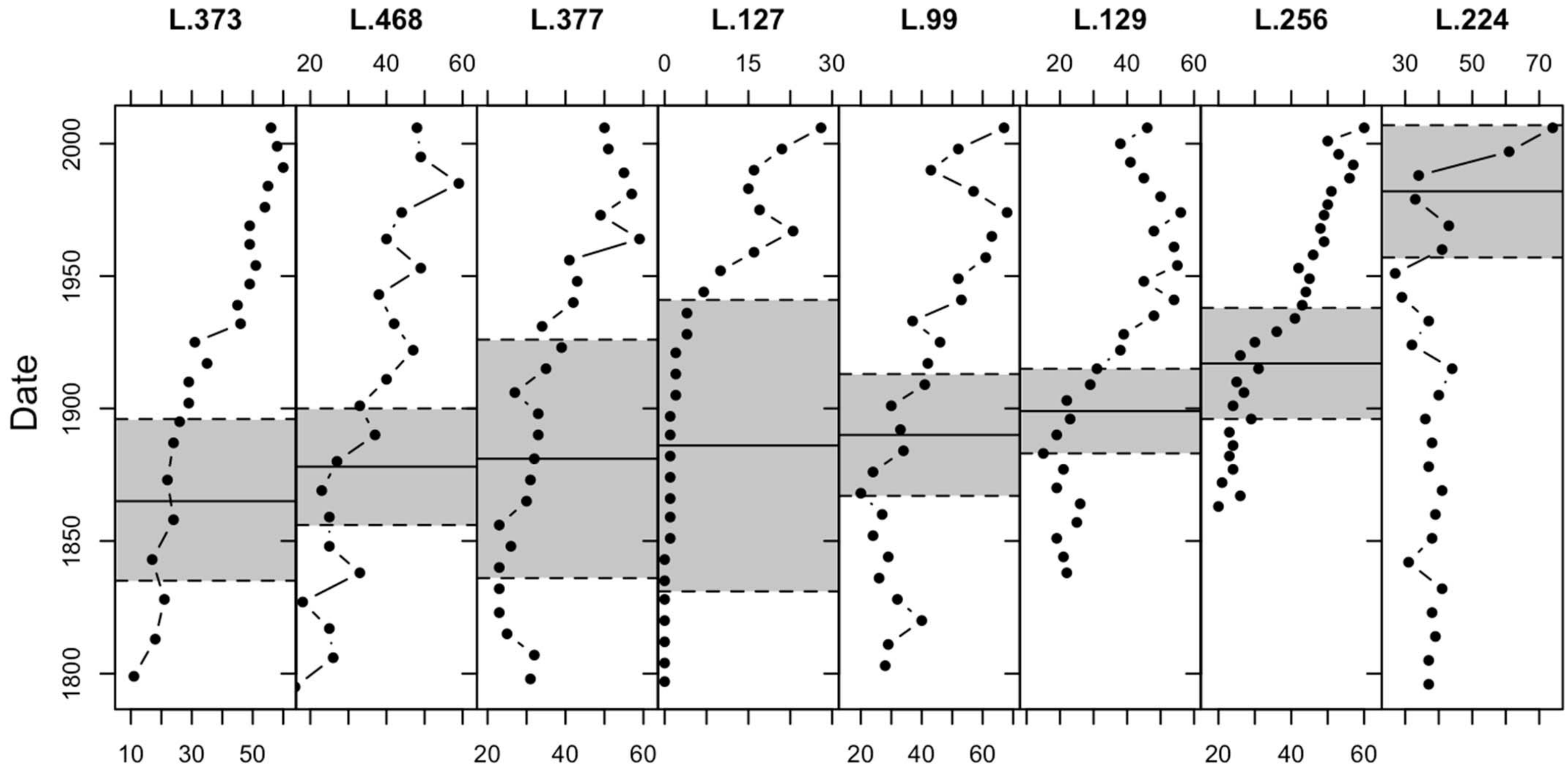
2) An assessment of the timing of changes in diatom and scaled-chrysophyte assemblages over the past 200 years;



ELA Lake 256 – Diatom Assemblage in Deep-water Sediment Core



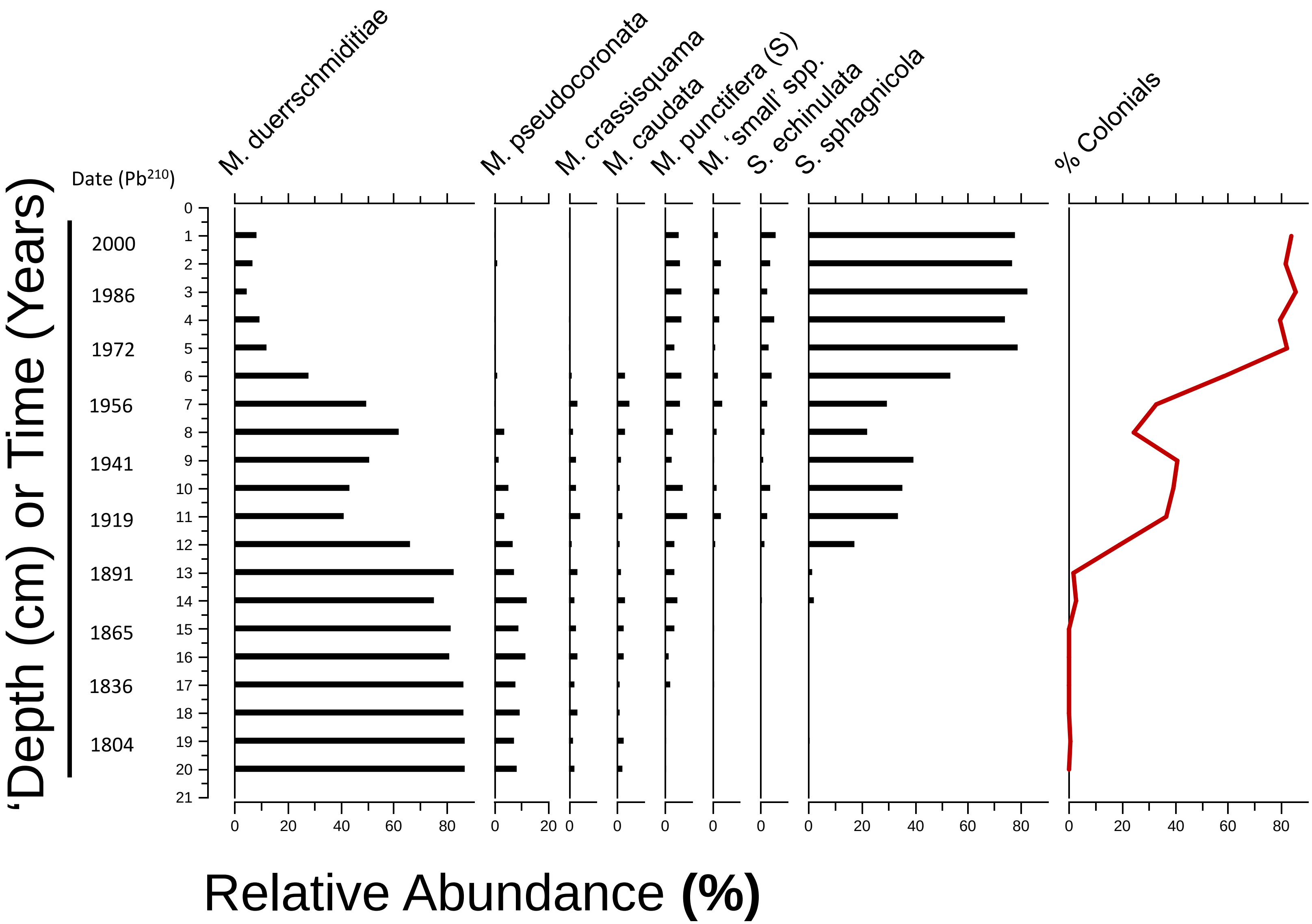
Wiltse (2014)



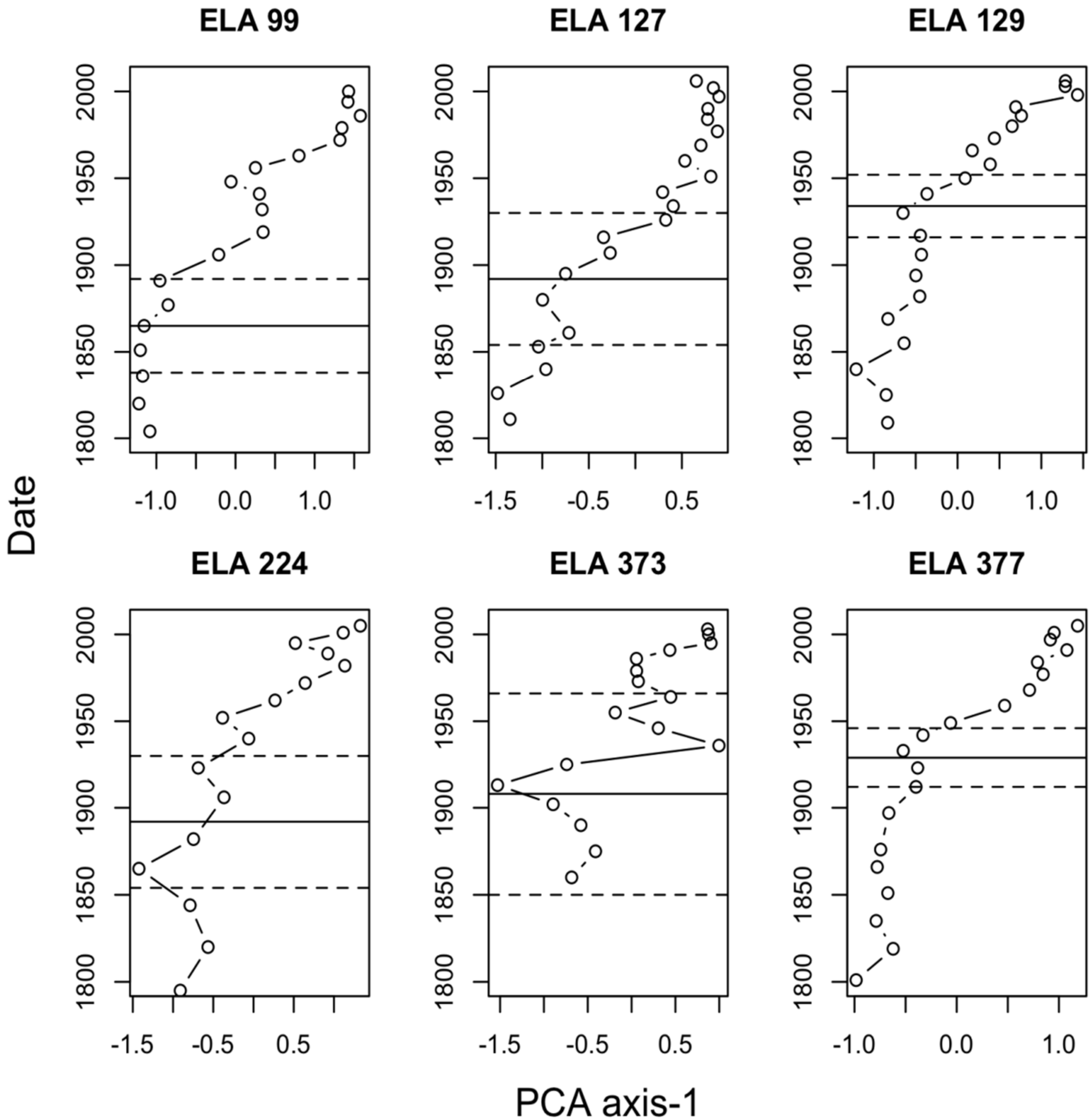
‘Small’ *Discostella* (Relative Abundance**)**

Wiltse (2014)

ELA Lake 99 – Scaled-chrysophyte Assemblage in Deep-water Core



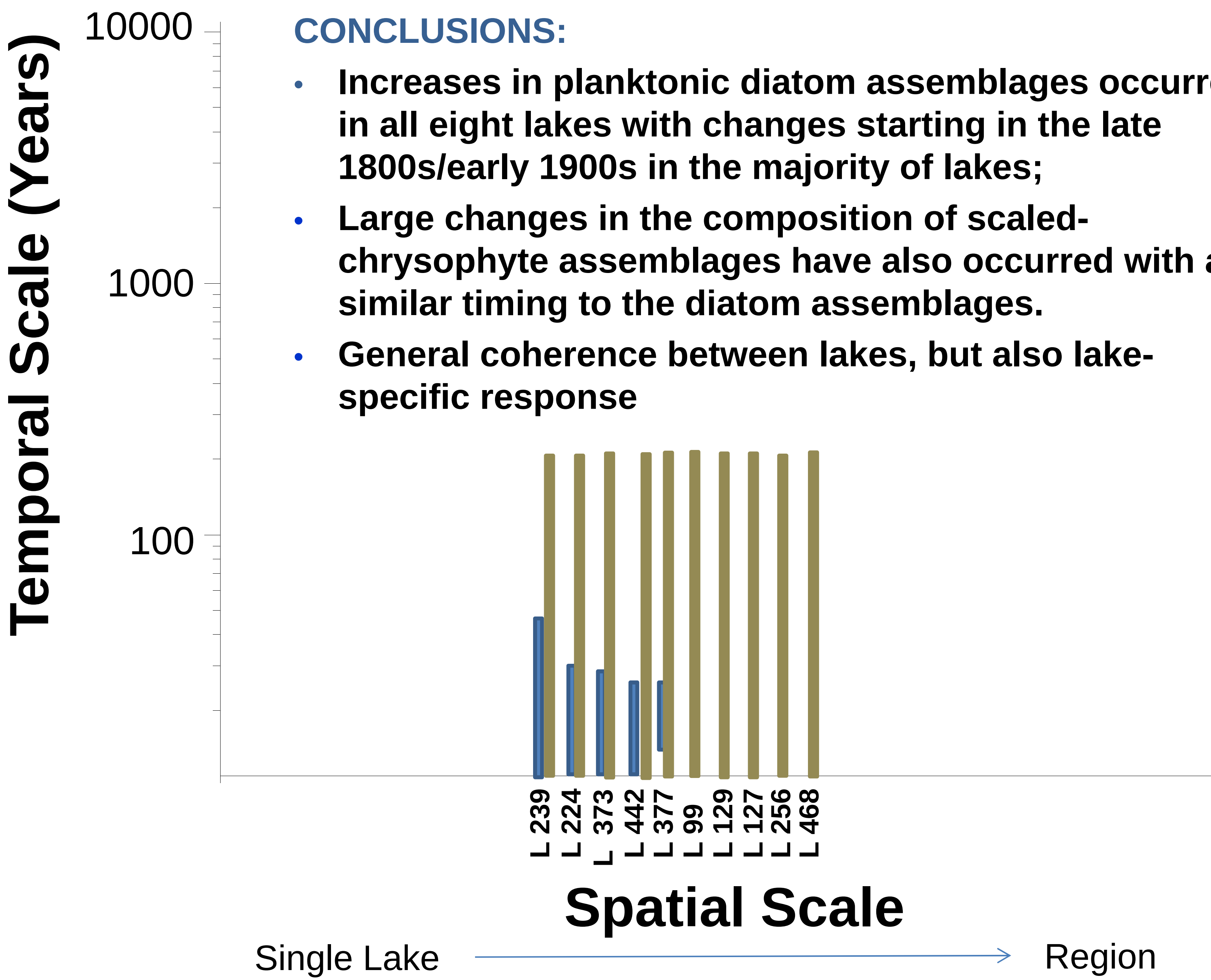
Flear (2012)



Flear (2012)

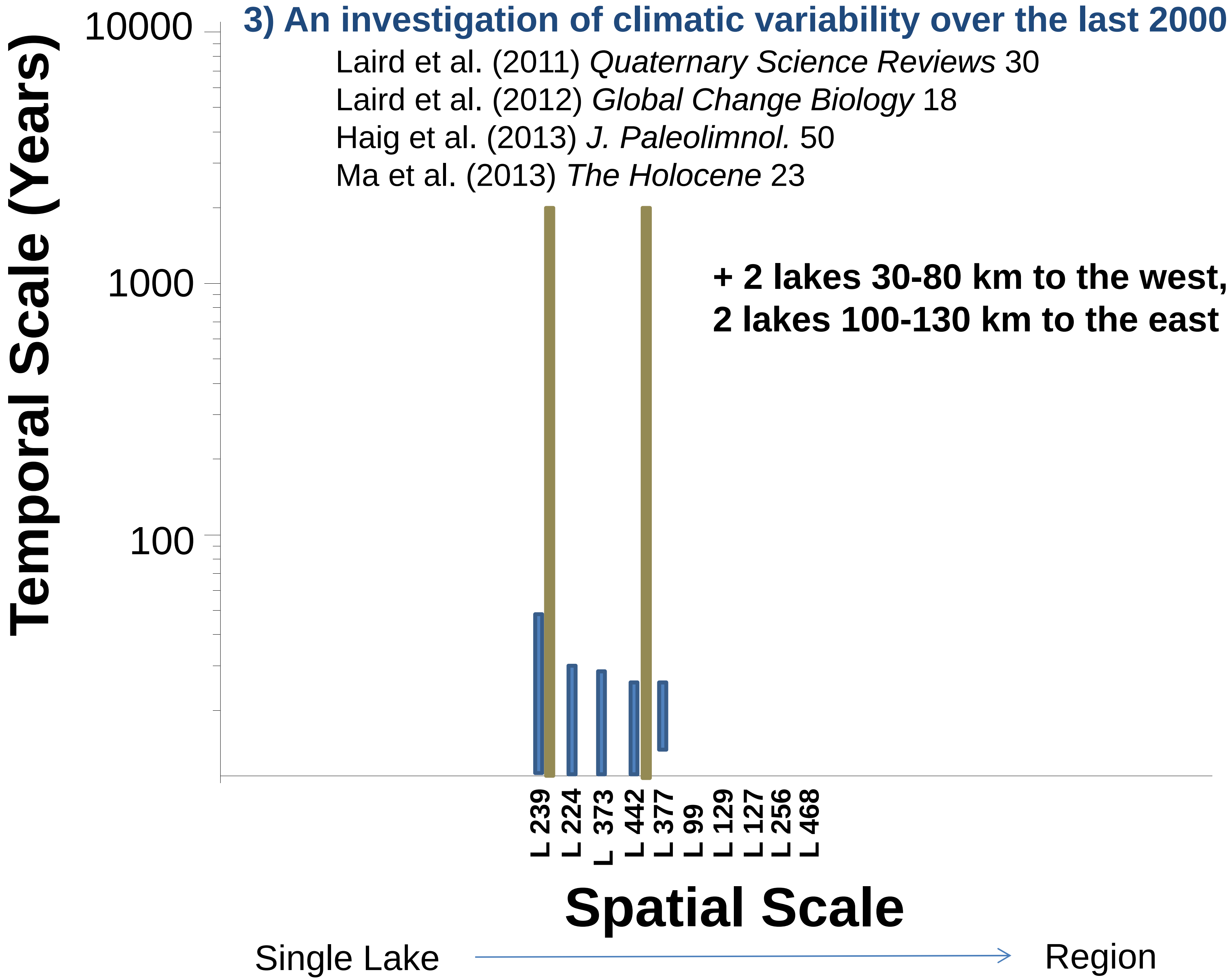
CONCLUSIONS:

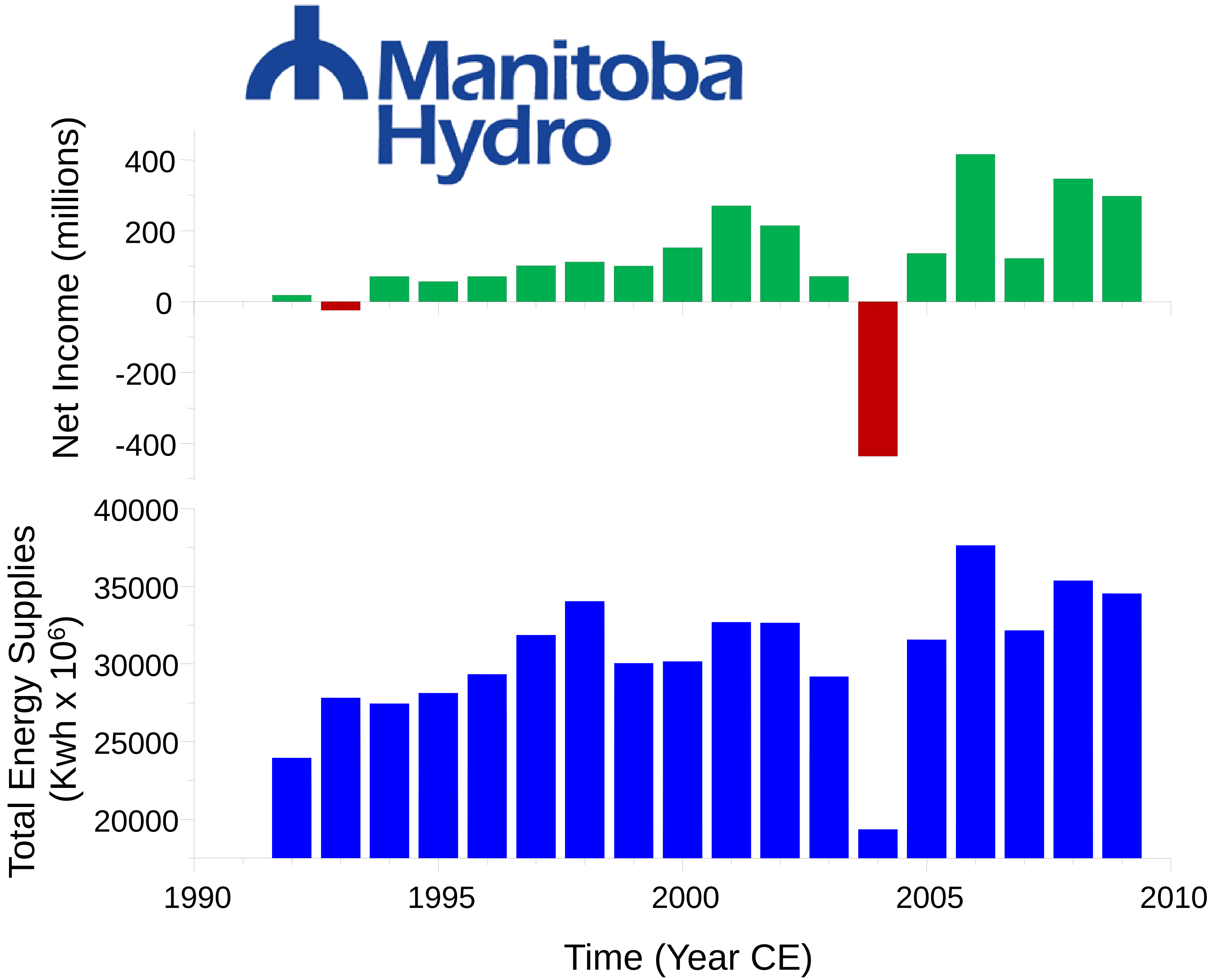
- **Increases in planktonic diatom assemblages occurred in all eight lakes with changes starting in the late 1800s/early 1900s in the majority of lakes;**
- **Large changes in the composition of scaled-chrysophyte assemblages have also occurred with a similar timing to the diatom assemblages.**
- **General coherence between lakes, but also lake-specific response**



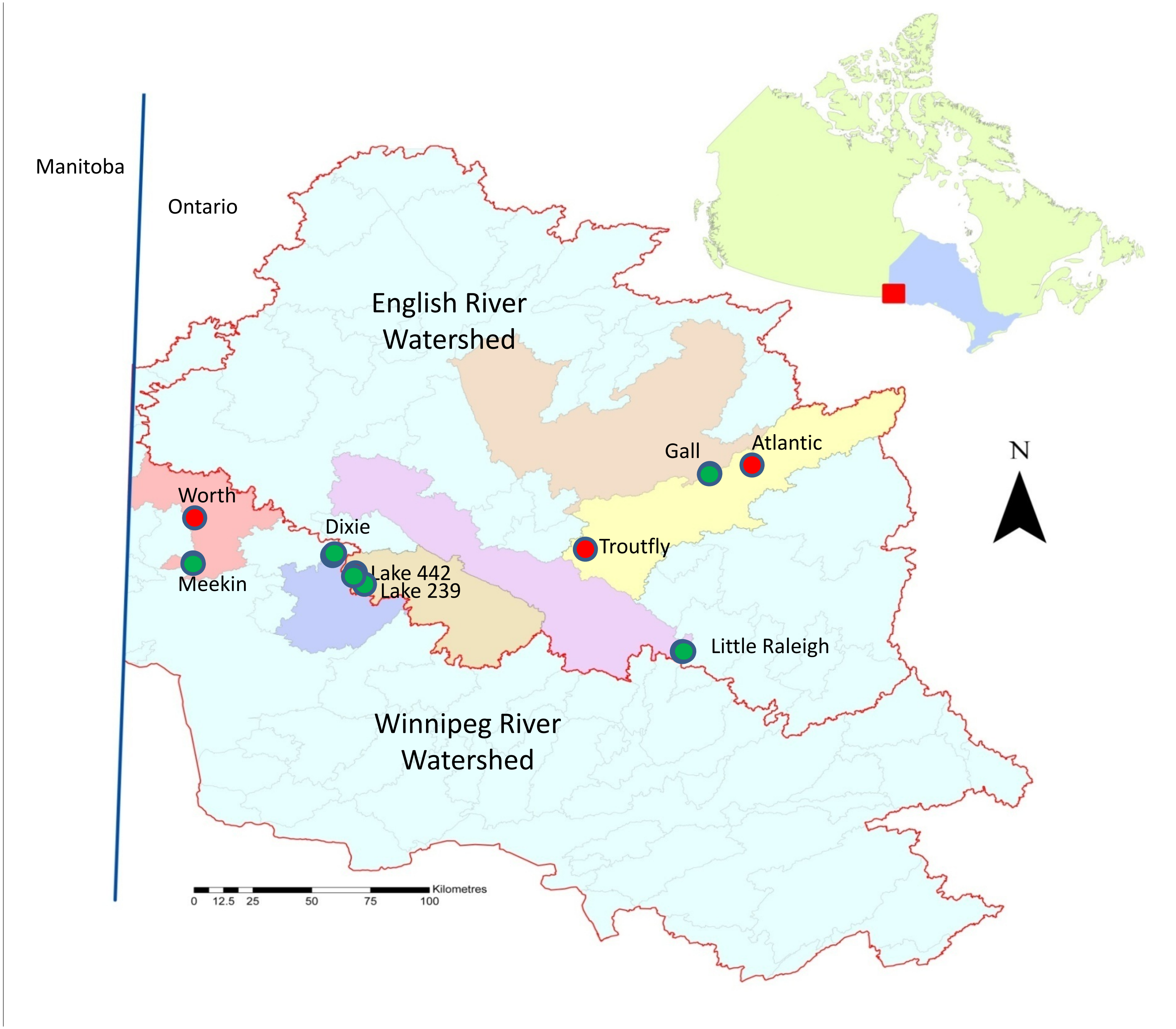
3) An investigation of climatic variability over the last 2000 years;

Laird et al. (2011) *Quaternary Science Reviews* 30
Laird et al. (2012) *Global Change Biology* 18
Haig et al. (2013) *J. Paleolimnol.* 50
Ma et al. (2013) *The Holocene* 23

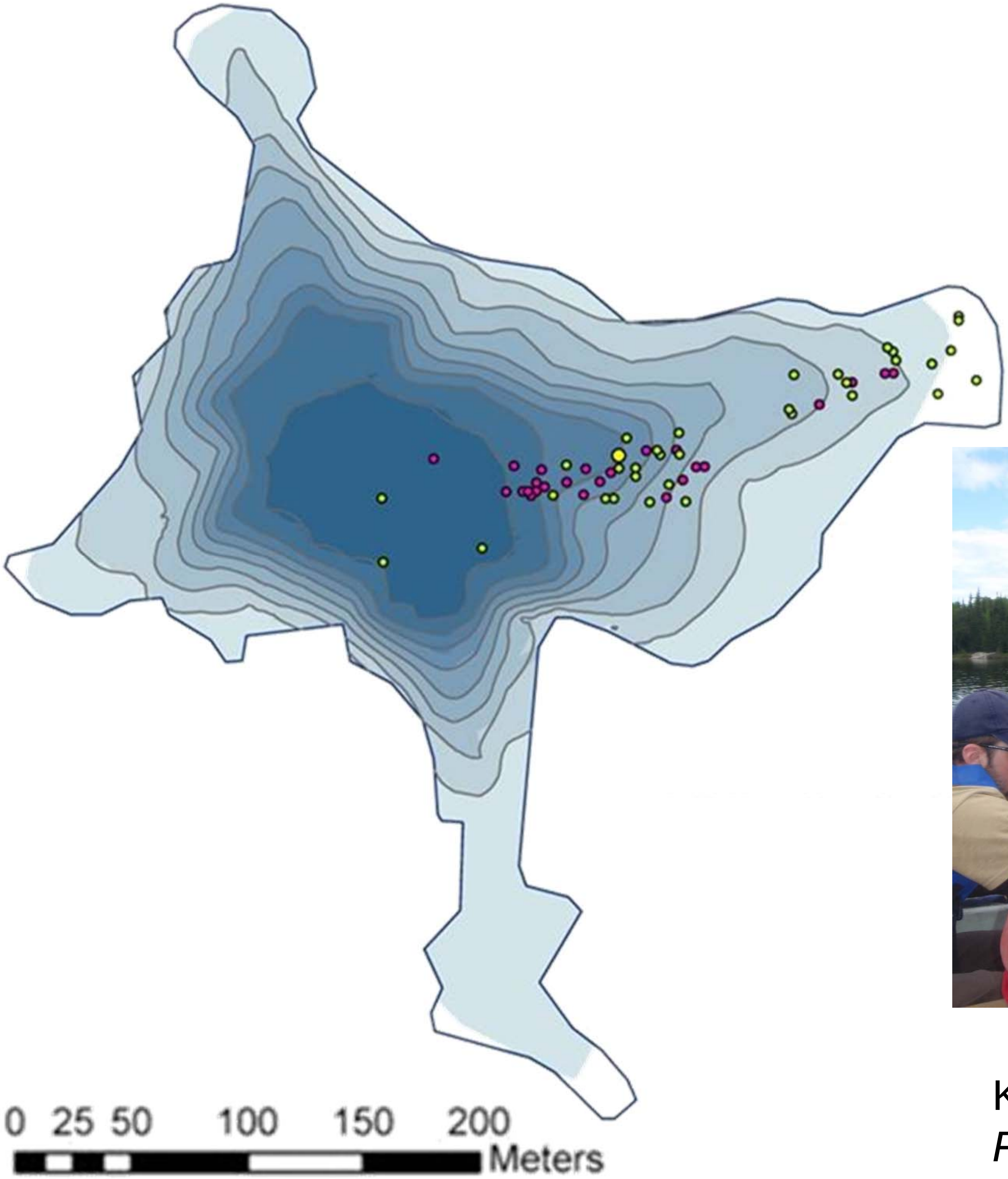




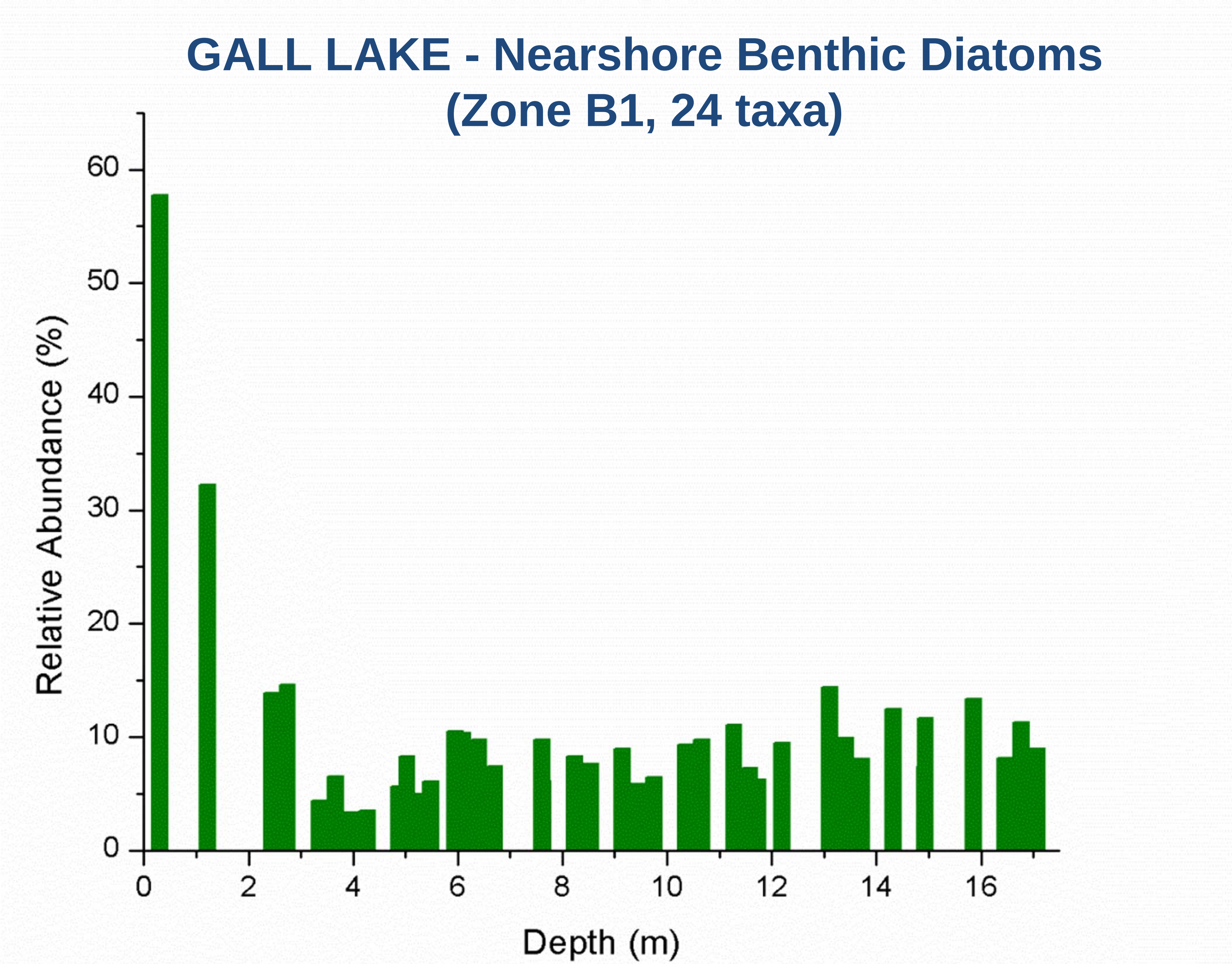
Manitoba Hydro
Net Income (millions)
400
200
0
-200
-400
Total Energy Supplies (Kwh x 10⁶)
40000
35000
30000
25000
20000
1990
1995
2000
2005
2010
Time (Year CE)


Manitoba
Ontario
English River Watershed
Gall
Atlantic
Worth
Dixie
Troutfly
Lake 442
Lake 239
Meekin
Little Raleigh
Winnipeg River Watershed
N
Kilometres
0 12.5 25 50 75 100

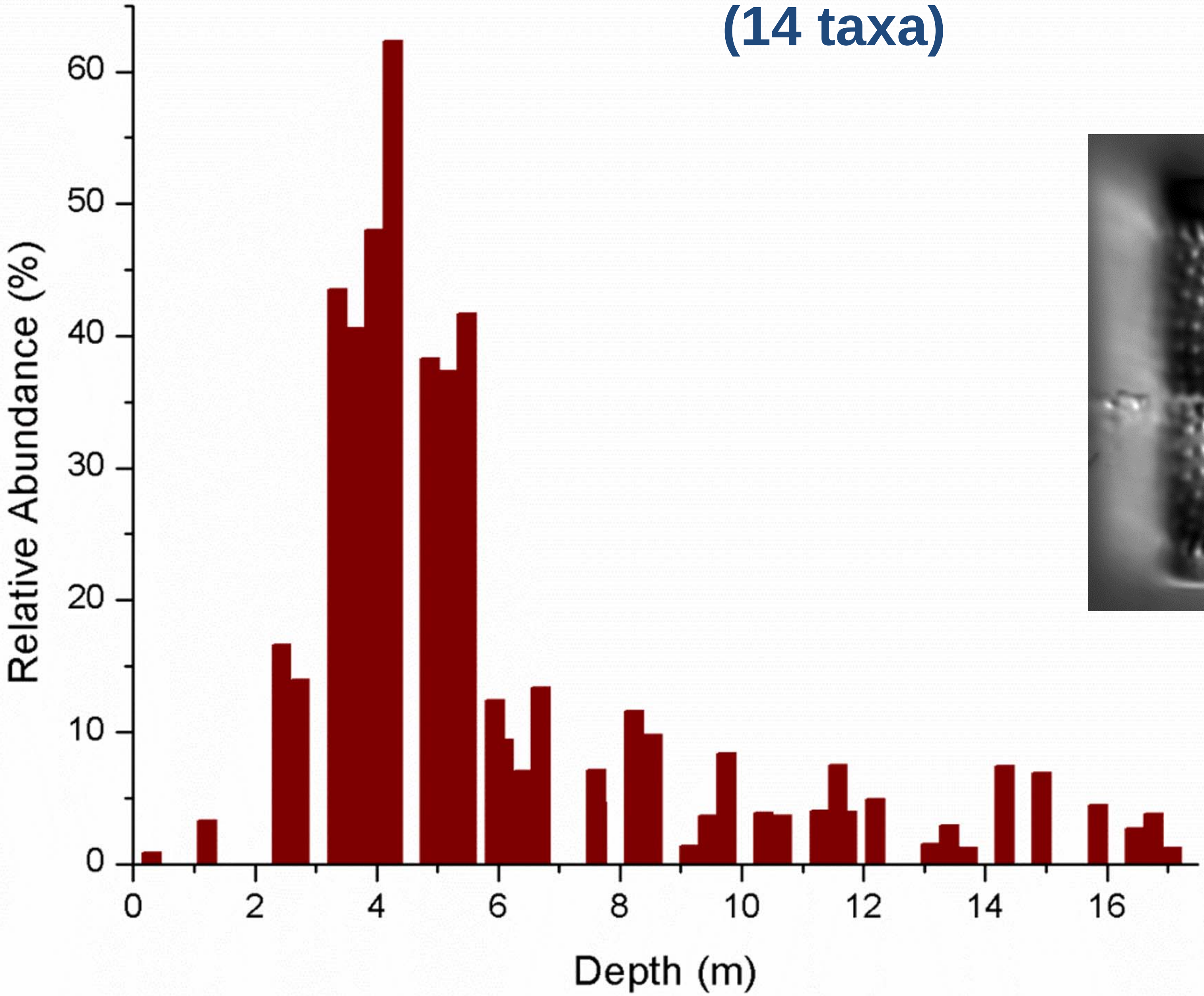
GALL LAKE – Calibration to lake depth (55 surface samples)

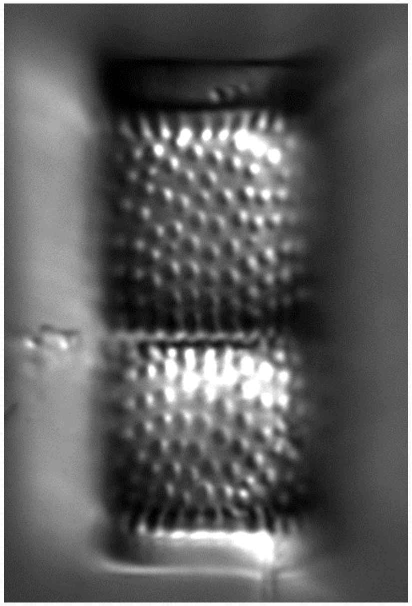


Kingsbury, Laird & Cumming (2012)
Freshwater Biology 57

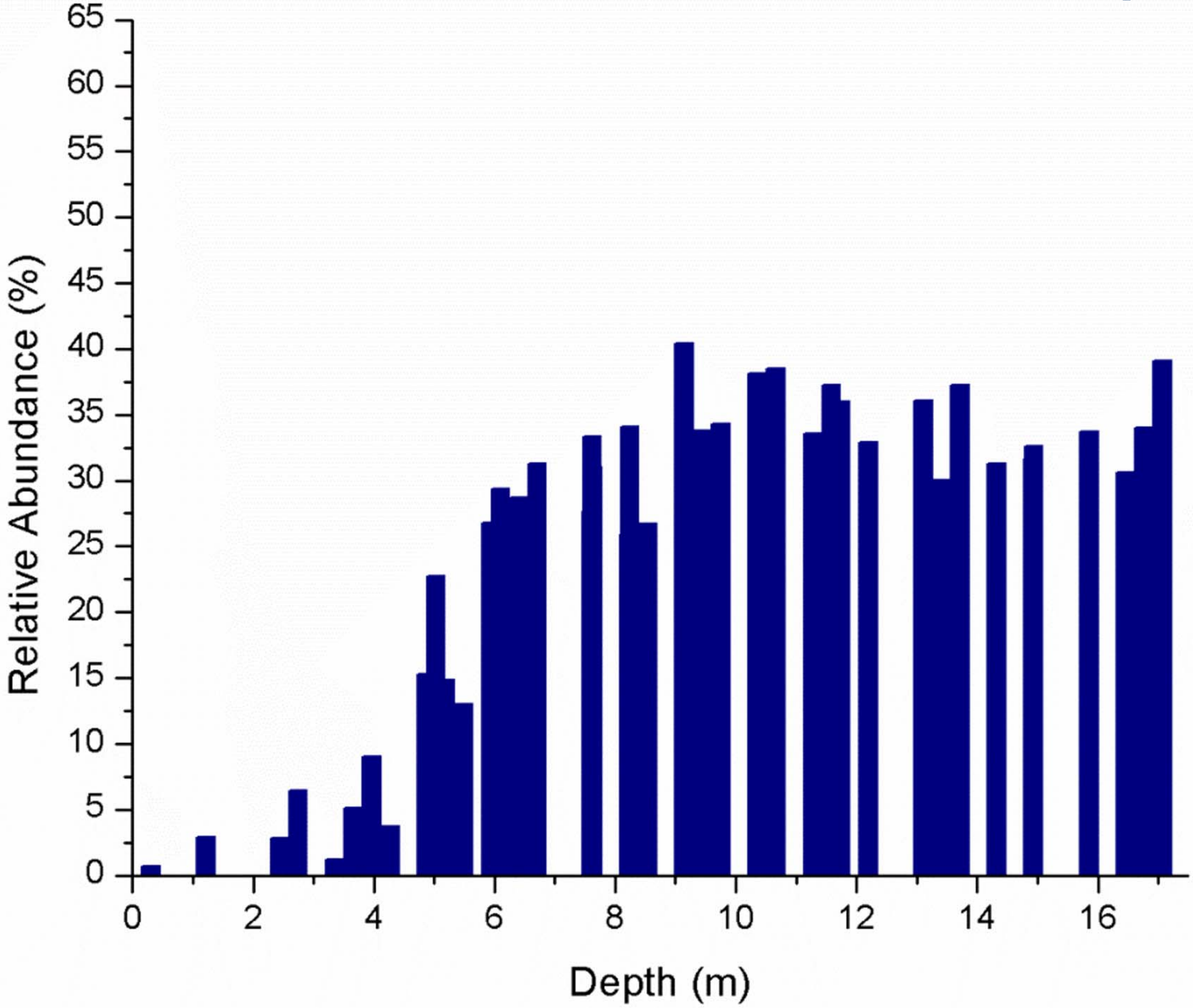

GALL LAKE - Nearshore Benthic Diatoms
(Zone B1, 24 taxa)
Relative Abundance (%)
Depth (m)
0
10
20
30
40
50
60
0
2
4
6
8
10
12
14
16

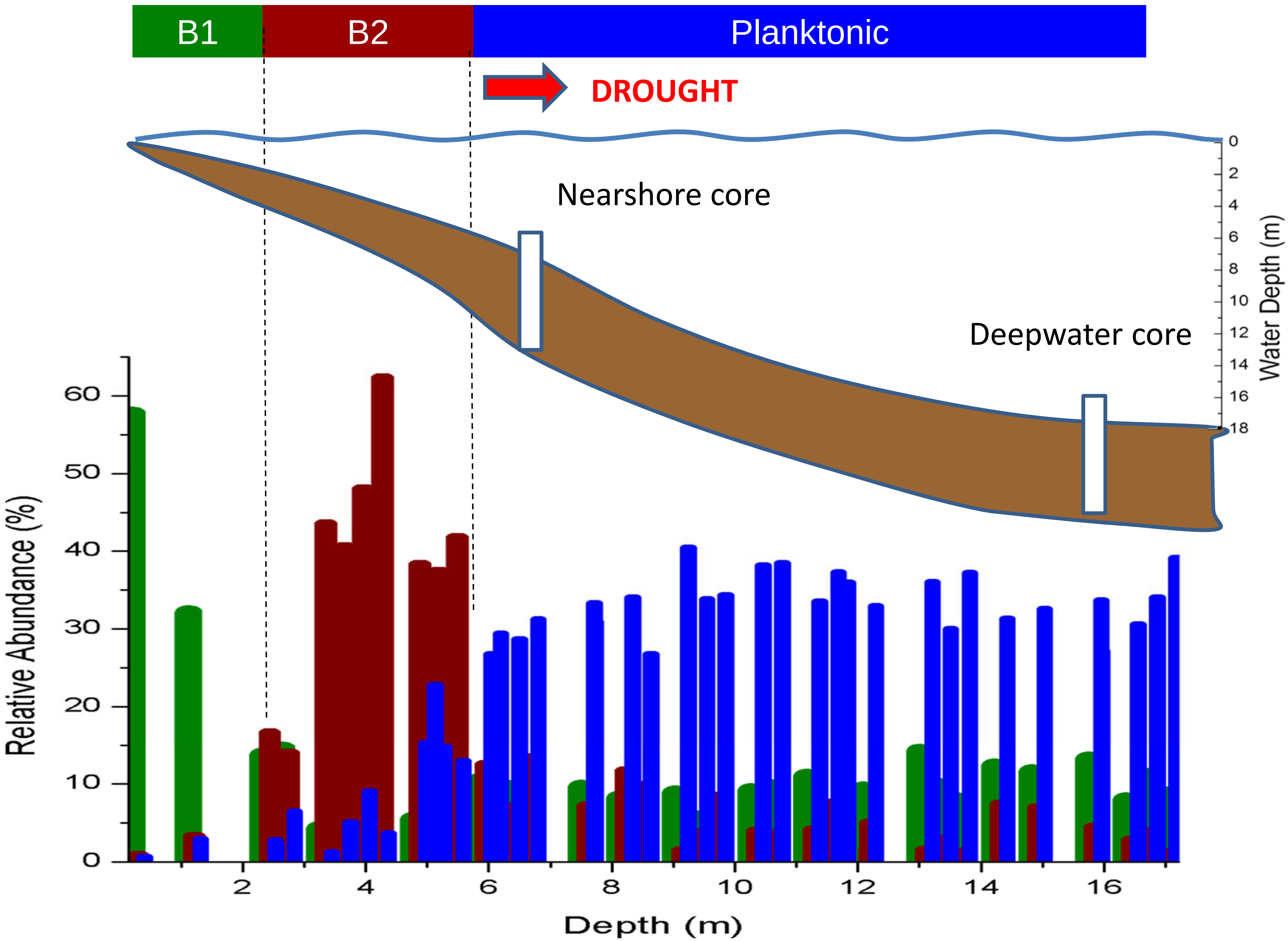
GALL LAKE - Mid-depth Benthic Diatoms (14 taxa)



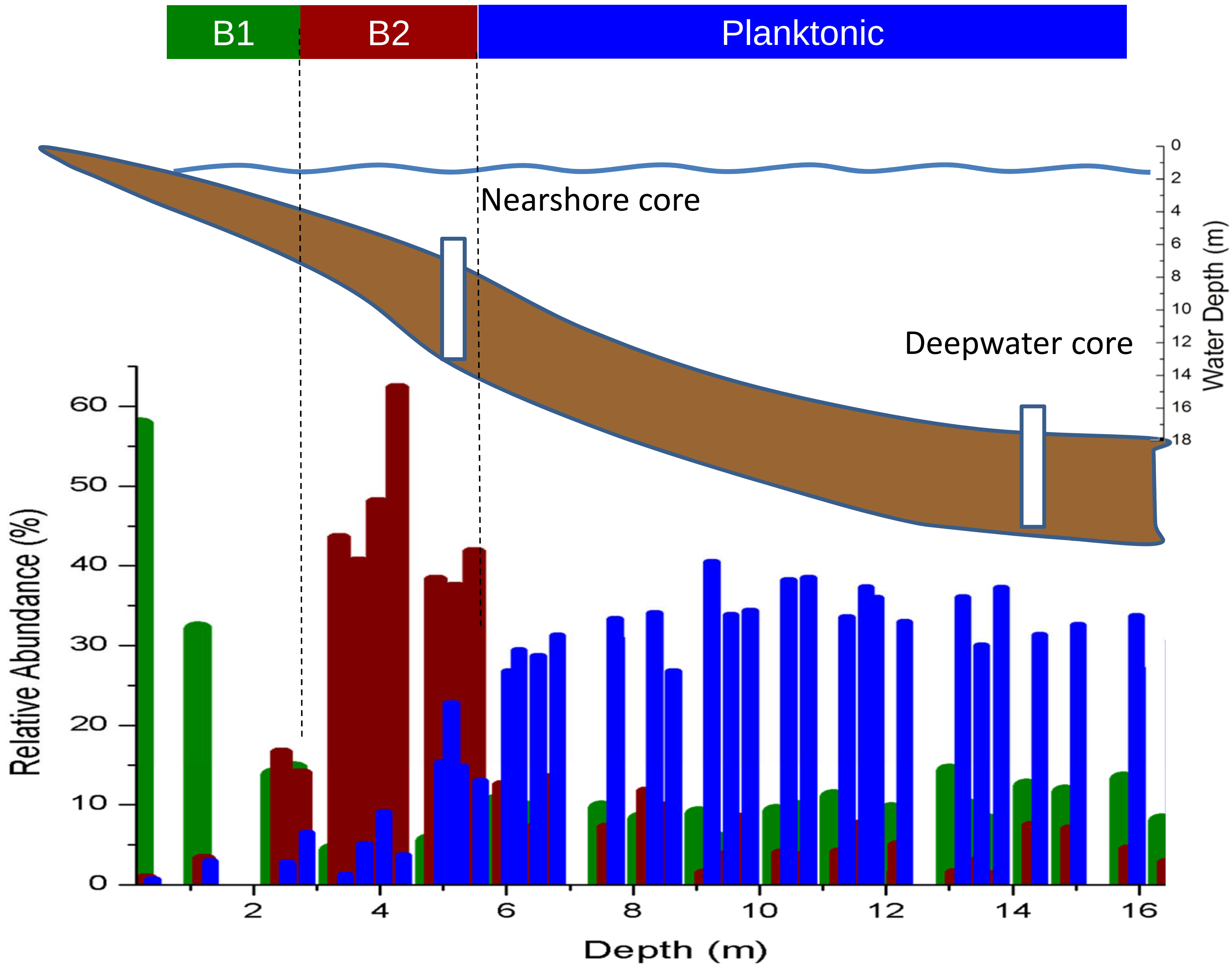


GALL LAKE - Planktonic Diatoms (8 taxa)

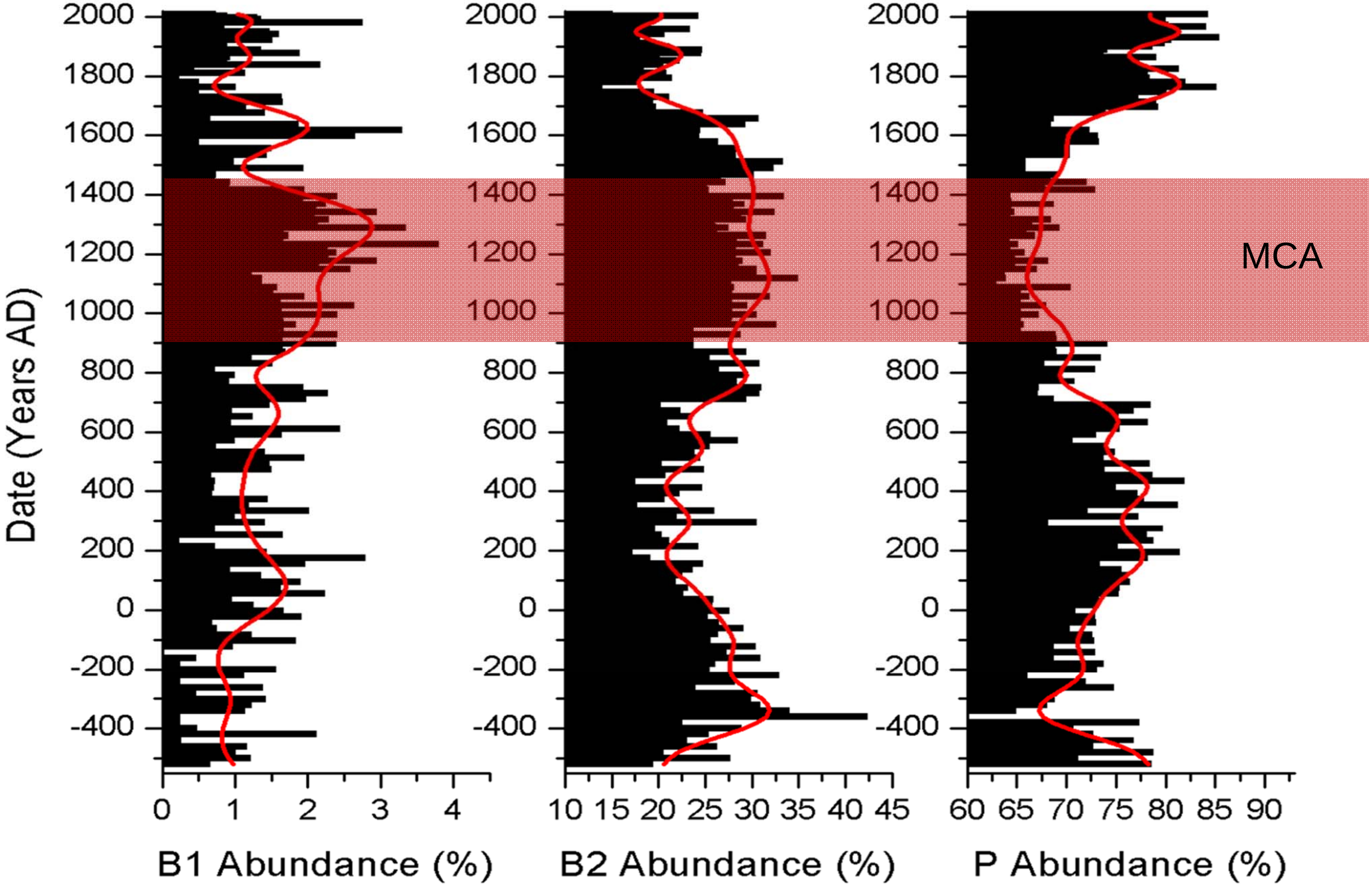




B1
B2
Planktonic
DROUGHT
Nearshore core
Deepwater core
Water Depth (m)
0
2
4
6
8
10
12
14
16
18
Relative Abundance (%)
0
10
20
30
40
50
60
2
4
6
8
10
12
14
16
Depth (m)

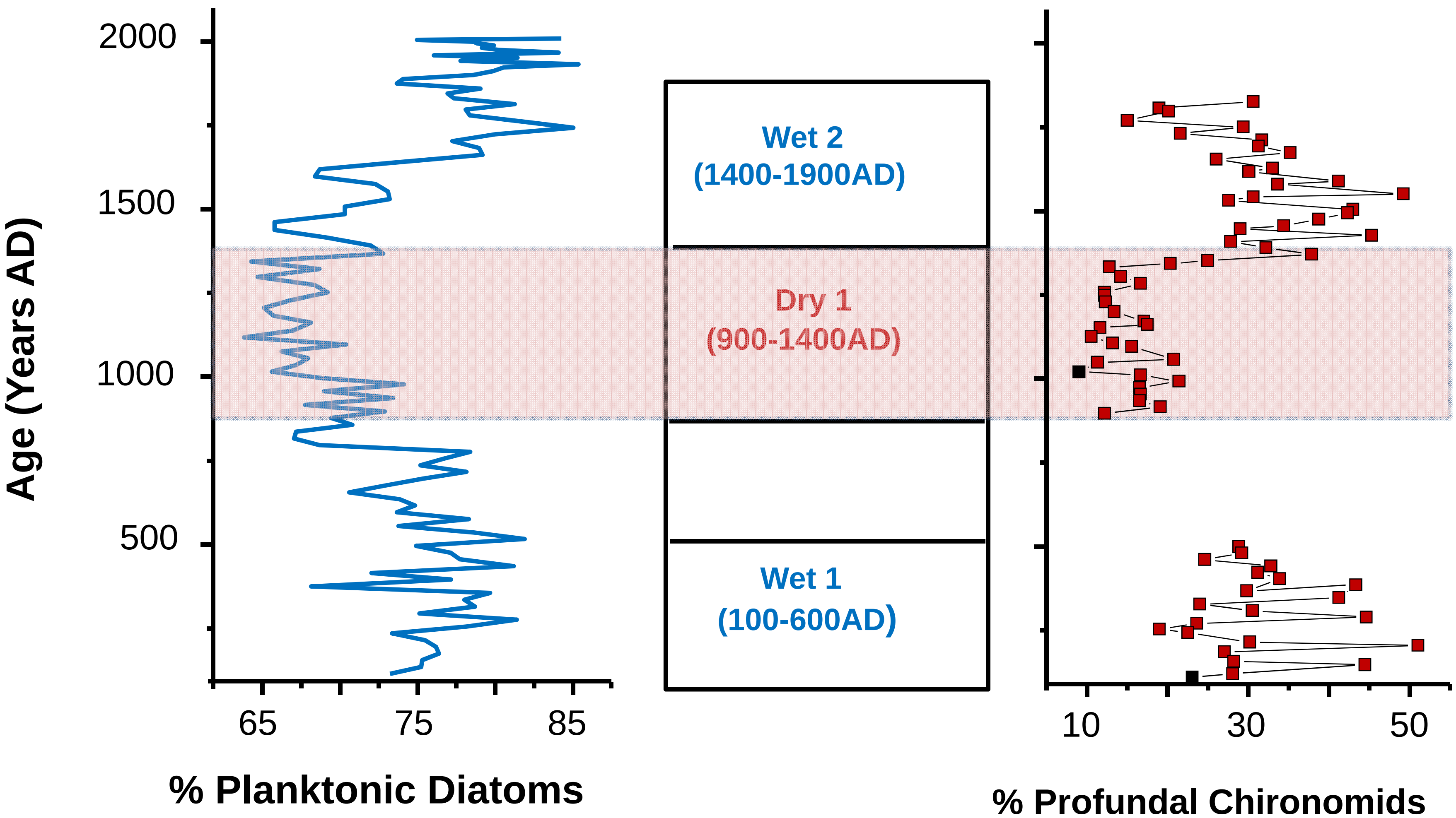

B1
B2
Planktonic
Nearshore core
Deepwater core
Water Depth (m)
0
2
4
6
8
10
12
14
16
18
Relative Abundance (%)
0
10
20
30
40
50
60
Depth (m)
2
4
6
8
10
12
14
16

GALL LAKE – Last 2500 years



Haig et al. (2013) J. Paleolimnol. 50

GALL LAKE – Multiproxy inference of MCA



Karmakar et al. (2013), Quat. Res.

3) An investigation of climatic variability over the last 2000 years;

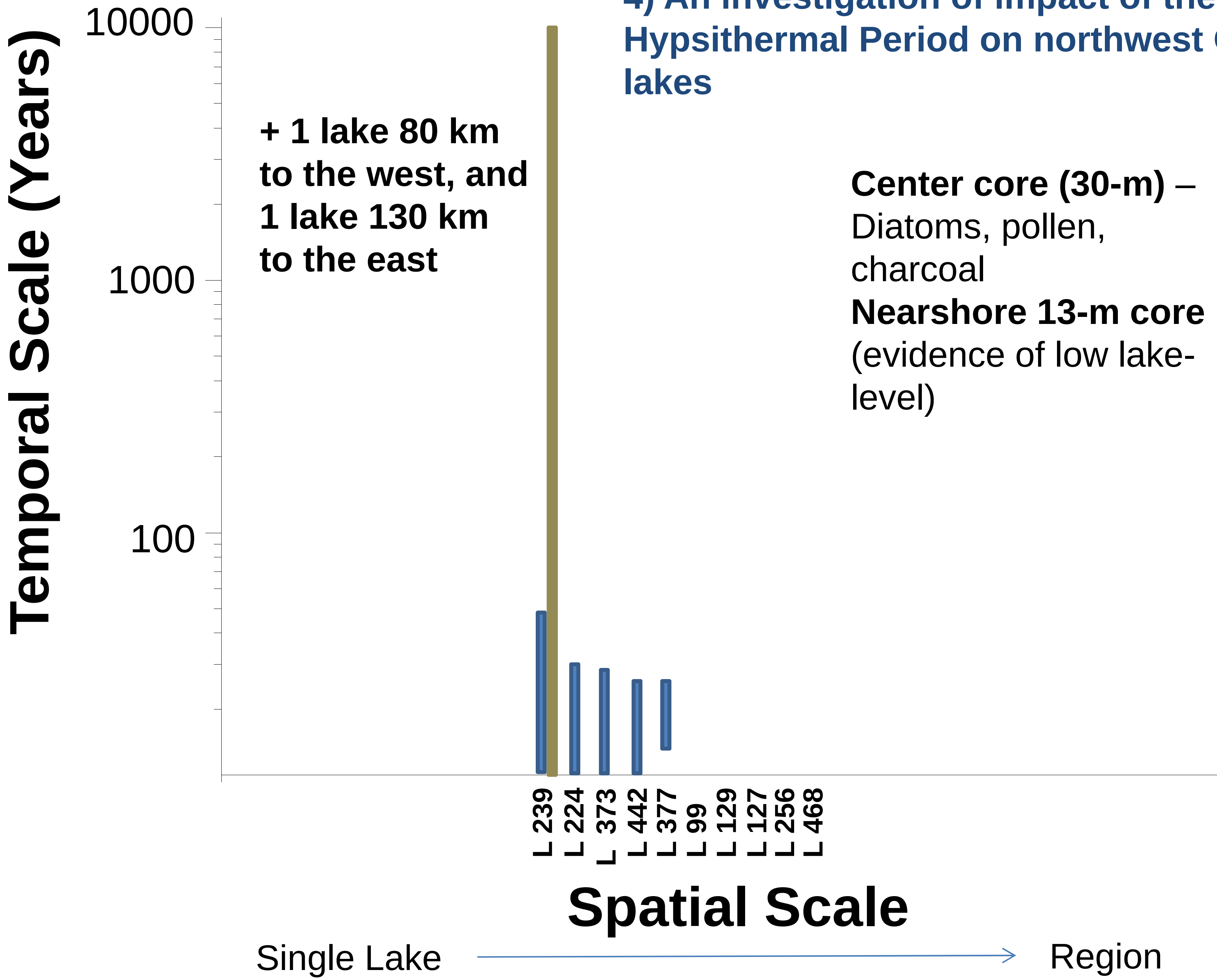
CONCLUSIONS:

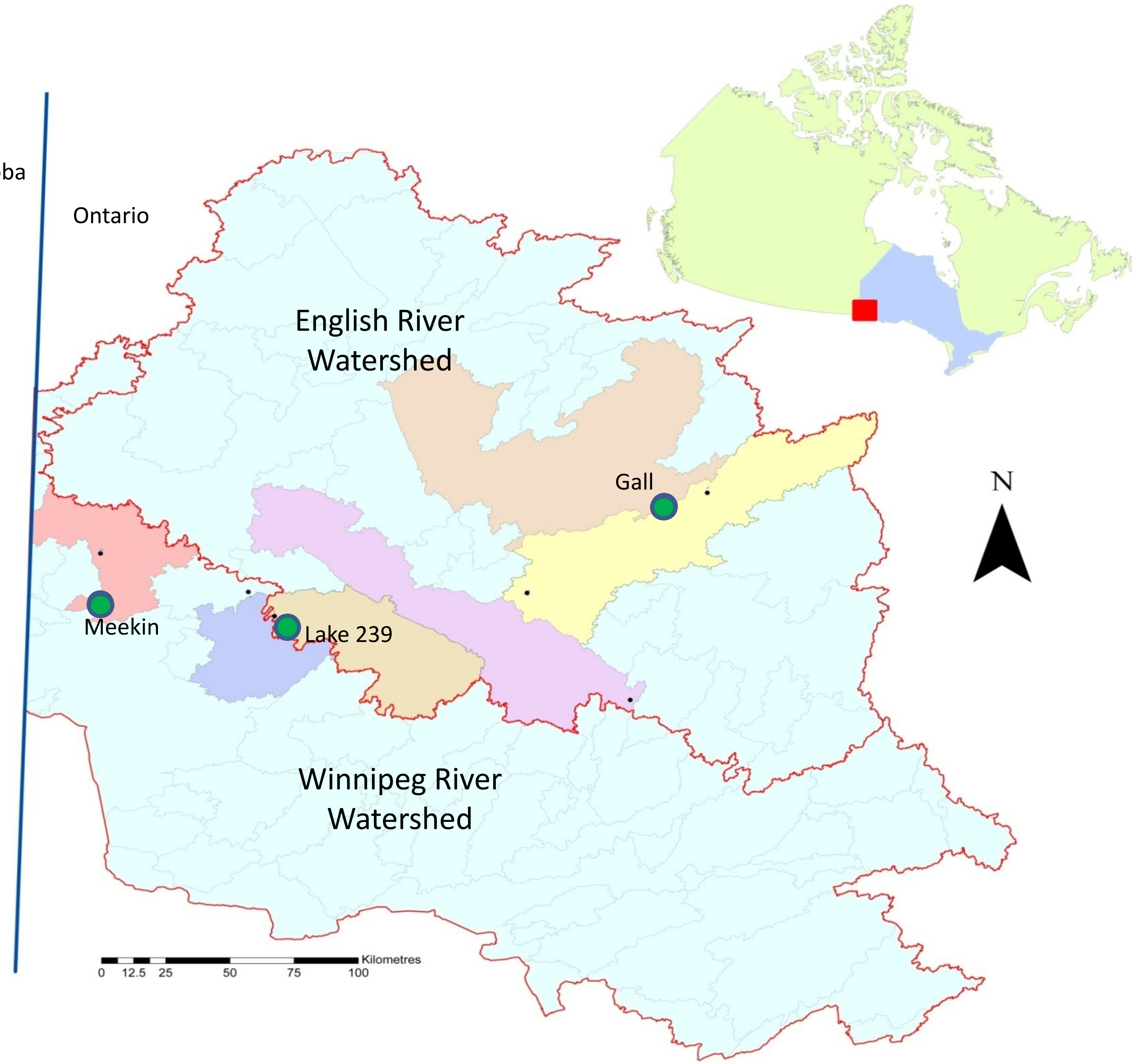
All six lakes experienced prolonged periods of increases in benthic taxa, that surpassed changes in the last century, suggesting either lower water levels or decreased inputs of DOC, both of which are associated with drought;

The only synchronous signal of increases in benthic taxa lakes across the WRDB occurred during the Medieval Climate Anomaly (MCA, c. 900-1400 CE);

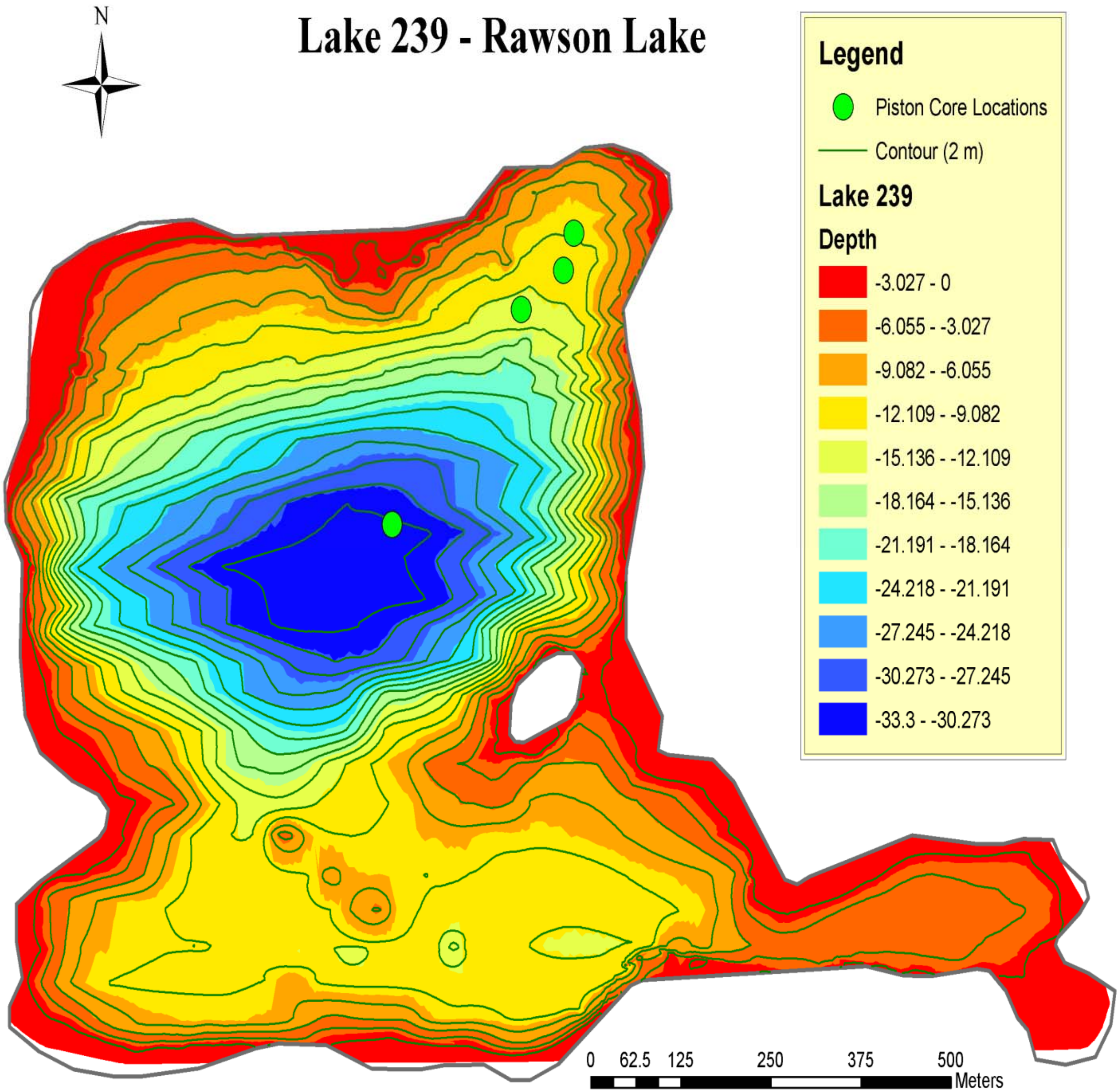
Laird et al. (2011) *Quaternary Science Reviews* 30
Laird et al. (2012) *Global Change Biology* 18
Haig et al. (2013) *J. Paleolimnol.* 50
Ma et al. (2013) *The Holocene* 23

4) An investigation of impact of the Hypsithermal Period on northwest Ontario lakes



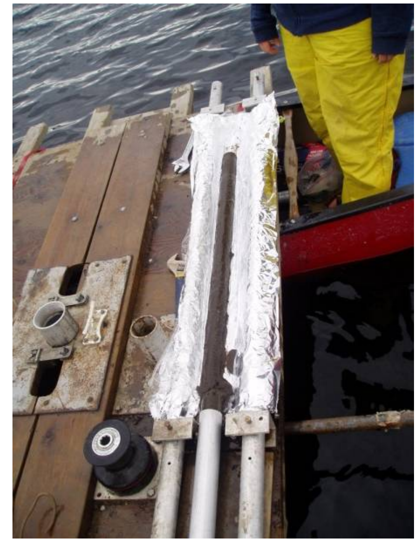
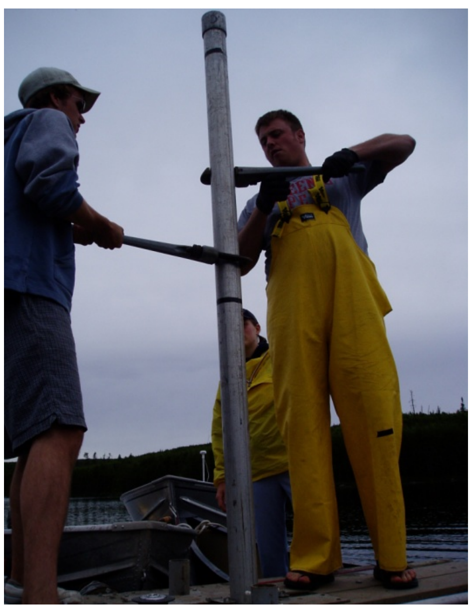


Manitoba
Ontario
English River Watershed
Winnipeg River Watershed
Gall
Meekin
Lake 239
N
Kilometres
0 12.5 25 50 75 100


N
Lake 239 - Rawson Lake
Legend
Piston Core Locations
Contour (2 m)
Lake 239
Depth
-3.027 - 0
-6.055 - -3.027
-9.082 - -6.055
-12.109 - -9.082
-15.136 - -12.109
-18.164 - -15.136
-21.191 - -18.164
-24.218 - -21.191
-27.245 - -24.218
-30.273 - -27.245
-33.3 - -30.273
0 62.5 125 250 375 500
Meters

ELA Lake 239 – Piston Coring

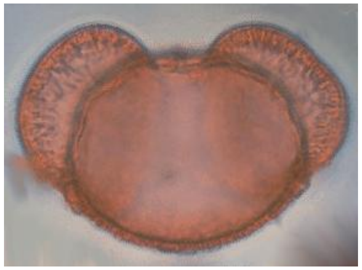


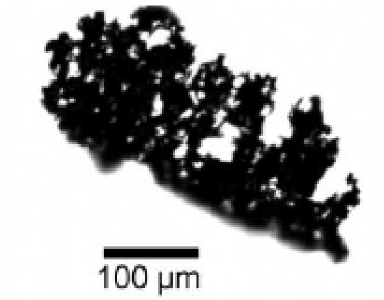
ELA Lake 239 (Deep Core)

Central Core – Proxies

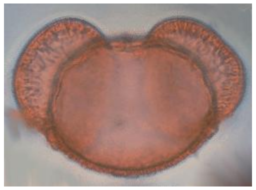
- **Pollen – terrestrial vegetation (Climate)**

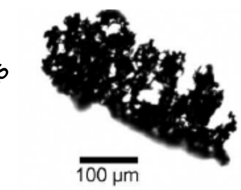


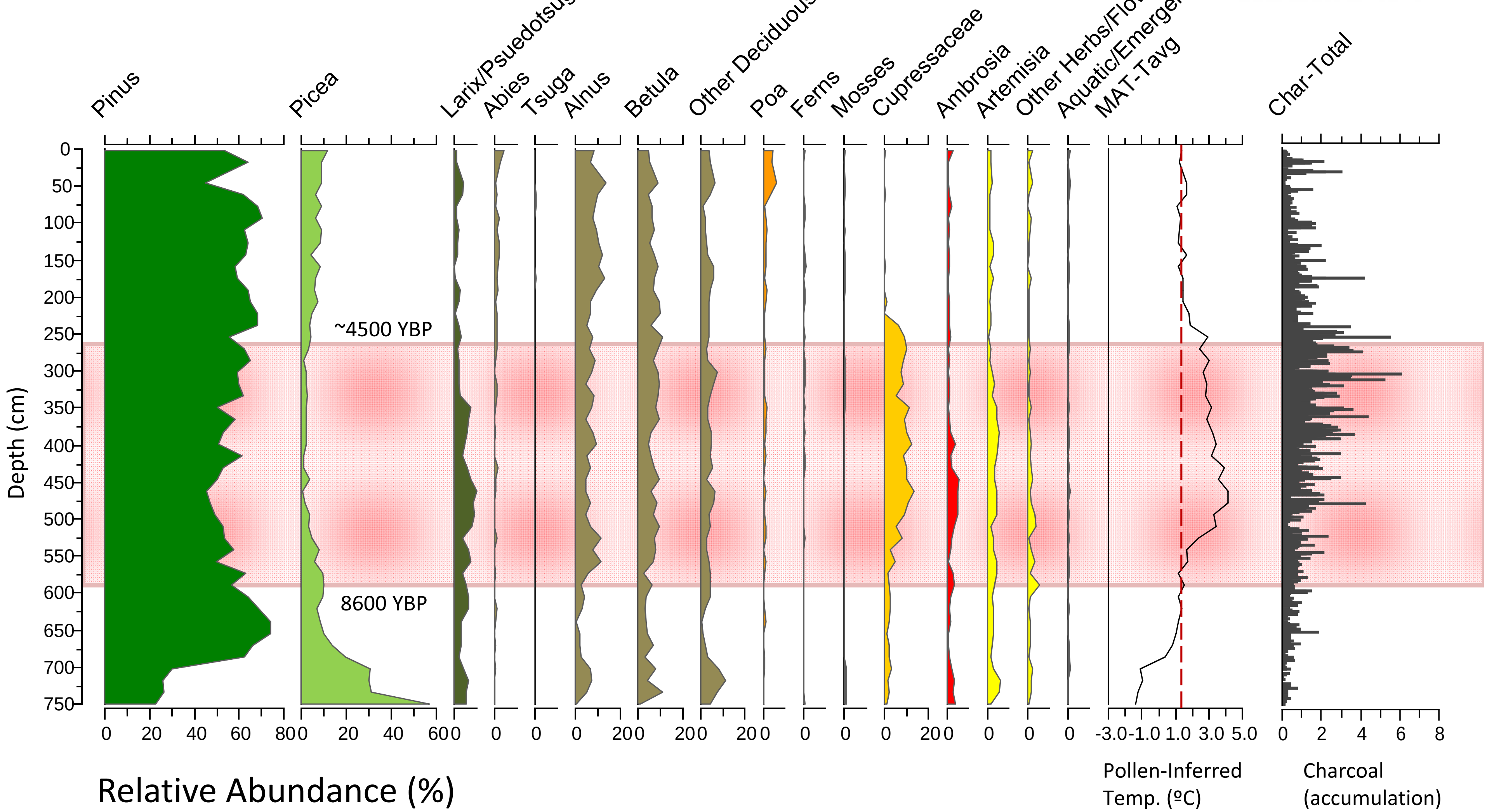
- **Charcoal – fire**



Lake 239 – Pollen and Charcoal

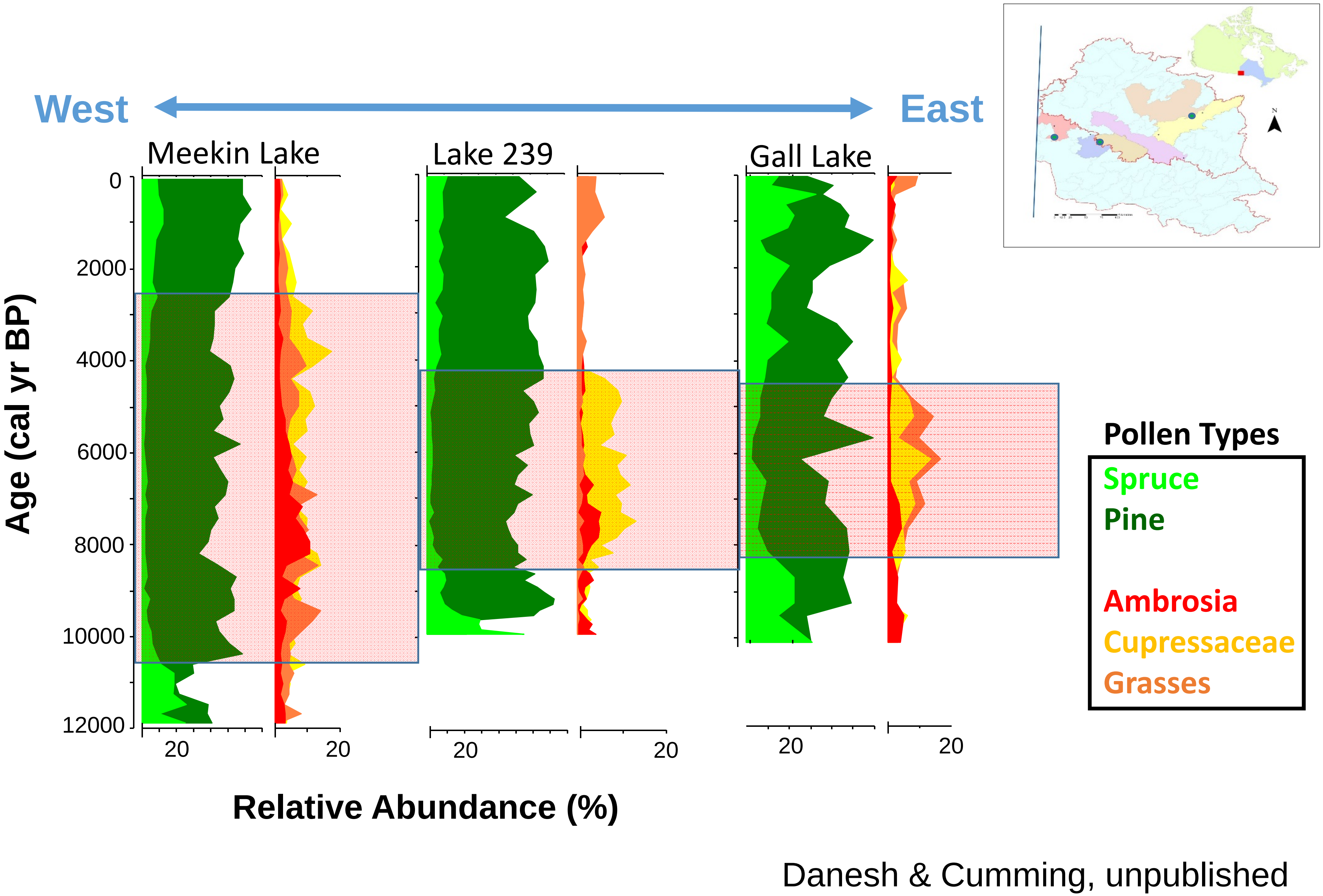






Pollen - Moos & Cumming (2011) *Quat. Sci. Rev.* 30

Charcoal- Moos & Cumming (2012) *Int. J. Wildfire* 21

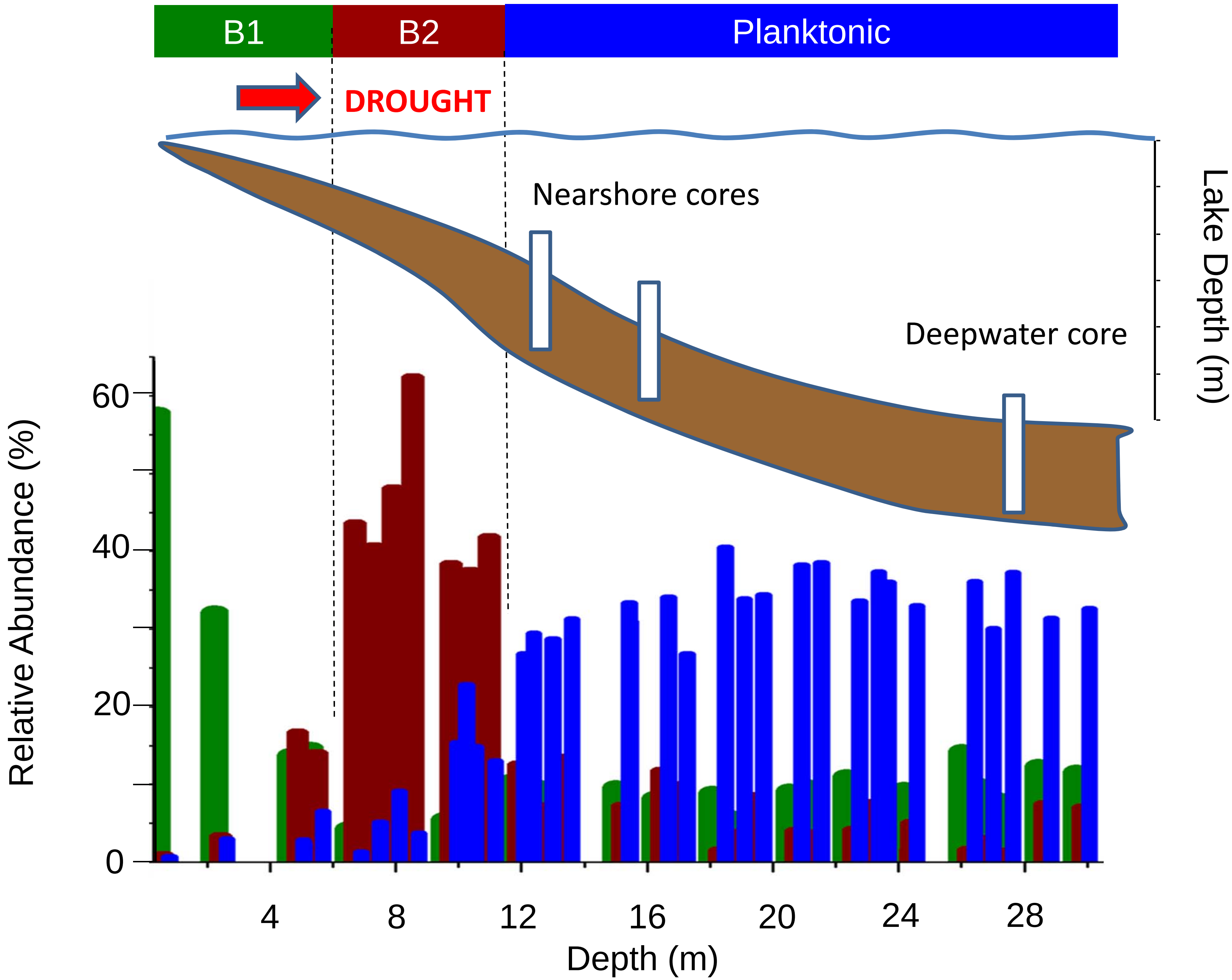

West
East
Meekin Lake
Lake 239
Gall Lake
Age (cal yr BP)
0
2000
4000
6000
8000
10000
12000
20
20
20
20
20
20
Relative Abundance (%)
Pollen Types
Spruce
Pine
Ambrosia
Cupressaceae
Grasses
Danesh & Cumming, unpublished

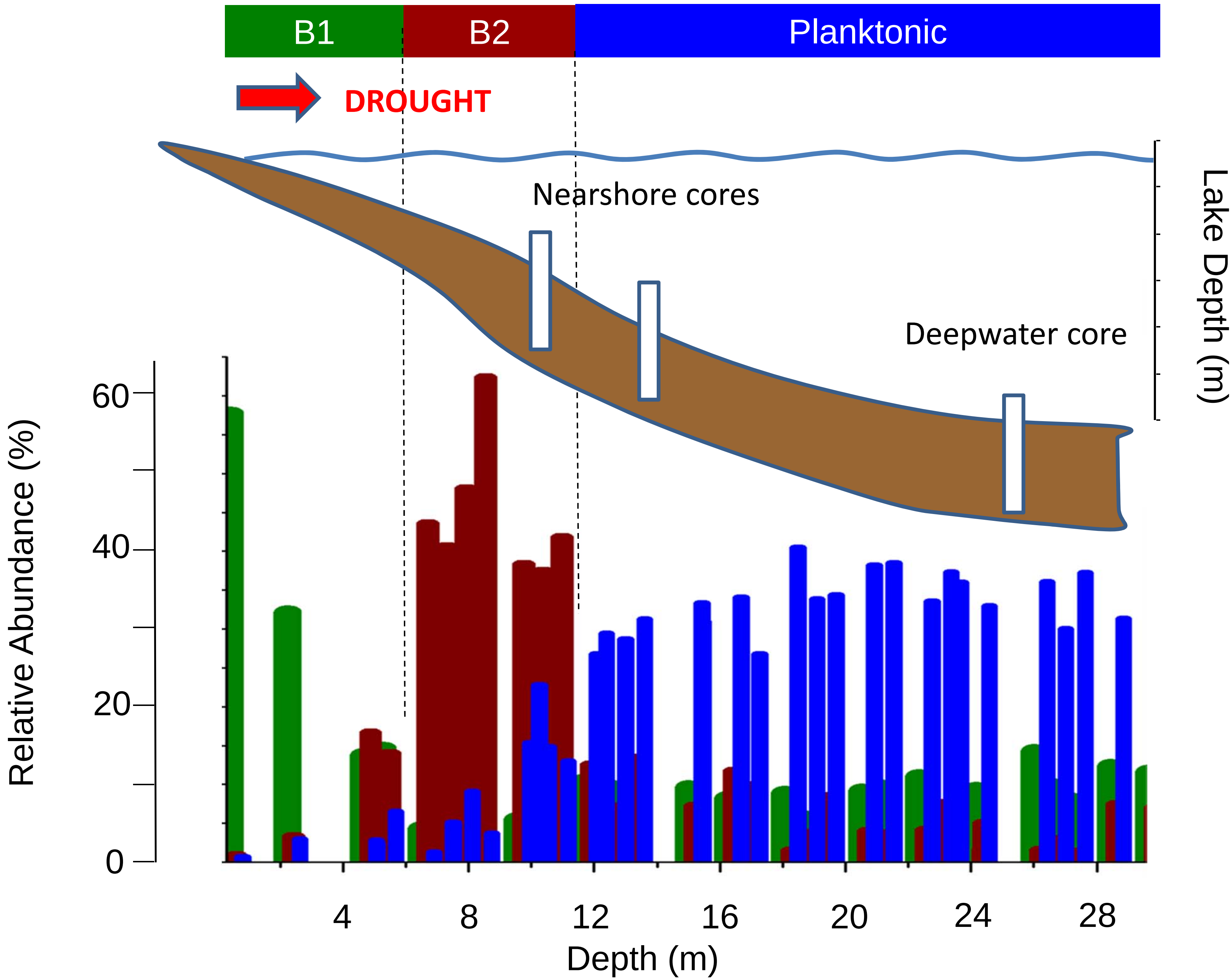
Hypisthermal Warm Period (Northwest ON)

- **Closed boreal forest -> parkland; warmer (~2.5 $^{\circ}$ C);**
- **2-3x increase in sedimentary charcoal and inferred fire frequency**

Change in lake level?

Change in water quality?


B1
B2
Planktonic
DROUGHT
Nearshore cores
Deepwater core
Lake Depth (m)
Relative Abundance (%)
0
20
40
60
4
8
12
16
20
24
28
Depth (m)



B1
B2
Planktonic
DROUGHT
Nearshore cores
Deepwater core
Lake Depth (m)
Relative Abundance (%)
60
40
20
0
4
8
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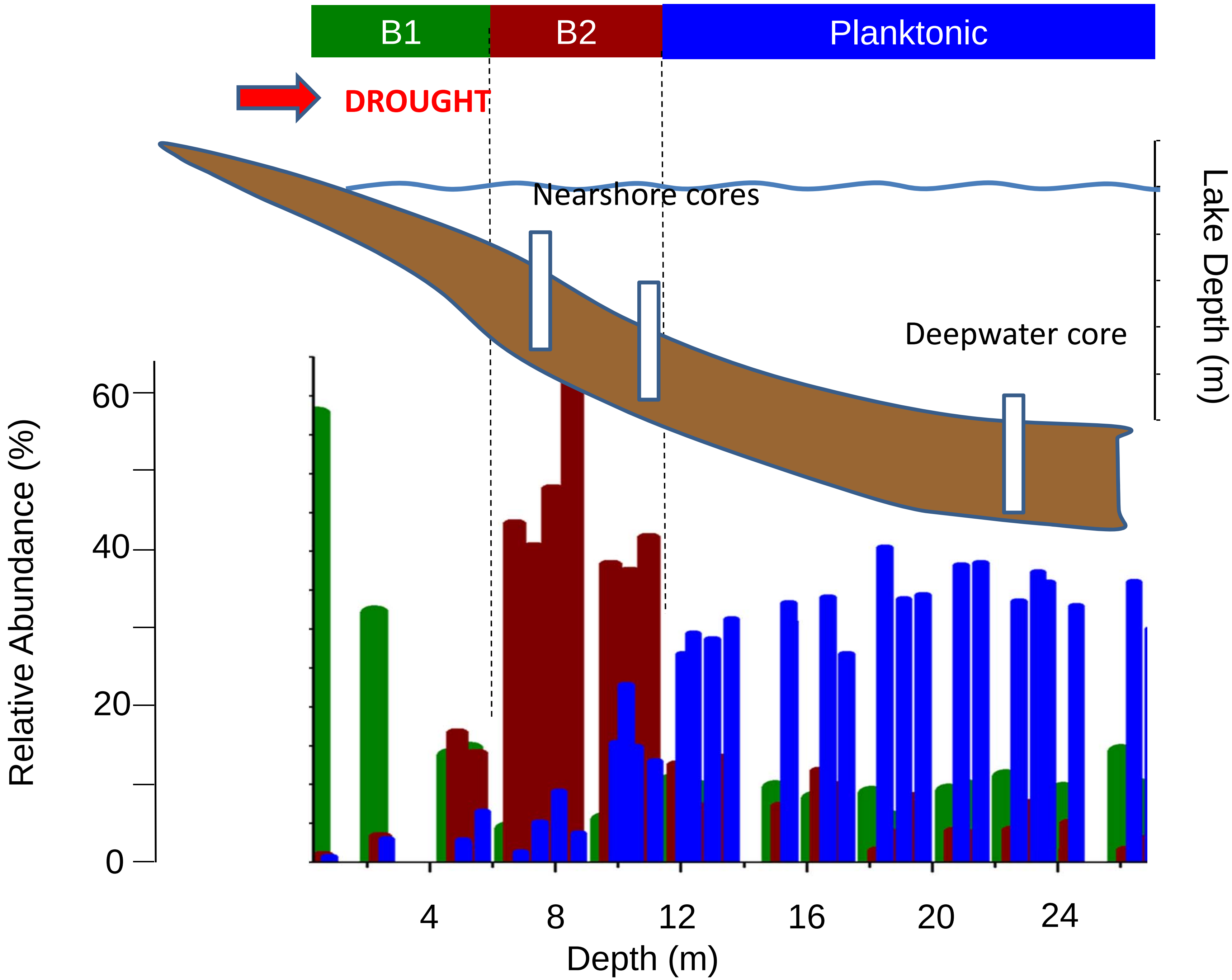
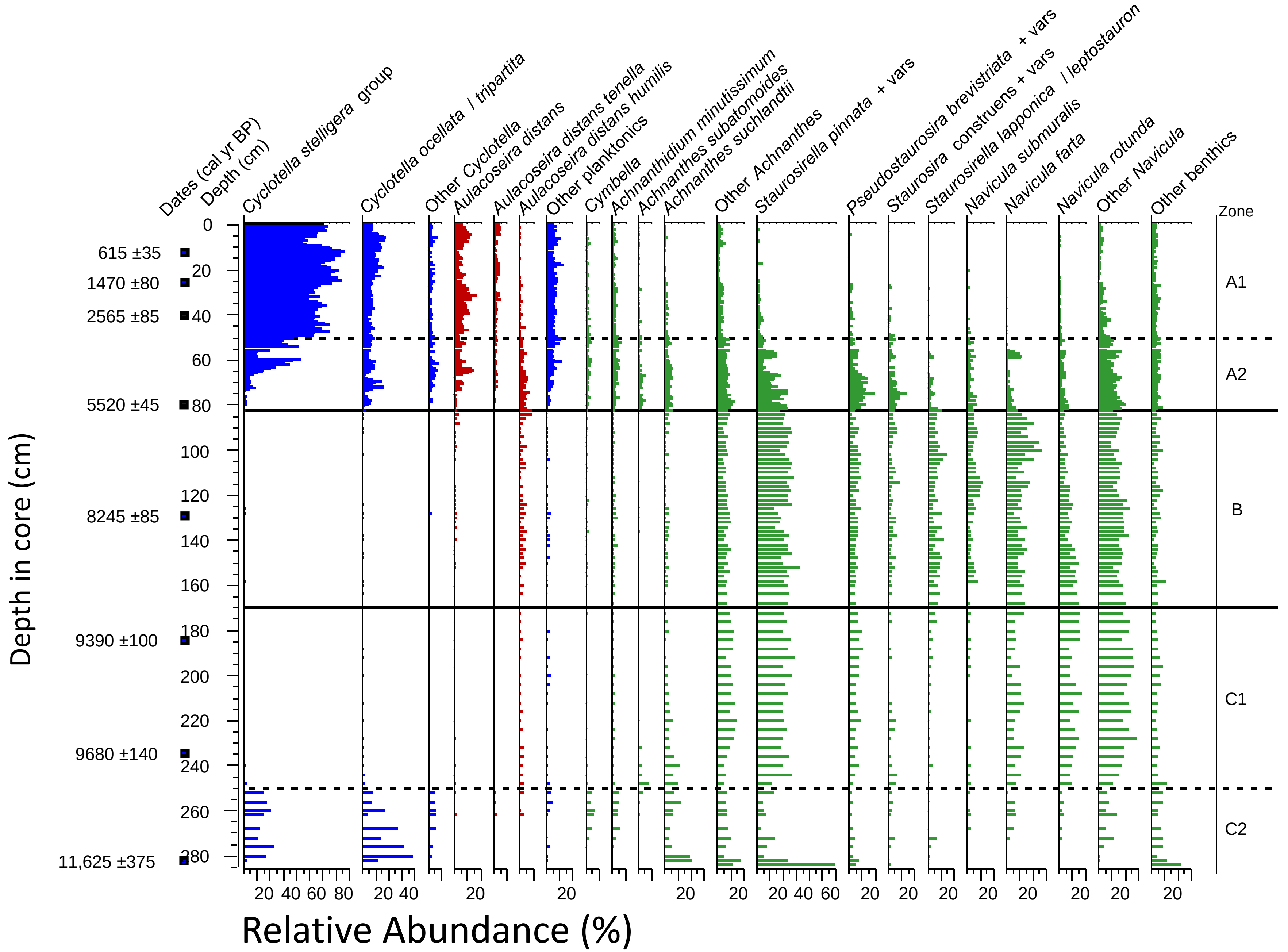
28
Depth (m)



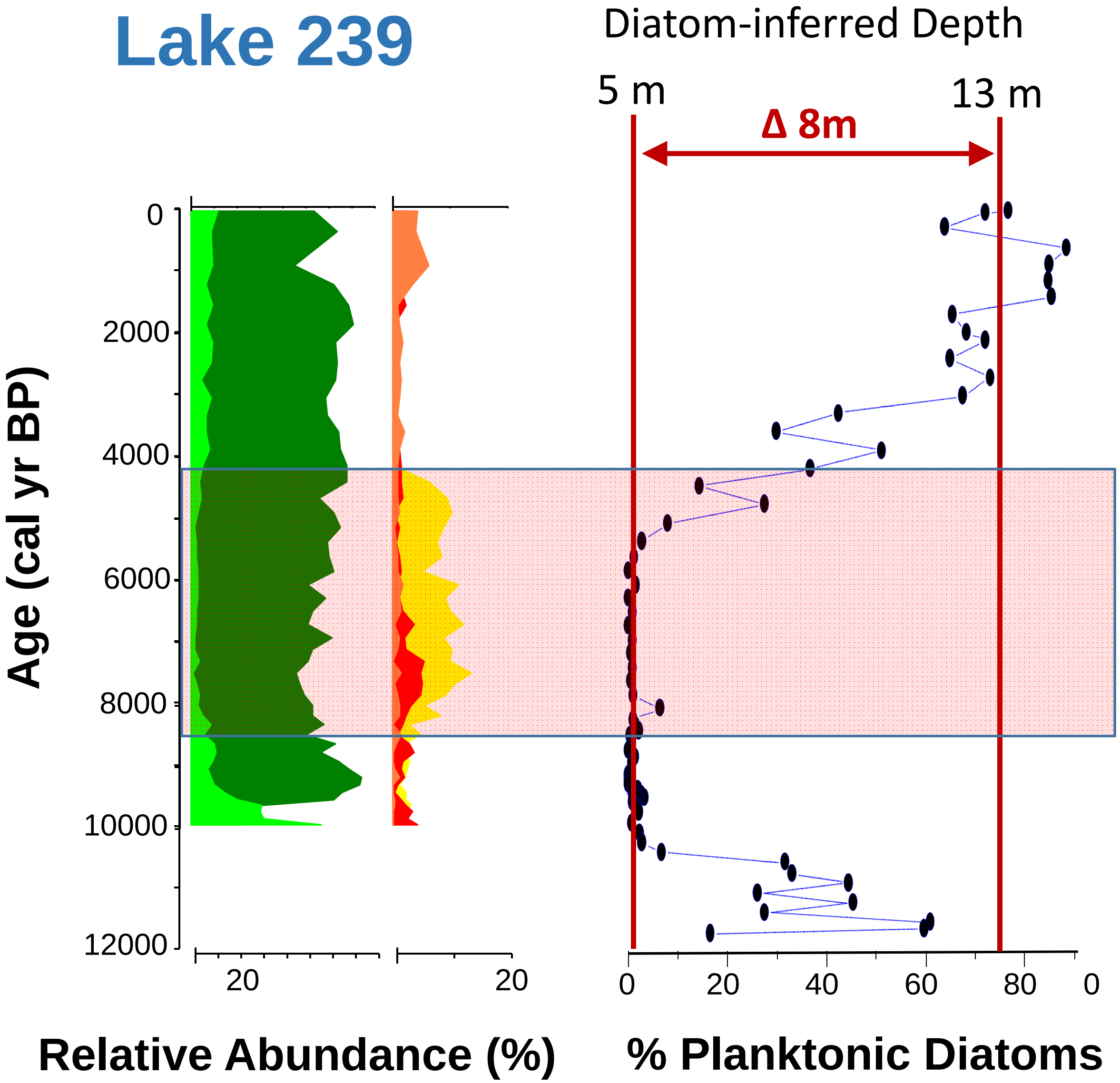
B1
B2
Planktonic
DROUGHT
Nearshore cores
Deepwater core
Lake Depth (m)
Relative Abundance (%)
0
20
40
60
4
8
12
16
20
24
Depth (m)

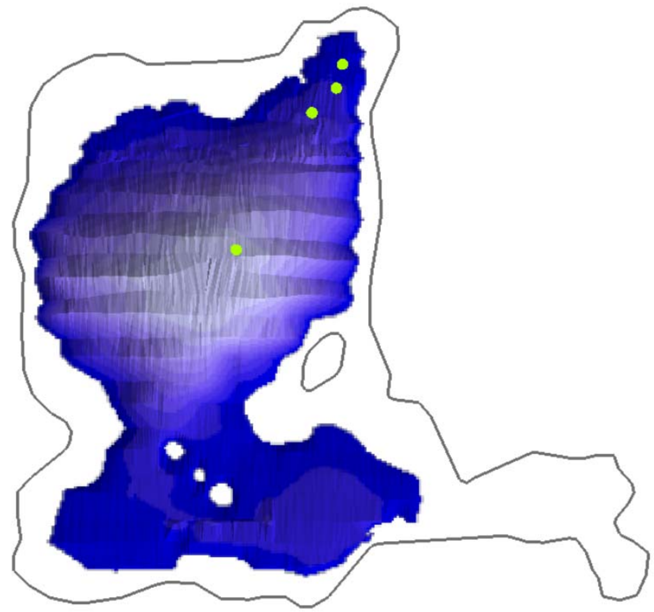
Lake 239 - Diatoms – 13-m near-shore core



Moos, Laird & Cumming (2009) *Quat. Sci. Rev.*

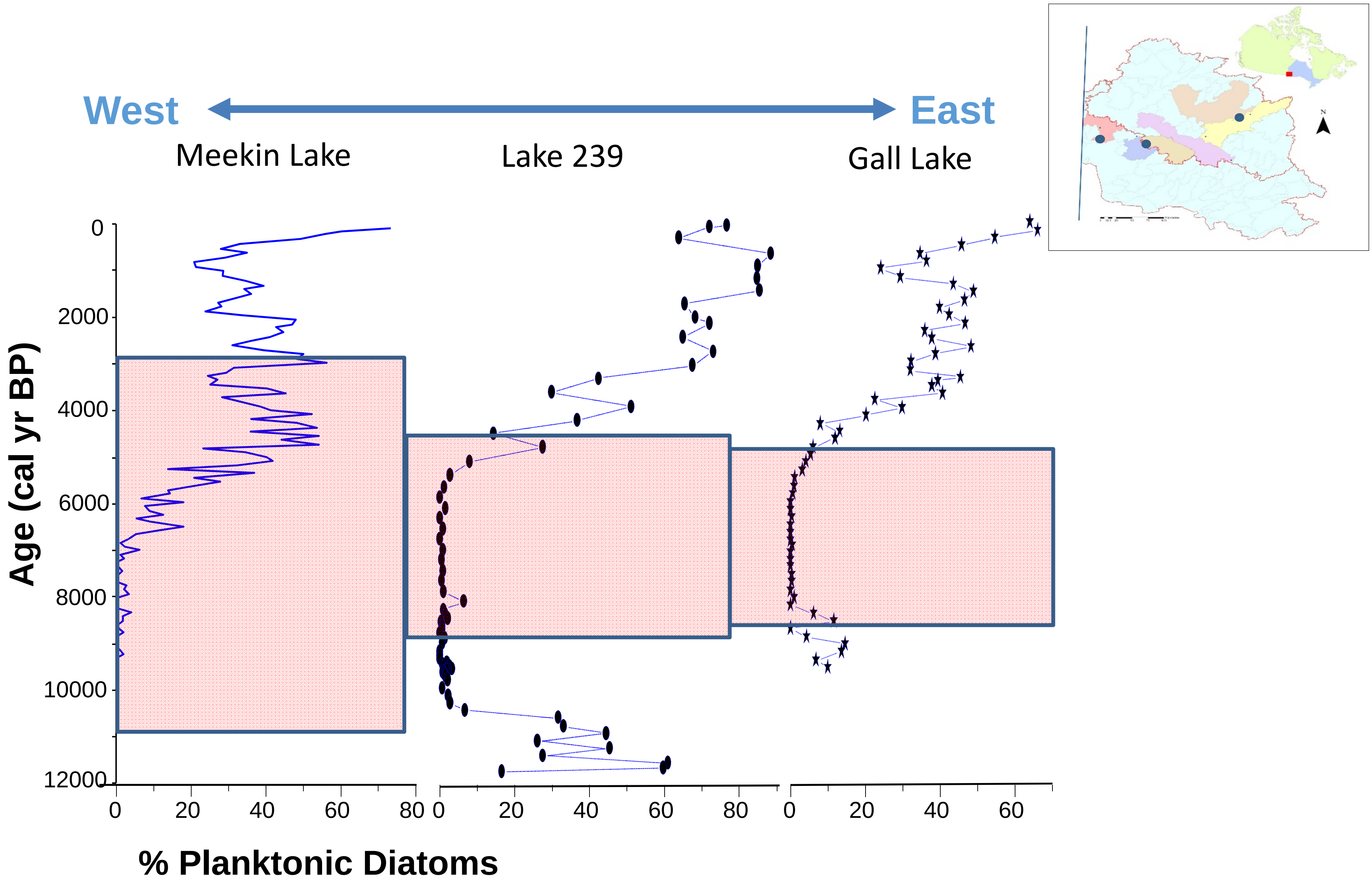
Lake 239





Danesh & Cumming, unpublished

Moos et al. (2009) *Quat. Sci. Rev.*



Karmakar et al. (2014) The Holocene

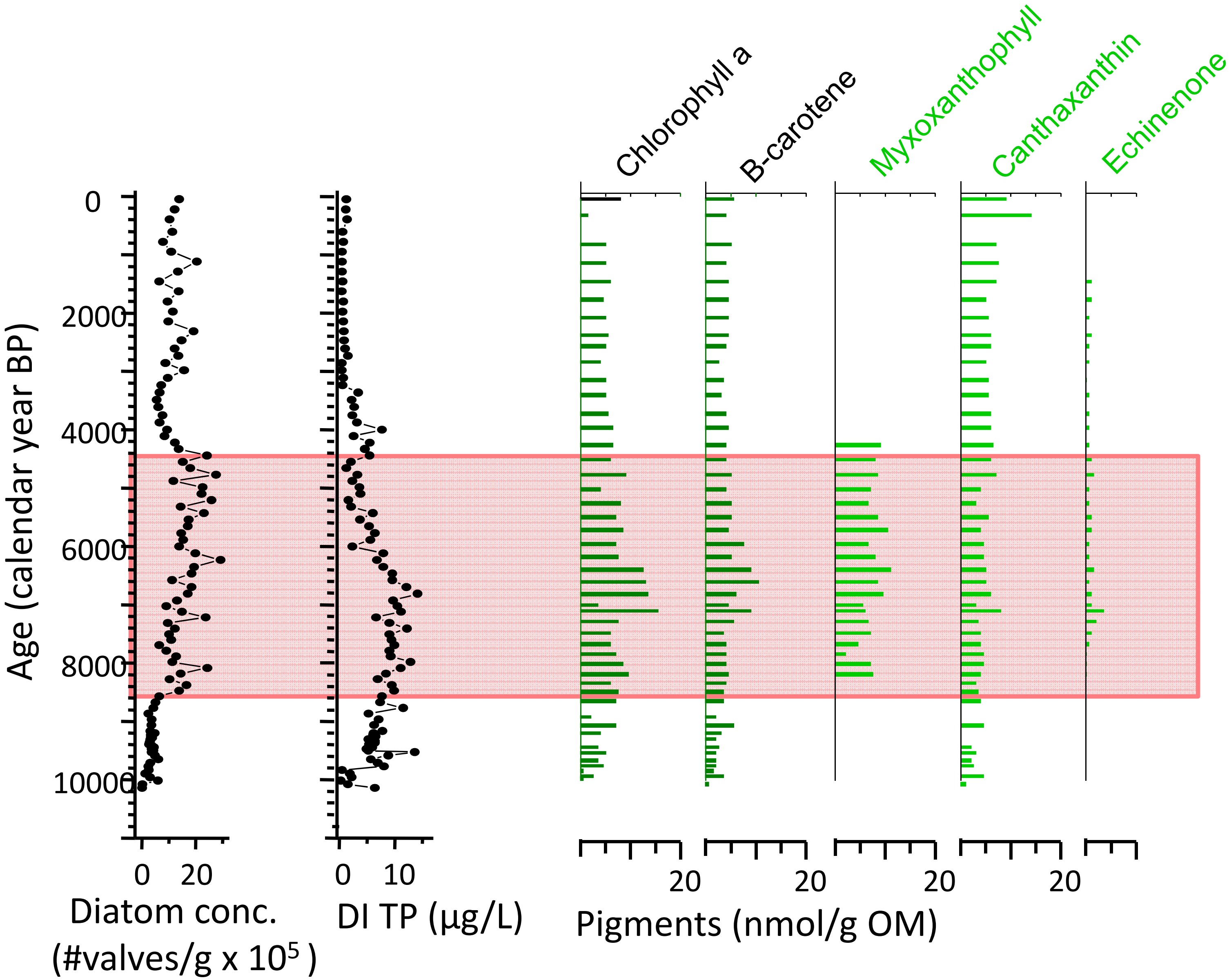
Hypsithermal Warm Period (Northwest ON)

- **Closed boreal forest -> parkland; warmer (~2.5 ° C);**

- **2-3x increase in sedimentary charcoal and inferred fire frequency**

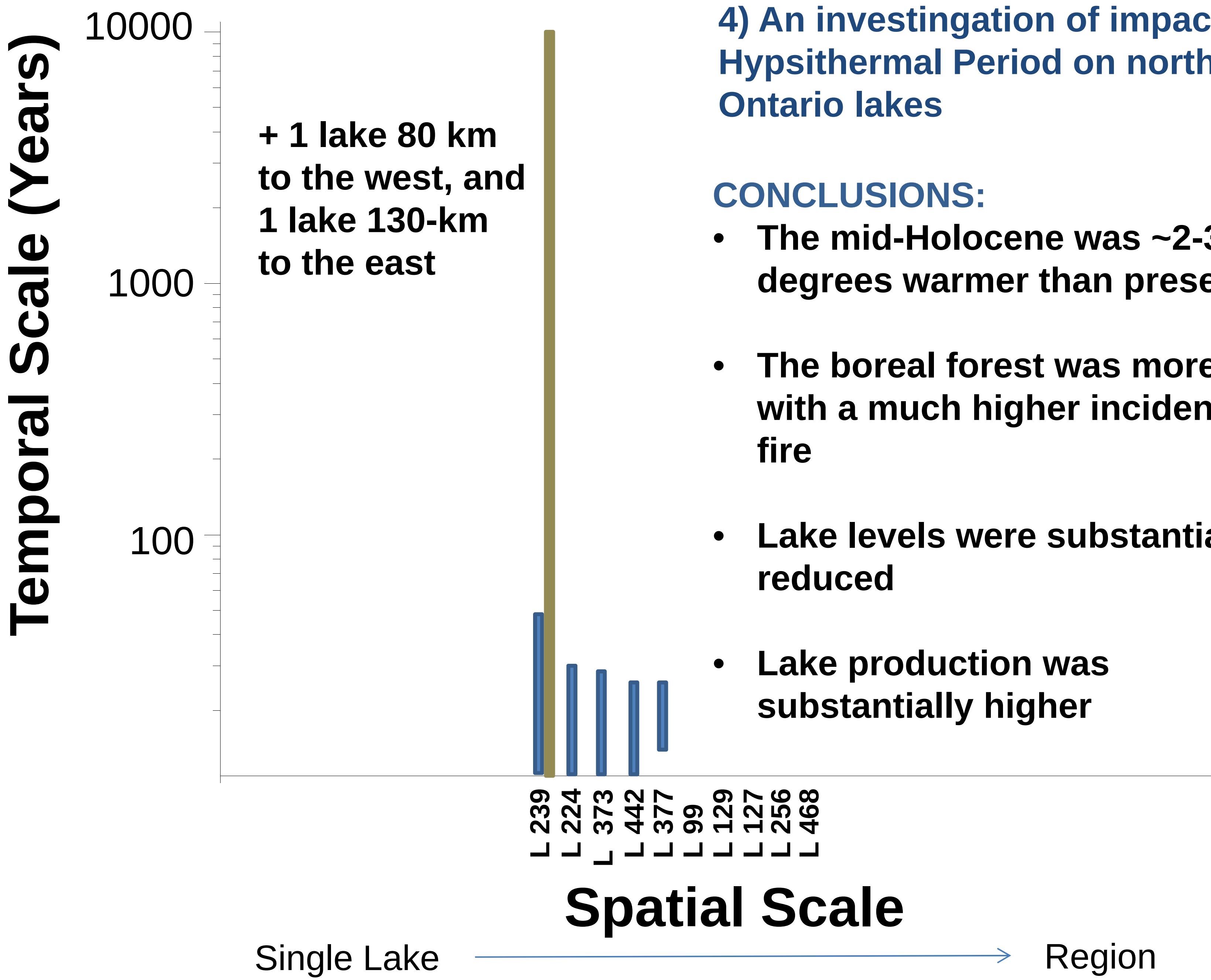
Change in lake level?
Change in water quality?

ELA Lake 239 (Deep Core)



Moos et al. (2009) The Holocene 19

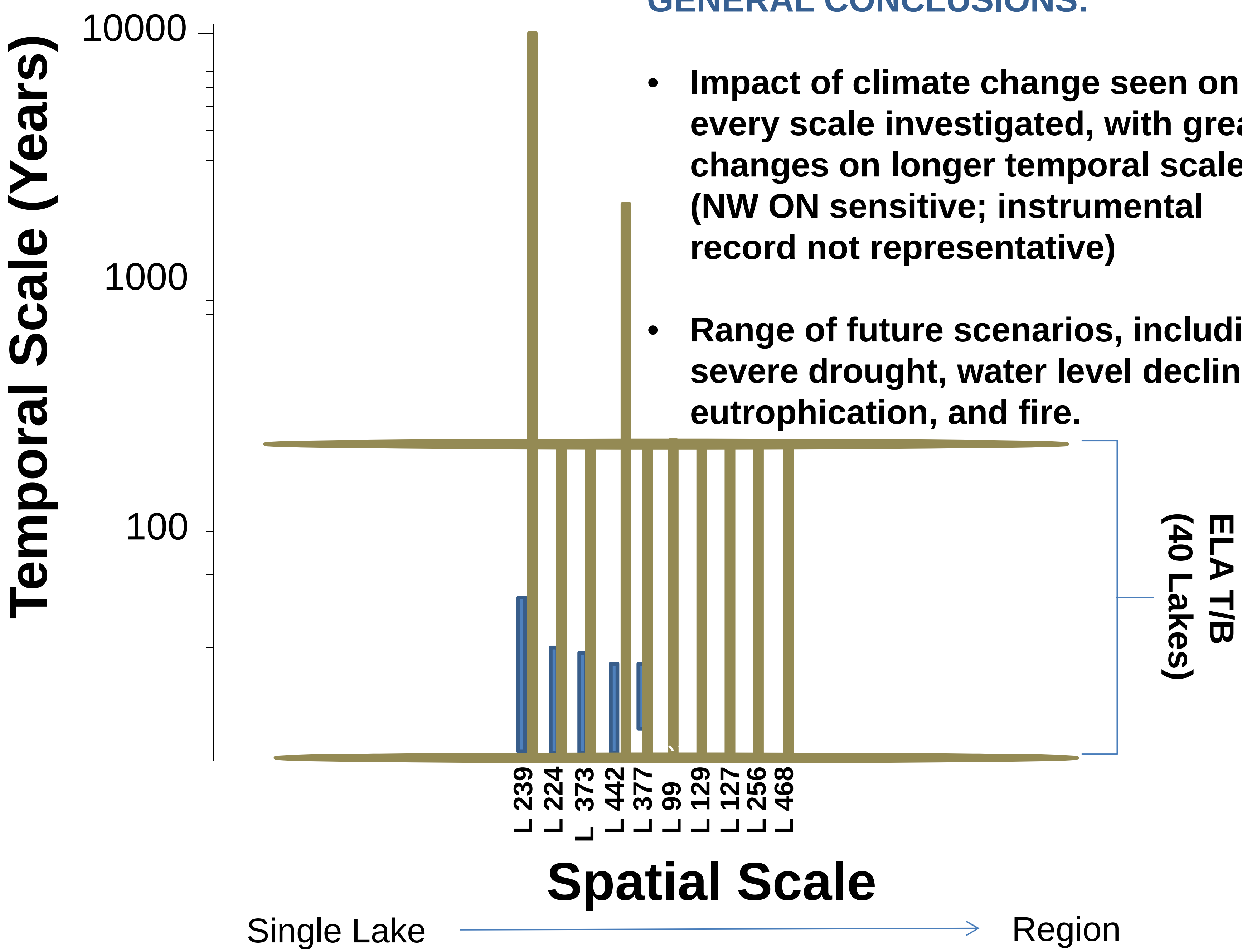
Karmakar (2014)



4) An investingation of impact of the Hypsithermal Period on northwest Ontario lakes

CONCLUSIONS:

- **The mid-Holocene was ~2-3 degrees warmer than present;**
- **The boreal forest was more open with a much higher incidence of fire**
- **Lake levels were substantially reduced**
- **Lake production was substantially higher**



GENERAL CONCLUSIONS:

- **Impact of climate change seen on every scale investigated, with greater changes on longer temporal scales (NW ON sensitive; instrumental record not representative)**
- **Range of future scenarios, including: severe drought, water level declines, eutrophication, and fire.**


Questions??

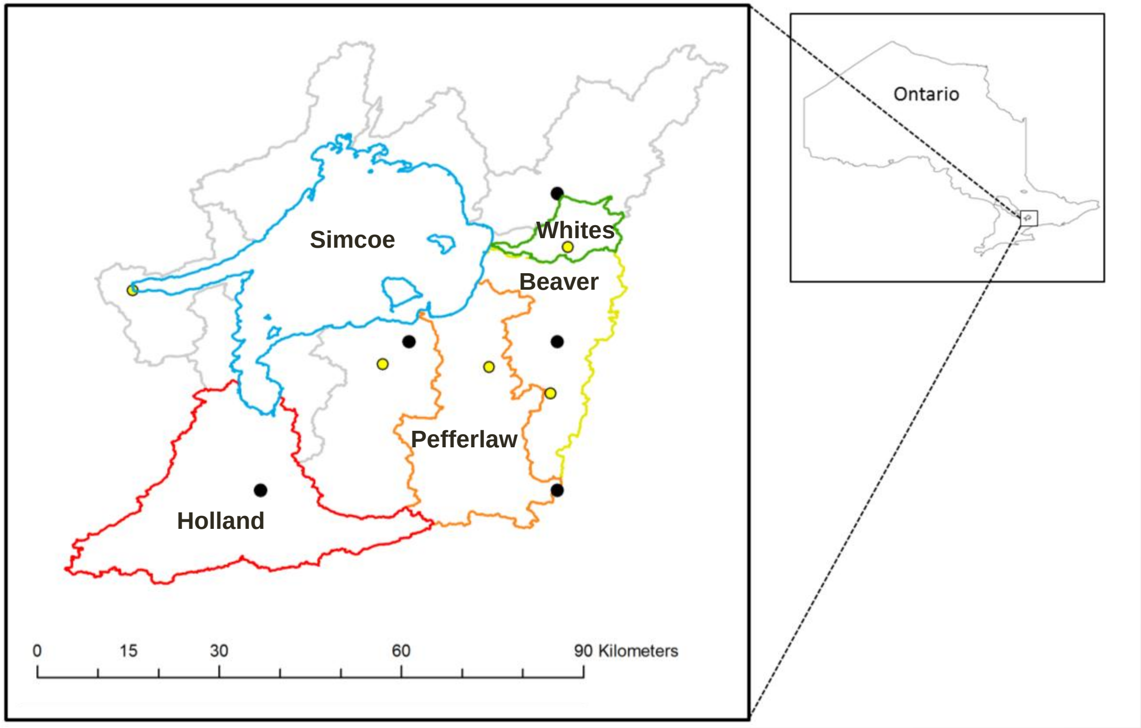
Determining "catchment sensitivity" to climate change

Flow and nutrient responses to changes in external stressors

Dr Jill Crossman and Professor Peter Dillon

Managing P inputs to Lake Simcoe

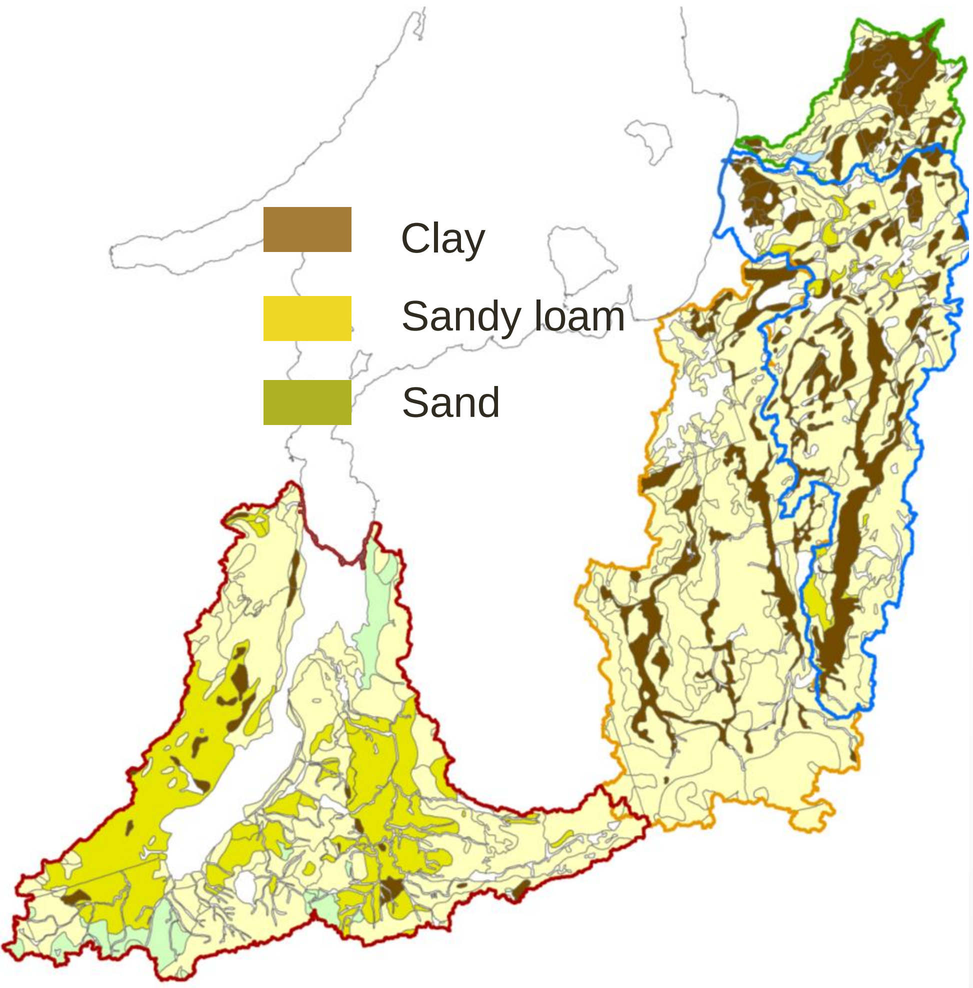
We compared hydrochemical sensitivity to climate change, across 4 neighbouring sites



And the effectiveness of management strategies within these catchments

Characteristic differences:

Geology influences surface overland flow and soil water residence times



Beaver and Whites: 27.5 to 41.9% clay

Holland and Pefferlaw: 8.3 to 12.6% clay

Leads to differences between catchments in hydrology and nutrient transport mechanisms

- May influence extent of hydrochemical response to CC

Why look at catchment sensitivity?

The extent to which hydrology and nutrient concentrations of a catchment respond to changes in climate

Uncertainty in climate change makes it difficult to have confidence that management strategies we select now will be effective in the future

Catchment sensitivity uses a "**bottom up**" rather than a "**predict then act**" approach

Means we can base management decision on a catchment's resilience to change, rather than just on what we predict that change might be

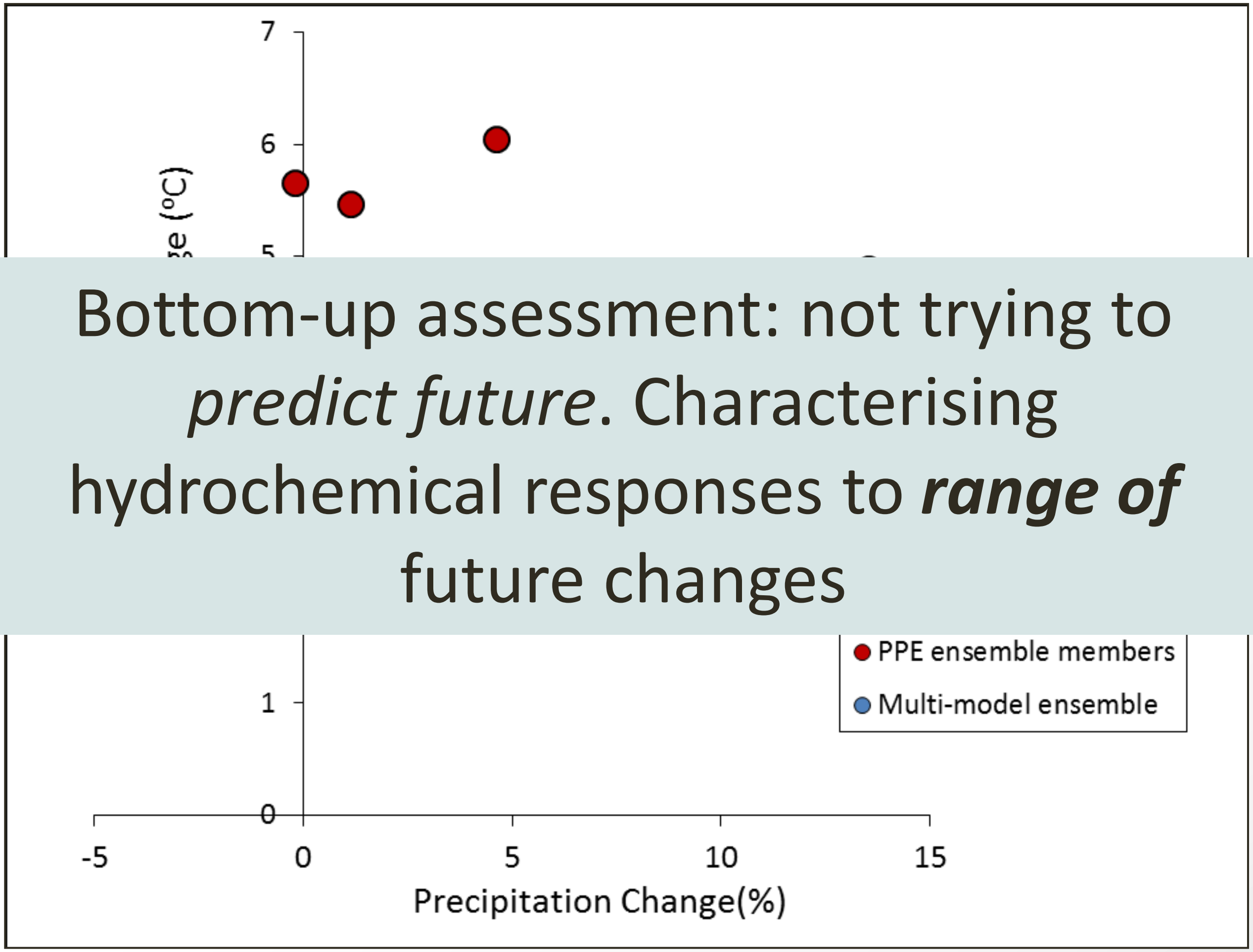
Climate Futures

To assess catchment sensitivity its important to explore a range of different futures, to include possible threshold effects

GCMs made by different scientists have different structures, and so project different futures under similar simulants. Traditionally, a comparison between different models (MME) was best way to look at range of futures

Now have PPEs: can make systematic alterations to a single GCM within scientifically accepted ranges. Generates model variants with specific responses (more or less extreme). More control over range of futures explored

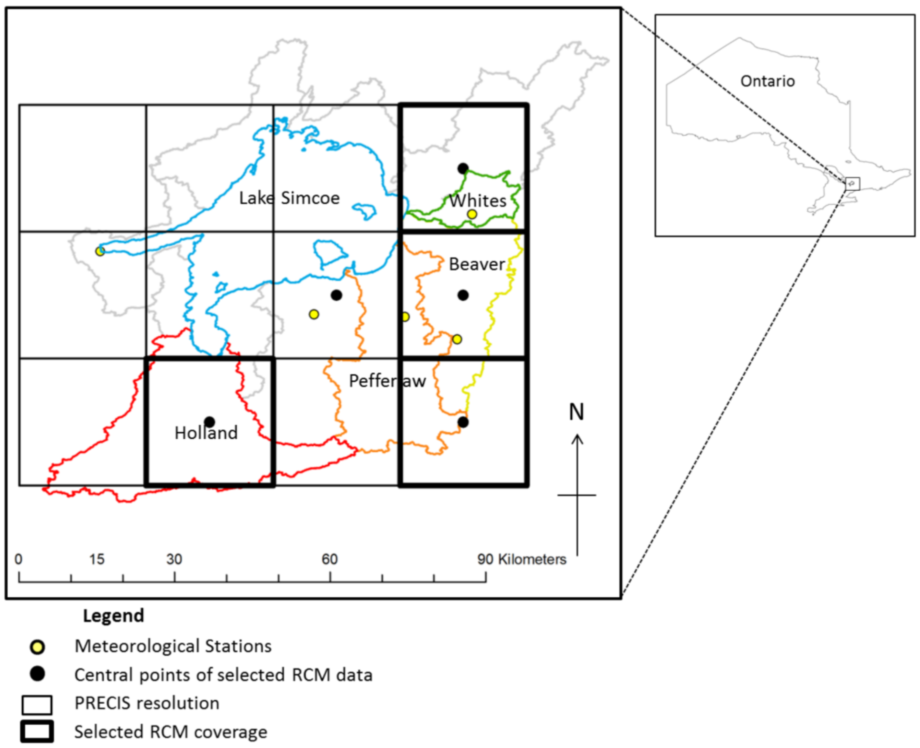
Climate Data



Bottom-up assessment: not trying to *predict future*. Characterising hydrochemical responses to ***range of*** future changes

Climate data

Selected 5 variants of the Met Office Hadley Centre PPE



Data has been regionally downscaled by IEESC using PRECIS

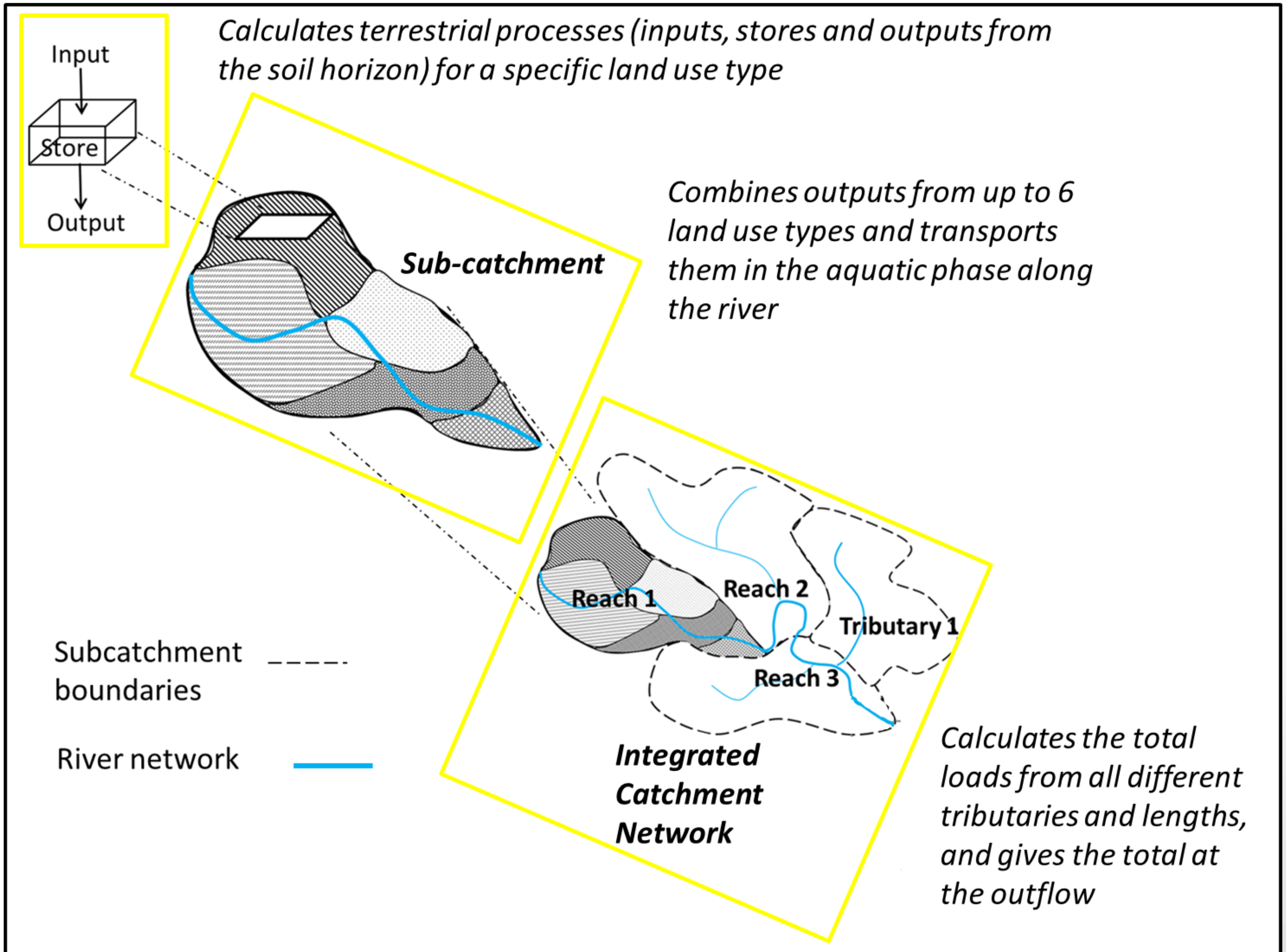
Individual CC dataset for each catchment

Compared a 30 year baseline (1968-1997) with two 30 year future periods (2020-2049 and 2060-2089)

- Climate data run through process-based hydrochemical models

Process-based Models:

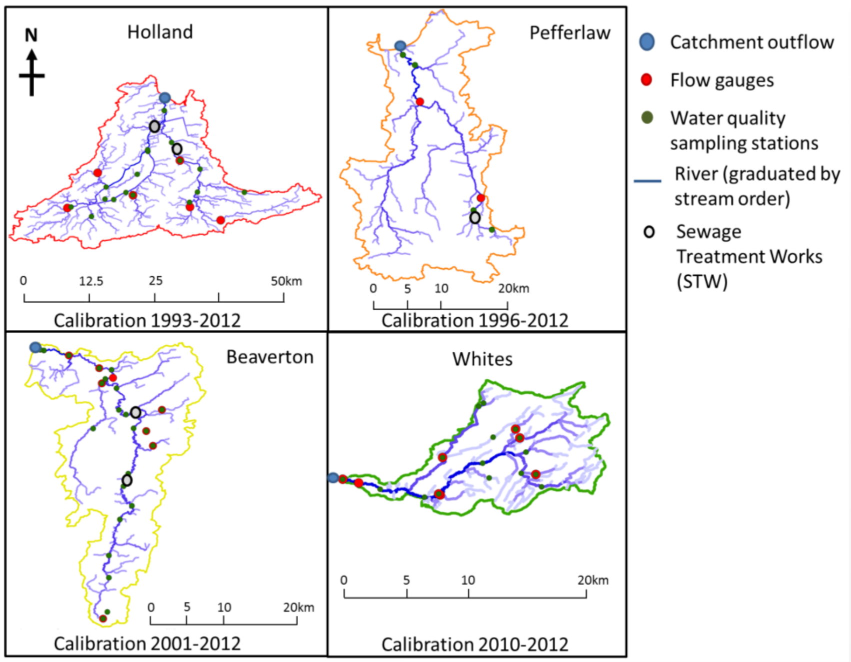
Chose INCA-P as it's distributed, so can model responses separately in tributaries to main channel



Integrated : models fluxes through terrestrial and aquatic phase. Good for management effects

Calibration results:

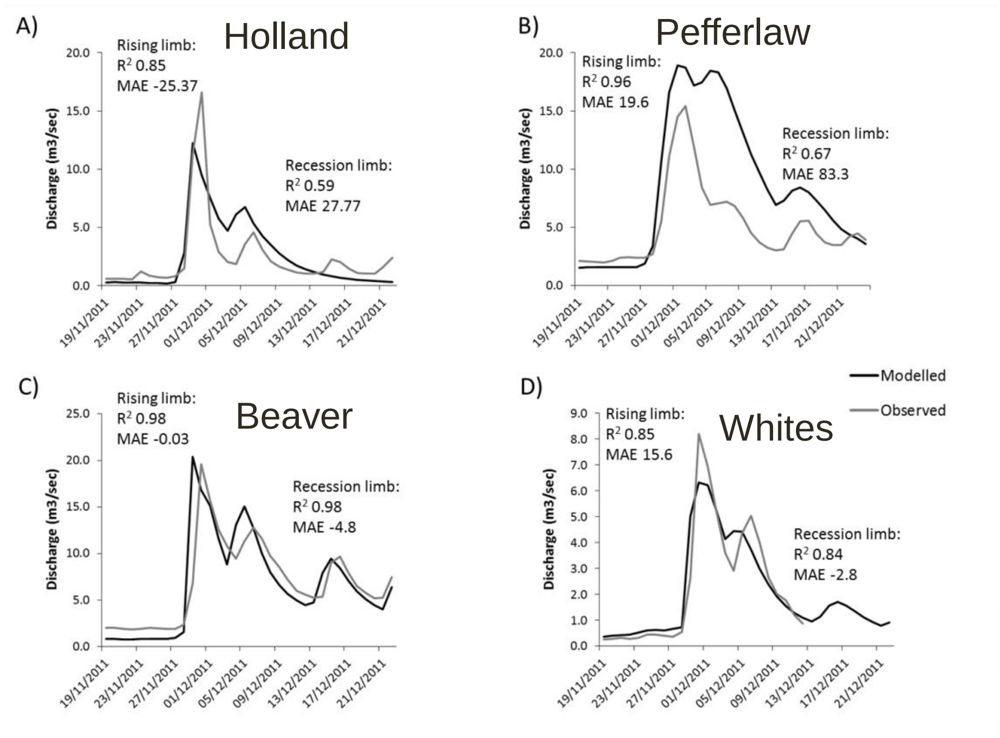
Calibrated over longest time period possible for each catchment



Assessed results based on fit to observed time-series data:

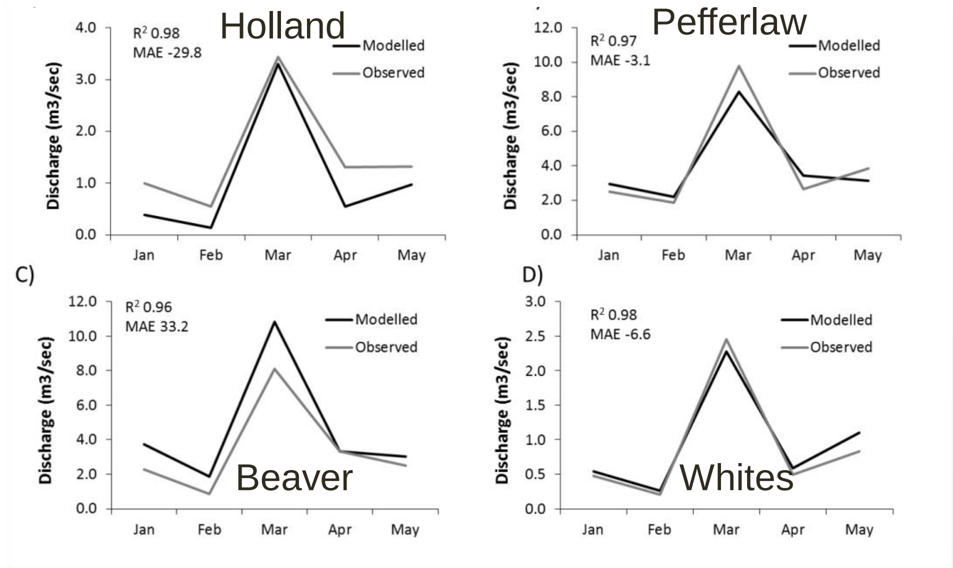
Catchment	Maximum Model coefficient					Model coefficient at downstream extent				
	Flow		TP Concentration		TP loads*	Flow		TP Concentration		TP loads*
	R^2	Model Error (MAE) (%)	R^2	MAE (%)	R^2	R^2	MAE (%)	R^2	MAE (%)	R^2
Holland	0.95	-24.78	0.72	-4.36	0.74	0.95	-24.78	@0.52	@-20.12	@0.60
Pefferlaw	0.91	+14.06	0.37	-23.4	0.71	0.91	+46.28	0.34	-23.41	0.61
Beaver	0.98	-15.30	0.79	+4.40	0.82	0.85	33.50	0.05	-58.37	0.72
Whites	0.92	+3.03	0.47	-26.34	0.94	0.92	+3.03	0.29	-26.34	0.77

Calibration results:



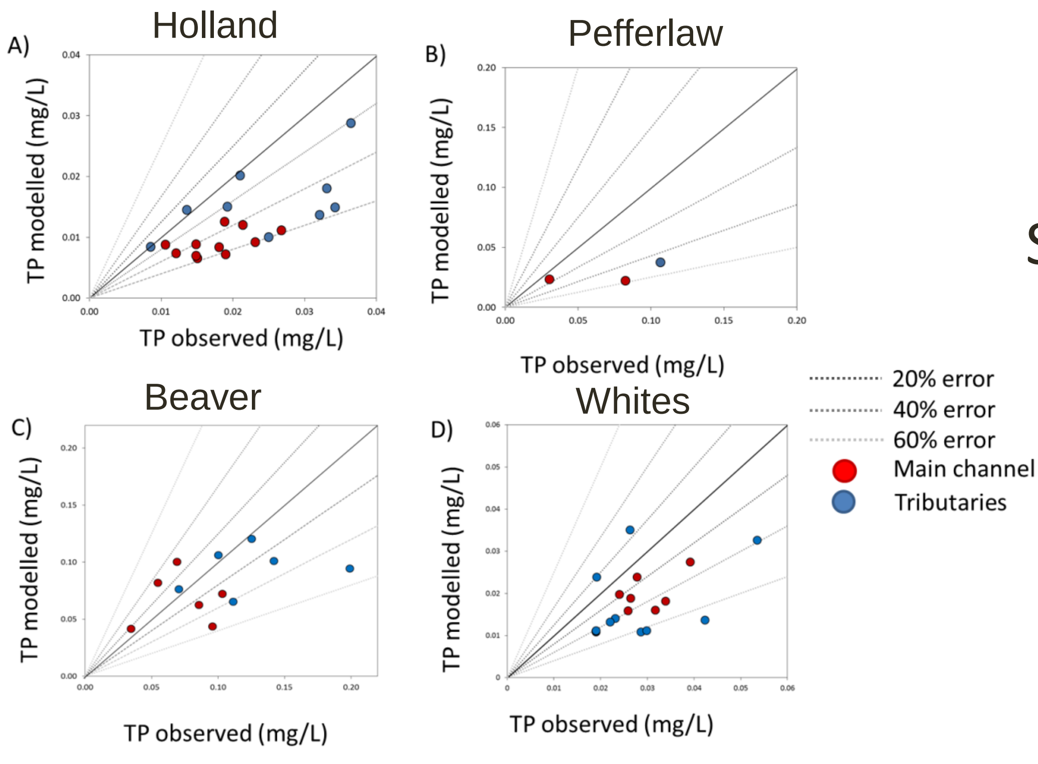
Also on process responses to specific key events

Rainfall response (rising and recession limb)

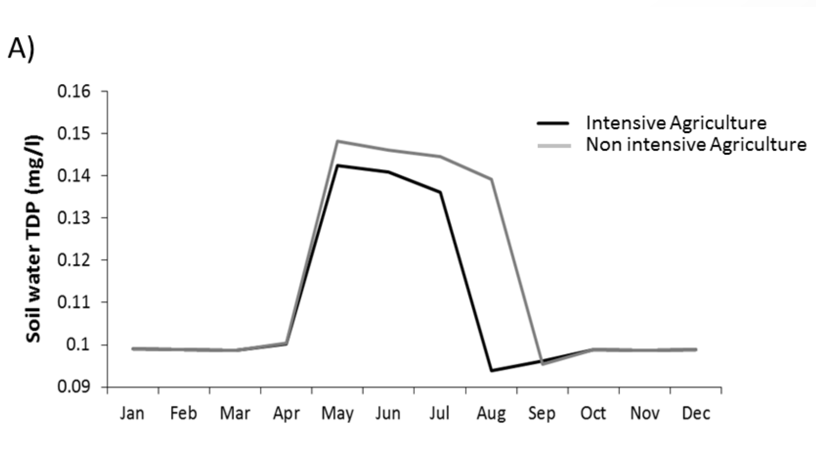


Snowmelt response

Calibration results:



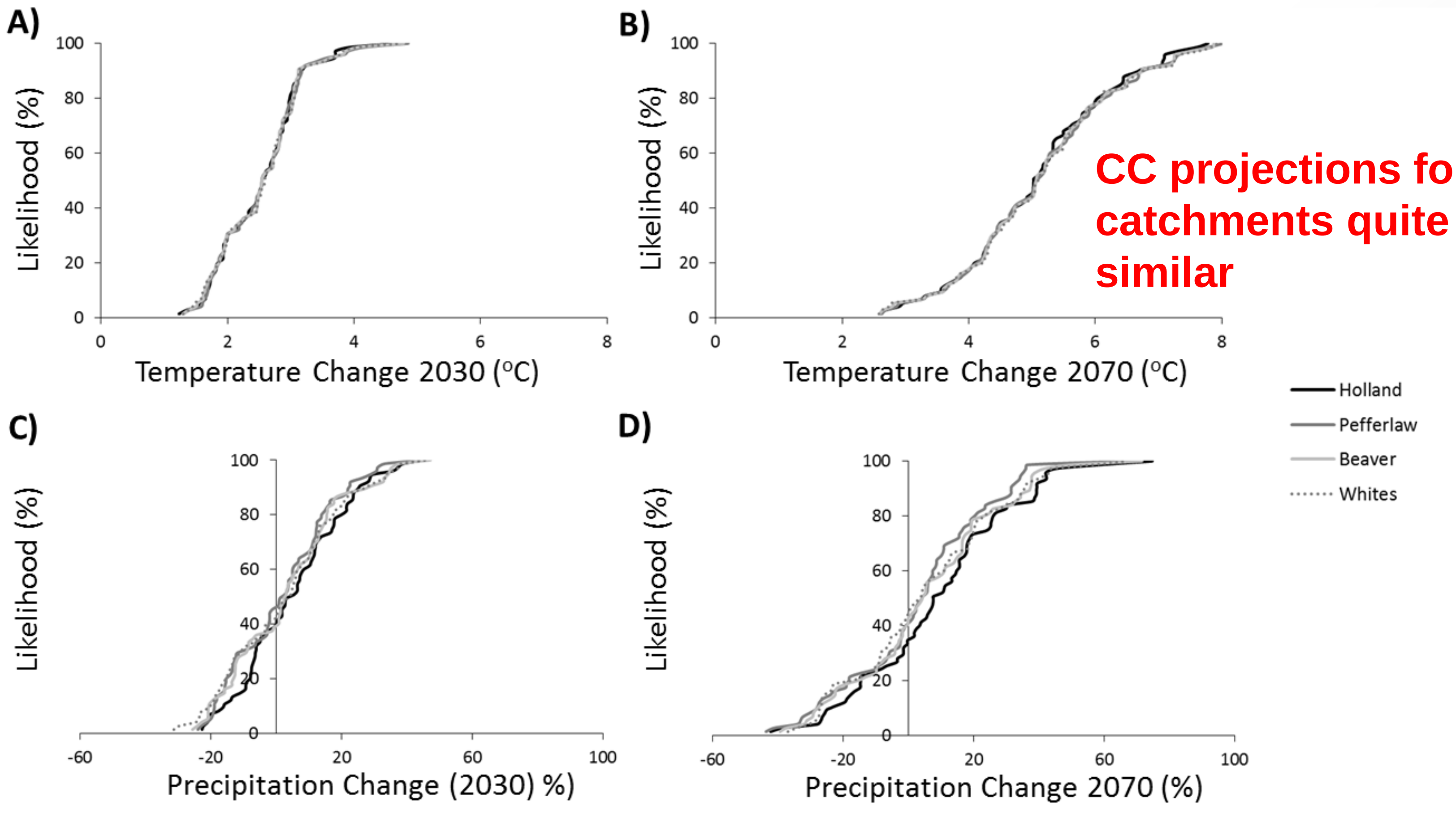
Spatial distribution of accuracy throughout catchments



Where there is no observed data – are responses logical?

Future Climate: CDFs

Changes in temperature and pptn more extreme and likely between 2030 and 2070

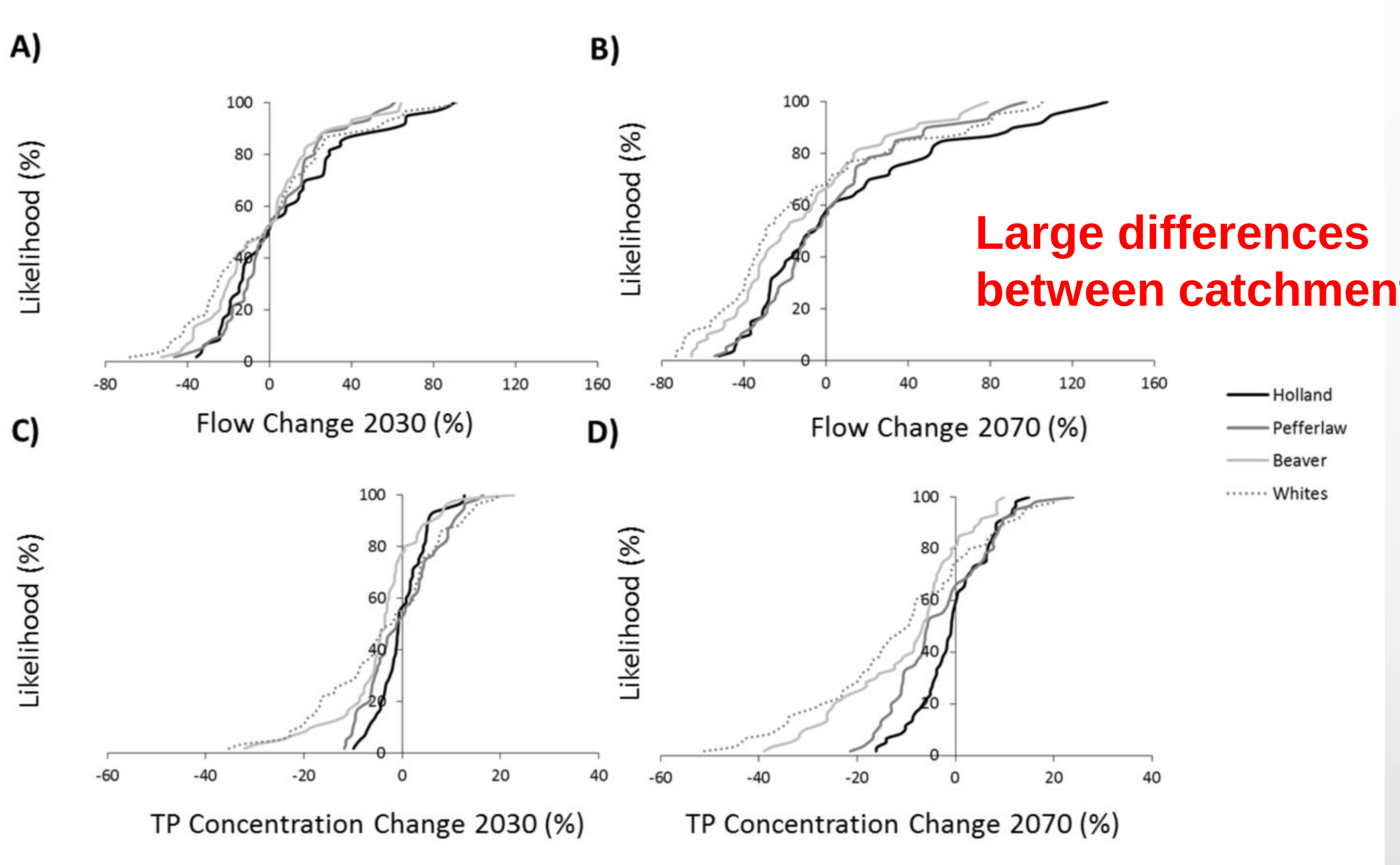


CC projections for catchments quite similar

- Large increases in temp and precipitation (in all catchments) in winter and spring. Reductions in summer and autumn.

Future hydrochemistry

Changes in flow and TP concn more extreme and likely between 2030 and 2070



Extent of winter increases, and summer/ autumn reductions varied between catchments. Direction of change in spring differed entirely.

Sensitivity

Relative index of sensitivity normalises catchment responses from differences in original driving forces

Catchment specific response defined by change per unit of pptn input

	HER sensitivity (mm changer in HER per mm change in pptn)	**TP sensitivity** (ug/l change in TP per mm change in pptn)
Holland	0.52	22.1
Pefferlaw	0.87	10.6
Beaver	0.94	58.3
Whites	0.94	142.7

B&W: OLF, macropore and tile drainage facilitates movement of soils and TP directly into rivers throughout the year

H&P: soil matrix flow and long soil water residence times results in complex interactions with soil sorption/saturation thresholds with more seasonal nutrient movement

Sensitivity and Uncertainty are connected

B&W (overland and macropore flow)

In the B&W sensitivity is highest in winter and spring: changes in P export are directly associated with large increases in runoff and soil erosion

Catchment	Season	Projected change in TP (ug/l) per mm of change in precipitation	Proportion of annual change (%)
Beaver	**Spring**	201.0	**86.2**
	Summer	4.9	2.1
	Autumn	13.5	5.8
	Winter	13.8	5.9
	Annual average	58.3	100
Whites	**spring**	28.3	5.0
	summer	5.5	1.0
	autumn	18.2	3.2
	winter	518.8	**90.9**
	Annual Average	142.7	100

Winter/Spring: period of highest CC uncertainty. These catchments therefore have the highest uncertainty in projections of TP concentrations

Sensitivity and Uncertainty are connected

H&P (soil matrix flow)

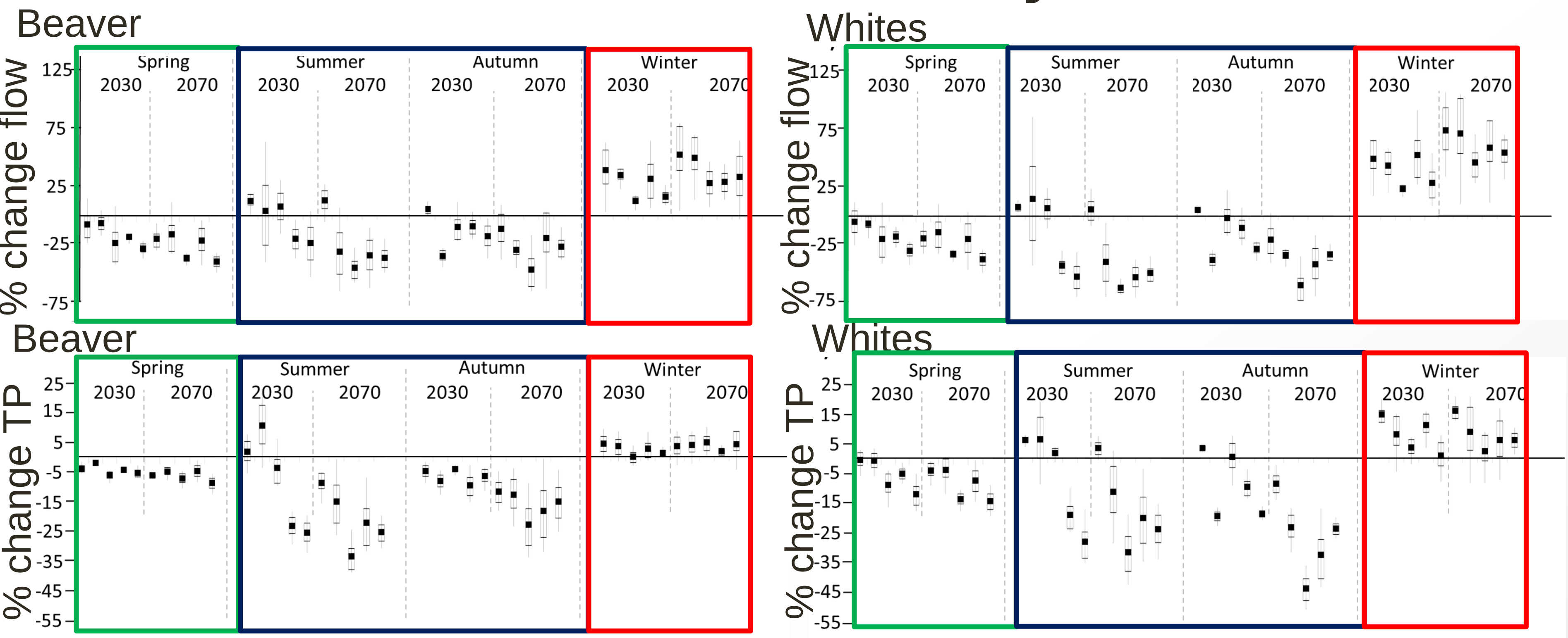
In the H&P sensitivity is highest in summer and autumn: changes in P export are associated with nutrient leaching through soils, which is highest after the addition of fertilisers

Catchment	Season	Projected change in TP (ug/l) per mm of change in precipitation	Proportion of annual change (%)
Holland	spring	5.9	6.7
	summer	24.4	27.6
	autumn	54.0	**61.1**
	winter	4.1	4.6
	Annual Average	22.1	100
Pefferlaw	spring	5.0	11.7
	summer	23.8	**56.1**
	autumn	4.0	9.5
	winter	9.7	22.7
	Annual Average	10.6	100

P declines after autumn, as surface pools are used up. By spring, leachate concentrations so low as to dilute in-stream.

Summer/Autumn: period of lowest CC uncertainty. These catchments therefore have the lowest uncertainty in projections of TP concentrations

Effect of sensitivity



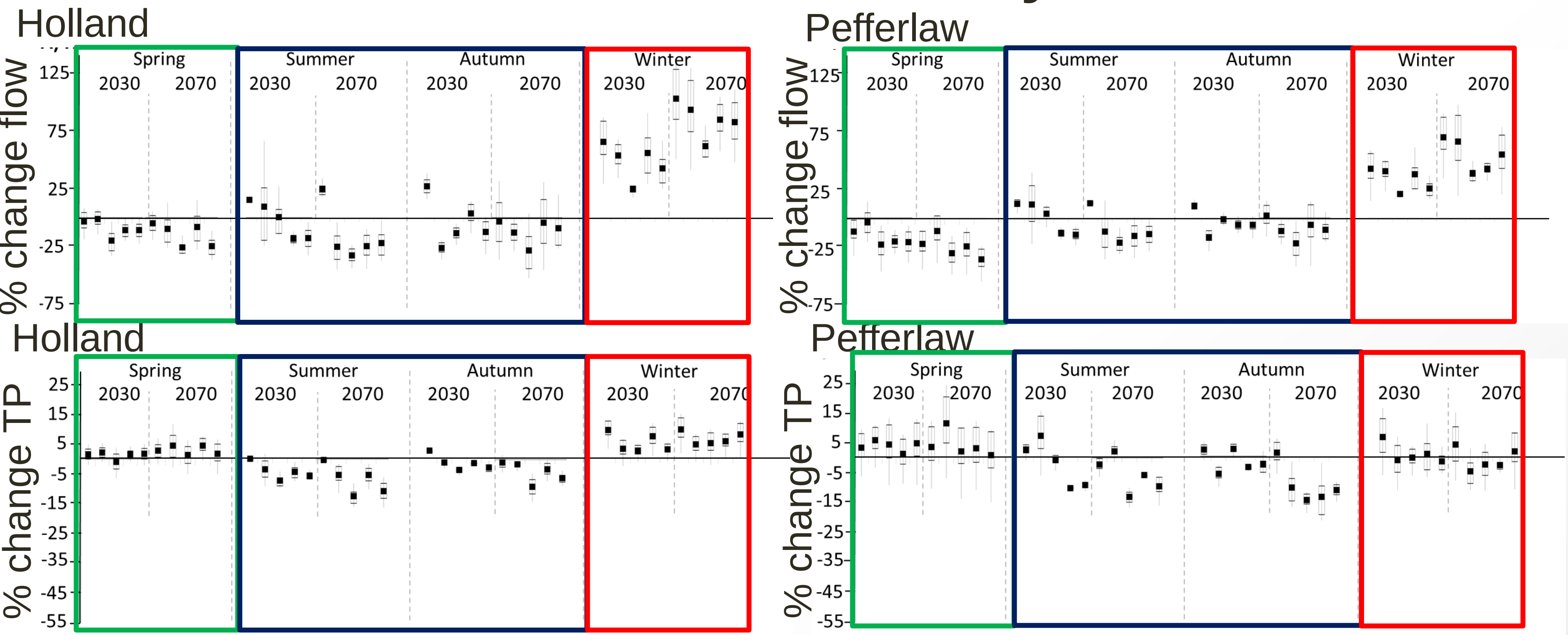
Direct, positive association between HER and TP throughout the year

Large annual reductions in TP loads

1) Reductions in flow during spring, summer and autumn = large reductions in TP concentrations

2) TP and flow only increase in winter

Effect of sensitivity



Positive association between HER and TP during most of year.

Changes generally smaller than in B&W (lower sensitivity)

Small annual increase in TP loads

1) Reductions in summer and autumn flow = TP reductions, increases in winter flow = TP increases

2) Reductions in spring flow = *increases* in TP concentrations! Less dilution of soil water concentrations

% change in annual load at 50% likelihood level

	2030	2070
Holland	3.5	-7.0
Pefferlaw	-2.4	-11.2
Beaver	-10.3	-25.3
Whites	-2.6	-39.7

(Ensemble average)

What does the sensitivity analysis tell us?

- Nutrient and flow responses are governed by geology (influencing flow pathways) and nutrient transport mechanisms
- Catchments with a high proportion of over-land or macropore flow are likely to be more sensitive to changes, especially during winter
- Here precipitation and HER rapidly transport P via OLF
- Strategies to reduce surface erosion or increase infiltration might be most effective
- Catchments with a larger proportion of soil matrix flow are less sensitive to change, and mainly during summer
- Here seasonal variability in soil P saturation influences water quality
- Reduce soil P-excess during summer

Management

- Important to consider every catchment as a distinct hydrological unit

- Develop a bottom-up approach to increase efficiency e.g catchment-tailored strategies which better reflect sensitivity

Investigated 4 different management strategies

Livestock access

Manure storage

Vegetation Planting

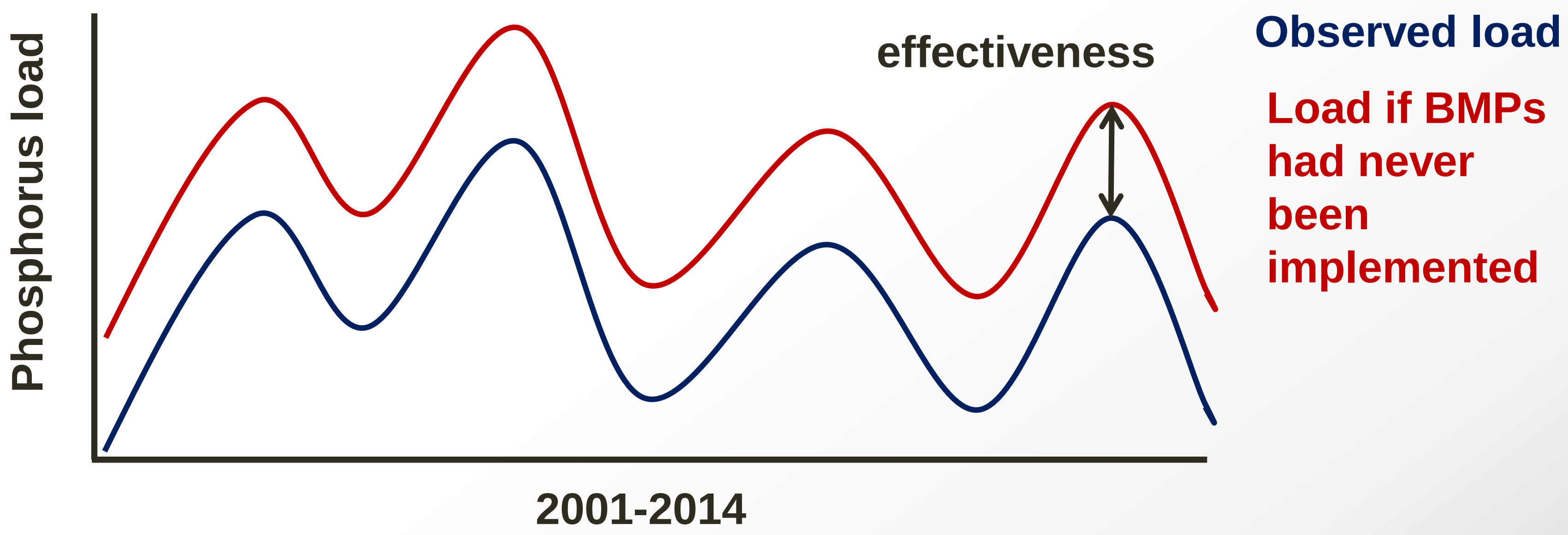
Septic System Upgrades

Has sensitivity affected BMP effectiveness to date?

Modelling based on measured data (43 sites in 2014; 25 in 2013)

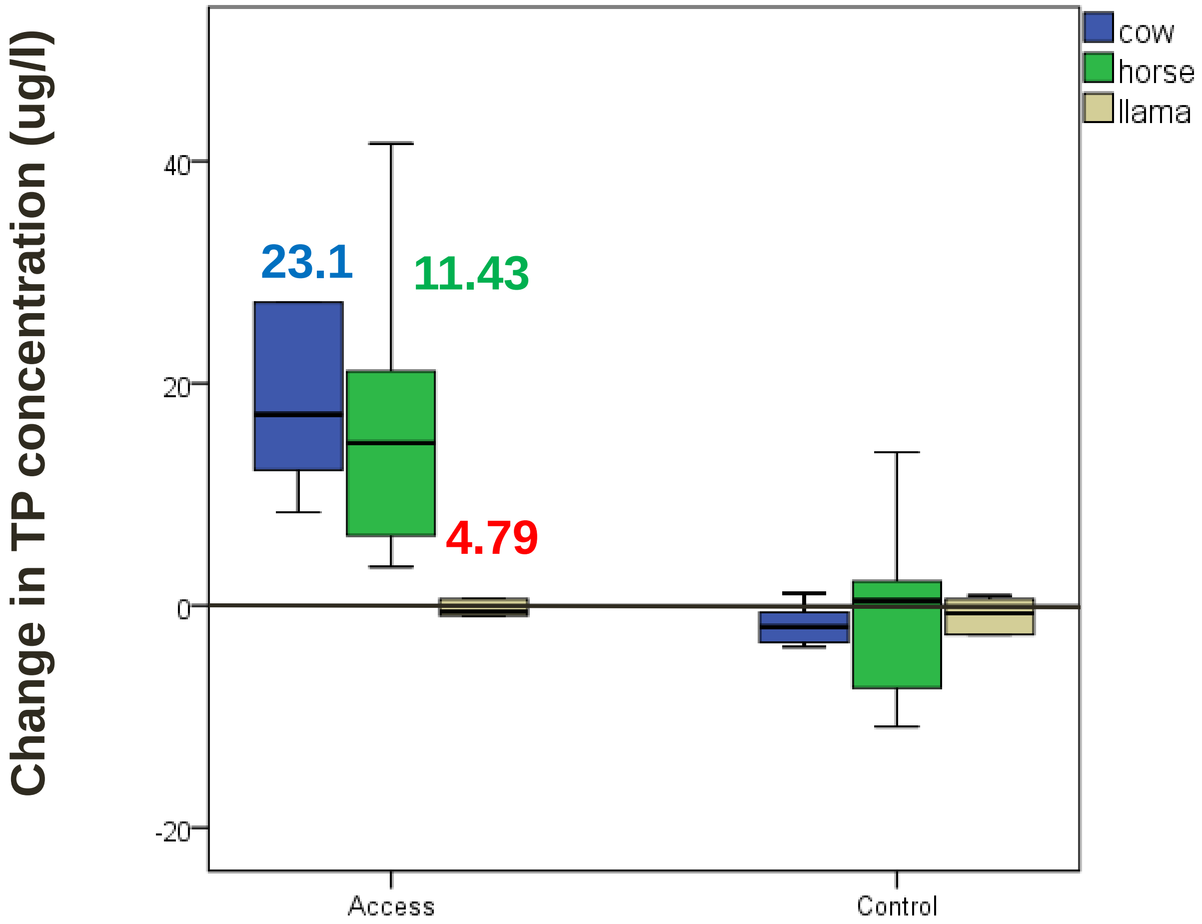
Management

No historical water quality data specifically collected at BMP sites (before implementation)

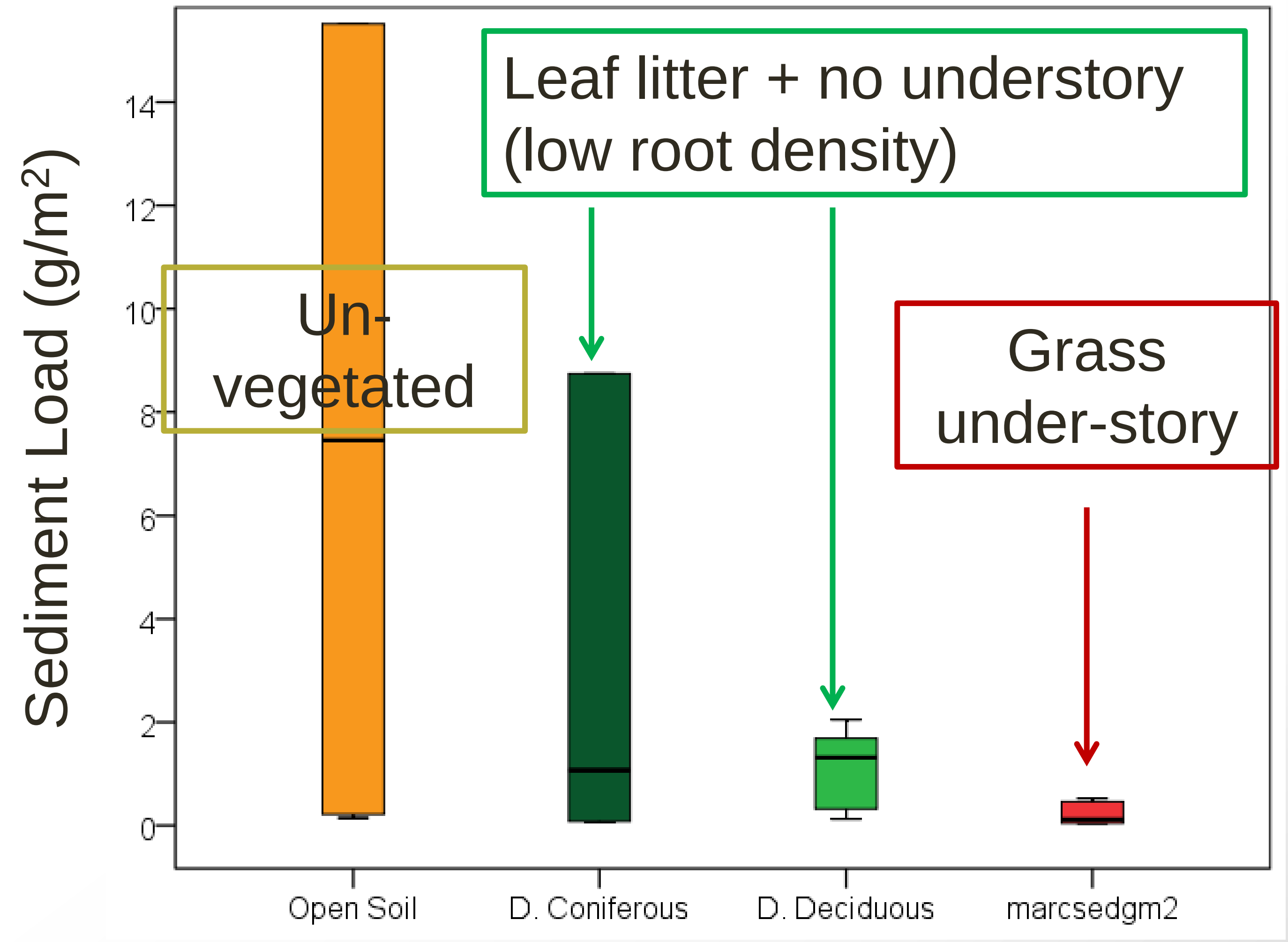


Use combination of new monitoring data and models to determine what TP loads would have been like today if BMPs had not been implemented

Monitoring the impact that livestock access to water has on TP concentrations



Monitoring the impact that vegetation has on soil erosion



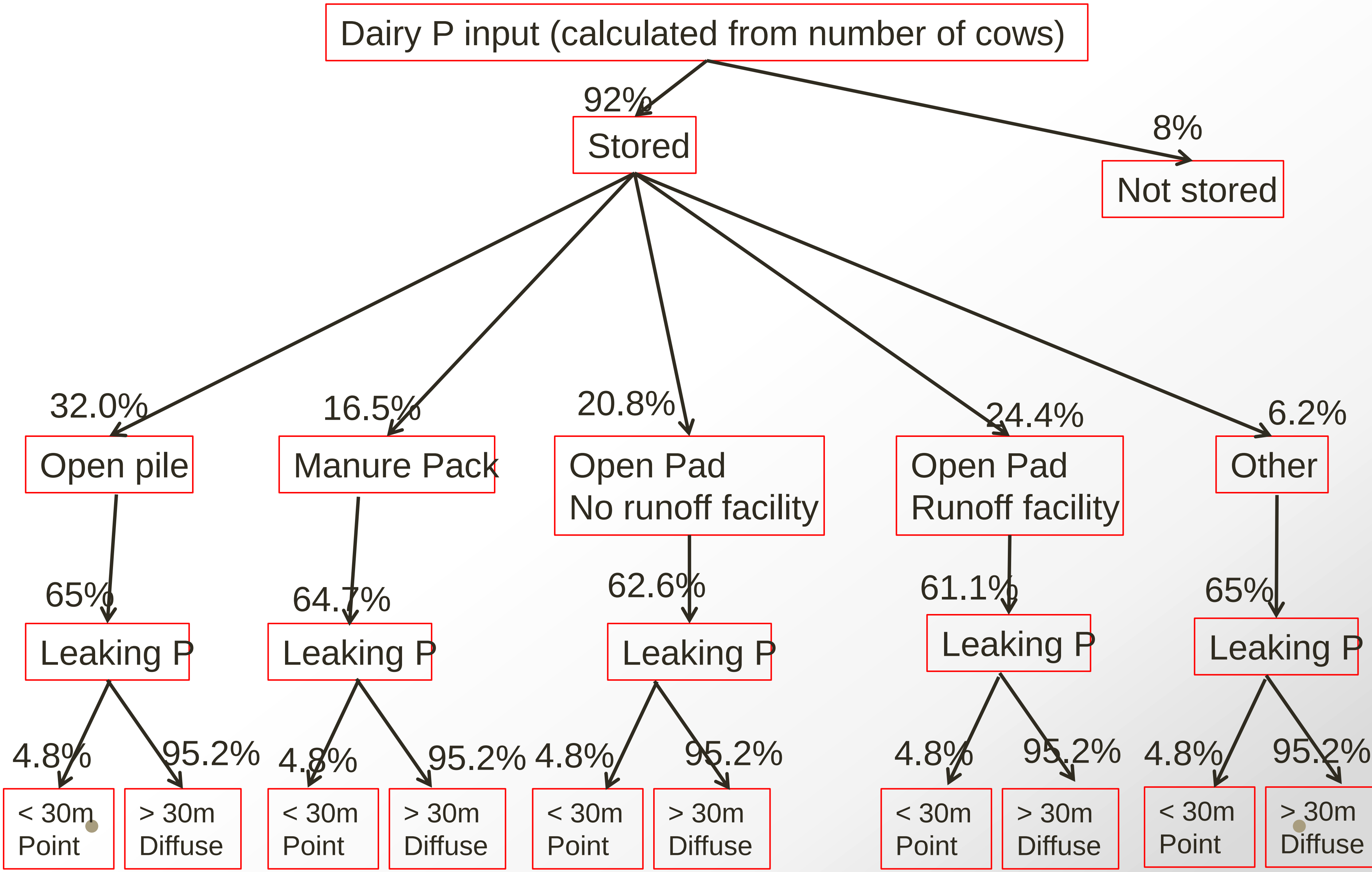
Determining change in P inputs (from rivers to soils) by upgrading leaking septic systems within 100m of watercourses

LEAP funding only given if system are within 100m of water. Assume prior to upgrade system leaks directly to river.

Used CANWET septic data, and Ontario building code to determine inputs of septic systems to individual subcatchments

Validated to current year (2013 and 2014) using intensive monitoring data at sites listed as "post upgrade"

Calculated P inputs in each subcatchment from different dairy - manure storage strategies



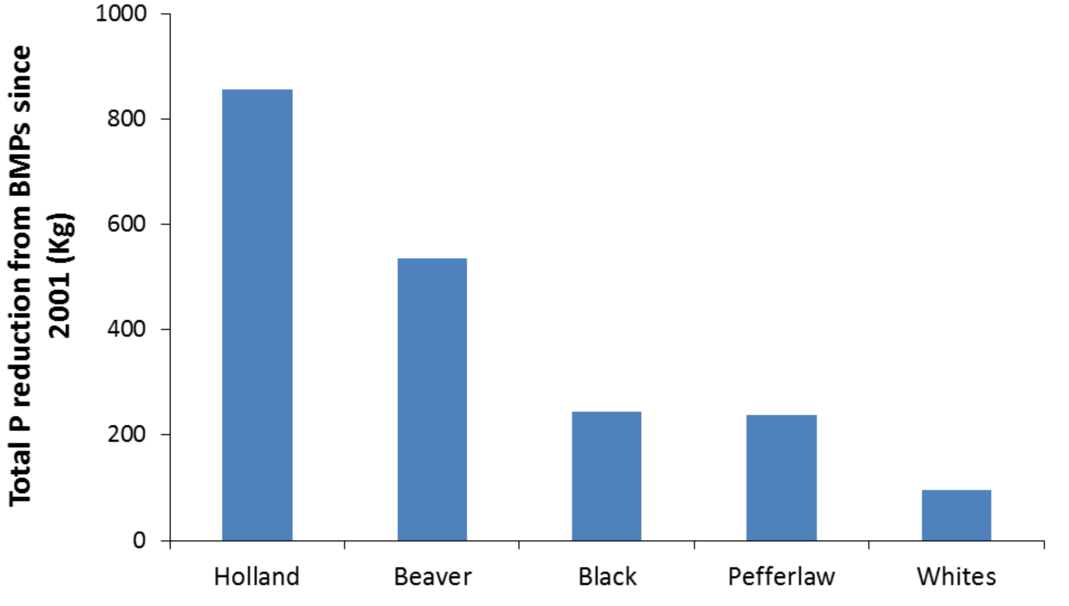
How was the field data used?

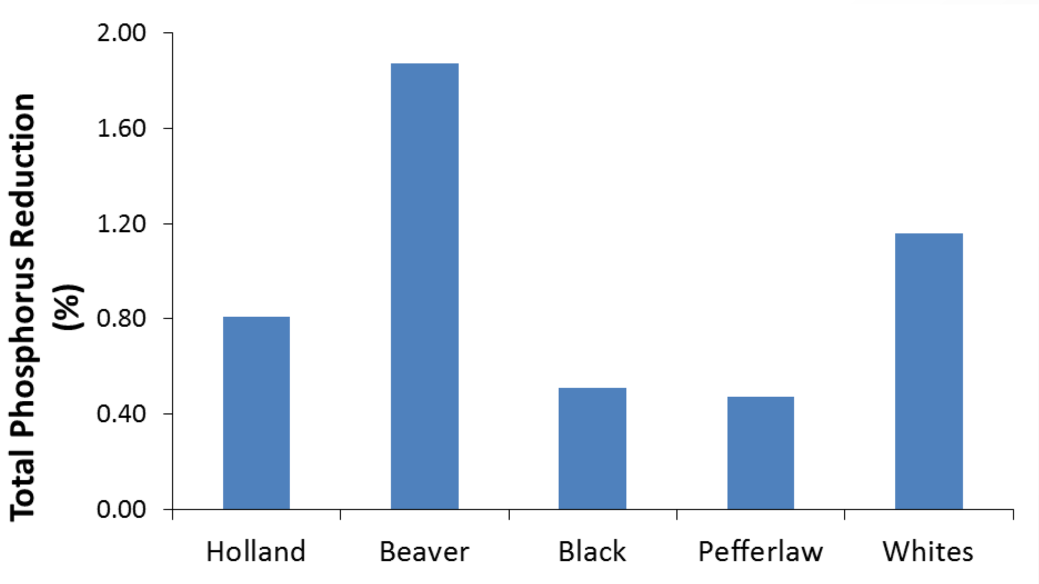
Combined new knowledge of BMP impacts on P inputs, into a time-series of P input data for the INCA model

A time-series accounts for implementation of different strategies, at different times, in different subwatersheds.

Enables us to “switch on” individual strategies in isolation, and determine the effectiveness of a single type of BMP

Results

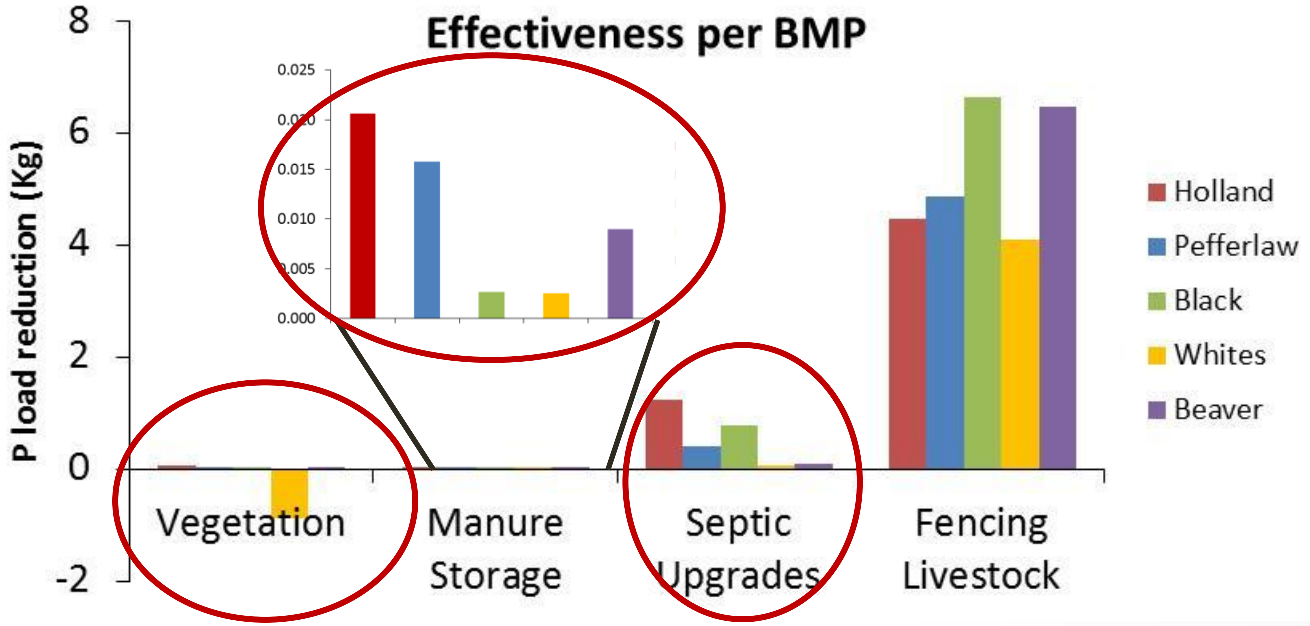




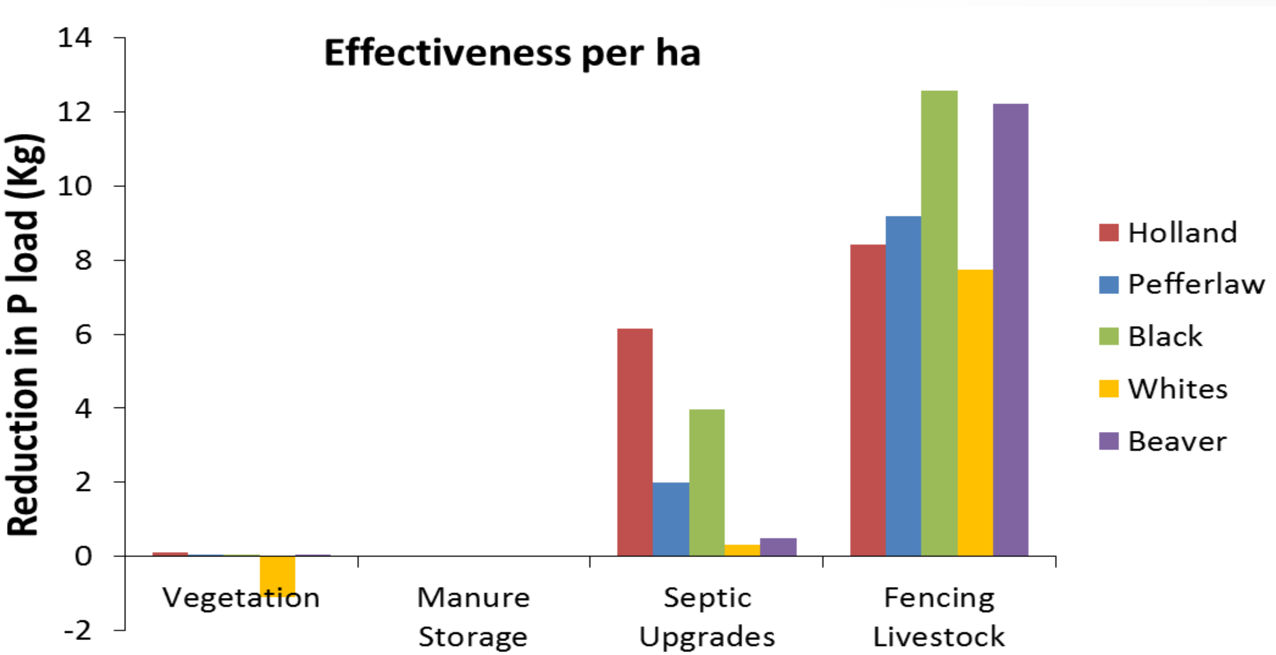
BMPs have reduced total P load to the lake by 1,971kg since 2001

Or 0.8% of the what the 14-year load would have been.

Results



Effectiveness varies between catchments



Some BMPs using up more area in order to attain their "effectiveness"

Overall Conclusions

- Nutrient and flow responses are governed by geology (influencing flow pathways) and nutrient transport mechanisms
- Sensitivity to climate change is highest in catchments with high proportions of over-land and macropore flow (Beaver and Whites), especially during periods of high runoff (spring melt)
- Choice of management strategy is of course important, however effectiveness varies widely between catchments associated with the same processes controlling sensitivity
- Strategies that re-direct nutrients through soils have to-date been more effective within catchments with greater soil matrix flow (Holland and Pefferlaw)
- But strategies we might expect to be effective in erosion-sensitive catchments (e.g. tree planting in B&W) may exacerbate issues at particularly sensitive times of year (spring melt)

Questions?

Thanks to: The Ministry of Environment, Dr Michelle Palmer, Dr Eleanor Stainsby, Professor Jennifer Winter, Dave Woods, Mitch Hall, Nathan Plousos

Incorporating Climate Change into Watershed Water Budgets

Don Ford, P.Geo.
Manager, Hydrogeology

The Living City Foundation

Toronto and Region Conservation for The Living City

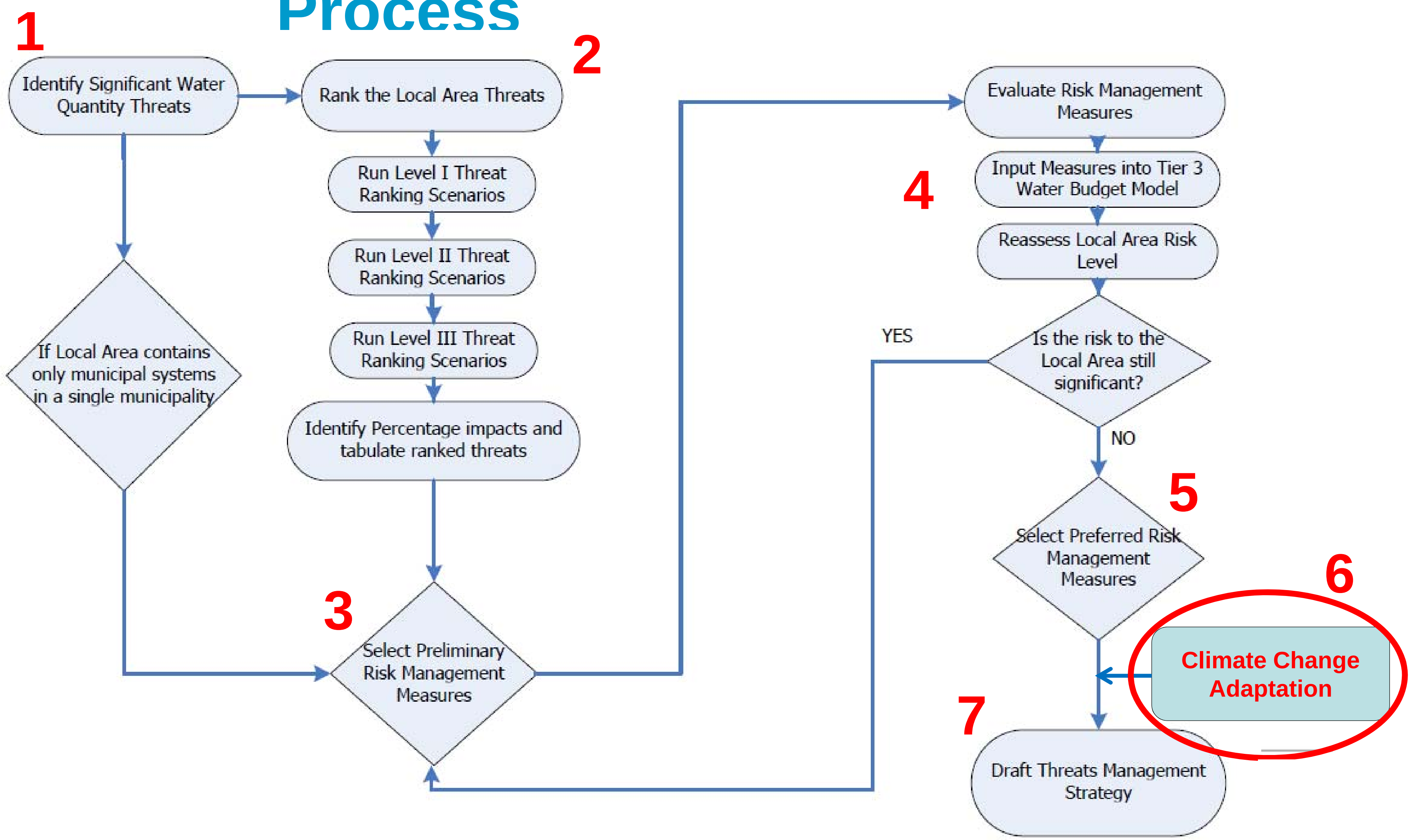
Overview

- Water Quantity Risk Assessment Process
- Risk Management Measures Catalogue
- Pilot Project Area
- Pilot Project Objectives
- Pilot Project Approach
- Community Engagement
- Key Findings
- Next Steps

Risk Management Measures Evaluation Process

1. Identify drinking water quantity threats
2. Rank the local area significant threats
3. Select preliminary risk management measures (scenarios) to manage the threats
4. Re-evaluate the risk level to the local area.
5. Select preferred measures
6. **Re-evaluate RMM for Climate Change adaptation**
7. Prepare a preliminary Threats Management Strategy

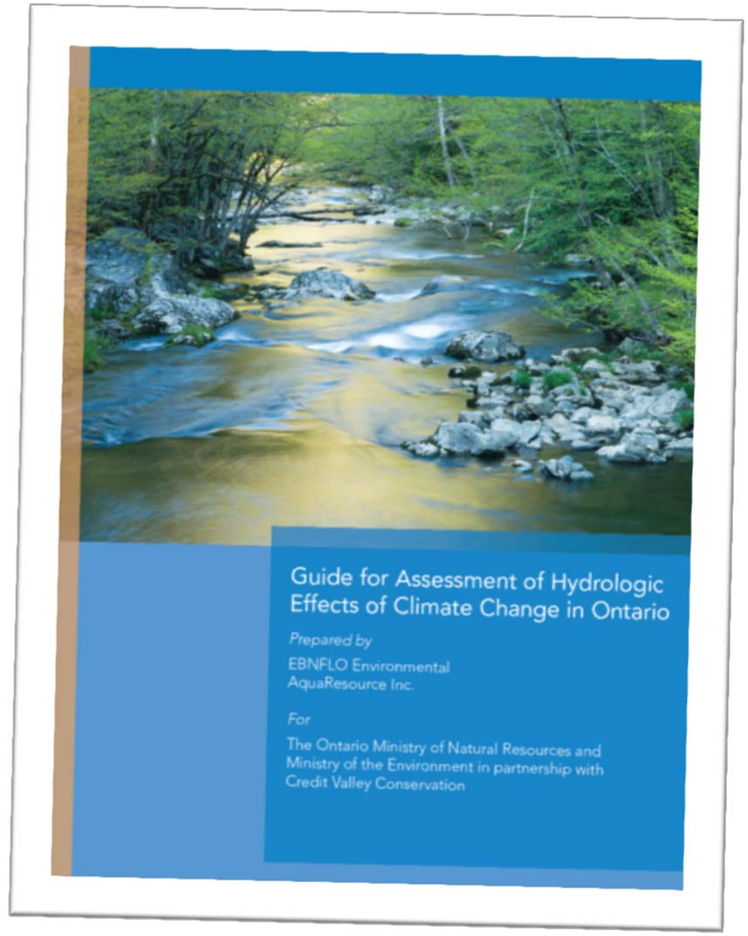
Water Quantity Risk Assessment Process



MNR Guide (2010)

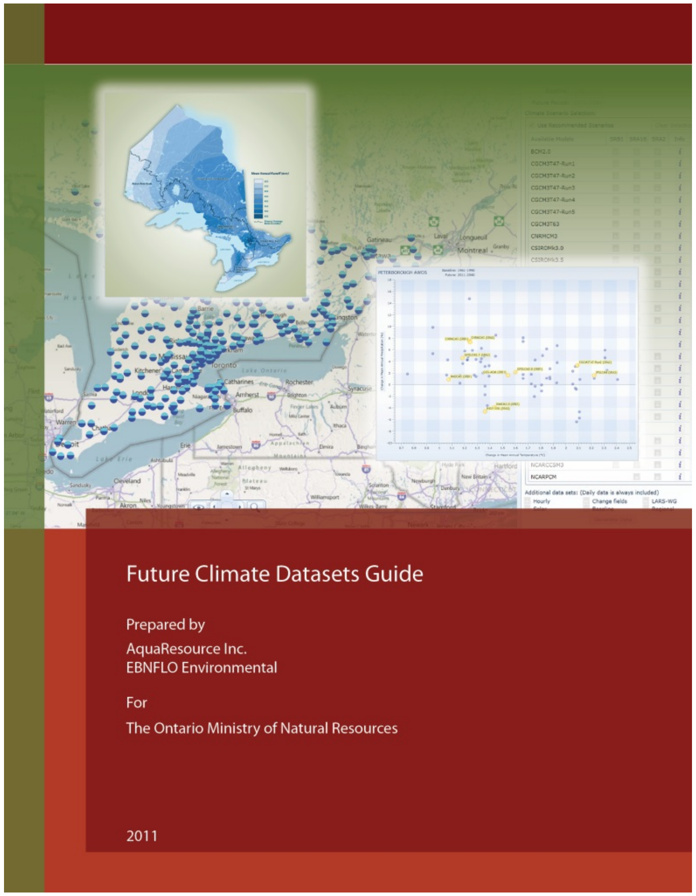
Guide Contents:

- Background on Observed and Projected Climate Change
- Global Climate Change Models (GCMs) and GHG Emission Scenarios
- Methods for Developing Local Climate Future Climate Data Scenarios
- Summary of Potential Hydrologic Impacts of Climate Change
- Step by Step Climate Change Impact Assessment and Case Study
- Available at http://waterbudget.ca



Climate Change Data Sets

- Change Fields (e.g., Temp., Precip.) calculated and applied to existing climate data for all 339 EC Ontario climate stations
  - 27 GCM runs
  - Up to 3 emission scenarios
- Weather generator output (4 GCMs & 3 emission scenarios)
- Regional Climate Model output



Available at http://waterbudget.ca

http://www.trcagauging.ca/RmmCatalogue/QuantityIndex.aspx — Risk Management Measures...

RMM Catalogue | Home | Quality Catalogue | Quantity Catalogue

Source Water Protection

Risk Management Measures Catalogue

Toronto and Region Conservation for The Living City

Ontario

Version: 6.0 - 4/5/2013

Home / **Quantity Home**

Water Quantity Risk Management Measures Catalogue

The **Water Quantity** section of the Risk Management Measures Catalogue is intended to be used where a Local Area has been assigned a significant risk level through the Tier 3 Water Budget and Local Area Risk Assessment Process. As part of an overall Risk Management Measures Evaluation Process (RMMEP), the Catalogue can be used in the drinking water source protection planning phase to select and evaluate preferred risk management measures to manage water quantity threats and inform the policy development process. Following the RMMEP, risk management measures are selected from the catalogue to undertake a quantitative evaluation of the effectiveness of the selected measure(s) and re-assignment of the risk level to a Local Area.

To allow the user to search for measures most applicable to the type of activities located in a source protection area, the Catalogue is structured in such a way that the user may browse by measure or threat and then filter by Sector or Management Target.

The risk management measures provided have been peer reviewed by a number of technical experts and have been identified as being applicable to address a particular or several drinking water quality threat (s). However, the Province of Ontario and Toronto and Region Conservation assume no liability for the risk management measures selected by the users.

Browse All Measures in the Catalog

Browse Measures

Search Specific Measures by Threat

Measures by Threat

Mail - Inbox ... | Risk Manage... | Presentation...

http://www.trcagauging.ca/RmmCatalogue/QuantityBrowse.as Risk Management Measures...

RMM Catalogue Home Quality Catalogue Quantity Catalogue

Source Water Protection

Risk Management Measures Catalogue

Toronto and Region Conservation for The Living City

Ontario

Version: 6.0 - 4/5/2013

Home / Quantity Home / Browse Quantity Measures

Water Quantity Risk Management Measures Catalogue

Keyword Search... Search

Filter by Sector: All

Filter by Management Target: All

Clear Filters

	ReferenceID	Measure Name	Measure Short Description
	QT028	Additional water storage facilities	Long-term additional storage to mitigate changes in local water quantity temporally and spatially.
	QT050	Alternatives to conventional water systems - dual water distribution	Separate the supply of treated water with the highest potable (drinking) water standards from the water for non-potable needs. These include fire fighting, landscape watering, toilet flushing, street cleaning and similar uses.
	QT051	Alternatives to conventional water systems - separate collection of wastewater for future re-use	Water and Wastewater Strategies that consider: - the collection of gray water (from showers, dishwashers, clothes washers) for use in heat pump systems for energy recovery and (after filtering) for non-potable uses such as irrigation and fire-fight
	QT001	Aquifer storage and recovery systems	Use of excess surface water to recharge aquifers to mitigate both impacts to groundwater and elevated surface water flow during storm events.
	QT032	Bioretention systems	Bioretention systems are naturally vegetated areas where runoff is directed for temporary

Mail - Inbox ... Risk Manage... Presentation...

http://www.trcagauging.ca/RmmCatalogue/QtyMeasureDetails | Risk Management Measures...

RMM Catalogue Home Quality Catalogue Quantity Catalogue

Source Water Protection

Risk Management Measures Catalogue

Toronto and Region Conservation for The Living City

Ontario

Version: 6.0 - 4/5/2013

Home / Quantity Home / Browse Quantity Measures / Measure Details

Printable Version
PDF Version

Risk Management Measures

Measure Information Sheet

Reference ID	QT028
Measure Name	Additional water storage facilities
Measure Description	Long-term additional storage to mitigate changes in local water quantity temporally and spatially.
Climate Change Adaptation	Yes

Management Targets

- Municipal Water Efficiencies
- Water supply increase

Click for More Information

Applicable Sectors:

- Commercial
- Agriculture
- Municipal
- Industry

Associated Threats:

Order	Threat Name	Effectiveness Comments	Applicability
19.1	Consumptive water use - surface water intakes	Small cost relative to benefit of stable water supply in periods of low water resources.	Groundwater: No Surface Water: Yes
19.2	Consumptive water use - wells	Small cost relative to benefit of stable water supply in periods of low water resources.	Groundwater: Yes Surface Water: No

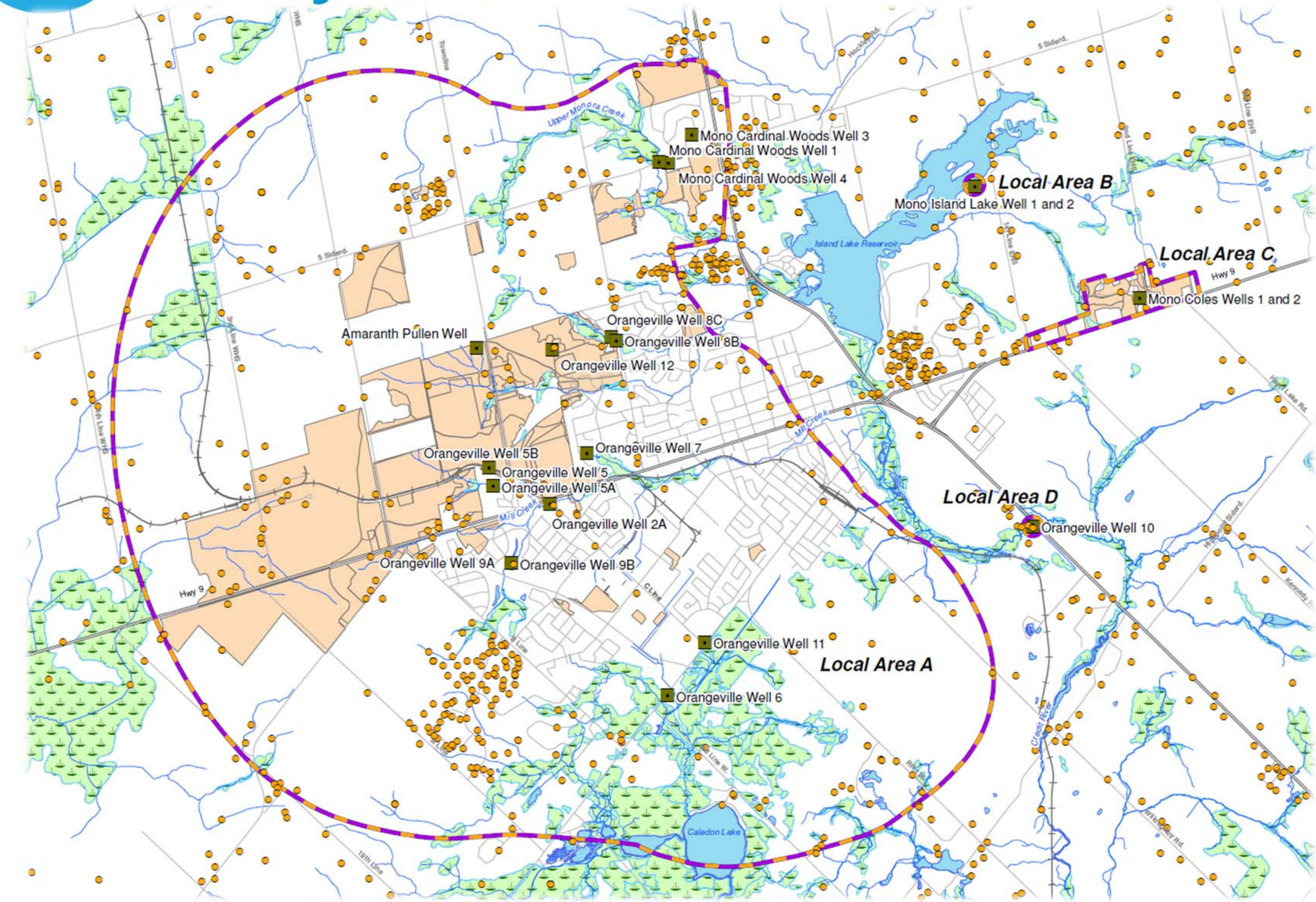
Additional Information Sources:

Infosheet - Agriculture and Agri-Food Canada, 2009 (Canada)
Water Storage Facilities for Livestock Watering Systems
View Details

URL of this Page: http://www.trcagauging.ca/RmmCatalogue/QtyMeasureDetails.aspx?id=35

Mail - Inbox ... Risk Manage... Presentation...

Study Area


Mono Cardinal Woods Well 3
Mono Cardinal Woods Well 1
Mono Cardinal Woods Well 4
Local Area B
Mono Island Lake Well 1 and 2
Local Area C
Mono Coles Wells 1 and 2
Orangeville Well 8C
Orangeville Well 8B
Amaranth Pullen Well
Orangeville Well 12
Orangeville Well 7
Orangeville Well 5B
Orangeville Well 5
Orangeville Well 5A
Orangeville Well 2A
Local Area D
Orangeville Well 10
Orangeville Well 9A
Orangeville Well 9B
Orangeville Well 11
Local Area A
Orangeville Well 6
Island Lake Reservoir
Caledon Lake
Upper Monora Creek
Mill Creek
Hwy 9
5 Sideroad
Hwy 9

Pilot Project Objectives

- Test the application of the Risk Management Measures Evaluation Process
- Evaluate the potential effectiveness of specific risk management processes
- Examine the potential effects of Climate Change on the Risk Assessment Findings

Guide
Water Quantity Risk Management Measures Evaluation Process

Prepared for:
The use of Source Protection Committees in preparation of the Source Protection Plans under the Clean Water Act

Prepared by:

Toronto and Region Conservation
5 Shoreham Drive
Downsview, ON M3N 1S4

Toronto and Region Conservation *for The Living City*

January, 2013

Approach

- Review previous model results and limitations
- Translate data into new model
- Input new water use and water level data
- Determine scenarios to be run with the new model
- Select Preliminary Risk Management Measures - RMM Catalogue
  - About 80 Water Quantity Risk Management Measures
  - Water Conservation and “Terrain” Management Targets (e.g., land-use, land-practice) to try to address Water Quantity Threats
- Test scenarios
- Input climate change dataset from MNR&F

Pilot: Climate Change Adaptation

- Selected 10 Future Local Climates – percentile method
- Input climates into MIKE SHE model
  - Generate recharge time series
- Input recharge into MODFLOW Groundwater flow model
- Re-evaluate RMM Scenarios

Example Measures

- Indoor water use reduction
- Outdoor water use reduction
- Industrial, commercial, and institutional (ICI) water efficiencies
- Municipal water loss management
- Water resource awareness
- Increase in recharge
- Increase in water supply
- Municipal water efficiencies
- Agricultural water efficiencies - crop management
- Agricultural water efficiencies - livestock management

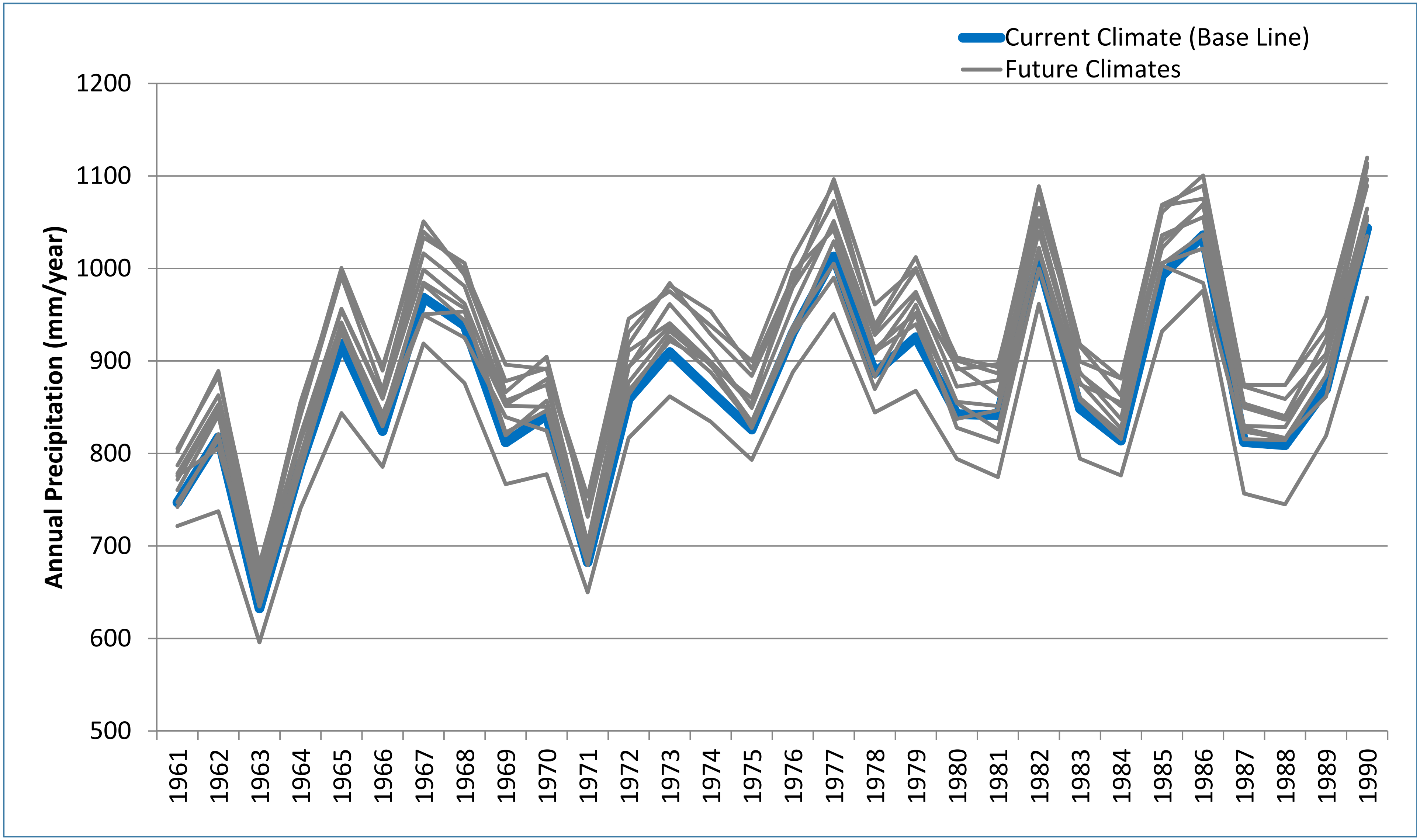
Community Engagement

- Key Issues:
  - Tier 3 Water Budget completed in 2013
  - Actions needed in Amaranth and East Garafraxa to manage water quantity risks for Orangeville residents
- Meetings with Town of Orangeville, Amaranth, East Garafraxa
  - Teleconference
    - Introduction to the project
  - Face-to-face Meeting 1:
    - Review of approach
  - Face-face Meeting 2:
    - Presentation of draft findings
    - Discussion of implications to municipalities

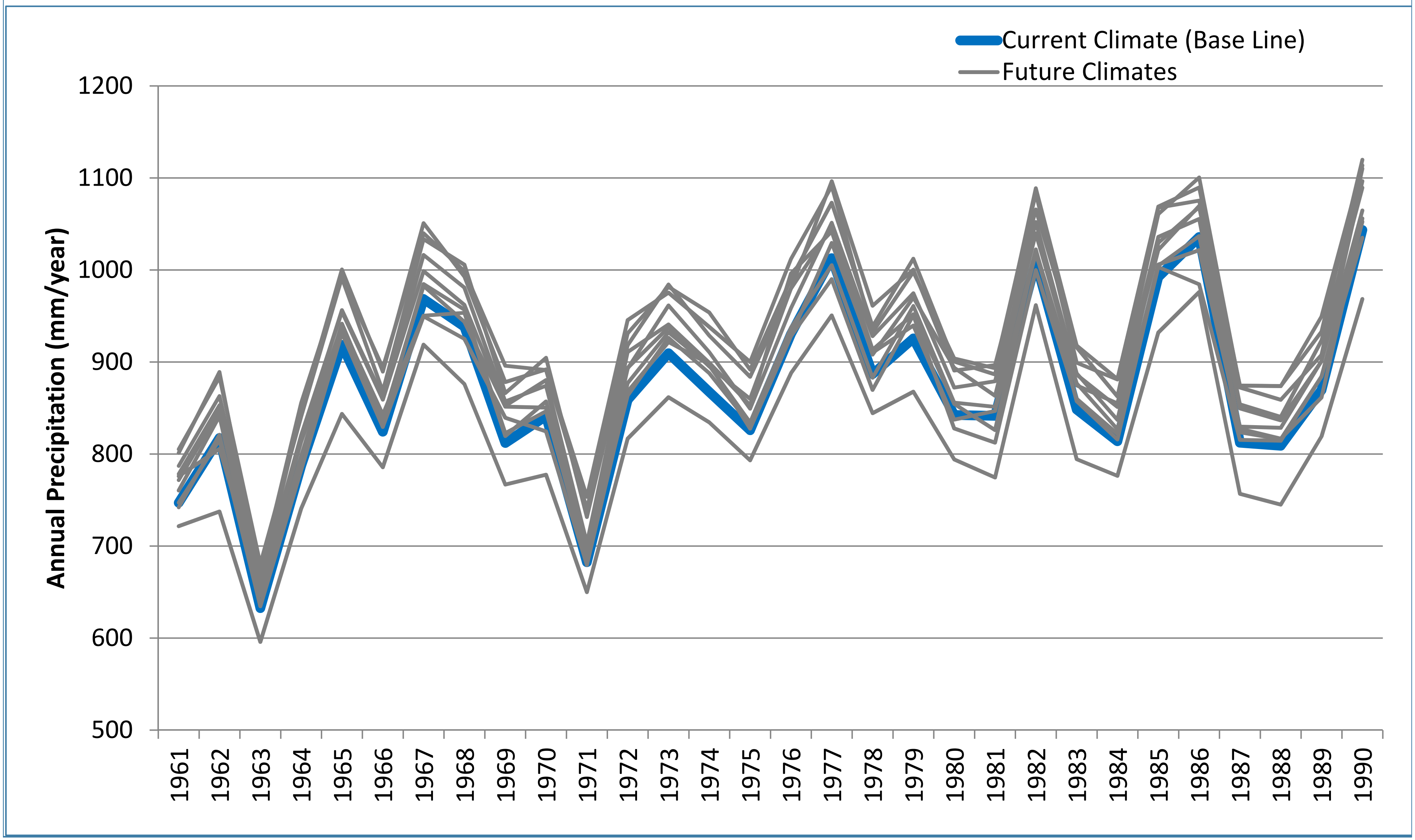
Climate Scenarios - Recharge

Scenario ID	Percentage of Base Case Recharge	Climate Change Scenario	Change in Mean Annual Temperature (Deg C)	Change in Mean Annual Precipitation (%)
CC 1	100%	CGCM3T47-Run2 - SRB1	2.11	0.91
CC 2	118%	CGCM3T47-Run3 - SRA2	1.61	8.1
CC 3	119%	CGCM3T47-Run3 - SRB1	1.45	8.52
CC 4	106%	CGCM3T47-Run5 - SRA2	2.18	2.34
CC 5	80%	CSIROMk3.5 - SRB1	1.35	-4.05
CC 6	107%	ECHAM5OM - SRB1	1.02	3.72
CC 7	116%	FGOALS-g1.0 - SRA1B	1.26	5.92
CC 8	107%	GFDLCM2.0 - SRB1	1.48	4.37
CC 9	98%	GISS-AOM - SRA1B	1.31	0.68
CC 10	103%	GISS-EH - SRA1B	0.86	2.58

Climate Change: Precipitation



Climate Change: Temperature



Climate Change Results - Drawdown

Well Name	Safe Additional in-Well Drawdown (m) (2013)	RMM Scenario G	CC 1	CC 2	CC 3	CC 4	CC 5	CC 6	CC 7	CC 8	CC 9	CC 10
		Total Max Drawdown	Total Max Drawdown	Total Max Drawdown	Total Max Drawdown	Total Max Drawdown	Total Max Drawdown	Total Max Drawdown	Total Max Drawdown	Total Max Drawdown	Total Max Drawdown	Total Max Drawdown
Orangeville Well 2A	4.1	3.3	3.1	1.6	1.6	2.5	5.2	2.6	1.8	2.6	3.4	2.9
Orangeville Well 5/5A	3.1	1.0	0.8	-0.6	-0.6	0.2	3.8	0.3	-0.4	0.3	1.1	0.6
Orangeville Well 6	3.6	3.5	3.3	1.7	1.7	2.7	5.5	2.8	1.9	2.8	3.6	3.2
Orangeville Well 7	10.1	8.7	8.5	7.2	7.1	8.0	10.5	8.1	7.3	8.1	8.8	8.4
Orangeville Well 8B	7.7	4.2	4.1	3.1	3.0	3.7	5.6	3.8	3.2	3.7	4.2	4.0
Orangeville Well 8C	8.6	3.8	3.7	2.8	2.7	3.3	5.2	3.4	2.9	3.4	3.9	3.6
Orangeville Well 9A/9B	4.8	2.2	2.0	-0.1	-0.2	1.1	5.6	1.3	0.1	1.3	2.4	1.7
Orangeville Well 10	36.7	6.2	6.2	6.1	6.0	6.1	6.4	6.1	6.1	6.1	6.2	6.2
Orangeville Well 11	7.4	6.6	6.4	4.6	4.6	5.7	8.7	5.9	4.9	5.8	6.7	6.2
Orangeville Well 12	13.1	9.7	9.5	8.3	8.2	9.0	11.4	9.2	8.4	9.1	9.8	9.4
Mono Cardinal Woods 1	4.8	2.9	2.8	2.2	2.1	2.6	3.8	2.6	2.2	2.6	2.9	2.8
Mono Cardinal Woods 3	3.0	2.0	1.8	1.2	1.2	1.6	2.8	1.7	1.3	1.7	2.0	1.8
Mono Coles 1 and 2	34.7	2.3	3.2	0.5	0.4	2.1	7.2	2.3	0.8	2.3	3.7	2.9
Mono Island Lake Wells	22.1	3.4	2.3	2.0	1.9	2.1	2.7	2.2	2.0	2.2	2.3	2.3
Amaranth Pullen Well	30.6	14.6	14.4	13.0	12.9	13.8	16.5	14.0	13.1	13.9	14.7	14.3
% of Base Case Recharge		100%	100%	118%	119%	106%	80%	107%	116%	107%	98%	103%

Climate Change Results – Discharge

Stream / Reach	Scenario C – Existing Conditions GW Discharge (L/s)	RMM Scenario D	CC 1	CC 2	CC 3	CC 4	CC 5	CC 6	CC 7	CC 8	CC 9	CC 10
		Percent Reduction (%)	Percent Reduction (%)	Percent Reduction (%)	Percent Reduction (%)	Percent Reduction (%)	Percent Reduction (%)	Percent Reduction (%)	Percent Reduction (%)	Percent Reduction (%)	Percent Reduction (%)	Percent Reduction (%)
North Arm of Lower Monora	20.0	19%	20%	-15%	-16%	6%	55%	6%	-11%	6%	23%	14%
South Arm of Lower Monora	5.3	19%	19%	-6%	-8%	10%	46%	9%	-4%	10%	22%	15%
Total Lower Monora	31.0	17%	17%	-11%	-13%	6%	47%	6%	-8%	6%	20%	12%
Upper Monora	38.0	15%	15%	-13%	-15%	5%	41%	4%	-10%	5%	18%	11%
Upper Mill	11.2	-15%	-13%	-112%	-117%	-50%	83%	-52%	-102%	-51%	-4%	-29%
Lower Mill	14.8	-8%	-7%	-89%	-94%	-38%	72%	-39%	-81%	-38%	0%	-21%
Island Lake Tributaries	19.7	6%	7%	-61%	-64%	-19%	74%	-20%	-54%	-19%	13%	-5%
Caledon Tributaries	16.6	6%	8%	-90%	-96%	-28%	95%	-29%	-80%	-28%	16%	-8%
Caledon Lake Wetlands	11.6	8%	9%	-39%	-42%	-8%	55%	-9%	-33%	-8%	13%	1%
Credit River	305.0	5%	6%	-13%	-14%	-1%	25%	-1%	-11%	-1%	7%	3%
% of Base Case Recharge		100%	100%	118%	119%	106%	80%	107%	116%	107%	98%	103%

Next Steps

- Policies by Source Protection Committees
- RMM Evaluation Process informs strategy development
- Could include:
  - identification of Moderate and/or Significant drinking Water Quantity Threats
  - identification of preferred Risk Management Measures
  - summary of expected Management Targets and/or policy outcomes that would comply with the water quantity source protection plan polices
  - summary of timelines, including public consultation, for implementation of the Risk Management Measures
  - a summary of consultations held with the affected stakeholder(s)
- Additional Scenarios – AR5?

Questions?

- Don Ford, TRCA

  dford@trca.on.ca
- Paul Chin, Matrix Environmental Services

  pchin@matrix-solutions.com

Thanks to:

Clara Tucker, MOECC

Scott Bates, Mike Garroway, MNRF

Developing a Place-Based Modelling Tool for Evaluating the Cost Effectiveness of Beneficial Management Practices in Agricultural Watersheds

Wanhong Yang

UNIVERSITY of GUELPH

November 27, 2014

Outline

- National and international environmental/ecological initiatives
- WEBs program in Agriculture and Agri-Food Canada
- A place based modelling tool
- The Best in Science Project (Water quantity + climate change and adaptation)

Environmental/Ecological Initiatives

- Canada – Great Lakes Water Quality Agreement, Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem, Lake Simcoe Clean-Up, Lake Winnipeg Basin Stewardship, …

- U.S. – Conservation Reserve Program, Environmental Quality Incentives Program, …

- Europe – Set-aside Program, Agri-environmental Schemes, …

Management/Policy Questions

- Allocating resources on landscape
- Targeting programs to critical locations or areas
- Assessing conservation effects
- Measuring program performance
- Determining effluent credits for water quality trading

Complexity of the Problem

- Spatial scales: Location, field, farm, subbasin, basin, region
- Time scales: Hourly, daily, monthly, yearly
- Multiple landscape practices and multiple benefits (flow, sediment, nutrient, wildlife, ...)
- Economic vs. hydologic vs. ecological dimensions
- Climate change and adaptation

The WEBs Program in Canada (2004 – 2013)

(Harker 2011)

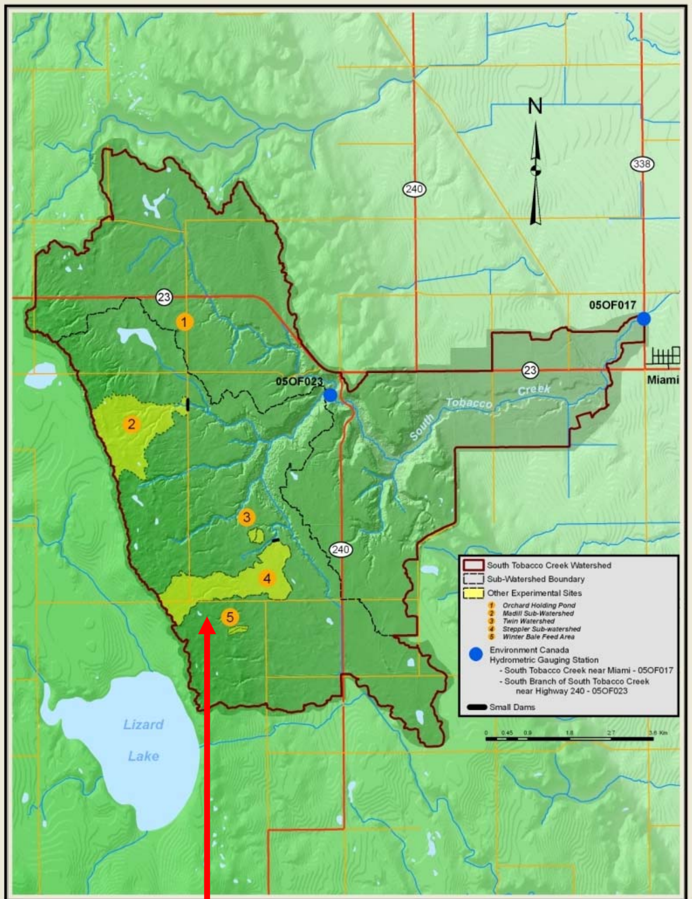
The purpose of the **W**atershed **E**valuation of **B**eneficial Management Practices (BMPs) program is to assess the environmental and economic performance of selected BMPs at the watershed scale.

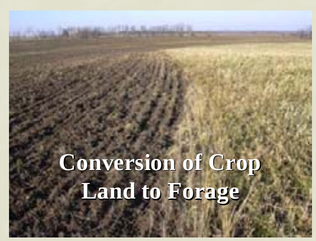
WEBs BMPs by Watershed

WEBs BMPs	BC	AB	SK	MB	ON	QC	NB	NS	PEI
Cattle exclusion fencing (off-stream water)	X	X			X			X	
Off-stream watering without fencing		X							
Riparian vegetation management				X					X
Nutrient input / mgt (synthetic; manure)		X	X			X		X	
Tillage / residue mgt				X		X			X
Crop rotations						X			
Perennial cover			X	X					
Use of less-toxic herbicides						X			
Winter bale-grazing			X	X					
Irrigation efficiency	X								
Diversion terraces, grassed waterways							X		
Surface runoff / tile drainage control					X	X			
Buffer strips		X					X		
Farmyard runoff management								X	
Runoff retention pond				X				X	
Wetland restoration			X						

(Harker 2011)

The STC and Steppler Watersheds (AAFC WEBs)





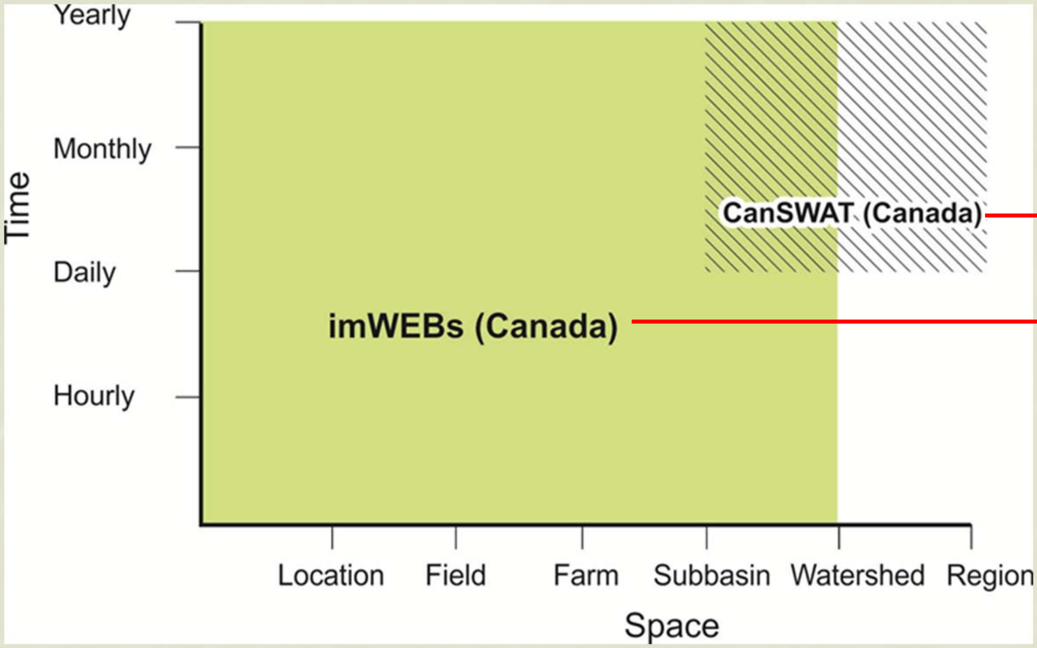
Five BMPs

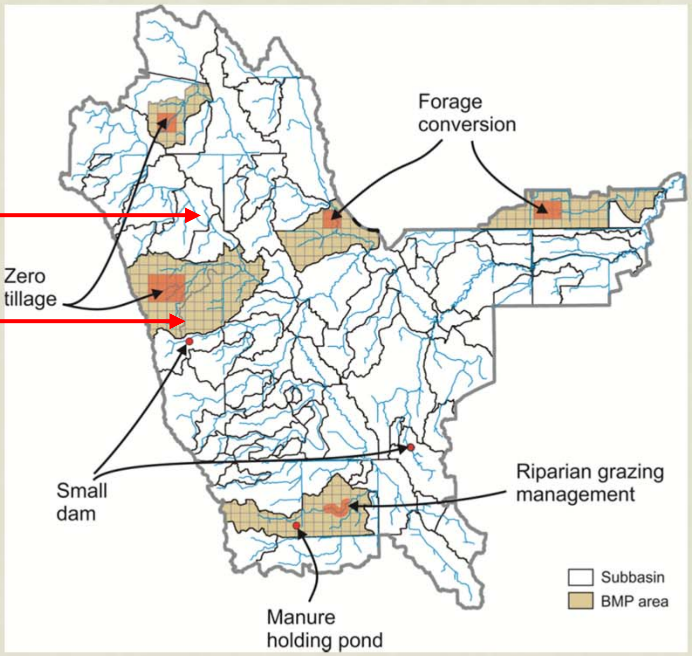
1. Small dams
2. Manure holding ponds
3. Riparian grazing management
4. Tillage management
5. Forage conversion

The Steppler experimental watershed – 200 ha

The STC watershed – 7,500 ha

Modelling in Space and Time



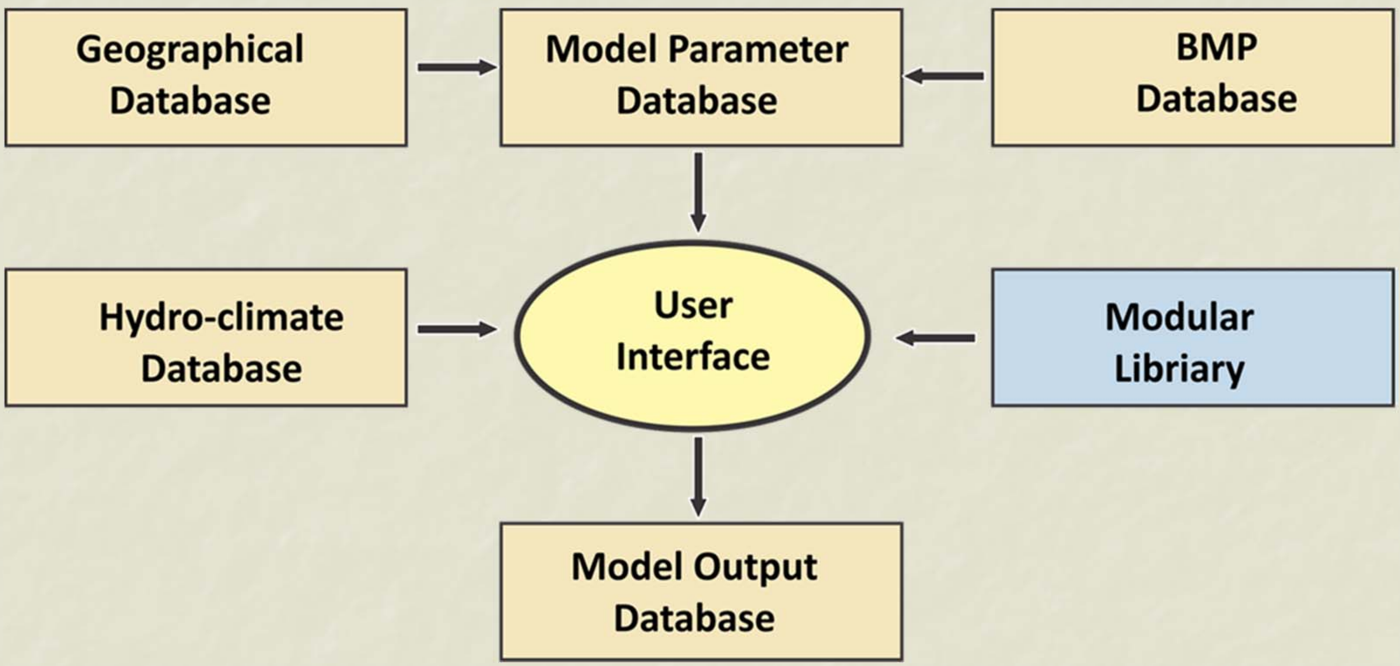


CanSWAT: Canadian Version of Soil and Water Assessment Tool (SWAT)
imWEBs: Integrated Modelling for Watershed Evaluation of BMPs

imWEBs Features

- A cell-based modular modelling system
- Specially designed for place-based BMP assessment at location/field/farm/watershed scales under Canadian cold condition
- Flexibility in defining model objectives and methods depending on project objective, data availability, watershed characteristics, and output of interest
- Flexibility in designing and evaluating spatial BMP scenarios
- Easy to integrate with economic and ecologic models

imWEBs Modular Structure



Hydrologic and Water Quality Processes

- Climate (PET, Spatial and temporal interpolation, …)
- Runoff (Precipitation and interception, Snow redistribution and snowmelt, Depression, Surface runoff and infiltration, Evapotranspiration, Percolation, Interflow, Groundwater flow, Overland flow and channel flow routing, …)
- Sediment (Erosion, Overland transport and channel routing, …)
- Plant growth
- Nutrients (Soil nutrients, Overland transport and channel routing, …)

imWEBs Outputs

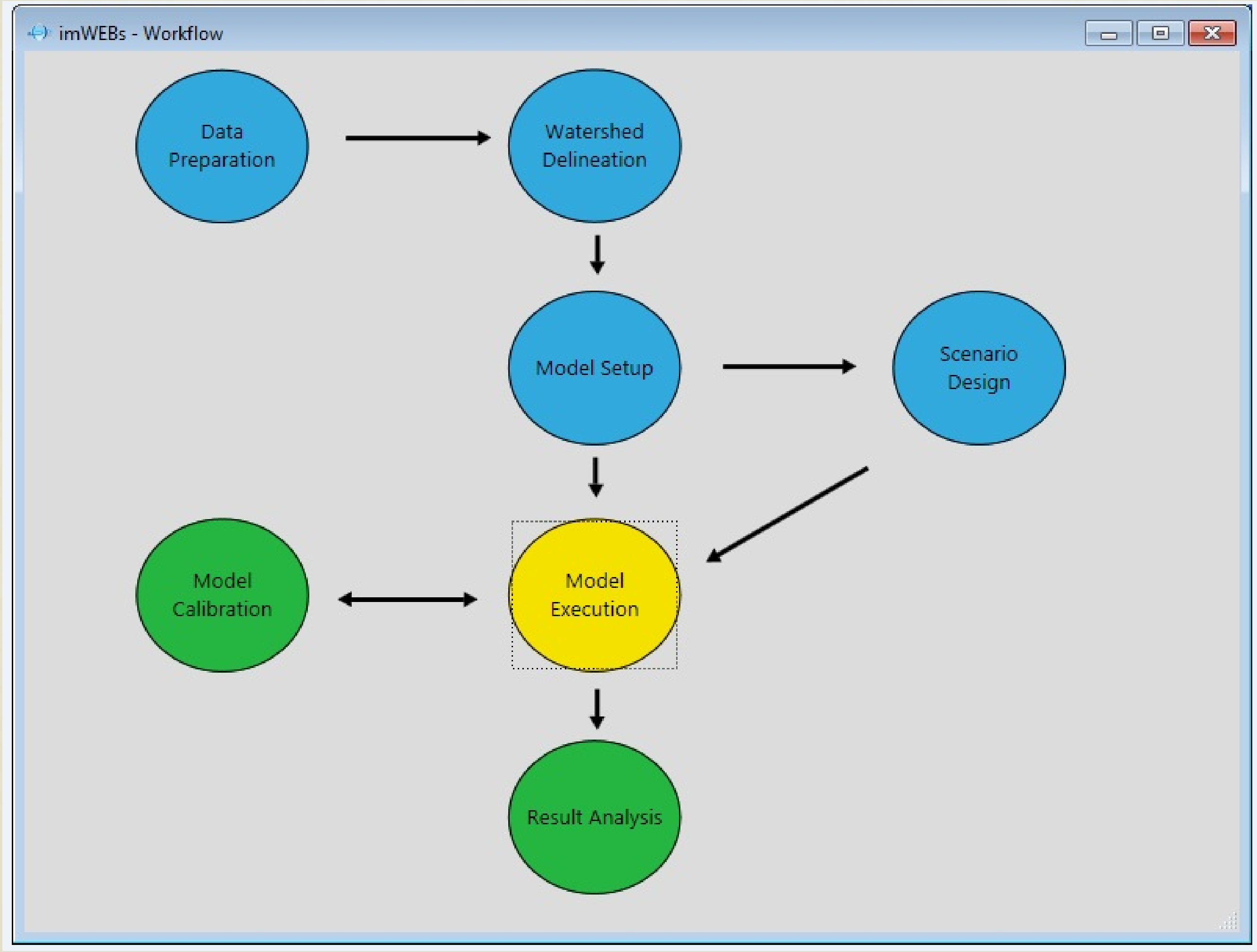
- **Time series**

  Time series of all types of variables at a user defined time interval (hourly, daily, monthly, yearly) and specified locations (location/cell, field, farm, sub-watershed, reach outlet, and BMP site)

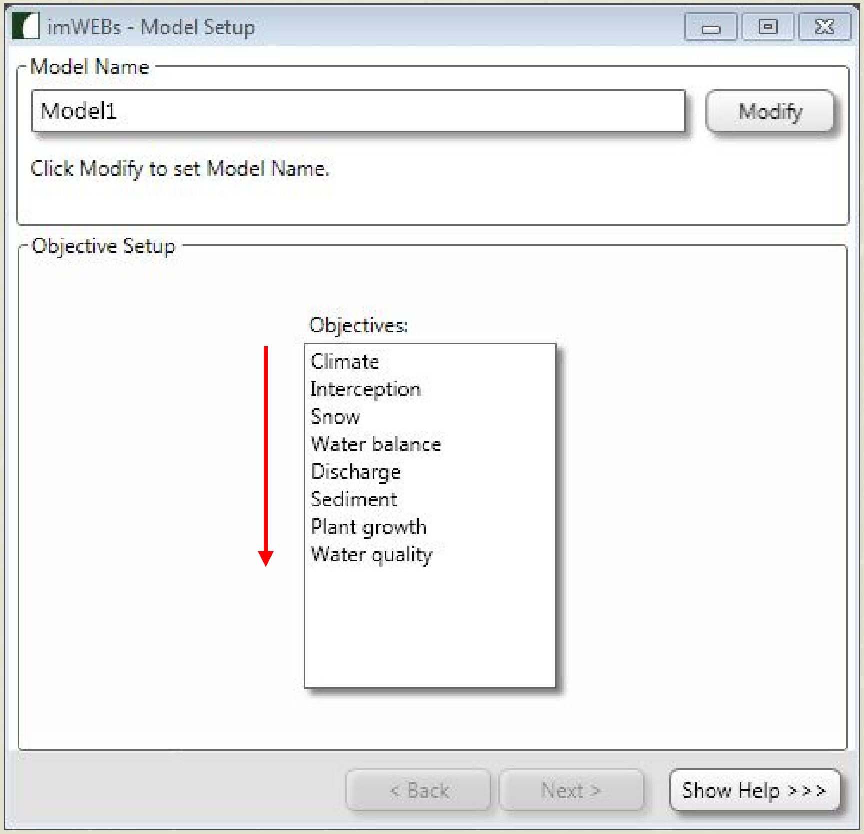
- **Spatial Distribution**

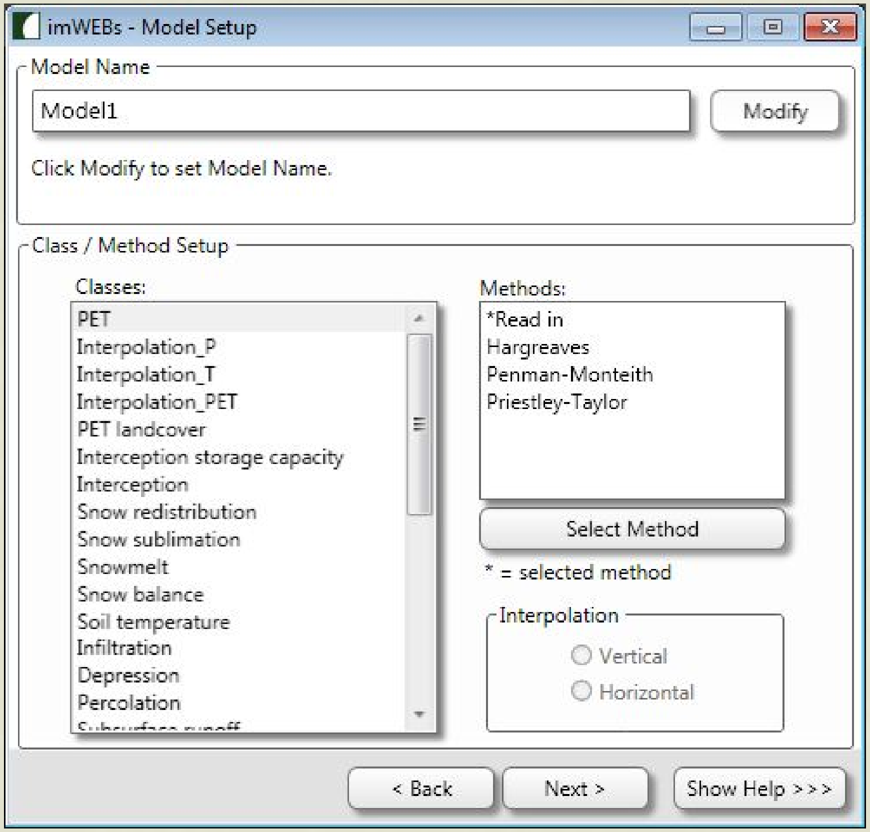
  Spatial distribution of all types of variables at a user defined time period and spatial scale (location/cell, field, farm, and sub-watershed/watershed)

Screenshot 1: imWEBs Workflow

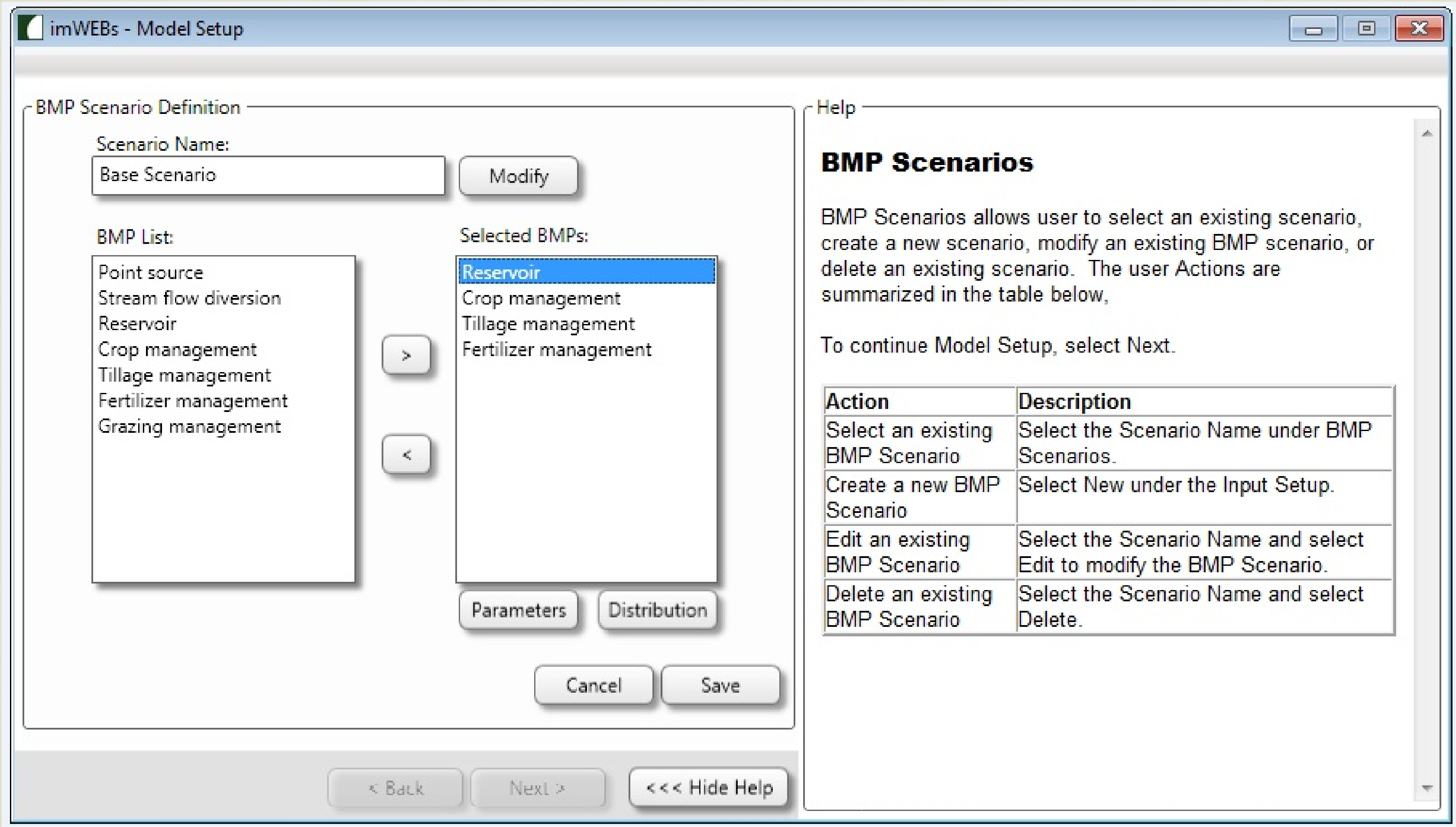


Screenshot 2: Objective & Method

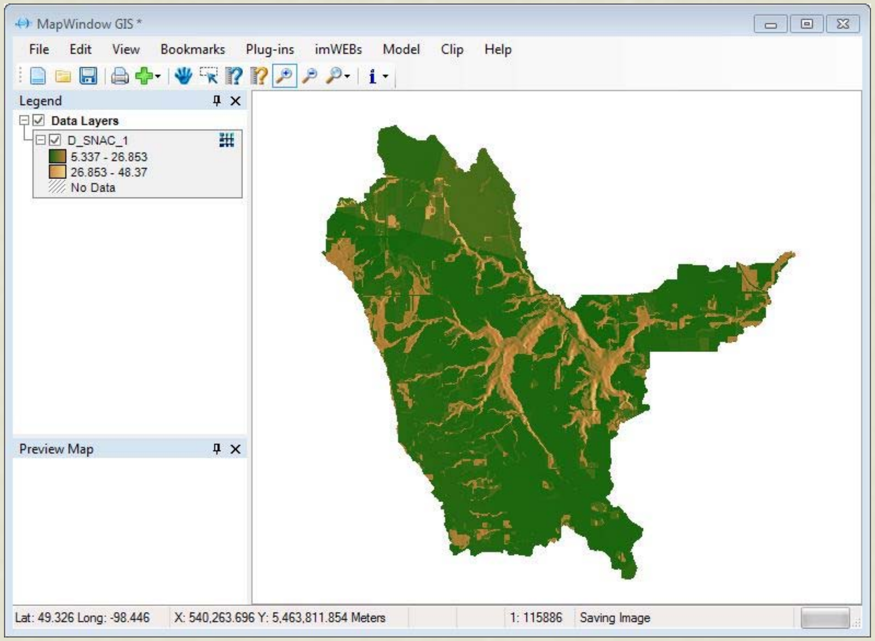


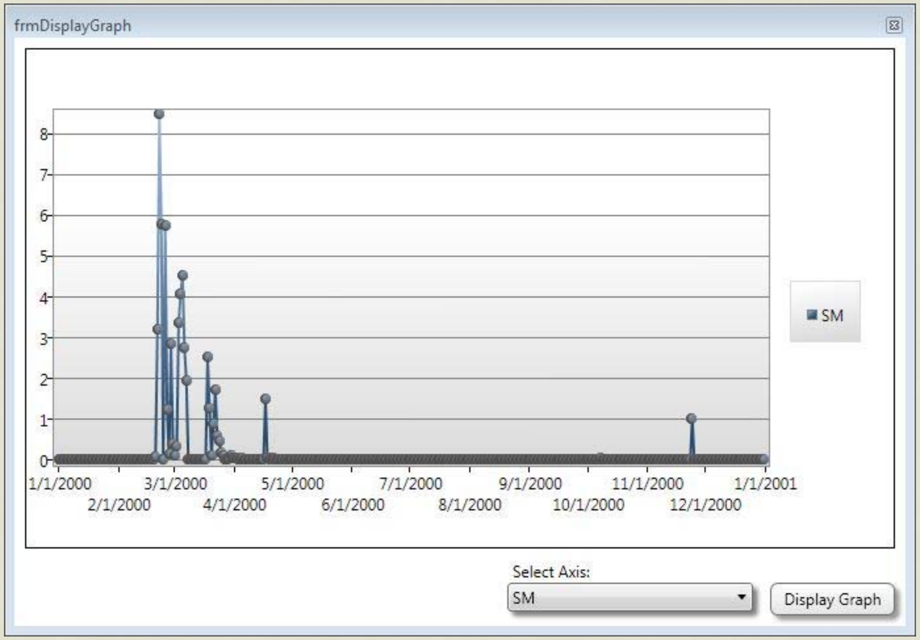


Screenshot 3: BMP Scenarios Design



Screenshot 4: Display





Best in Science Project 2014-2016

- The Location and timing matter: Assess water quantity effects of agricultural management practices under climate change and adaptation options

- Adapt/develop a place-based watershed modelling tool for examining water quantity effects of agricultural management practices

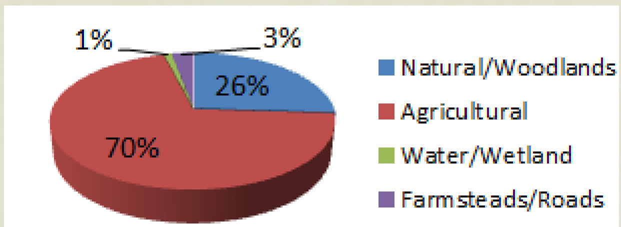
- Integrate an agent based model with the watershed modelling tool to characterize farmer behaviour and production choices, and to estimate corresponding water quantity effects under different climate change and adaptation options

- Set up, calibrate and validate the place-based modelling tool for a representative watershed and conduct climate change and adaptation scenario assessment

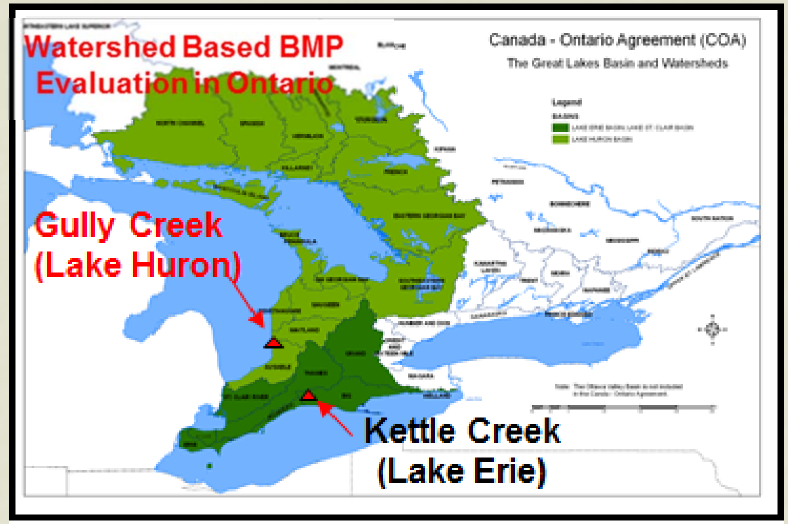
- Evaluate the strengths and limitations of the place-based modelling tool and identify future development directions for Ontario conditions

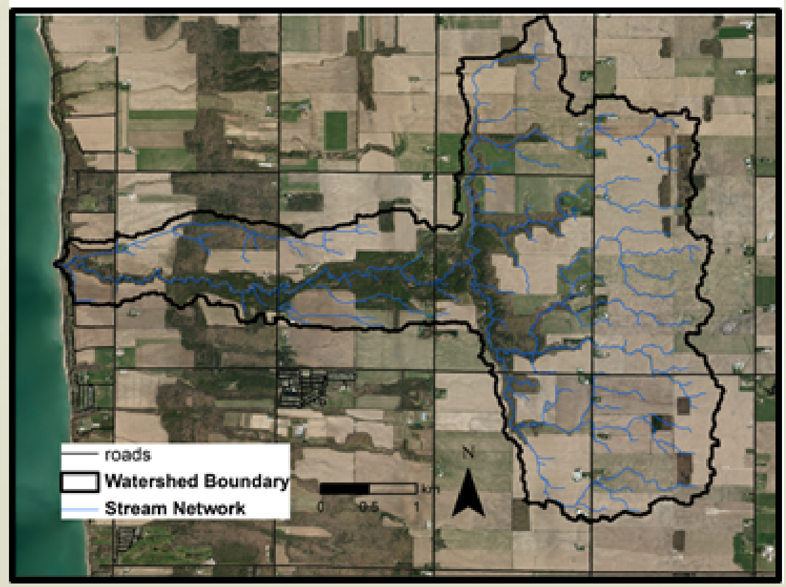
The Gully Creek Watershed in Ontario

- Size: 14.3 km2
- Soils: 75% clay loam (remainder loam, sandy loam)
- Topography: 50% of ag. area has 2-5% slopes (steeper along gully) (5m LiDAR)
- Landuse:

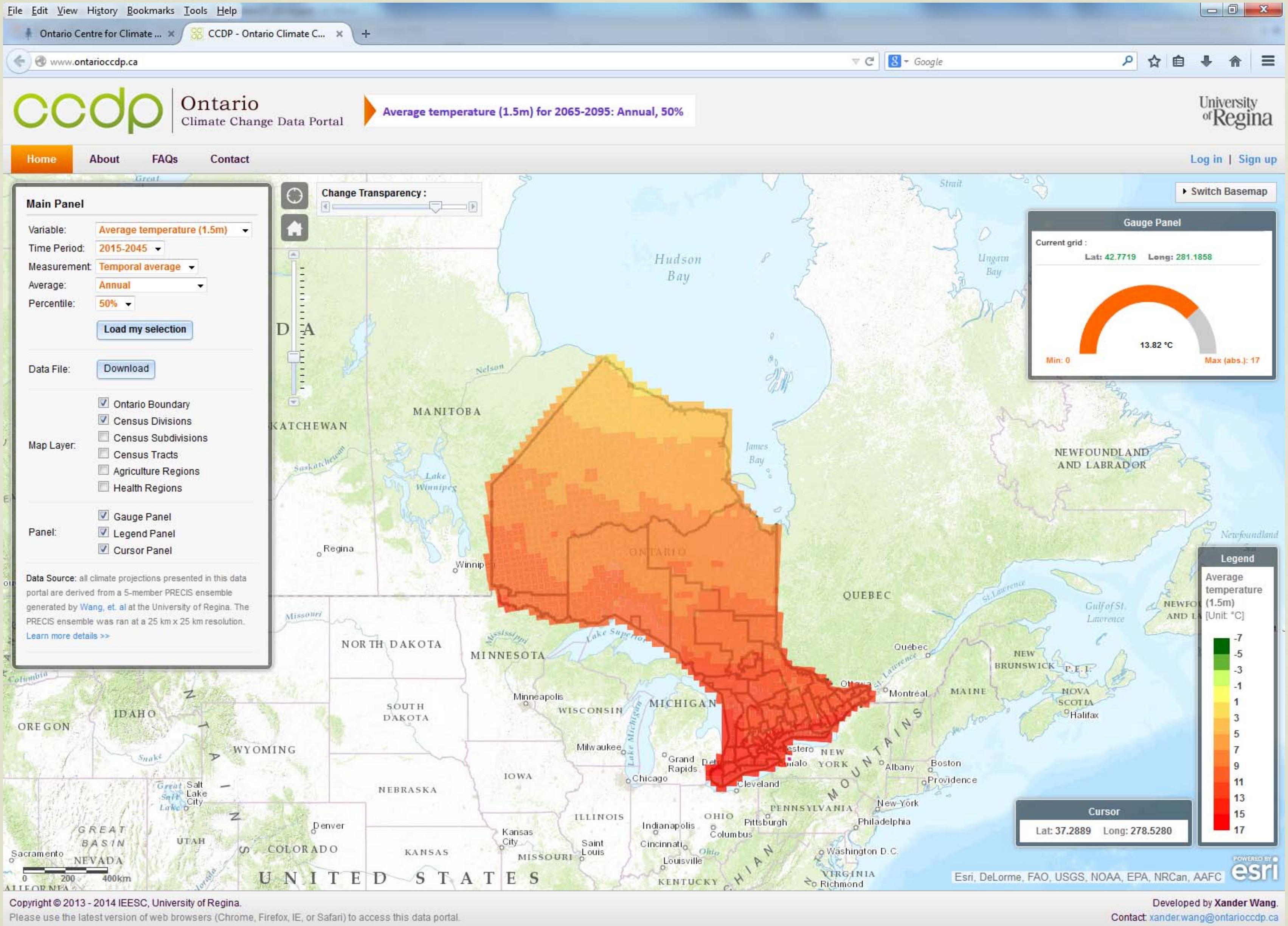


- Dominant crops: corn, soybeans, winter wheat
- Dominant livestock: broiler chickens (some dairy and hogs)
- Dominant BMPs present: (and evaluated)
  - Conservation tillage
  - Nutrients applied at BMP rates (NMP)
  - Fall cover crop (WW under seeded to red clover)
  - Water and Sediment Control basins (WASCoBs)





Climate Change Data Portal



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Climate Change Impact Assessment

William Gough
Vidya Anderson
Kristen Herod

Best in Science Symposium - November 27 2014

Ministry of Environment and Climate Change

UNIVERSITY OF TORONTO

Outline

* U of T Climate Lab at UTSC overview of Ontario Projects
* CCIA Methodology
    * Projections
* Climate Change and Human Health in Ontario
    * Heat Stress
    * West Nile

Outline

- U of T Climate Lab at UTSC overview of Ontario Projects
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Ontario Projects Overview

* Extreme Cold Weather Alerts – Toronto
    * Gough et al. 2014 (Urban Climate)
    * CCiA using SDSM downscaled data
* Fate of Ontario's Far North Palsas
    * Tam et al. 2014 (AAAR)
* Growing Potatoes in Toronto's Far North
    * Len Tsuji and Nicole Spiegelaar
* Agricultural Potential of the Great Clay Belt
    * Ni Chen, Marney Isaac
* Ontario Tourism – Provincial Parks and Metro Zoo
    * Hewer et al. 2014
* Risk to human health in Ontario
    * Anderson and Herod

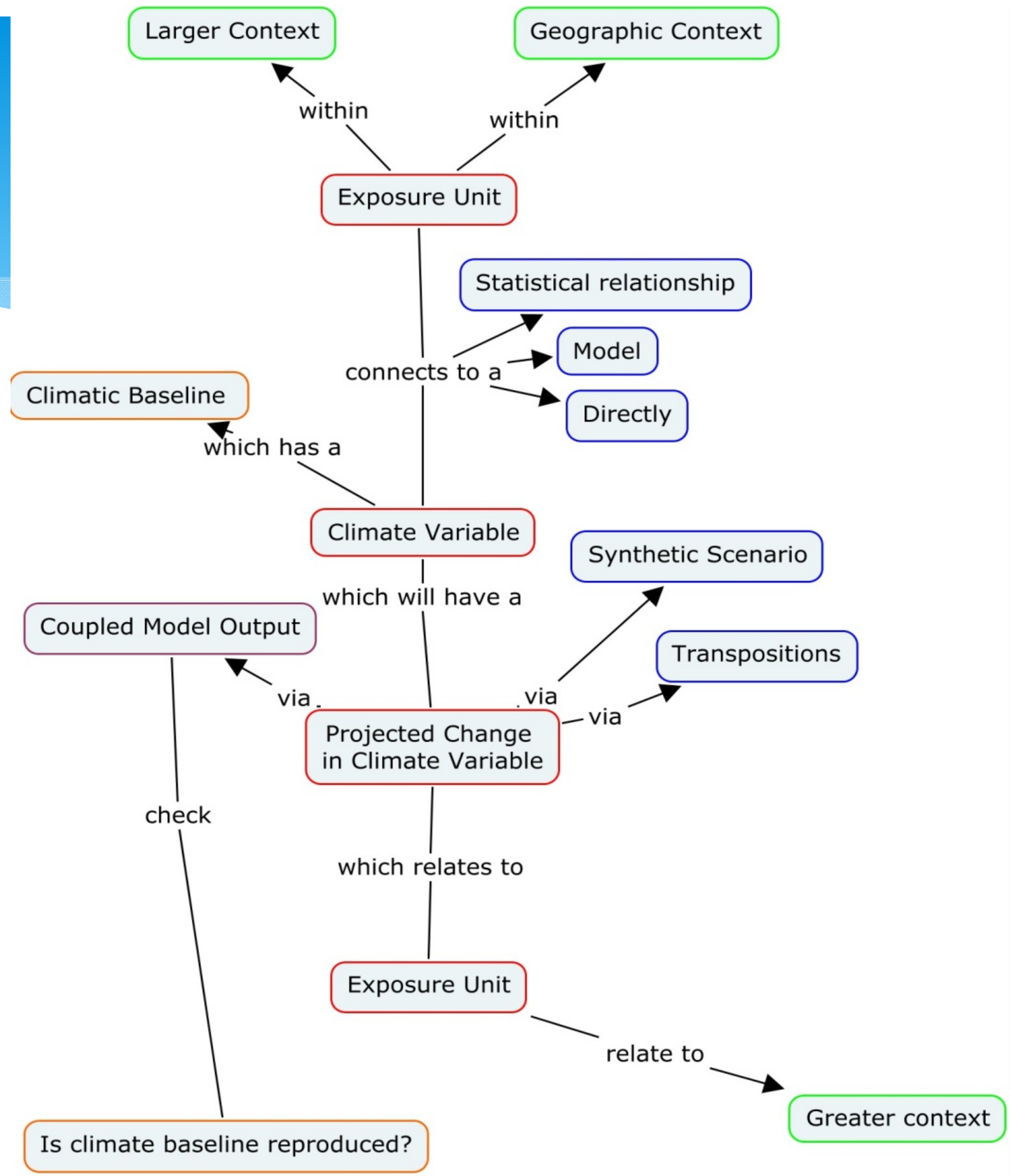
Outline

- U of T Climate Lab at UTSC overview of Ontario Projects
- CCIA Methodology
    - Projections
- Climate Change and Human Health in Ontario
    - Heat Stress
    - West Nile

Climate Change Impact Assessment (CCIA) Methodology

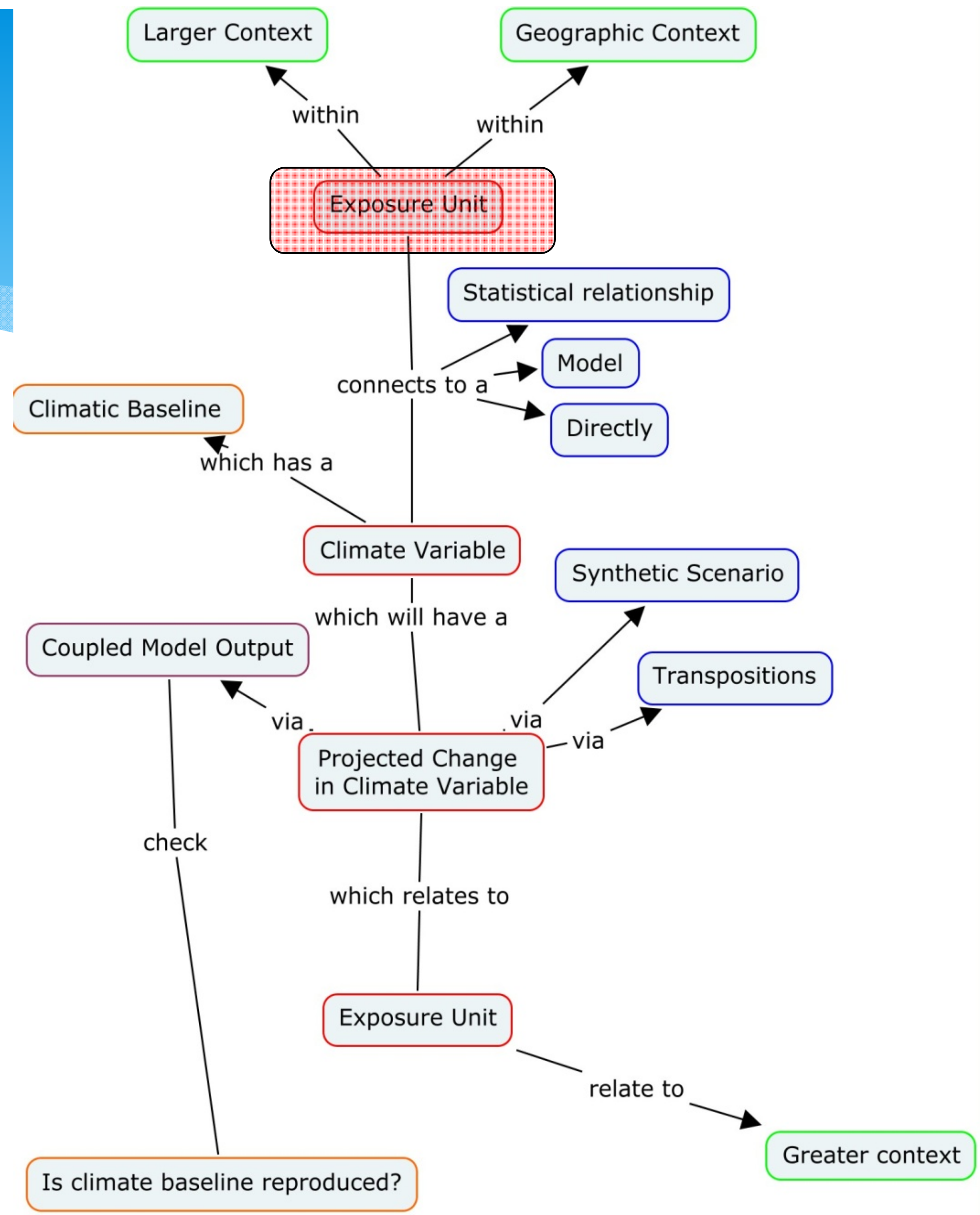
* How do we assess the potential impacts of climate change?
* Framework proposed as part of IPCC 2nd assessment report (1996)
* "The Essential CCIA"

The Essential CCIA



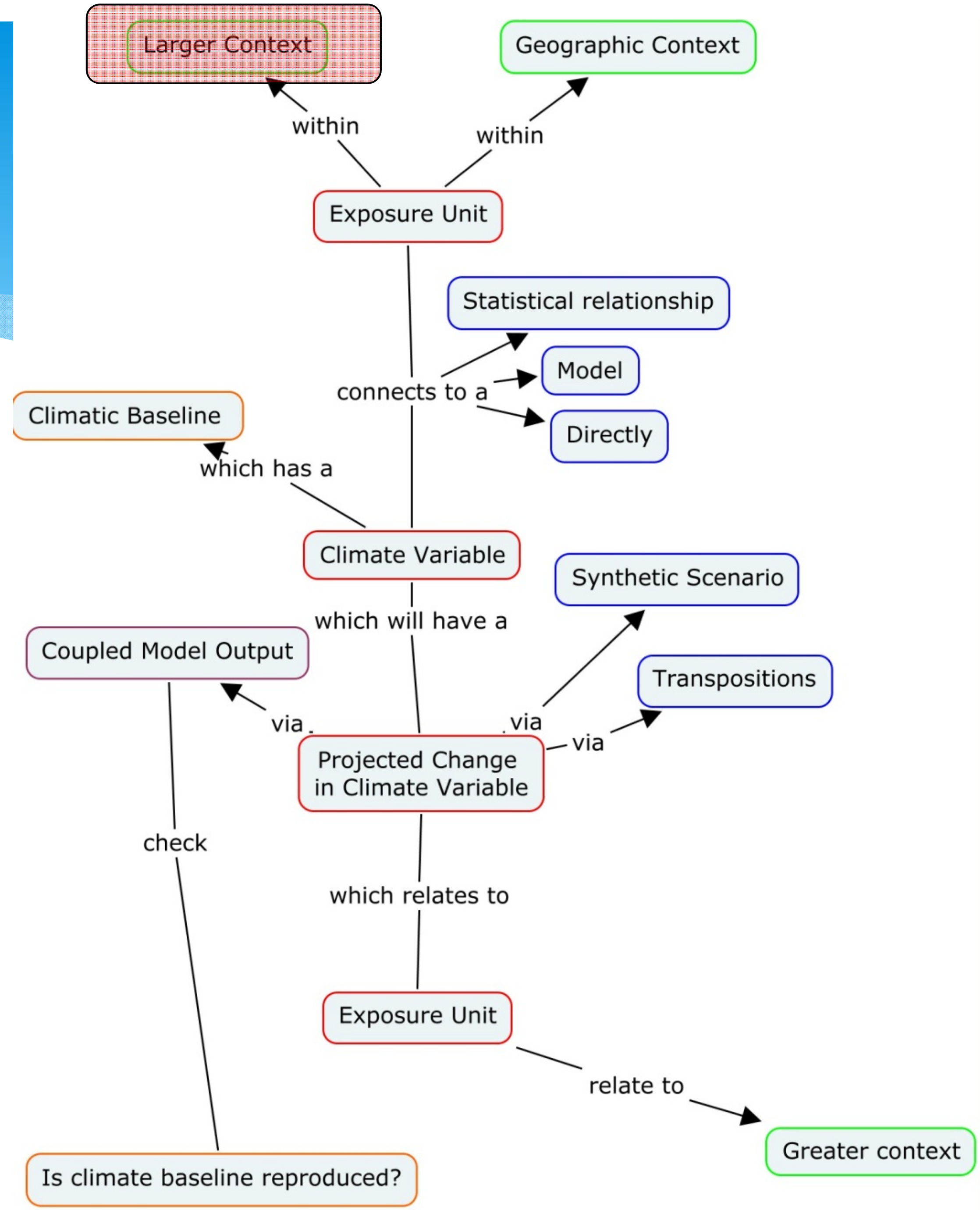
Essential CCIA

* Let's consider a local example
* Exposure Unit
  * Extreme Cold Weather Alerts (ECWA) in Toronto
  * Temperature and windchill thresholds



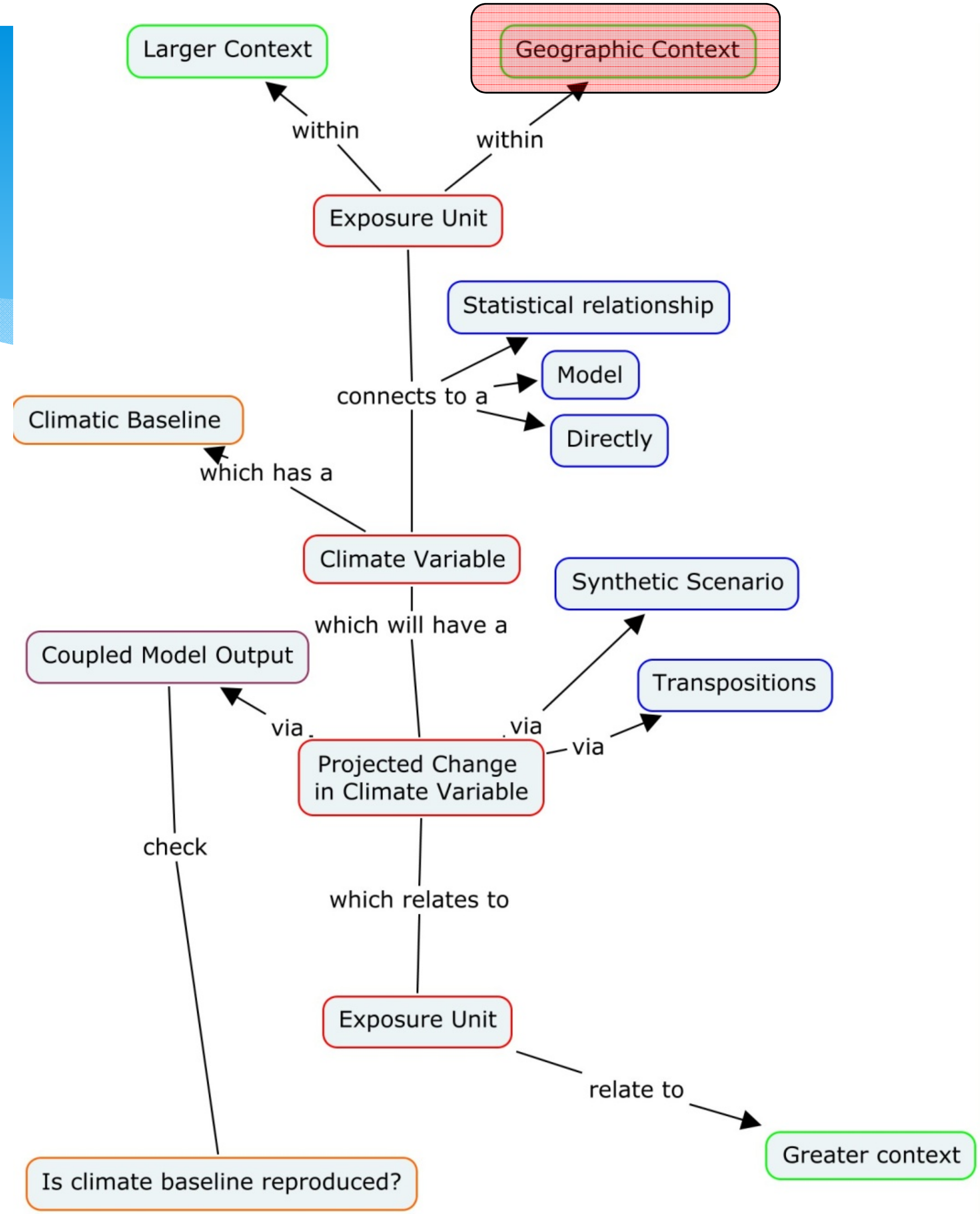
Essential CCIA

- Larger Context
  - Health concerns
    - Emergency response
  - Energy demands



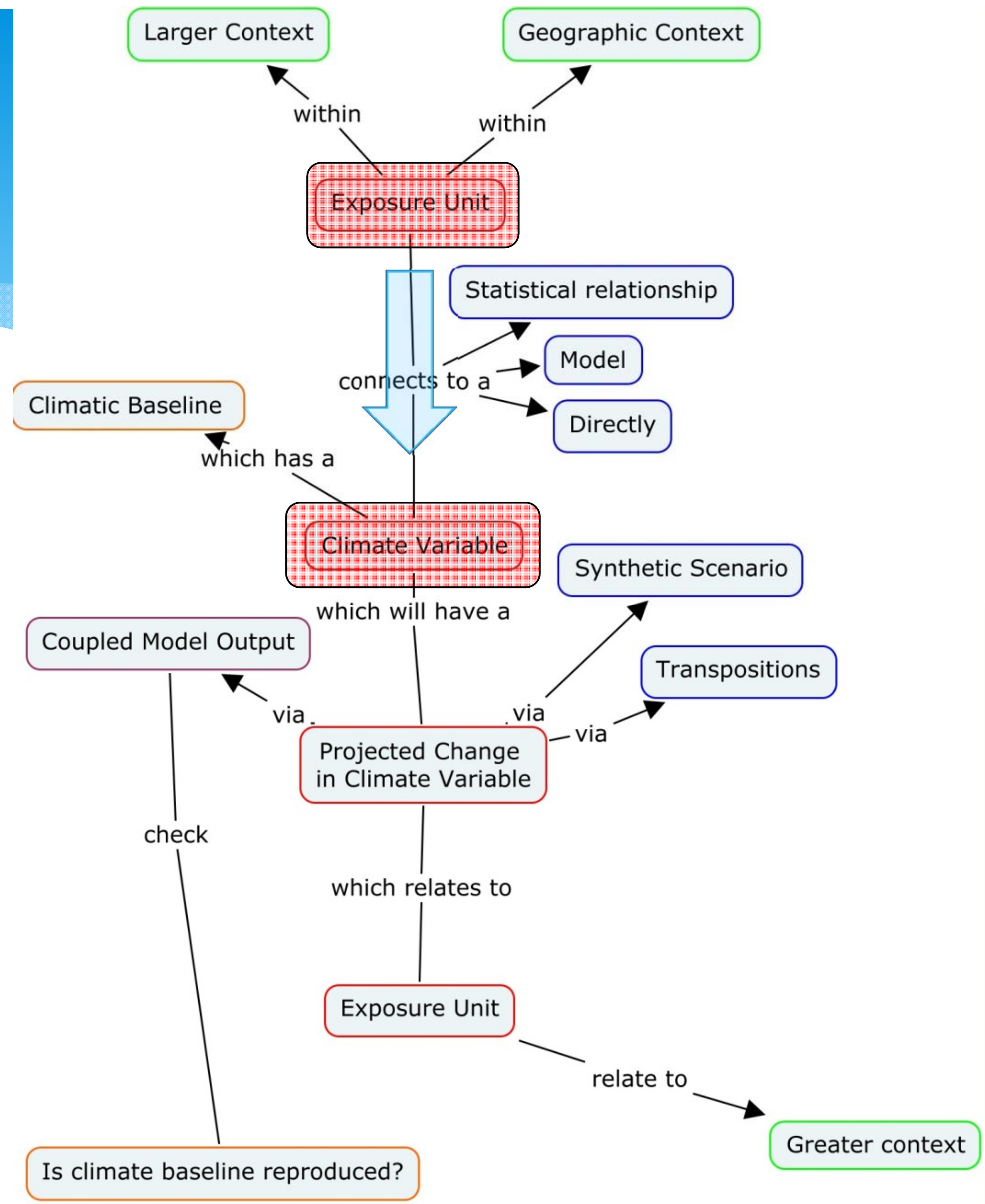
Essential CCIA

- Geographic Context
  - Ontario



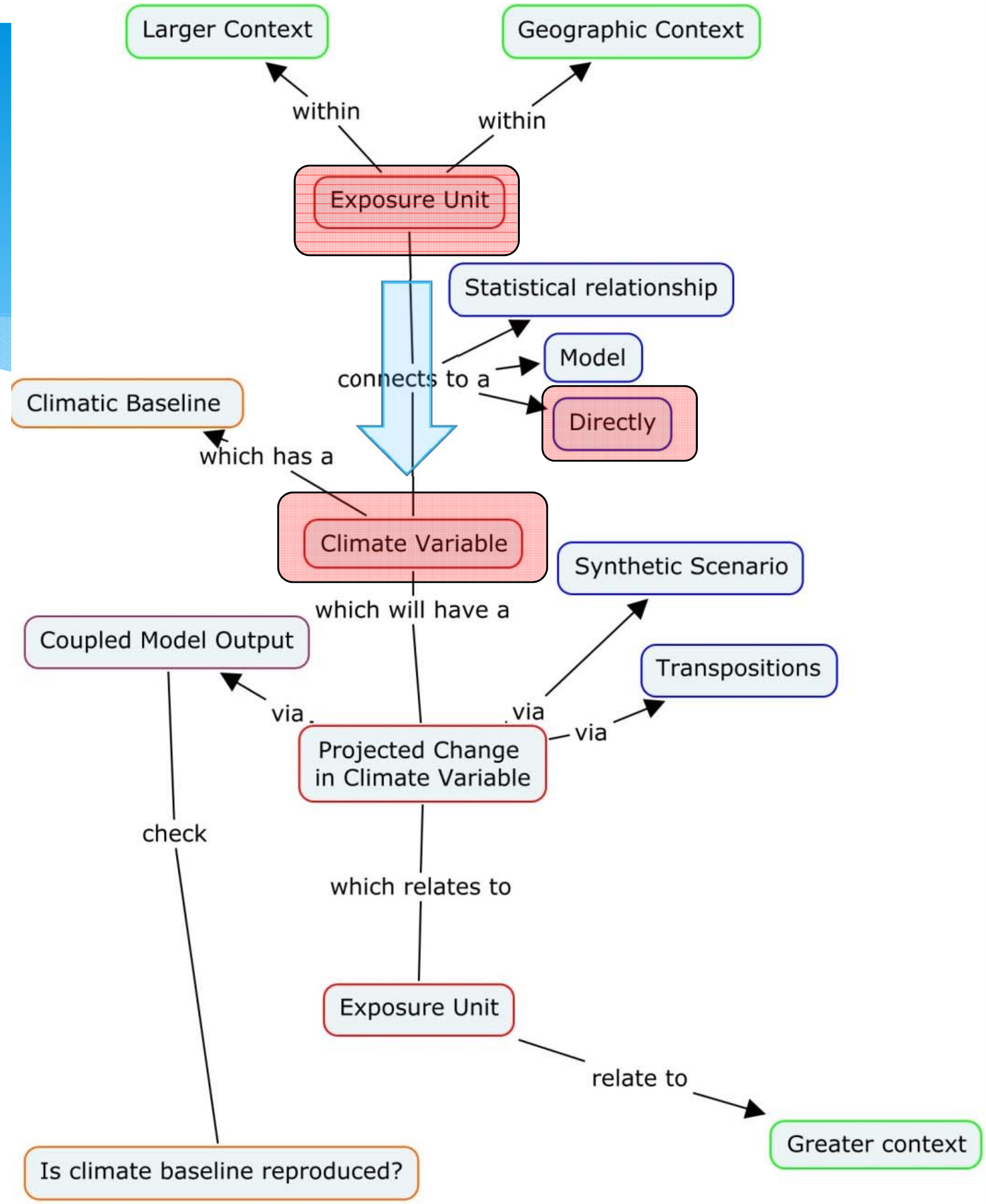
Essential CCIA

- Climate Variables
  - Temperature, windchill



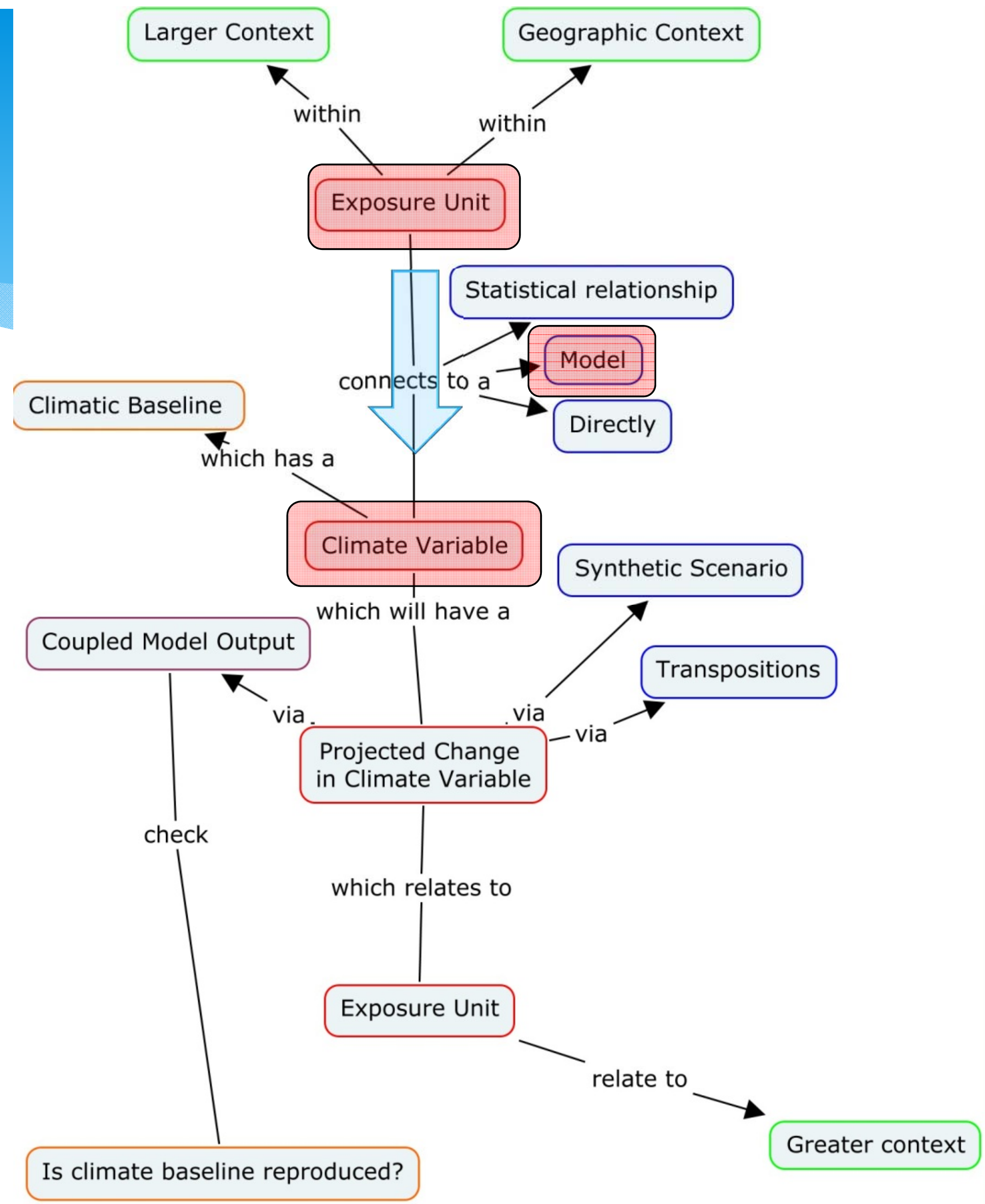
Essential CCIA

- Linking Exposure Unit to Climate Variables
- In this case directly via temperature
- Direct -15°C
- Windchill proxy -10°C



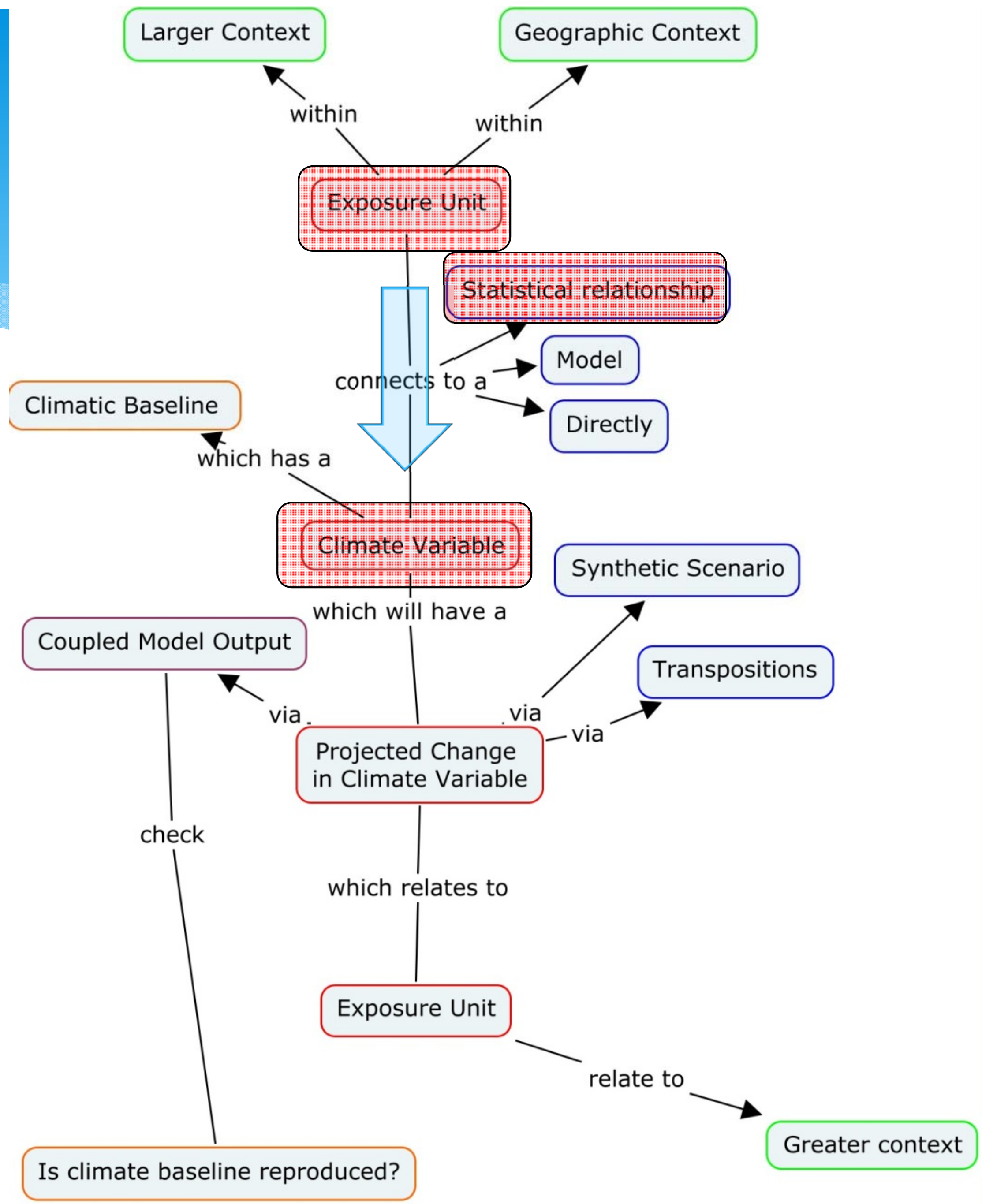
Essential CCIA

- Model
- Complex linkage between Exposure Unit and climate variables
- Eg. River discharge, lake levels, energy demand



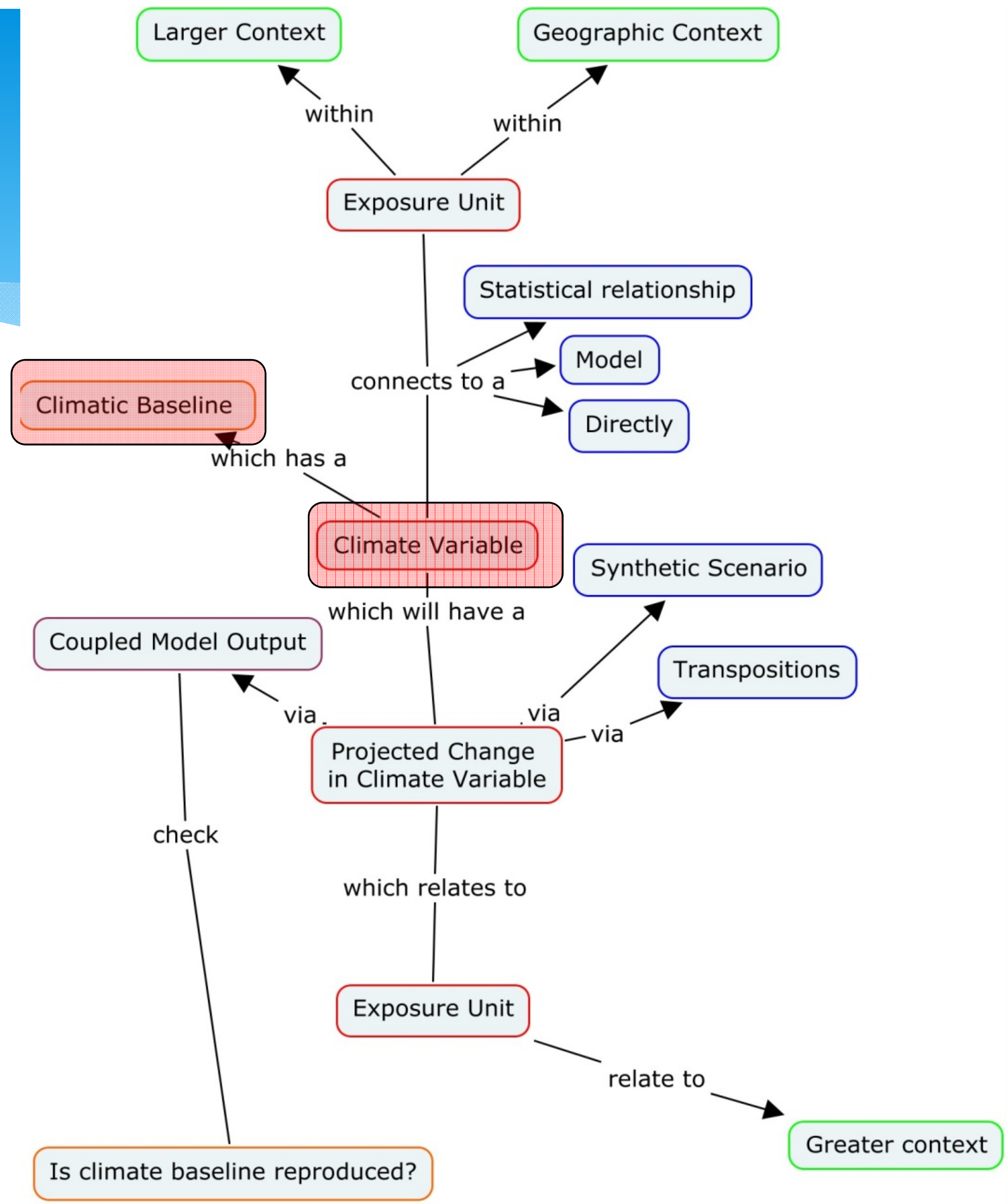
Essential CCIA

- Statistical relationship
- Correlation analysis which links Exposure Unit to climate variables
- Eg. Heating degree-days and plant growth



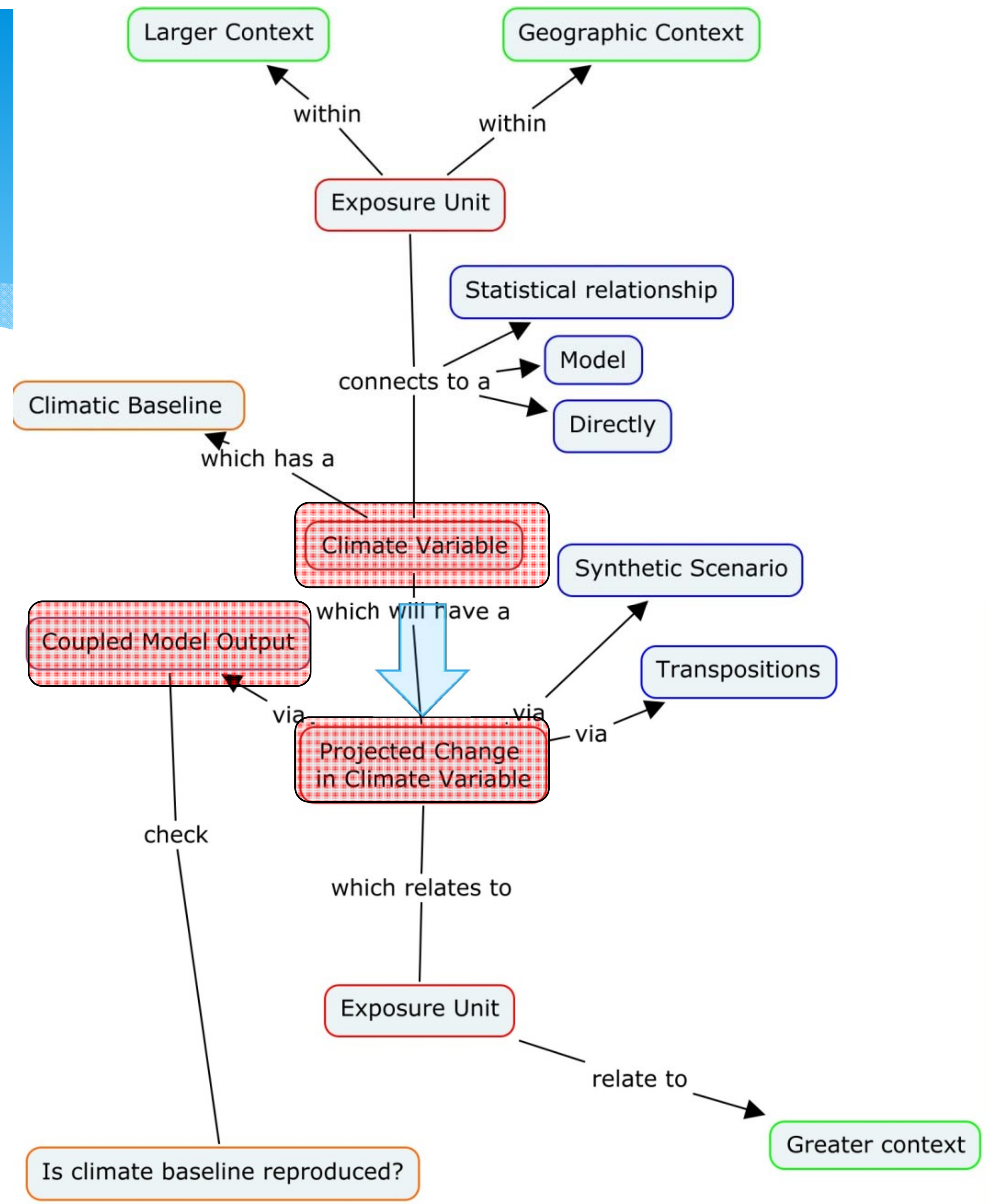
Essential CCIA

* Climatic Baseline
  * How has exposure unit behaved in the past as a function of climate variable?
  * Frequency of ECWAs (2004 to present)



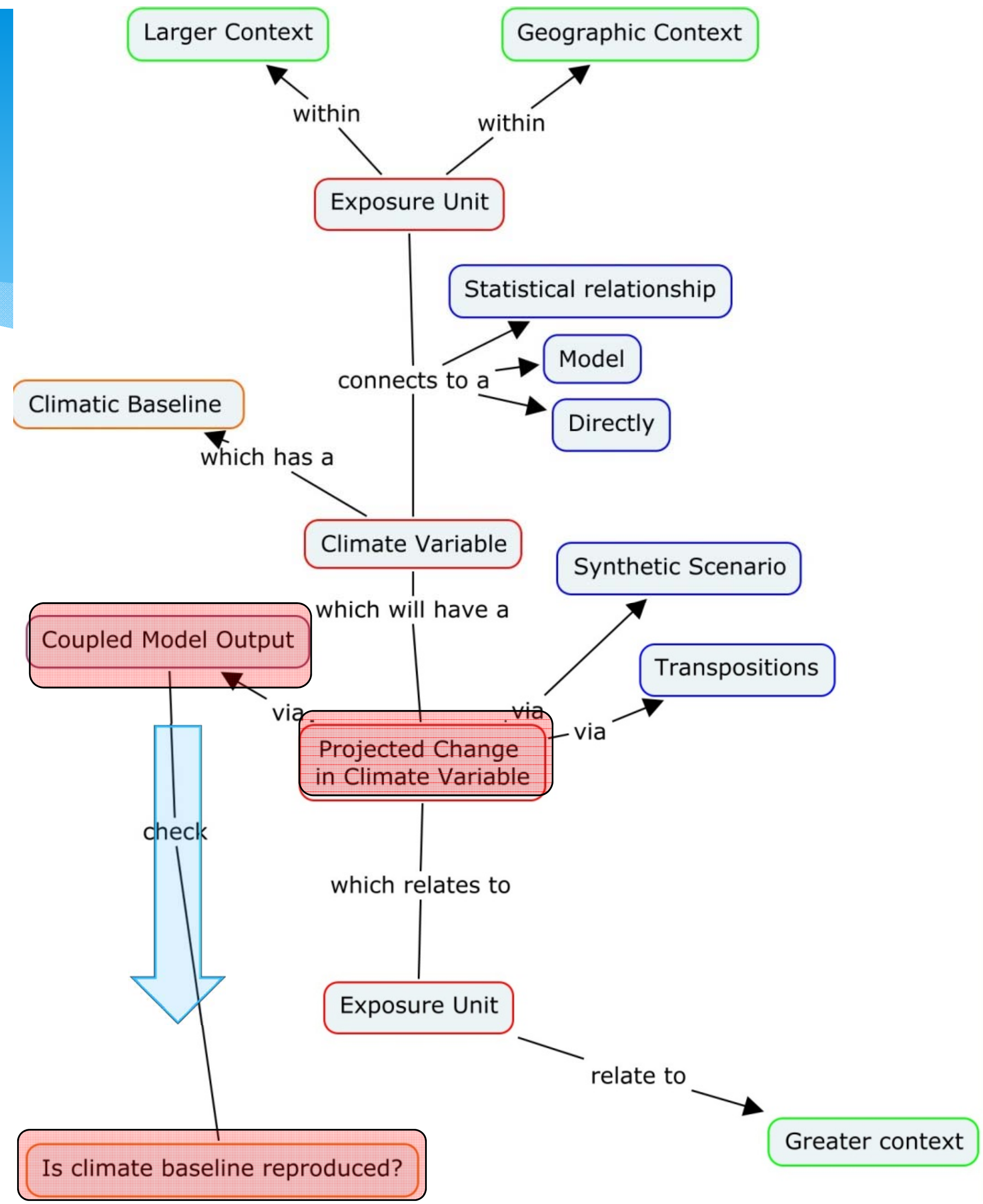
Essential CCIA

* Scenario Generation
  * GCMs
  * Data available from Scenarios Network or other repository
  * Downscaling as needed
  * SDSM used (MOE funded project – 95 Ontario stations)



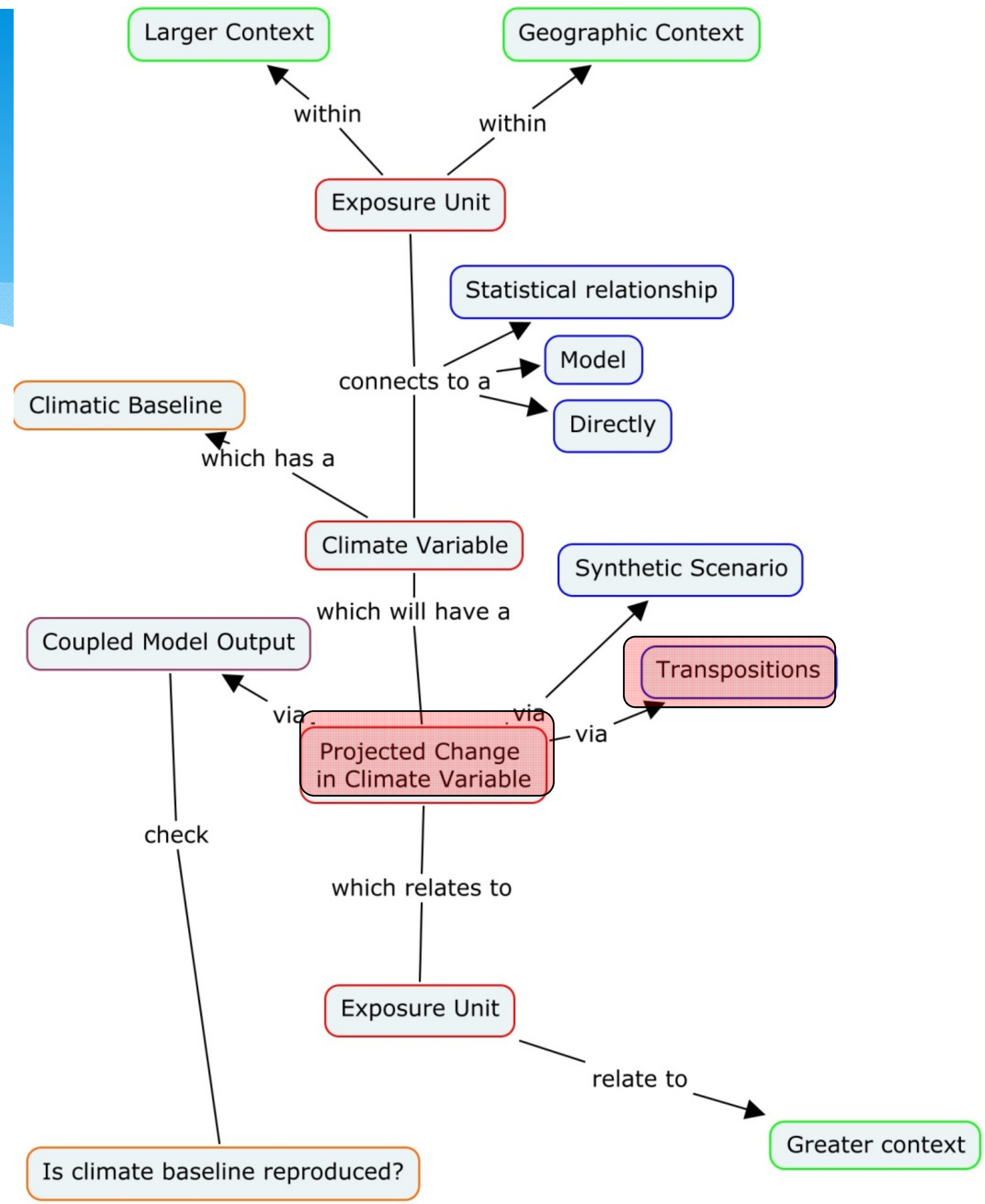
Essential CCIA

* Reproducing climate baseline with GCM
* Validity of the model(s) chosen



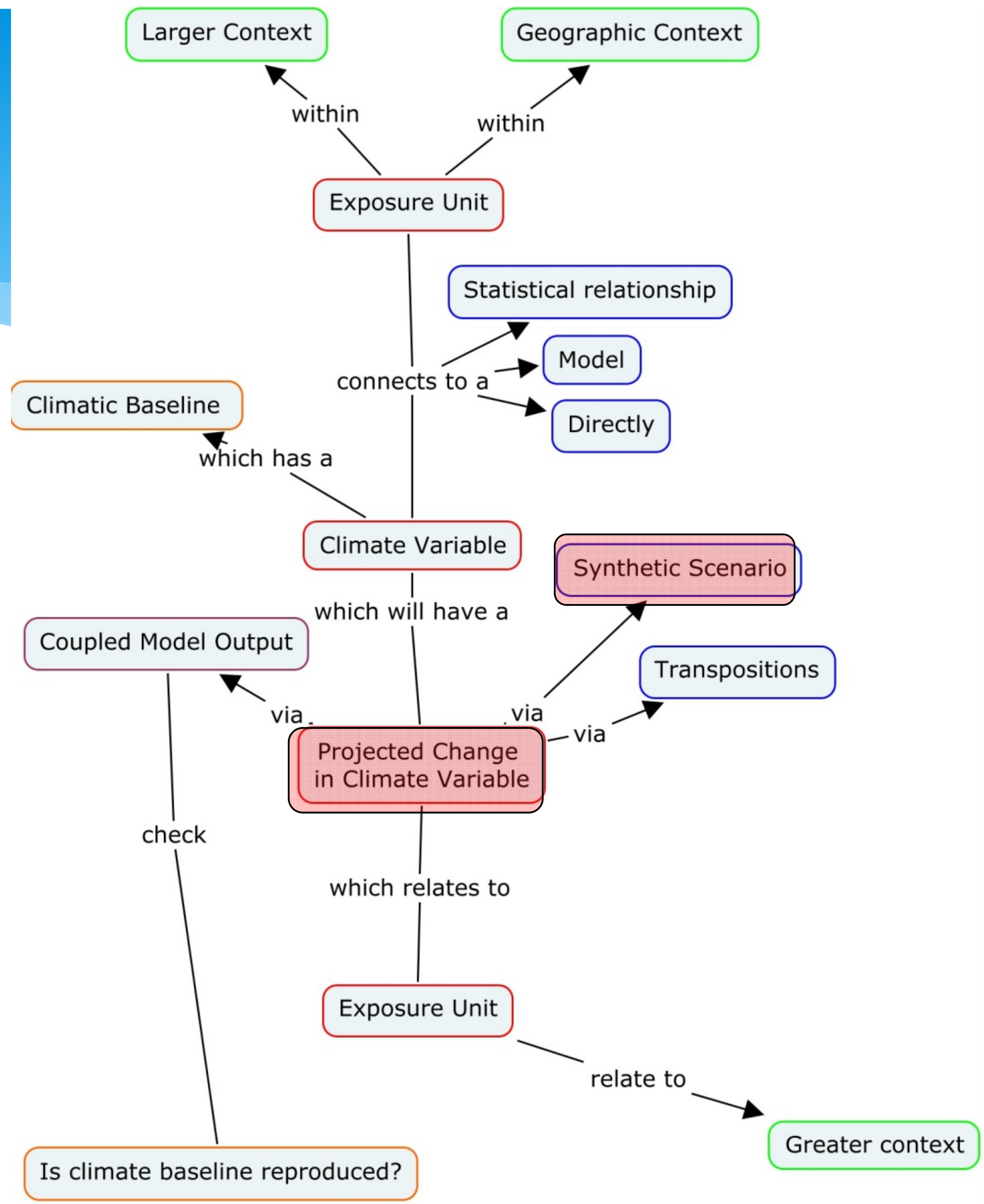
Essential CCIA

- Spatial transpositions could be used
  - Data from another city
- Climate analogues (temporal transposition)
  - Use data from Toronto's past
- Not commonly used



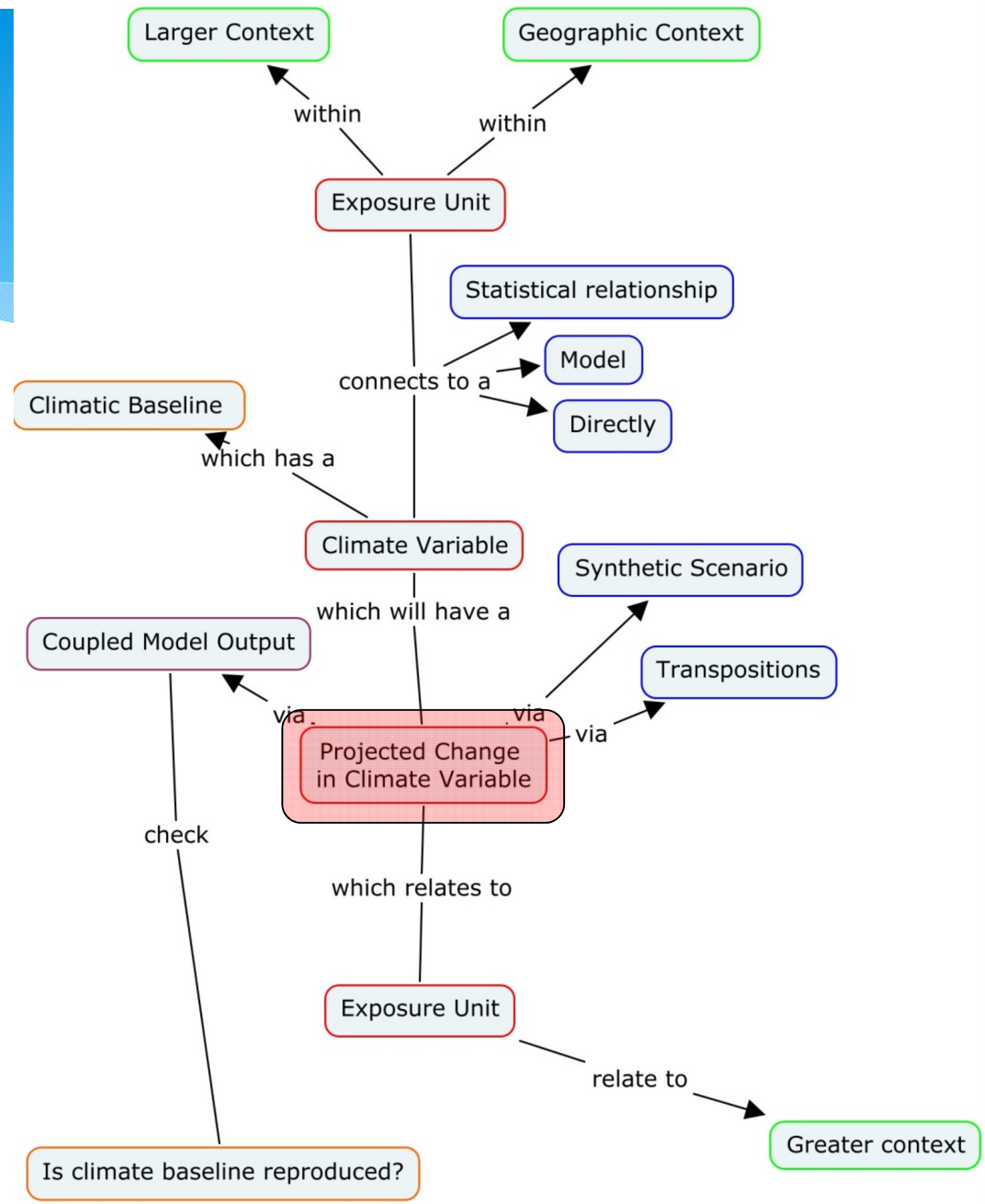
Essential CCIA

- Synthetic scenarios
- 1 °C
- 5 °C
- What if?
- Useful as a sensitivity analysis



Essential CCIA

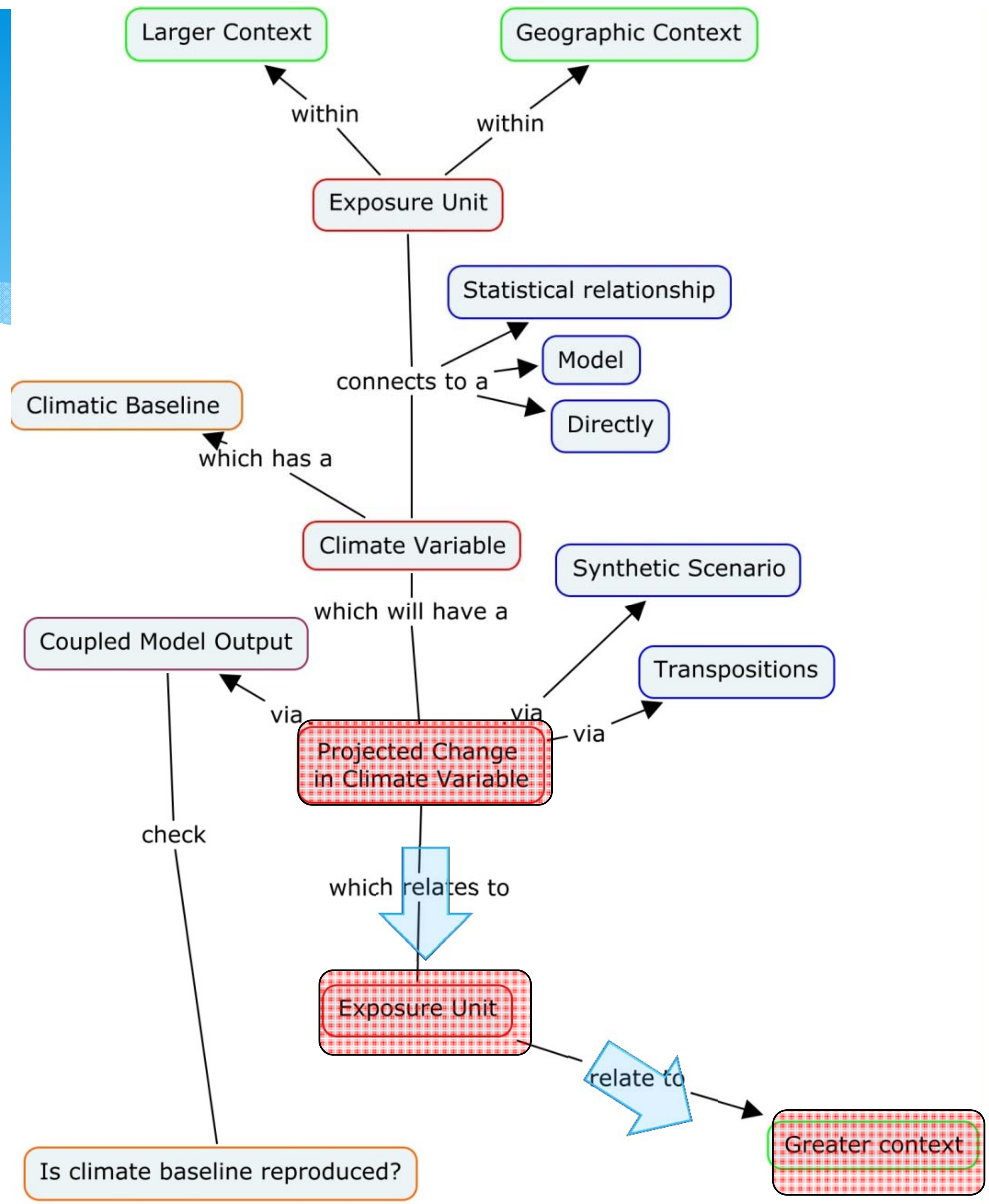
* Projected Changes
* Frequency of ECWAs in the projected data



Essential CCIA

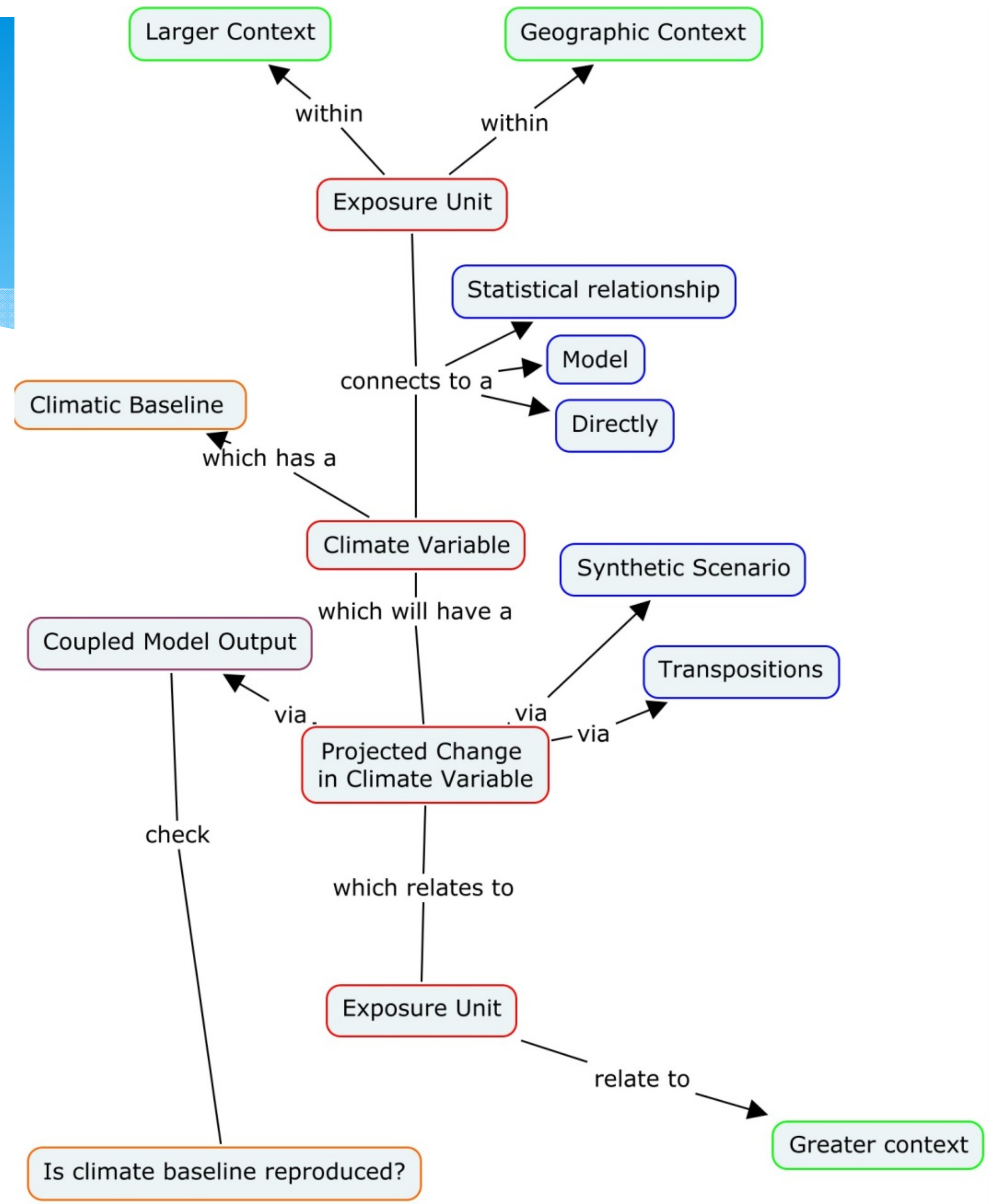
- Projected Changes to Exposure Unit(s)
  – Heat alert frequencies

- Greater context
  – Energy demand
  – Health impacts



Recap

* The Essential CCIA



Outline

- U of T Climate Lab at UTSC overview of Ontario Projects
- CCIA Methodology
  - Projections
- Climate Change and Human Health in Ontario
  - Heat Stress
  - West Nile

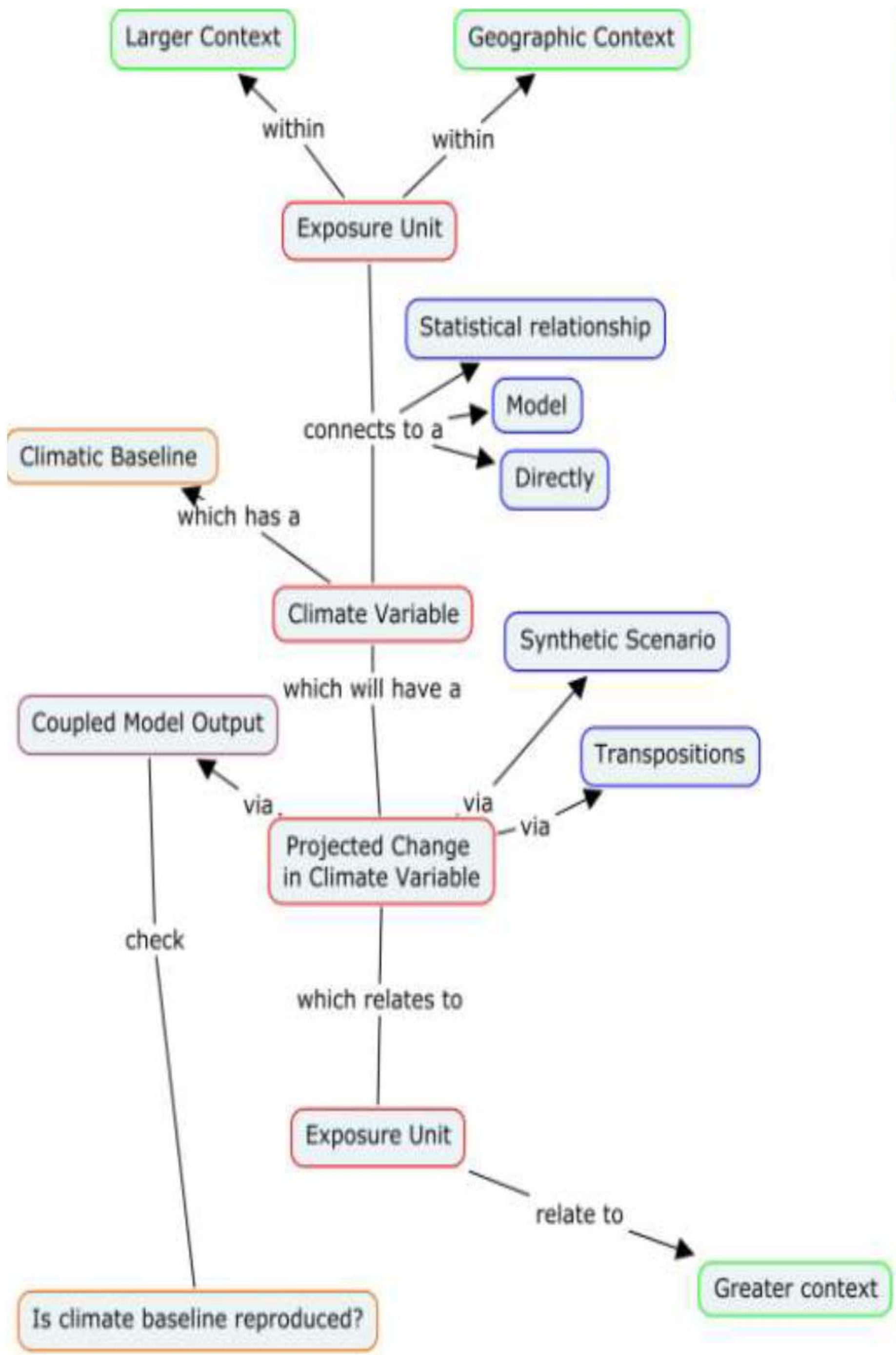
Projecting Climate Change Impacts & Risks to Human Health in Ontario

MOECC funded project

William Gough
Vidya Anderson
Kristen Herod

Climate Modelling Study

- Assess the impacts of climate change on human health and forecast key health risks across Ontario
- Identify climate related health variables, required for the health models
- Generate projection scenarios for the 2020s, 2050s and 2080s for each of the 36 public health unit areas
- Provide graphical representation to illustrate the spatial distribution of health risks



CCIA

Components	
Larger Context	Impacts of climate change on human health
Geographic Context	Ontario
Exposure Unit	
Climate Variable	
Projected Change	

Health Effects

Heat Stress	• **Heat waves** • **Wet Bulb Global Temperature (WBGT)**
Vector-Borne Diseases	• **West Nile Virus (WNV)** • Lyme disease
Waterborne Diseases	• E-Coli • Cyanobacteria
Foodborne Diseases	• Salmonella • Cyanobacteria
UV exposure	• Basal Cell Carcinoma • Squamous Cell Carcinoma
Air Pollution	• Ozone concentration

Methods

Climate Baseline

- 30 years of data for weather stations across Ontario

Temperature and Precipitation Anomalies

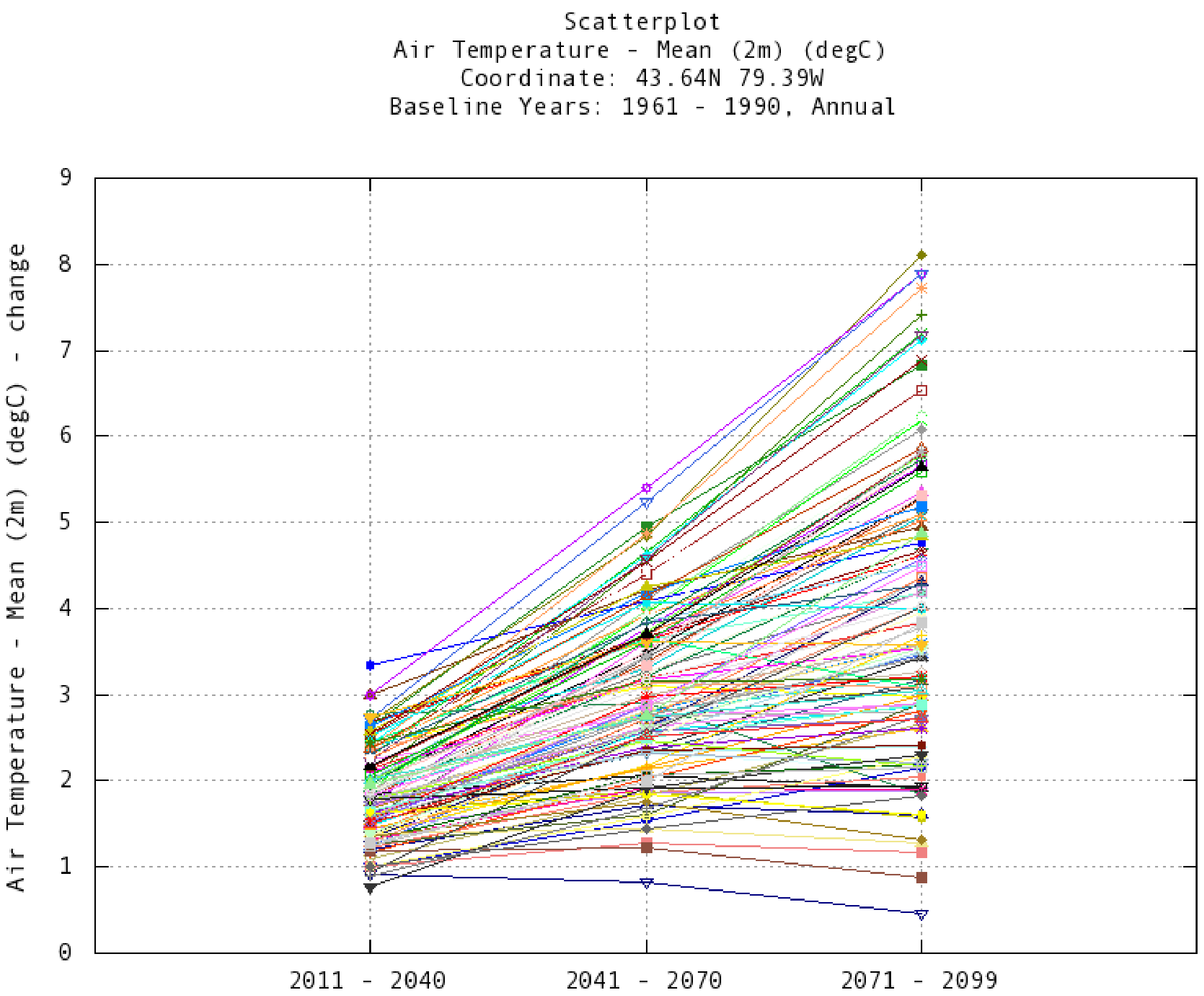
- UTSC Ensemble Tool
- SR-A2 (worst case) scenario, average overall models

Health and Climate Relationships

- IPCC AR5 report
- Peer reviewed articles

Baseline – Weather Stations

Anomalies



Scatterplot
Air Temperature - Mean (2m) (degC)
Coordinate: 43.64N 79.39W
Baseline Years: 1961 - 1990, Annual
Air Temperature - Mean (2m) (degC) - change
0
1
2
3
4
5
6
7
8
9
2011 - 2040
2041 - 2070
2071 - 2099

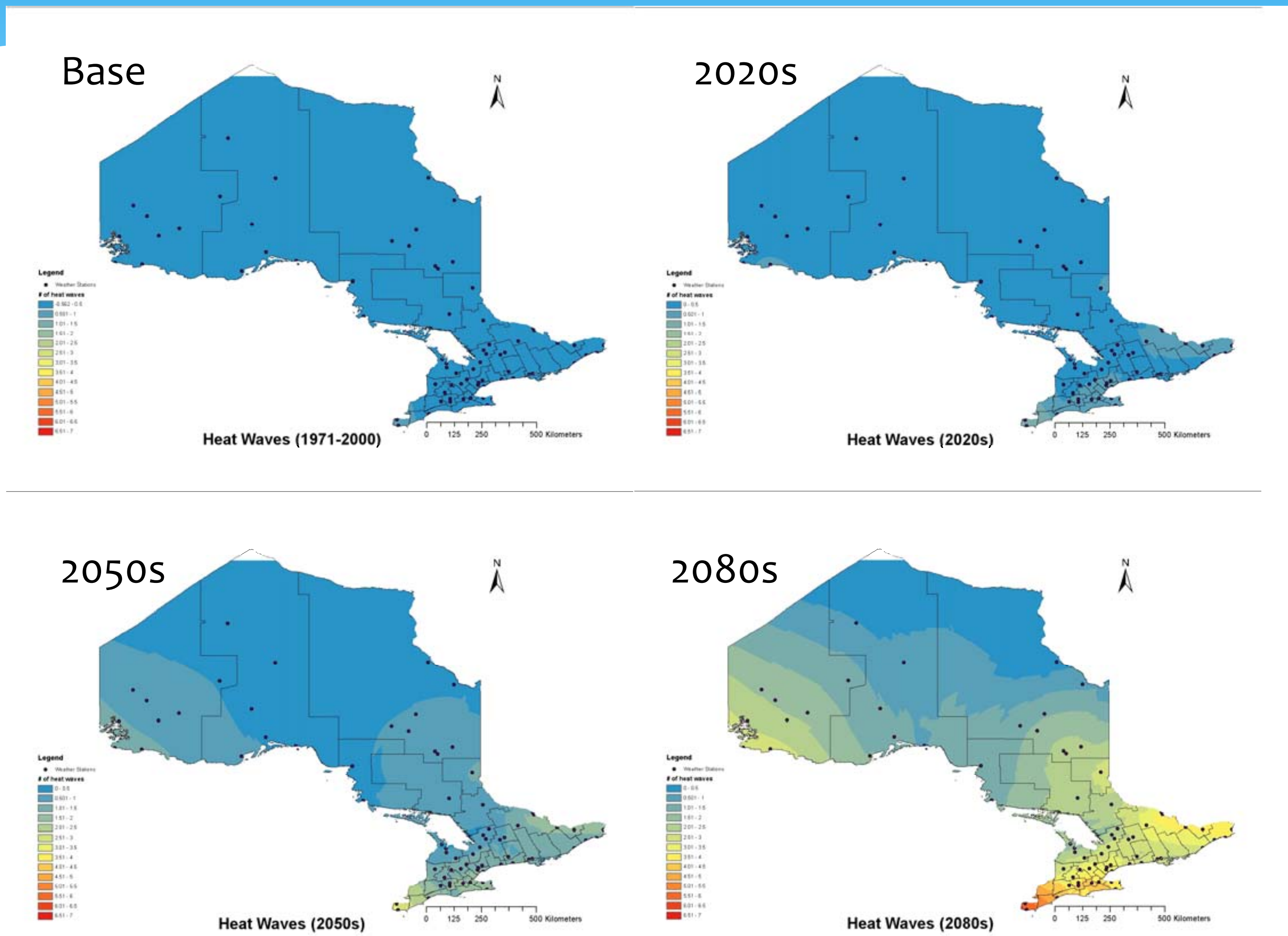
Results

* Baseline created for each weather station
* Raster surface of continuous data generated
  * Source data was imported into ArcGIS and interpolated
* Average value per health unit was determined
* The results were organized in two ways
  * Maps – 1 map for each health effect and time period (baseline, 2020s, 2050s, 2080s)
  * Tables – 1 table for each health effect which includes each health unit and time period

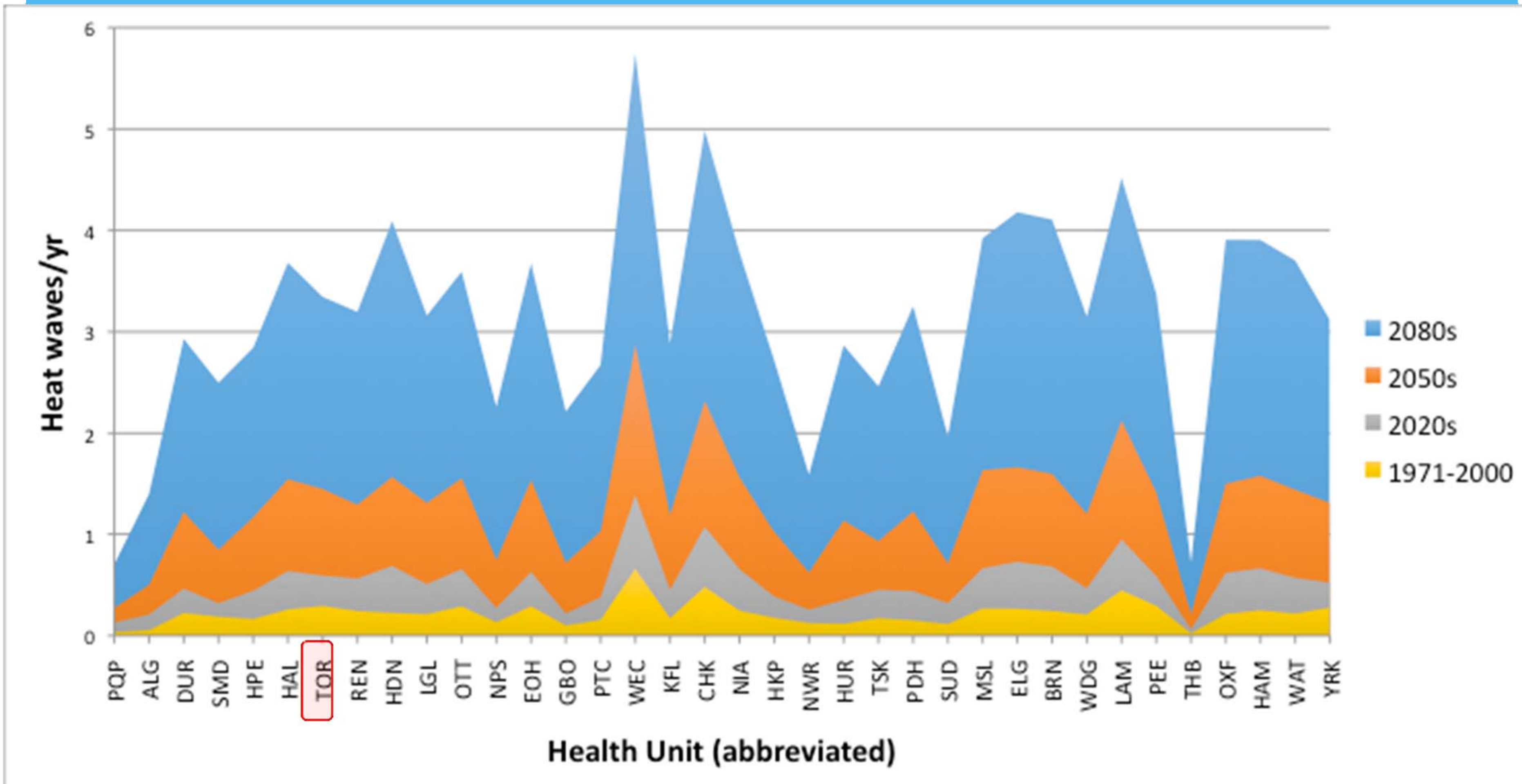
Exposure Unit: Heat Stress

- Methods used include
  - Heat waves
    - 3 consecutive days above 32 degrees Celsius
  - Wet Bulb Global temperature
    - Max temperature x 0.9
    - Above 26 degrees is considered moderate risk
- Rising temperature will likely cause many more heat related effects in the future

Distribution of heat waves



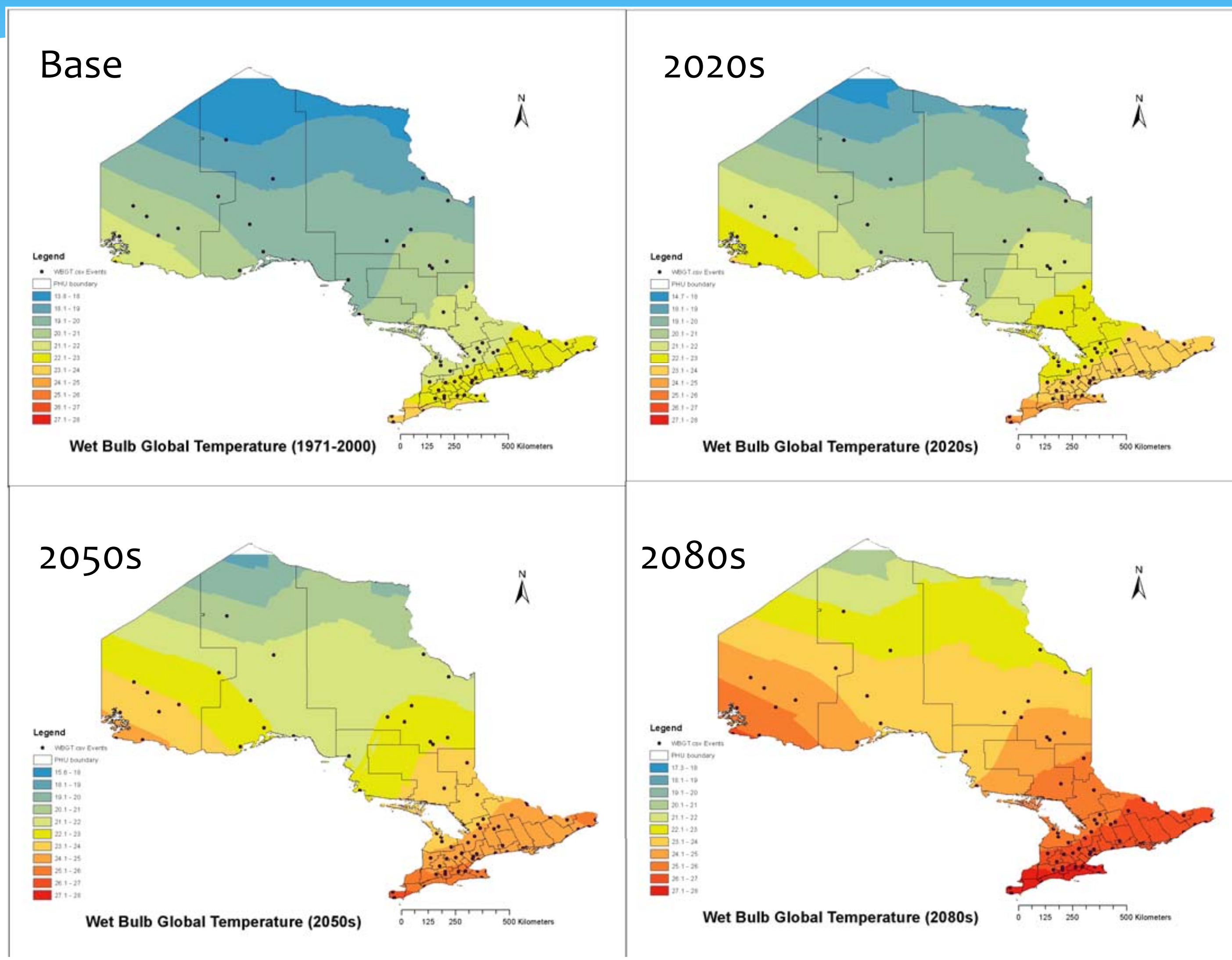
Heat waves per Health Unit



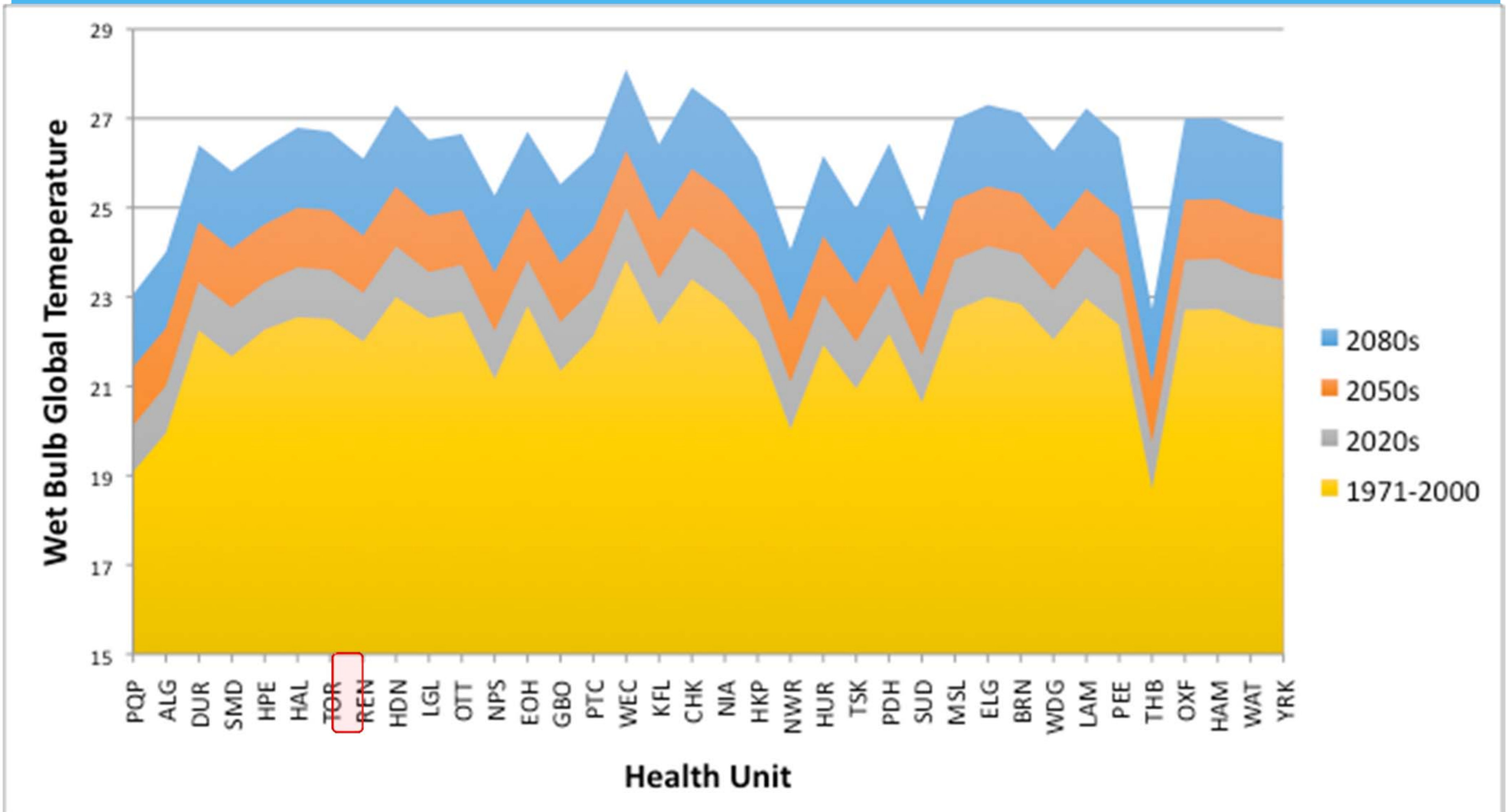
Sample Heat wave data

Health Units	1971-2000	Stdev	2020s	Stdev	2050s	Stdev	2080s	Stdev
Porcupine	0.03	0.06	0.13	0.16	0.27	0.31	0.70	0.77
The District of Algoma	0.05	0.02	0.21	0.05	0.50	0.09	1.40	0.26
Durham Regional	0.22	0.03	0.46	0.04	1.22	0.08	2.93	0.12
Simcoe Muskoka District	0.19	0.04	0.32	0.09	0.85	0.20	2.50	0.29
Hastings and Prince Edward Counties	0.16	0.04	0.44	0.09	1.17	0.13	2.84	0.28
Halton Regional	0.26	0.01	0.64	0.03	1.55	0.06	3.68	0.12
Toronto Public Health	0.29	0.01	0.59	0.03	1.45	0.07	3.34	0.14
Renfrew County and District	0.24	0.05	0.56	0.13	1.29	0.27	3.20	0.41
Haldimand-Norfolk	0.23	0.03	0.69	0.04	1.57	0.13	4.09	0.20
Leeds, Grenville and Lanark District	0.21	0.04	0.51	0.09	1.31	0.13	3.16	0.22

WBGT

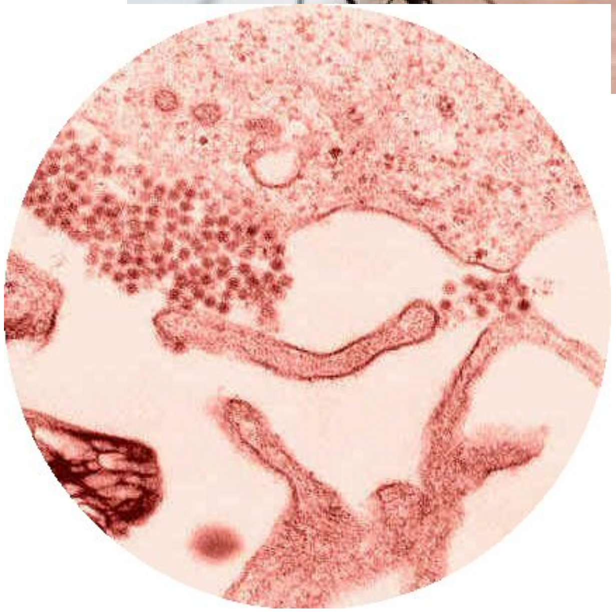

Base
Wet Bulb Global Temperature (1971-2000)
2020s
Wet Bulb Global Temperature (2020s)
2050s
Wet Bulb Global Temperature (2050s)
2080s
Wet Bulb Global Temperature (2080s)
Legend
500 Kilometers

WBGT per Health Unit



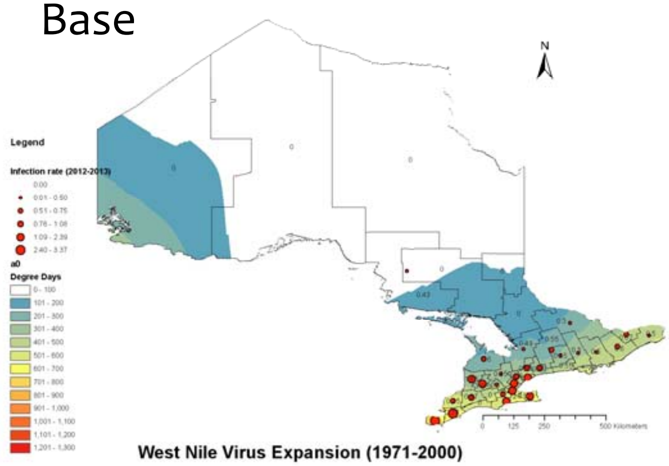
Exposure Unit: West Nile Virus

* Methods used include
  * Extrinsic Incubation Period (EIP)
    * For WNV to occur there must be a 12 day period where the degree- days above 14.3 degrees Celsius is 82
  * Degree-Days
    * If the EIP is met then all subsequent degree days are accumulated to find the final degree day per location
* Rising temperature will likely increase the number of cases of West Nile in Ontario, and perhaps the geographical extent of West Nile in Ontario

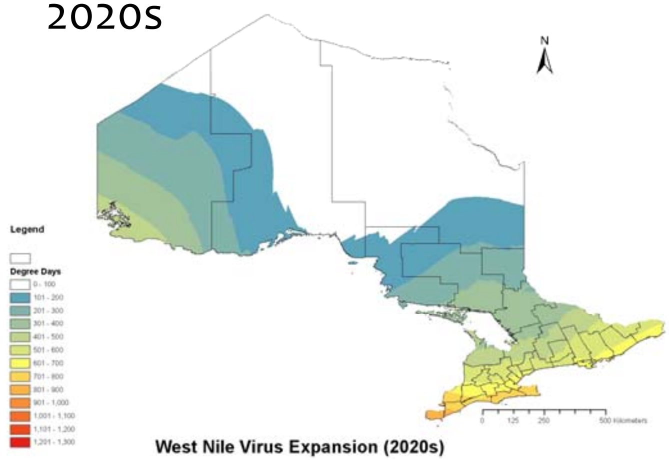


West Nile Virus

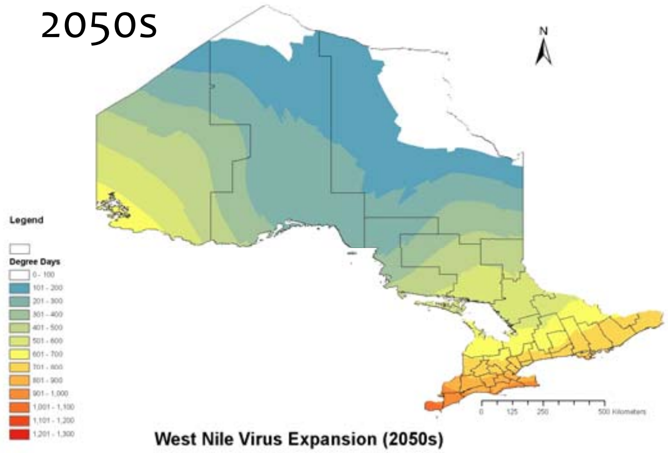
Base



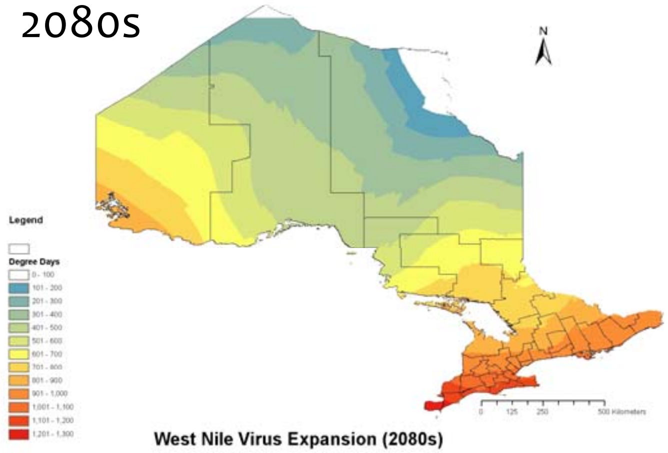
2020s



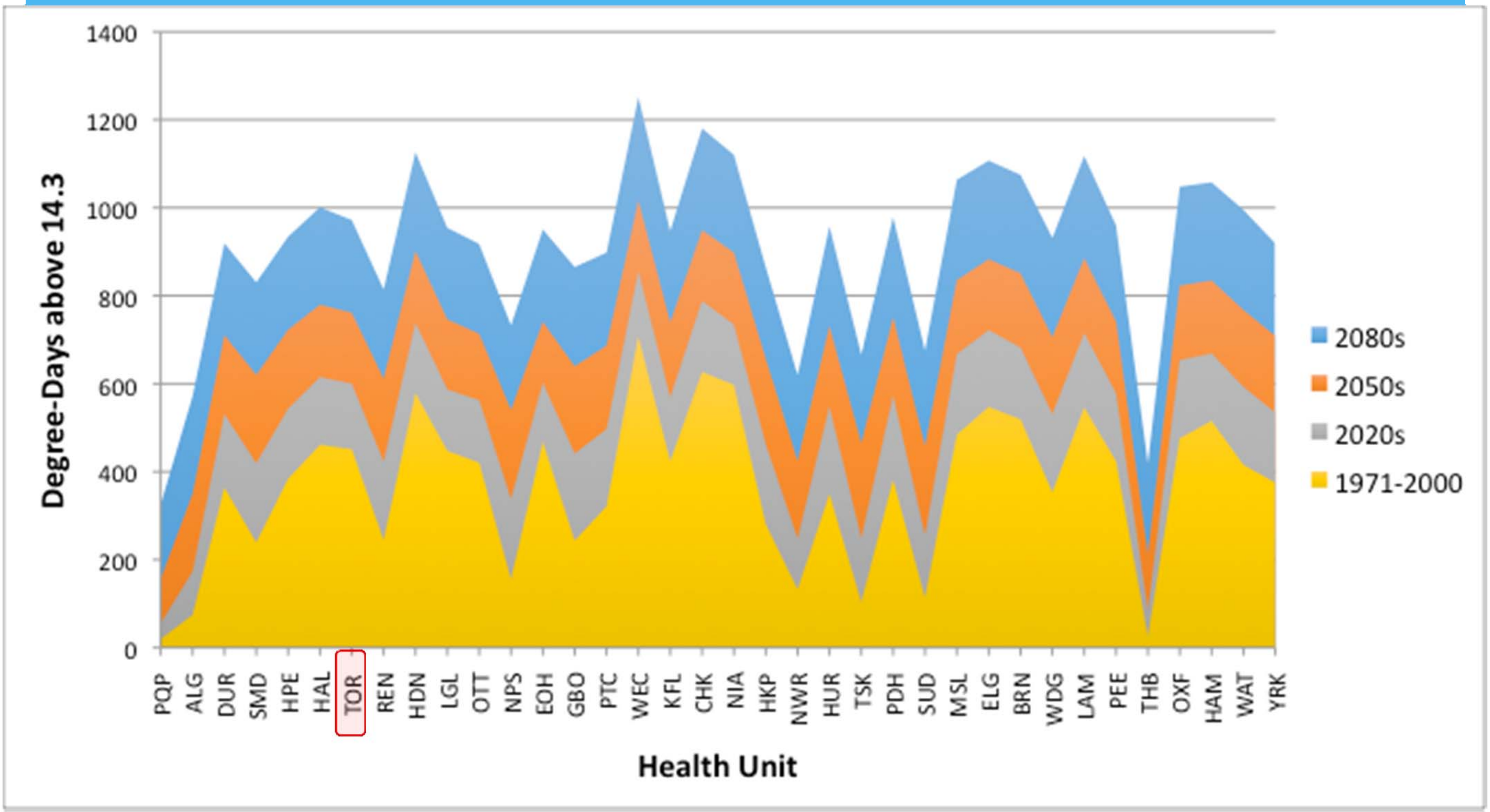
2050s



2080s



West Nile Risk per Health Unit



Discussion

* According to the A2 model, as temperatures rise the number of heat waves increases exponentially
* Wet bulb global temperature increases at the same rate as temperature
* The degree-days increase linearly with temperature, but first the threshold EIP must be met before mosquitoes can transmit West Nile Virus

Conclusion

* In conclusion, it is evident that climate change will increase the severity of several health effects
* Preparations should be made over the next decades to avoid potential disasters and mitigate the affects of climate change

UNIVERSITY OF TORONTO

Recap

* U of T Climate Lab at UTSC overview of Ontario Projects
* CCIA Methodology
  * Projections
* Climate Change and Human Health in Ontario
  * Heat Stress
  * West Nile

High-Resolution Regional Climate Modelling In Support of Adaptation in Ontario

Ontario

November 28, 2014

John Liu

Senior Science Advisor on Climate Change

Ontario Ministry of the Environment and Climate Change

Outline

- **An Overview of climate modelling activities at the Ministry of the Environment and Climate Change to support adaptation:**
  - ✓ Why and How did we carry out climate modelling over Ontario?
  - ✓ Some current climate modelling results;
  - ✓ What have we used these data for?
  - ✓ Potential future activities.

<u>Why</u> do we need to study climate change over Ontario? (1)


Finch Avenue Wash Out in 2005

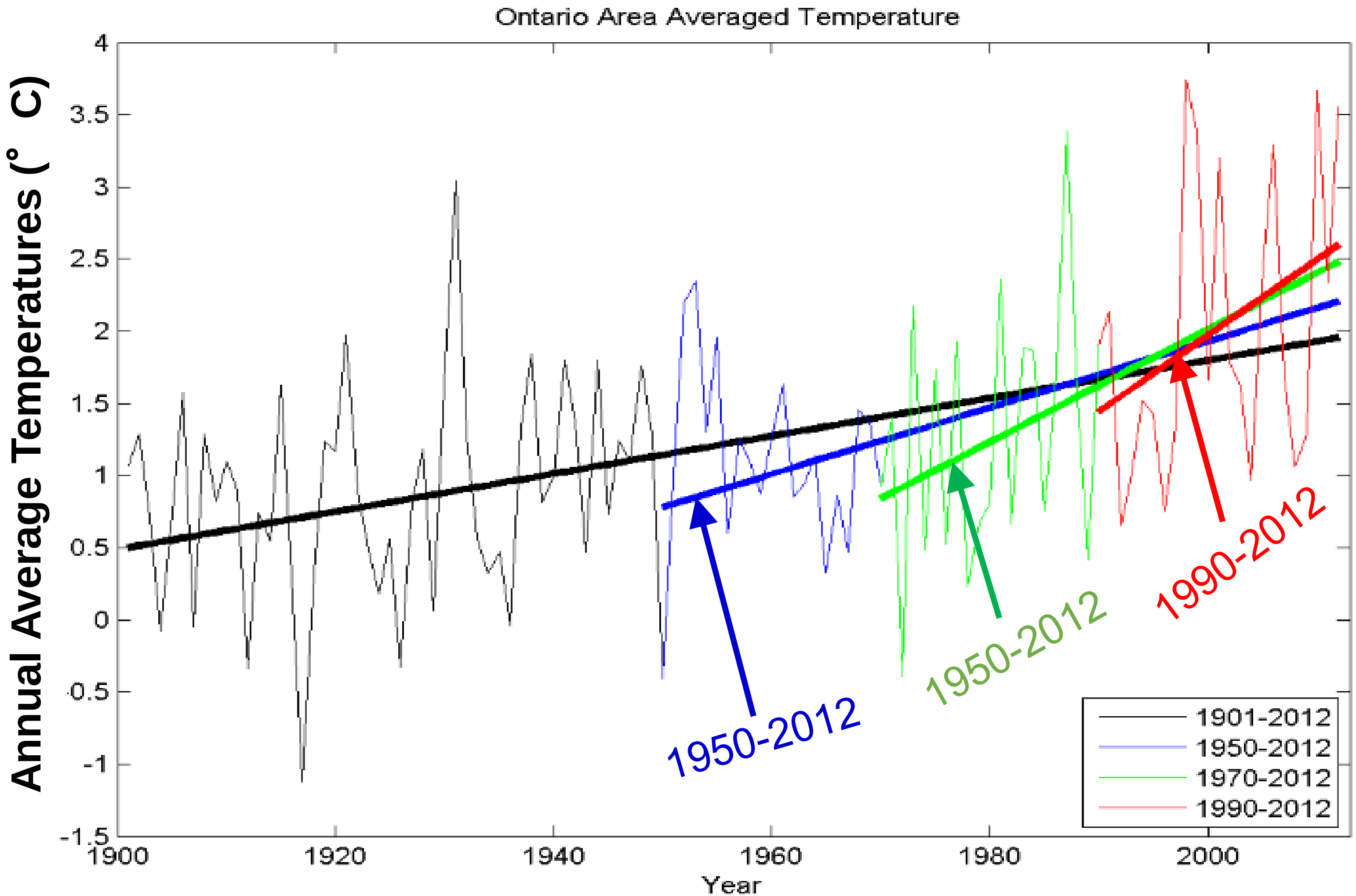
Great Lakes water level hit record low in 2013


2013 Toronto Flooding

Algae bloom in Lake Erie, August 2014

Why do we need to study climate change over Ontario? (2)

Ontario as a whole has been experiencing accelerated warming.

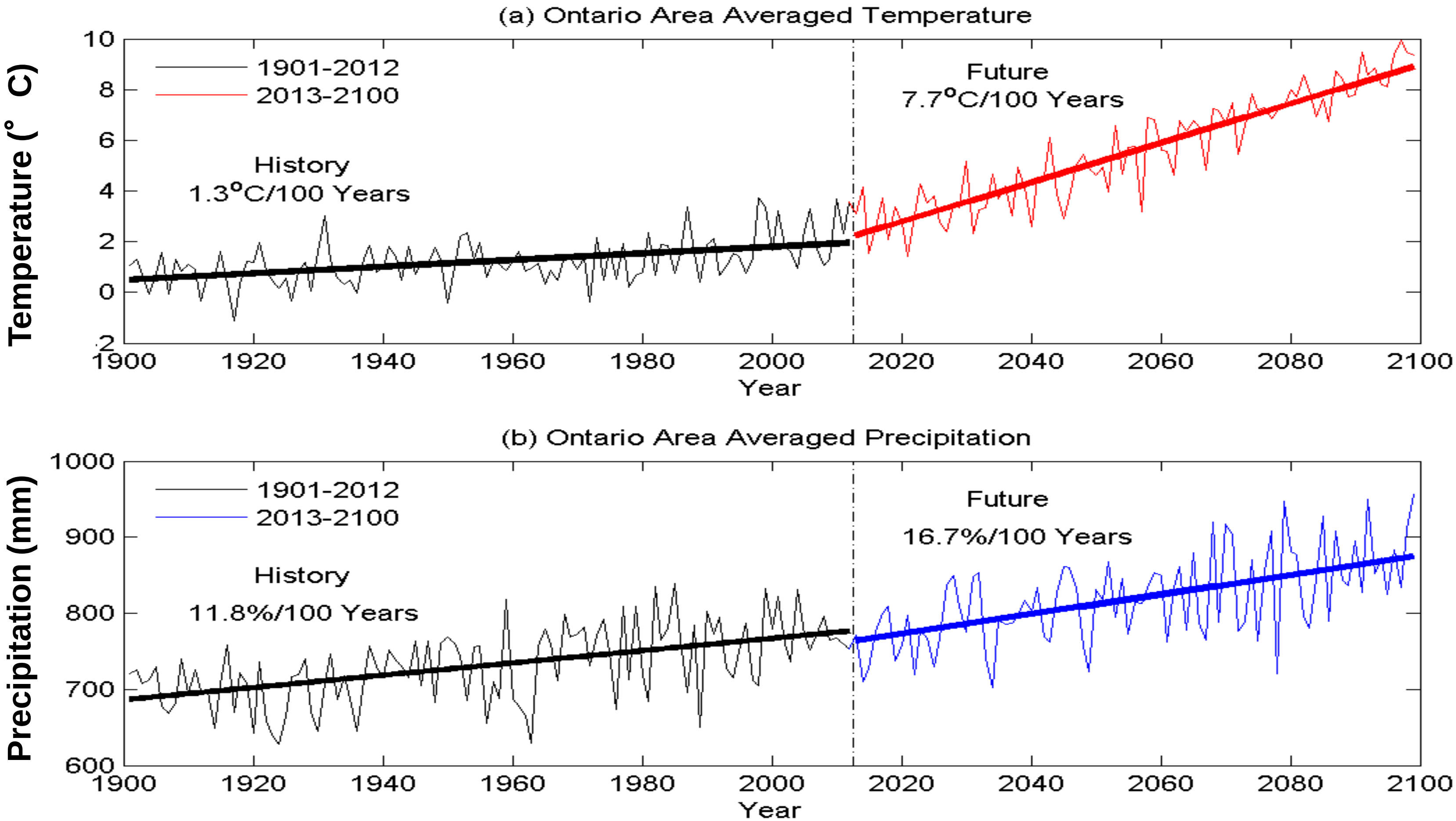


Analysis is carried out by York University based on observed data from http://badc.nerc.ac.uk/view/badc.nerc.ac.uk__ATOM__dataent_12562237733328276.

Ontario

Why do we need to study climate change over Ontario? (3)

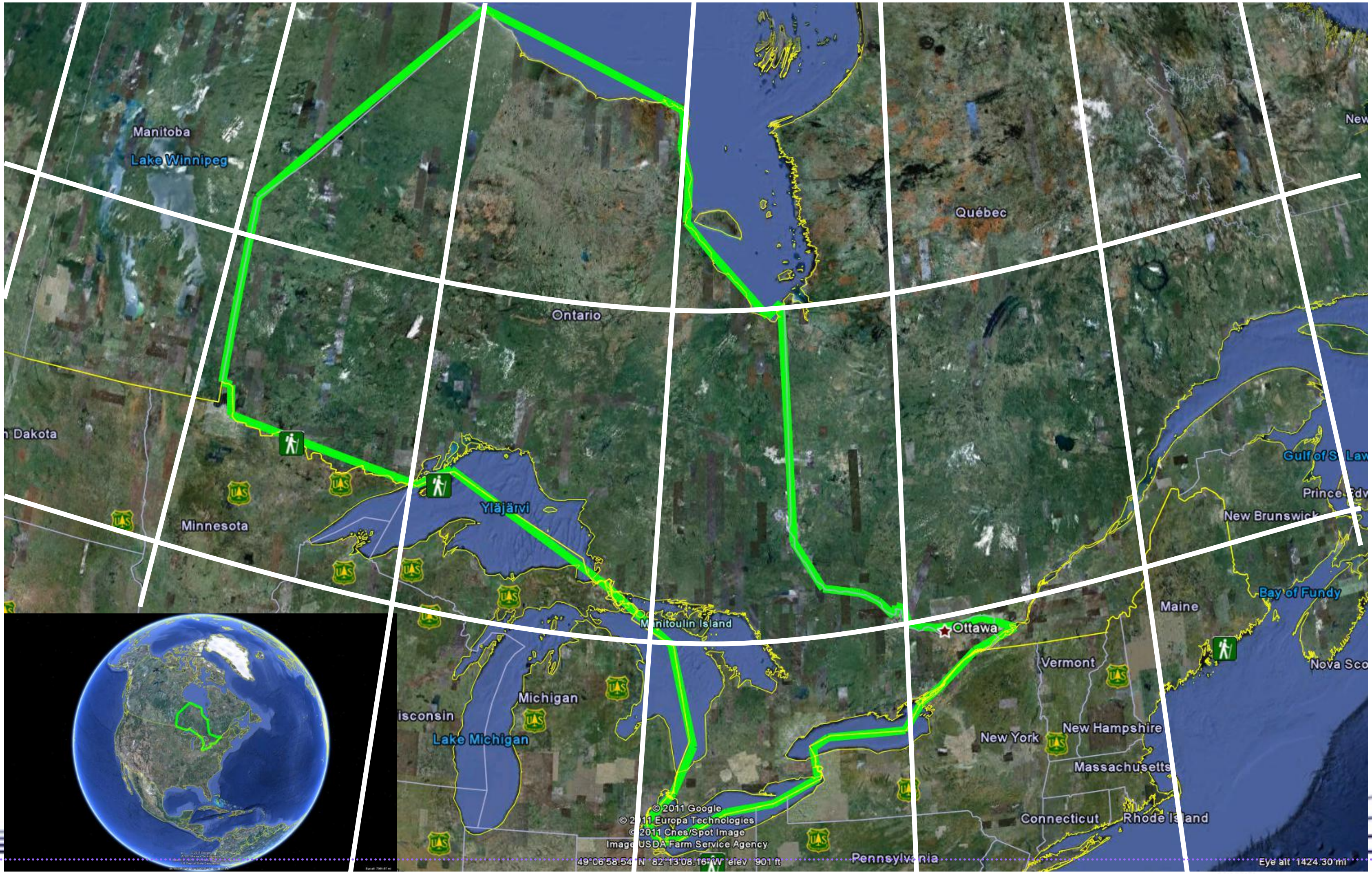
Annual temperature & precipitation have been changing in the past, will change more rapidly in the future.



- **Historical**: based on the CRU data;
- **Future**: ensemble using all available IPCC AR5 RCP8.5 projections;
- **Bias-corrected** and area-weighted averages over the entire province, York University.

Ontario

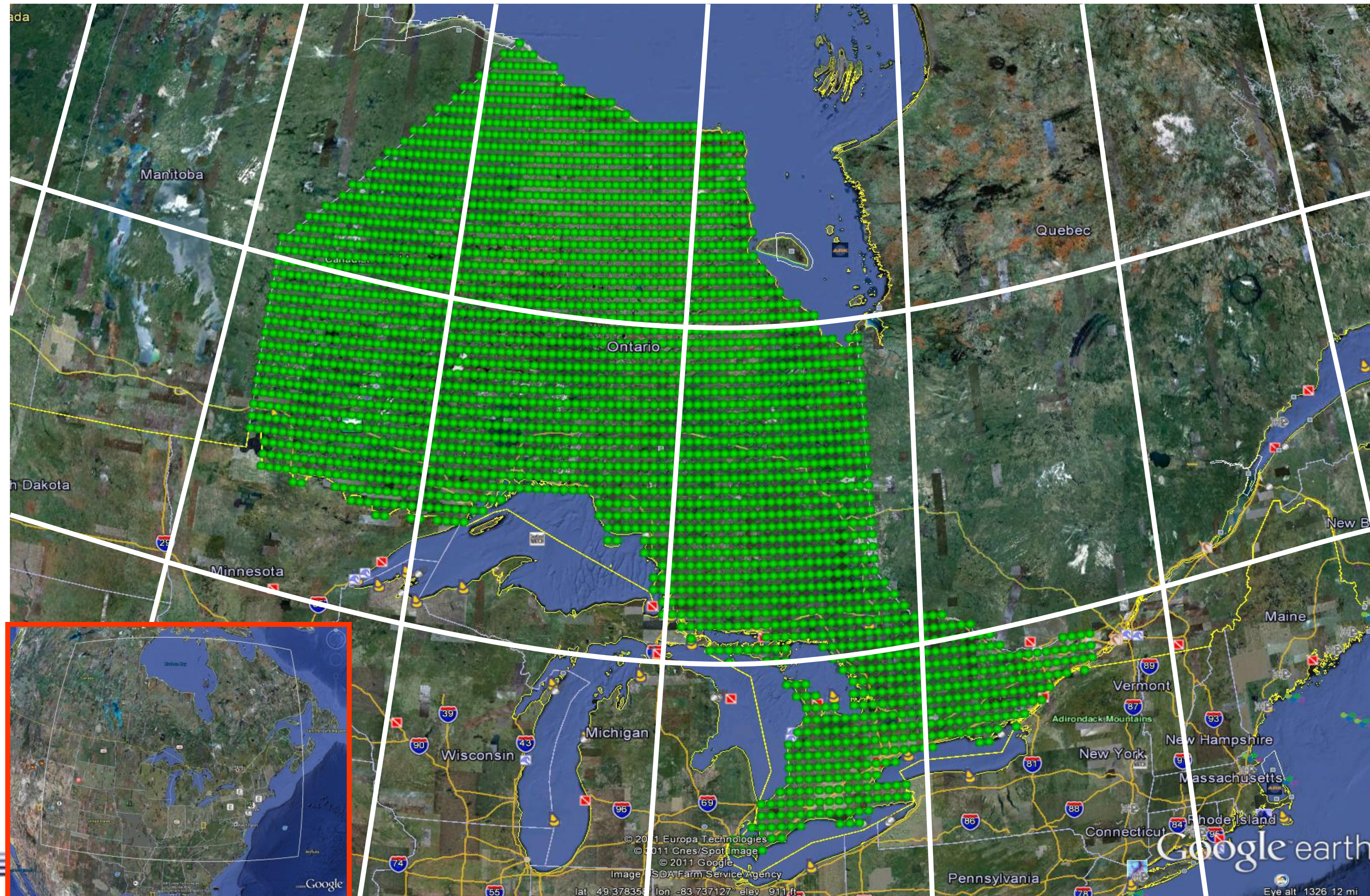
How Did We Do It - Downscaling



Downscaling: from Very Large Tiles in
Global Climate Models (GCMs)

Ontario

<u>How</u> Did We Do It – Downscaling(2)

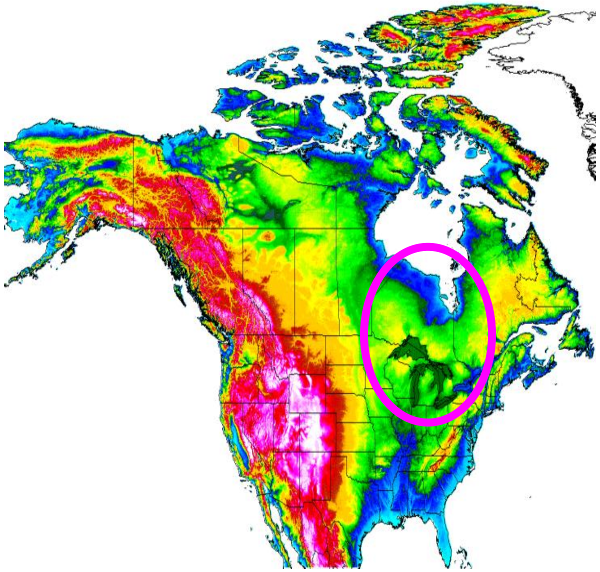


* Shown are the URegina PRECIS domain and grids over Ontario at ~25km resolution

Ontario

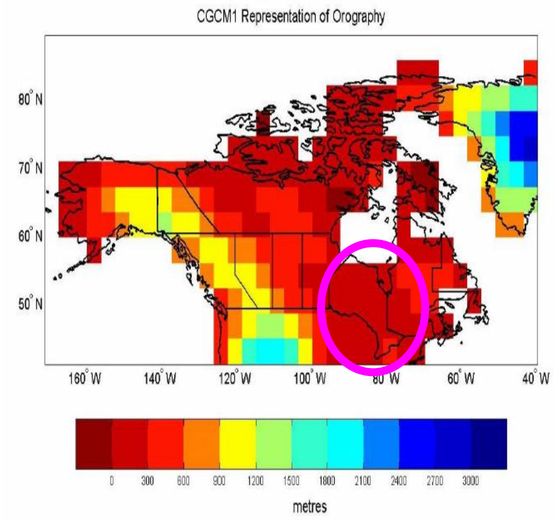
<u>Why</u> Do We Need Regional Climate Models (1)

- Refining models provides a clearer picture of the province's topography

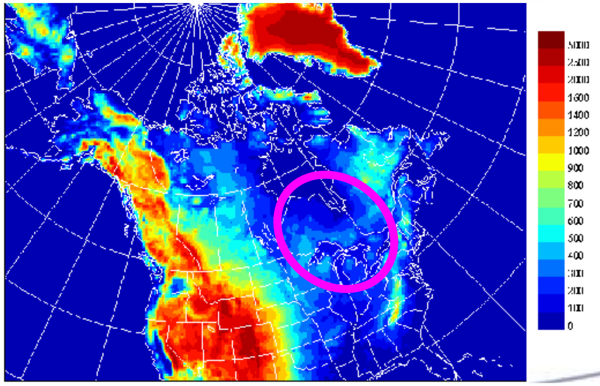


PRESENT (Measured / Observed Terrain)

GLOBAL MODEL

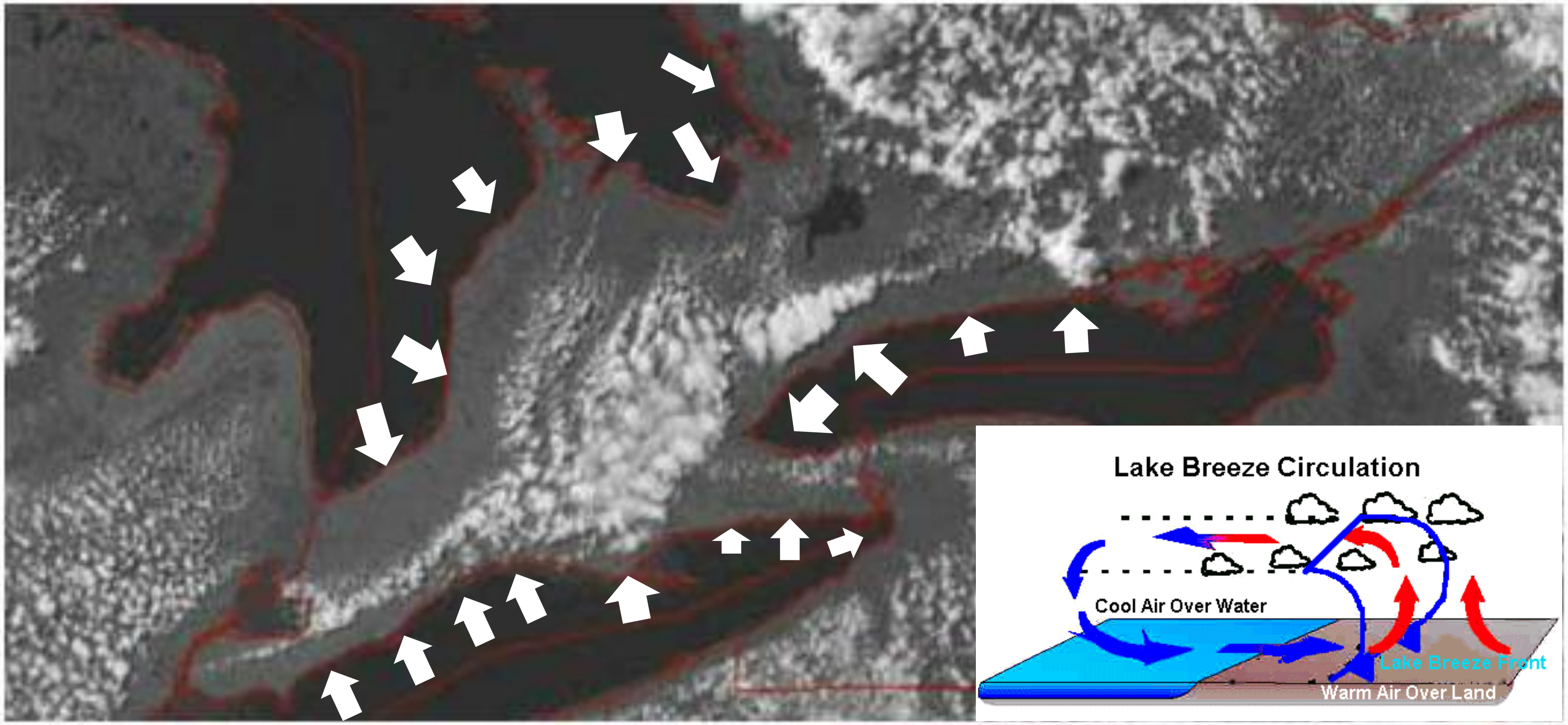


REGIONAL MODEL



Why Do We Need Regional Climate Models (2)

- Regional climate models are able to better simulate the severe weather/ climate systems caused by the Ontario specific geophysical features.



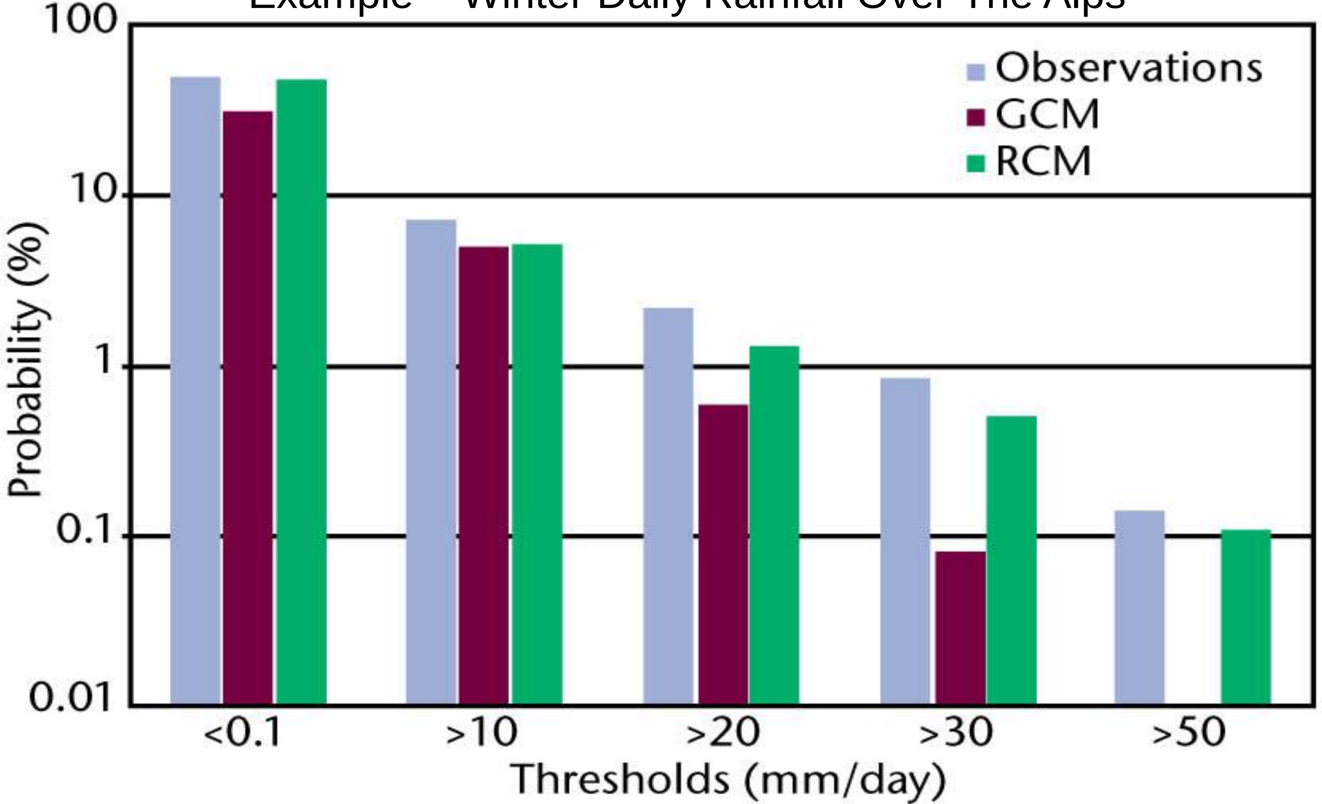
A satellite image shows cloud formations over land surrounding the lakes. This is the result of summer lake breezes creating thunderstorms over Southern Ontario. Arrows were drawn to illustrate lake breeze surface wind directions.

Satellite Image from: http://www.ec.gc.ca/meteo-weather/default.asp?lang=En&n=279AC7ED-1&offset=2&toc=hide

<u>Why</u> Do We Need Regional Climate Models (3)

- Regional climate models are able to better simulate observed data compared to global climate models which increases confidence in projections of future climate

Example – Winter Daily Rainfall Over The Alps



Ontario

Completed Regional Climate Modelling Projects funded through Transfer Payments

Year	Recipient	Project
2008-2009 (completed)	OURANOS	Modelling distribution of trends of major climate indicators across Ontario (45km x 45km grids) using a Canadian model
	University of Regina	Modelling distribution of trends of major climate indicators across Ontario (10km x 10km grids) using a UK model
2009-2010 (completed)	University of Toronto/SciNet	Modelling Ontario's climate change at high-resolution (10km x 10km grids) with US model on the SciNet Supercomputer System
	University of Regina	Modelling Ontario's climate change at high resolution (25km x 25km grids) with UK PRECIS Model and further downscaling to 10km x 10km resolution
	University of Toronto-Scarborough	Developing future climate change projections over Ontario at annual, seasonal and monthly scales using statistics
	York University	Assessing potential changes in extreme winds over Ontario using high resolution data from observation and models
2010-2011 (completed)	York University	Developing high-resolution (45km x 45km grid) probabilistic climate projections over Ontario from multiple Regional and Global Climate Models
	University of Regina	Developing high-resolution (25km x 25km) probabilistic climate projections over Ontario from large ensemble runs of the UK model
	University of Toronto/SciNet	Improving regional climate modelling over Ontario at high-resolution (10km x 10km grids) with US model on the SciNet Supercomputer System
2012-2013 (completed)	York University	Developing High-Resolution (45km x 45km) Probabilistic Climate Projections of Extreme Events over Ontario from Multiple Regional and Global Climate Models.
	University of Regina	Developing Future Projected IDF Curves across the Entire Province and to Make the Project Results and All Associated Data Publicly Available on a Data Portal.
	Trent University	Assessing climate impacts using Ontario-specific high resolution climate data for the Lake Simcoe watershed
	Engineers Canada	A pilot vulnerability assessment of the impacts of climate change on a municipal water treatment plant in southern Ontario

Ontario

Products Resulted from the MOECC-funded Regional Climate Modelling Projects

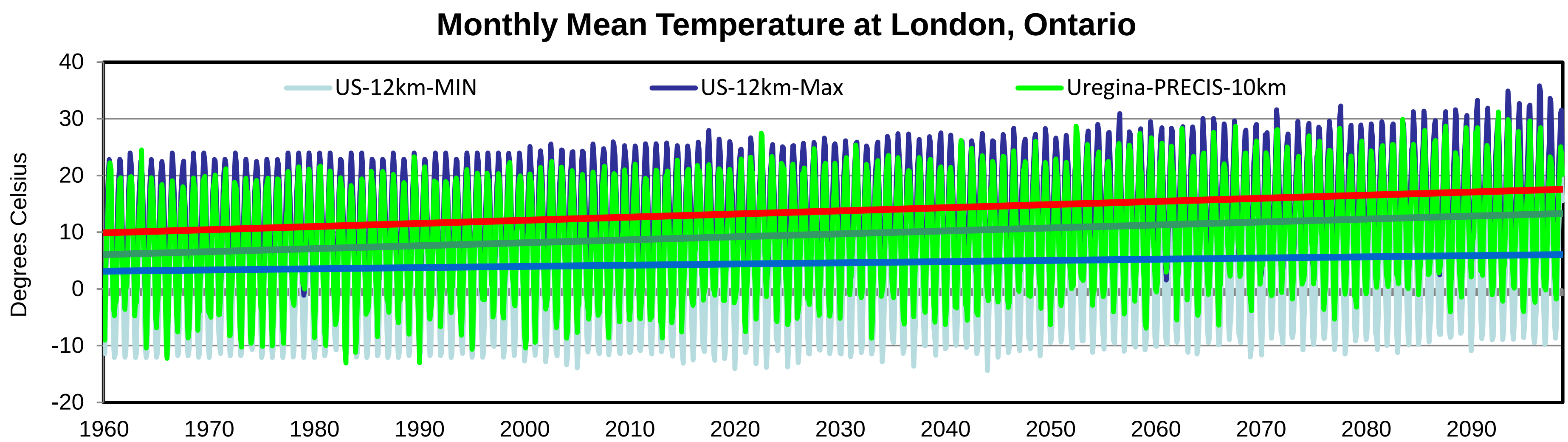
Ontario-Specific High Resolution Climate Data from MOECC-Funded Projects

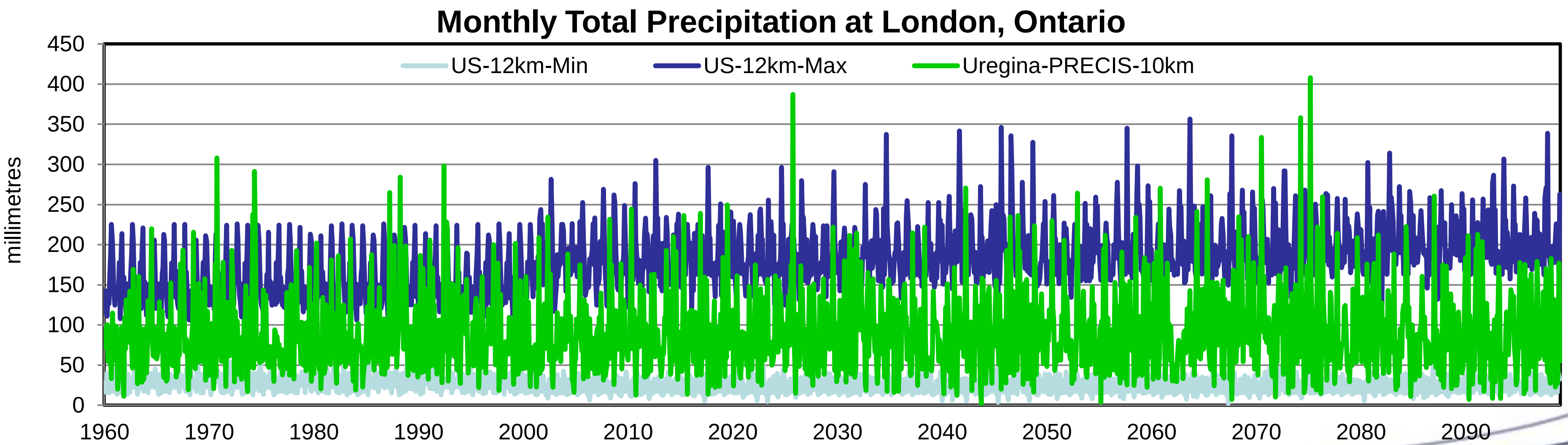
Publicly Available Data Resulting from Completed Projects

1. Annual Mean Temperature
2. Mean Diurnal Range (Mean of the period max-min])
3. Mean daily temperature
4. Mean daily maximum temperature
5. Mean daily minimum temperature
6. Max Temperature of Warmest Period
7. Min Temperature of Coldest Period
8. Temperature Annual Range
9. Mean Temperature of Wettest Quarter
10. Mean Temperature of Driest Quarter
11. Mean Temperature of Warmest Quarter
12. Mean Temperature of Coldest Quarter
13. Heat wave return-period analyses
14. 99th percentile of daily maximum temperature - probabilistic
15. 1st percentile of daily maximum temperature - probabilistic
16. 99th percentile of daily minimum temperature - probabilistic
17. 1st percentile of daily minimum temperature - probabilistic
18. Cooling Degree Days (CDD) - probabilistic
19. Heating Degree Days (HDD) – probabilistic
20. Annual Precipitation
21. Precipitation of Wettest Period
22. Precipitation of Driest Period
23. Precipitation Seasonality
24. Precipitation of Wettest Quarter
25. Precipitation of Driest Quarter
26. Precipitation of Warmest Quarter
27. Precipitation of Coldest Quarter
28. Intensity, Duration and Frequency (IDF) curves at selected monitoring locations
29. Flooding return-period analyses
30. Snow water equivalent (“SWE”)
31. Monthly mean of SWE
32. Max daily SWE
33. 99th percentile of daily precipitation rate- probabilistic
34. Specific humidity
35. Relative humidity
36. Surface winds gusts and return-period analyses
37. Soil moisture
38. Soil temperature
39. Total clouds
40. Net surface long wave radiation flux
41. Net surface short wave radiation flux
42. Total downward short wave radiation flux
43. Intensity, Duration and Frequency curves across all of Ontario
44. Daily maximum, minimum, and average air temperature.
45. Daily total precipitation
46. Hourly temperature
47. Hourly total precipitation
48. Hourly surface relative humidity
49. Hourly surface solar radiation
50. Hourly surface wind speed
51. Hourly surface wind direction
52. Heat waves (strength and length) - Length in days, season, year
53. Maximum humidex - day, month, season, year
54. Hot day- Length in days, season, year
55. Hot night- Length in days, season, year
56. Cold day - Length in days, season, year
57. Cold night - Length in days, season, year
58. Days with more than 5 consecutive days of precipitation
59. Days with more than 10mm precipitation - month, season, year
60. Days with more than 20mm precipitation- month, season, year
61. Heavy precipitation above 95 percentile - month, season, year
62. Frequency of heavy precipitation by types - month, season, year

Ontario

University of Regina PRECIS Results vs US Downscaled Results*





* data from the US Lawrence Livermore National Laboratory

Ontario

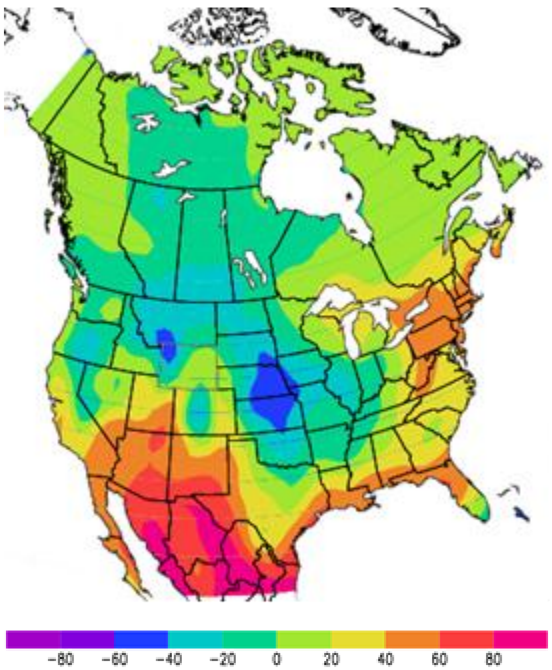
York U Results – Probabilistic Projection

Changes in Cooling Degree Days in 2046-65

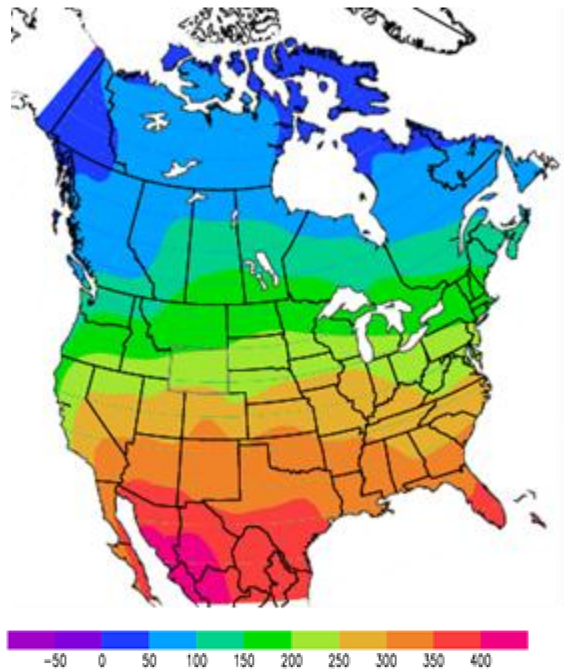
$$CDD = \begin{cases} T-18, & T > 18, \\ 0, & T \le 18. \end{cases}$$

Percentile:

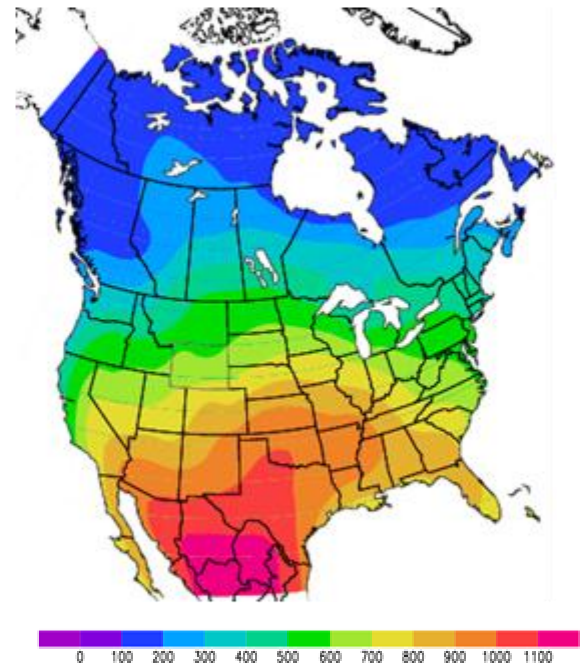
10th



50th



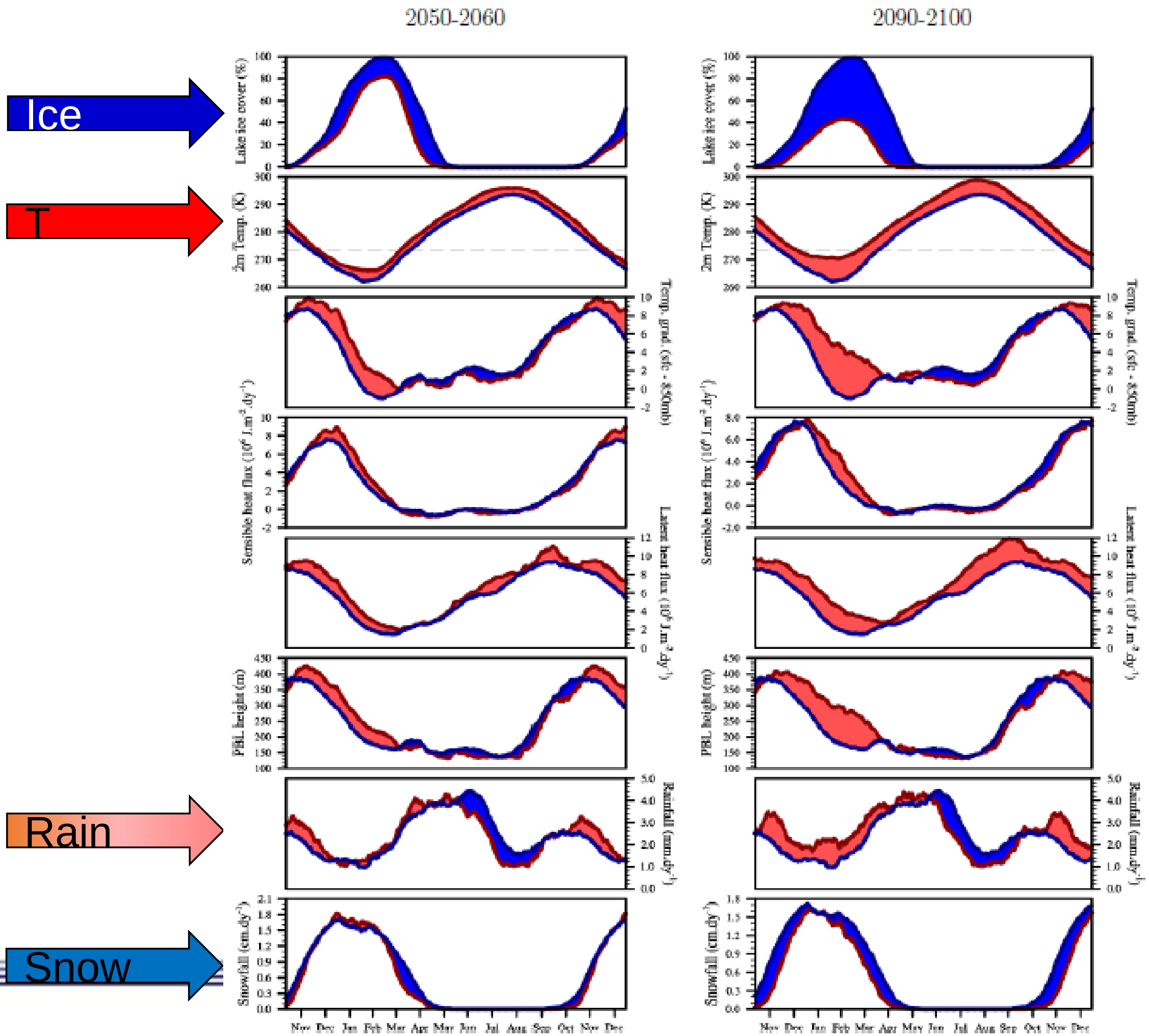
90th



More cooling energy required in future summers!

Ontario

U of T Results – Great Lakes Basin



Future Projected vs 1979-2000 Normals

Work Has Been Recognized by Top Journals

1. Wang, X. et al, **2014**: High-resolution probabilistic projections of temperature changes over Ontario, Canada, ***Journal of Climate*** (American Meteorological Society, SCI IF = 4.362), 27, 5259-5284**.**
2. Gula, J., W. R. Peltier, **2012**: Dynamical Downscaling over the Great Lakes Basin of North America Using the WRF Regional Climate Model: The Impact of the Great Lakes System on Regional Greenhouse Warming. ***Journal of Climate***, **25**, 7723–7742. doi: http://dx.doi.org/10.1175/JCLI-D-11-00388.1
3. Wang, S. et al **2014**: Comparison of interpolation methods for estimating spatial distribution of precipitation in Ontario, Canada, ***International Journal of Climatology*** (Wiley, SCI IF = 2.886), doi:10.1002/joc.3941**.**
4. Wang, X. et al. **2014**: High-resolution temperature and precipitation projections over Ontario, Canada: A coupled dynamical-statistical approach. *Quarterly* ***Journal of the Royal Meteorological Society***, *doi: 10.1002/qj.2421*.
5. Wang, X. et al. **2014**: Projected increases in intensity and frequency of rainfall extremes through a regional climate modeling approach. ***Journal of Geophysical Research – Atmospheres***, doi:10.1002/2014JD022564
6. Wang, X. et al. **2014** Projected increases in near-surface air temperature over Ontario, Canada: a regional climate modeling approach. ***Climate Dynamics***, doi:10.1007/s00382-014-2387-y
7. Wang, X. et al, **2013**: A stepwise cluster analysis approach for downscaled climate projection - A Canadian case study, ***Environmental Modelling & Software*** (Elsevier, SCI IF = 3.476), Volume 49, Pages 141-151, ISSN 1364-8152, http://dx.doi.org/10.1016/j.envsoft.2013.08.006.
8. Yao, Y et al: **2012:** Climate change impacts on Ontario wind power resource, ***Environmental Systems Research*** (Springer), August 2012, 1:2.

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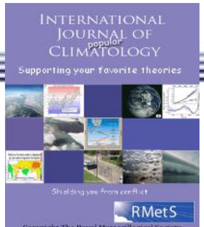
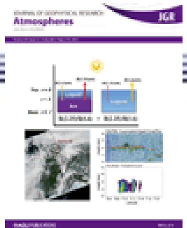


tario

RCP8.5

Average Climate Indicators

1 Ontario Climate Facts **Average Climate Indicators**

Historical 112-year trend (1901-2012) based on Climate Research Unit (CRU*) climate data

Temperatures-related indicators

- **Annual** temperature increased 1.31°C
- **Winter** (December, January, February):
  - Temperatures increased 2.2 °C [1.2 ~3.3] °C over
  - 1901-2012 [Values in square brackets indicate 95% confidence intervals].
  - More warming in the north than the south.
  - Frost days per year decreased 18 [-32 ~ -4] days (over the period 1979-2009)
- **Summer** (June, July, August):
  - Temperatures increase 1.0°C [0.4 ~ 1.5]°C
  - More warming in the north than the south.

Precipitation (low confidence)

- **Annual** precipitation increased 4.9%[3.5~6.2]%
- **Winter** precipitation increased 9.5% [6.8 ~ 12.3]%
  - More increasing in south and central than in north
- **Summer** precipitation increased 1.7% [0 ~ 3.0]%
  - More increasing in northern west and central than elsewhere

Future expected change by 2081-2100 from 1981-2010, based on the high end RCP8.5 AR5 scenario

Long-term temperature and precipitation changes will depend on future greenhouse gas emissions

- The pattern of projected change is the same for all scenarios, but less pronounced with lower emissions.
- The IPCC projects global mean warming is *likely* to be in the range 2.6 °C ~ 4.8°C with the RCP8.5.

Temperature is likely to increase significantly in Ontario

- **Annual** temperature warming by 6.1°C
- **Winter** temperature:
  - Warming by 8.7 °C
  - More warming in the north than elsewhere
  - 49 fewer frost days
- **Summer** temperature:
  - Warming by 4.4 °C
  - More warming in north and south-west than elsewhere

Precipitation is likely to increase(low confidence)

- **Annual** precipitation: increase by 13.6%
- **Winter** Precipitation: increase by 24.2%
- **Summer** precipitation: increase by 9.7%

LAMPS Laboratory of Mathematical Parallel Systems

novus ENVIRONMENTAL

York University

novus Environmental

August 6, 2014

*CRU: http://badc.nerc.ac.uk/view/badc.nerc.ac.uk__ATOM__dataent_12562237733278276

RCP8.5
Extreme Climate Indicators

2 Ontario Climate Facts

Extreme Climate Indicators*

Historical 35-year trend (1979-2013) based on The NCEP Climate Forecast System Reanalysis (CFSR*)

Annual temperature-related indicators

- Minimum of maximum T increased 5.7 [2.6~8.7]°C
- Maximum of maximum T decreased 0.23 [-2.4~2.0]°C
- Minimum of minimum T increased 6.9 [3.2~10.6]°C
- Maximum of minimum T increased 0.1 [-1.5~1.7] °C
- Diurnal temperature range decreased 0.87 [-1.3~ -0.4]°C
- Hot-days increased 13 [1~25] days
- Hot-nights increased 16 [4~28] days
- Heat wave days increased 9 [-1~19] days
- Heat wave strength increased 74°C
- Cold-days decreased 15 [-29~ -4] days
- Cold-nights decreased 26 [-39~ -13] nights
- Icing-days decreased 13 [-25~-1] days

Annual precipitation-related indicators

- Wet-days increased 5[-5~16] days
- Heavy precipitation days (R10) increased 5 [2~8] days
- Very heavy precipitation days (R20) increased 2 [1~3] days
- Very wet days (R95p) increased 2 [1~4] days
- Consecutive wet and dry days did not change

Future expected change by 2081-2100 from 1981-2010, based on the high end RCP8.5 AR5 scenario

Annual temperature-related indicators are likely to

- Minimum of maximum T increase 11.7°C
- Maximum of maximum T increase 4.9°C
- Minimum of minimum T increase 14°C
- Maximum of minimum T increase 4.5 °C
- Diurnal temperature range decrease 1.1°C
- Hot-days increase 108 days
- Hot-nights increase 123 days
- Heat wave days increase 38 days
- Heat wave strength increase 1427°C
- Cold-days decrease 27 days
- Cold-nights decrease 33 nights
- Icing-days decrease 43 days

Annual precipitation-related indicators are likely to

- Wet-days increase 7 days
- Heavy precipitation days (R10) increase 5 days
- Very heavy precipitation days (R20) increase 2 days
- Very wet days (R95p) increase 3 days
- No change in consecutive wet and dry days

*CFSR: https://climatedataguide.ucar.edu/climate-data/climate-forecast-system-reanalysis-cfsr

Extreme Climate Indicators: http://www.wmo.int/pages/prog/wcp/wcdmp/documents/WCDMP_72_TD_1500_en_1.pdf

URegina Ontario Climate Factsheet Based on AR4 A1B (Moderate) Emission Scenario

Ontario Climate Factsheet

Historical (1900-2012) trends based on the Environment Canada climate data set [1]

Temperatures have increased in Ontario

Annual average temperature:

- increased 1.6 °C [1.3 to 1.9] [2] °C over 1900-2012

Winter temperature:

- Mean temperatures increased 2.0 °C [1.4 to 2.5] °C
- Maximum temperature has increased 1.3 °C [0.7 to 1.8] °C
- Minimum temperature has increased 2.5 °C [1.9 to 3.2] °C

Summer temperature:

- Mean temperature has increased 1.3 °C [1.0 to 1.6] °C
- Maximum temperature has increased 0.8 °C [0.5 to 1.1] °C
- Minimum temperature has increased 2.0 °C [1.5 to 2.4] °C

Precipitation appears to have increased too

- Long-term trend estimation for precipitation is very uncertain because only sparse observations were available during the first few decades of the 20th century
- Annual precipitation has increased 17 % [11 to 22]%
- Winter precipitation has increased 20% [8 to 32]%
- Summer precipitation has increased 6% [2 to 10]%

Future projected changes under a balanced emissions scenario (IPCC A1B) [3]

Regional projections for Ontario at 2050s and 2080s [4]

Annual average temperature:

- Warming of 4.1 °C [1.7 to 4.8] °C by 2050s
- Warming of 5.6 °C [2.6 to 7.0] °C by 2080s

Winter average temperature:

- Warming of 5.0 °C [2.2 to 6.3] °C by 2050s
- Warming of 6.6 °C [3.3 to 8.8] °C by 2080s

Summer average temperature:

- Warming of 3.7 °C [1.5 to 4.4] °C by 2050s
- Warming of 5.0 °C [2.3 to 6.7] °C by 2080s

Annual average total precipitation:

- Increase of 7% [1 to 12]% by 2050s
- Increase of 9% [2 to 17]% by 2080s

Winter average total precipitation:

- Increase of 19% [6 to 28]% by 2050s
- Increase of 25% [9 to 38]% by 2080s

Summer average total precipitation:

- Decrease of 0.1% [-7 to 9]% by 2050s
- Decrease of 7% [-12 to 11]% by 2080s

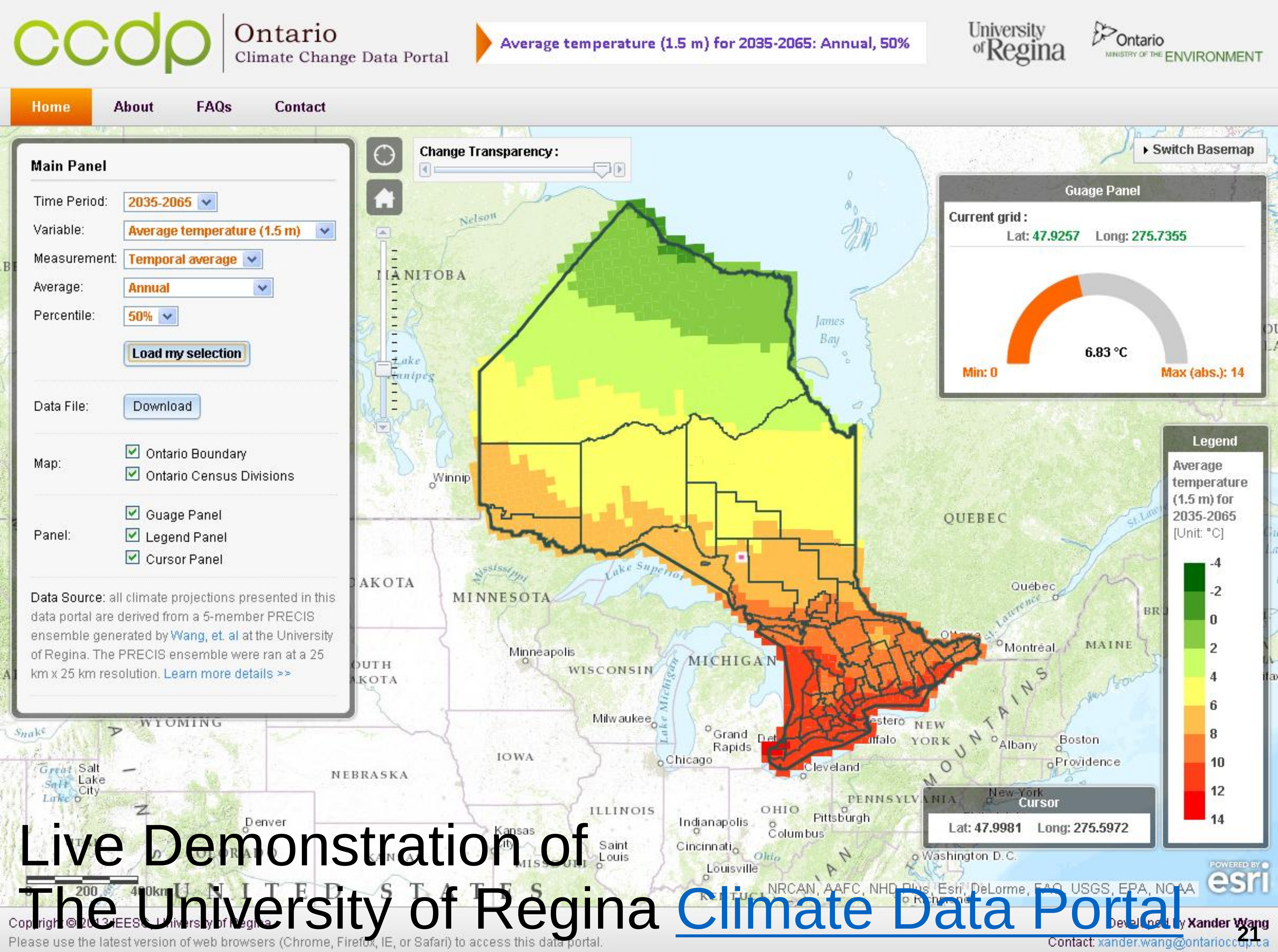
50-year and 100-year severe storms with flooding potentials:

- Increase of 12% [7 to 18]% by 2050s
- Increase of 31% [19 to 43]% by 2080s

In the upcoming decades throughout this century, warming is projected across the entire Province of Ontario; winters will likely become much wetter while summers are expected to be slightly drier.

University of Regina

1. More information available at: http://ec.gc.ca/dccha-ahccd/Default.asp?lang=En&n=B1F8423A-1.
2. Amounts in square brackets indicate approximate 10th to 90th percentile range.
3. More information available at: https://www.ipcc.ch/publications_and_data/ar4/wg1/en/spmsspm-projections-of.html.
4. Based on the University of Regina's probabilistic projections (http://ontarioccdp.ca) of changes at 50th percentile relative to 1960-1990. Amounts in square brackets indicate the likely range of projected changes at 10th and 90th percentiles.



Live Demonstration of The University of Regina [Climate Data Portal]

OCCP

Ontario Climate Change Projections

Username * ziwang Password *

Create new account Request new password

Log in

YORK UNIVERSITÉ UNIVERSITY

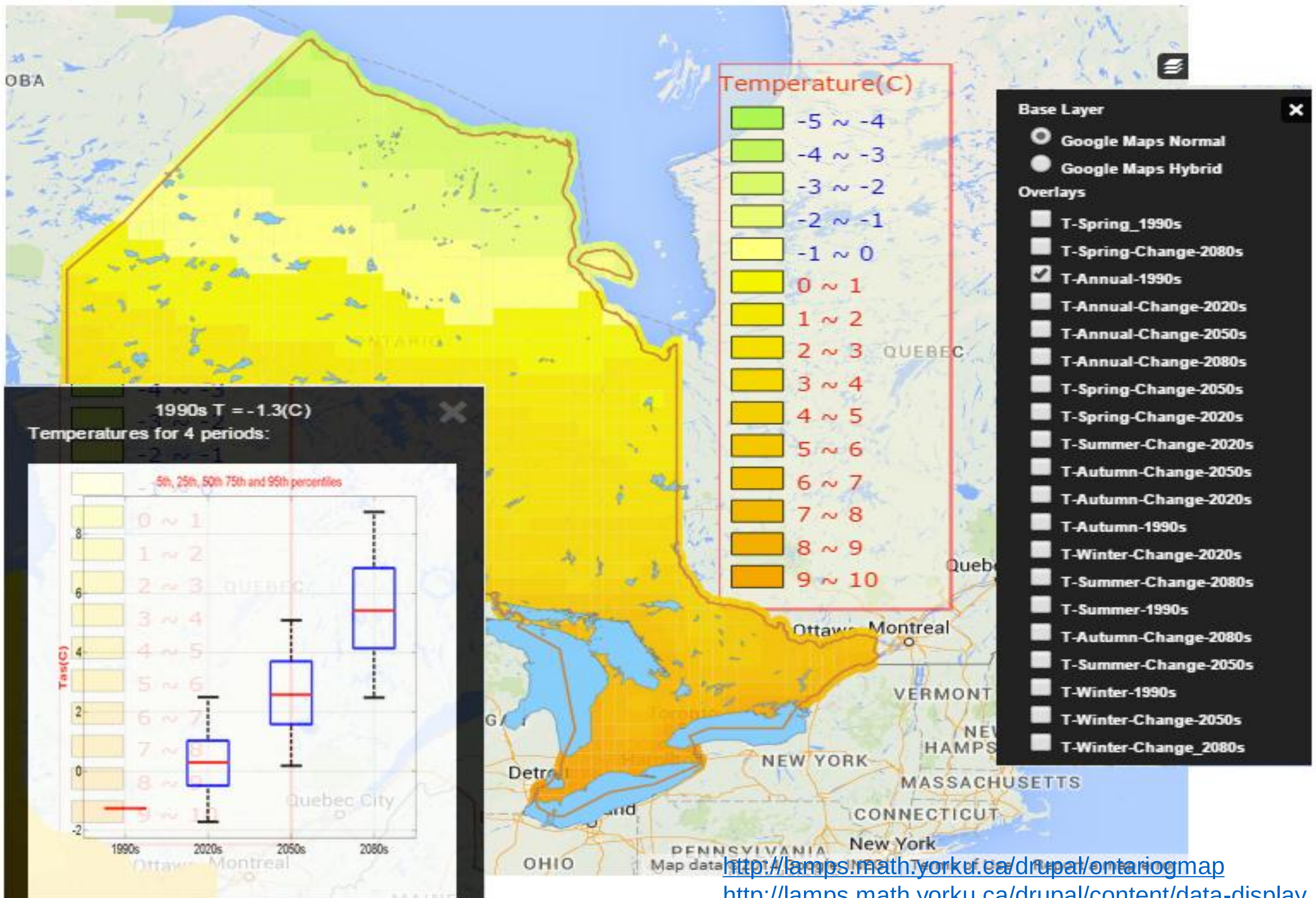
Home | Climate Information | Data Display | Data search and Download | Case Studies | Documents

Home » Data Display » Temperature

AR5 Grid Data

- Temperature »
  - Mean of Mean »
    - Annual
    - Spring
    - Summer
    - Autumn
    - Winter
  - Mean of Maximum »
    - Annual
    - Spring
    - Summer
    - Autumn
    - Winter
  - Mean of Minimum »
    - Annual
    - Spring
    - Summer
    - Autumn
    - Winter
- Precipitation »
  - Annual
  - Spring
  - Summer
  - Autumn
  - Winter
- Extreme T-Indices »
  - Maximum of Max T
  - Minimum of Min T
  - Heat Wave Period
  - Frost Days
  - Hot-Days
  - Summer Days
  - Tropical Nights
  - Diurnal T Range
- Extreme Pr-Indices »

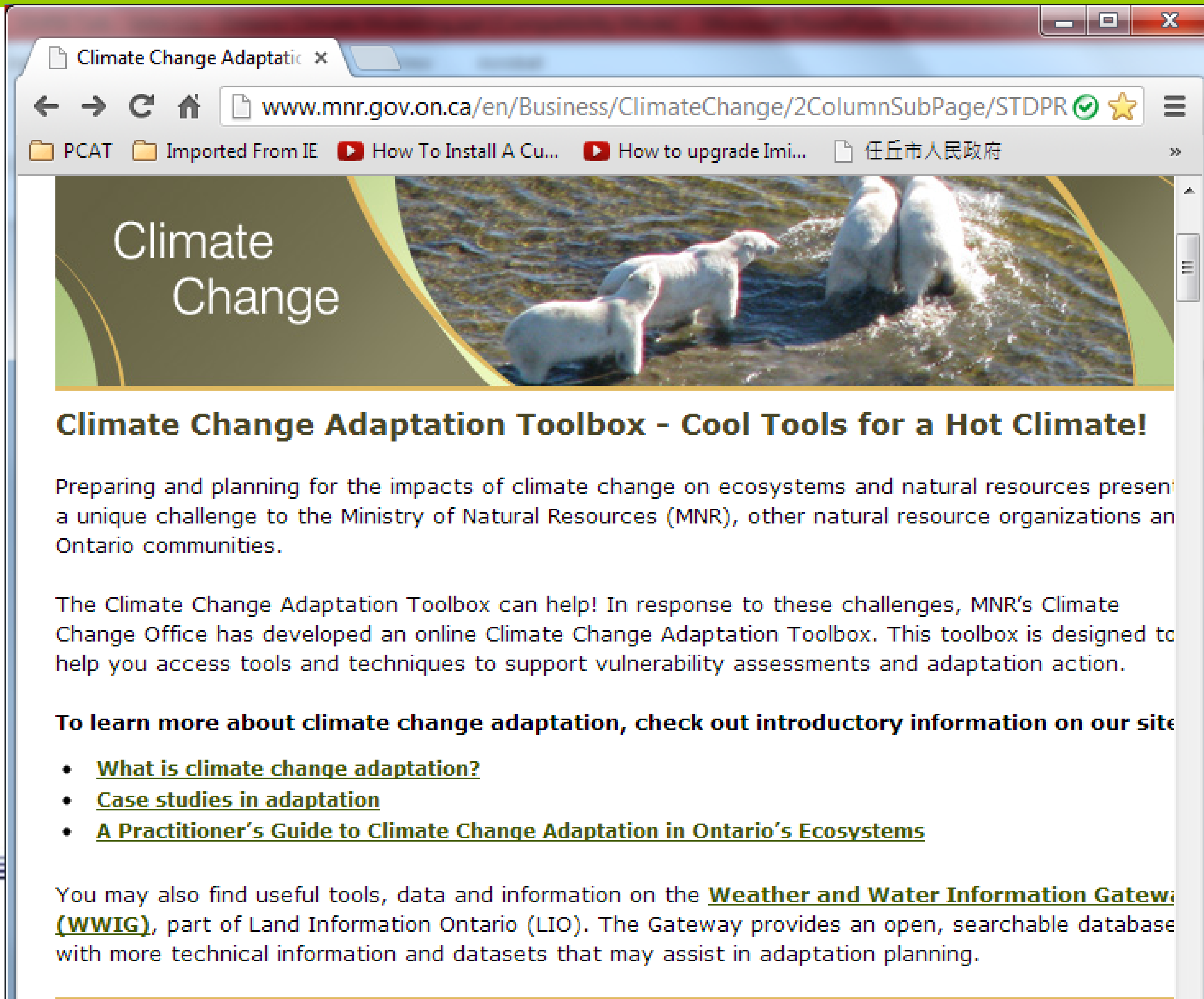
Mean of Mean Temperature



http://lamps.math.yorku.ca/drupal/ontariogmap

http://lamps.math.yorku.ca/drupal/content/data-display

Project Summaries Are Also Posted at the MNR Climate Change Adaptation Tool Box



Climate Change Adaptatic ×

www.mnr.gov.on.ca/en/Business/ClimateChange/2ColumnSubPage/STDPR

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Climate Change

Climate Change Adaptation Toolbox - Cool Tools for a Hot Climate!

Preparing and planning for the impacts of climate change on ecosystems and natural resources present a unique challenge to the Ministry of Natural Resources (MNR), other natural resource organizations an Ontario communities.

The Climate Change Adaptation Toolbox can help! In response to these challenges, MNR's Climate Change Office has developed an online Climate Change Adaptation Toolbox. This toolbox is designed to help you access tools and techniques to support vulnerability assessments and adaptation action.

To learn more about climate change adaptation, check out introductory information on our site

- What is climate change adaptation?
- Case studies in adaptation
- A Practitioner's Guide to Climate Change Adaptation in Ontario's Ecosystems

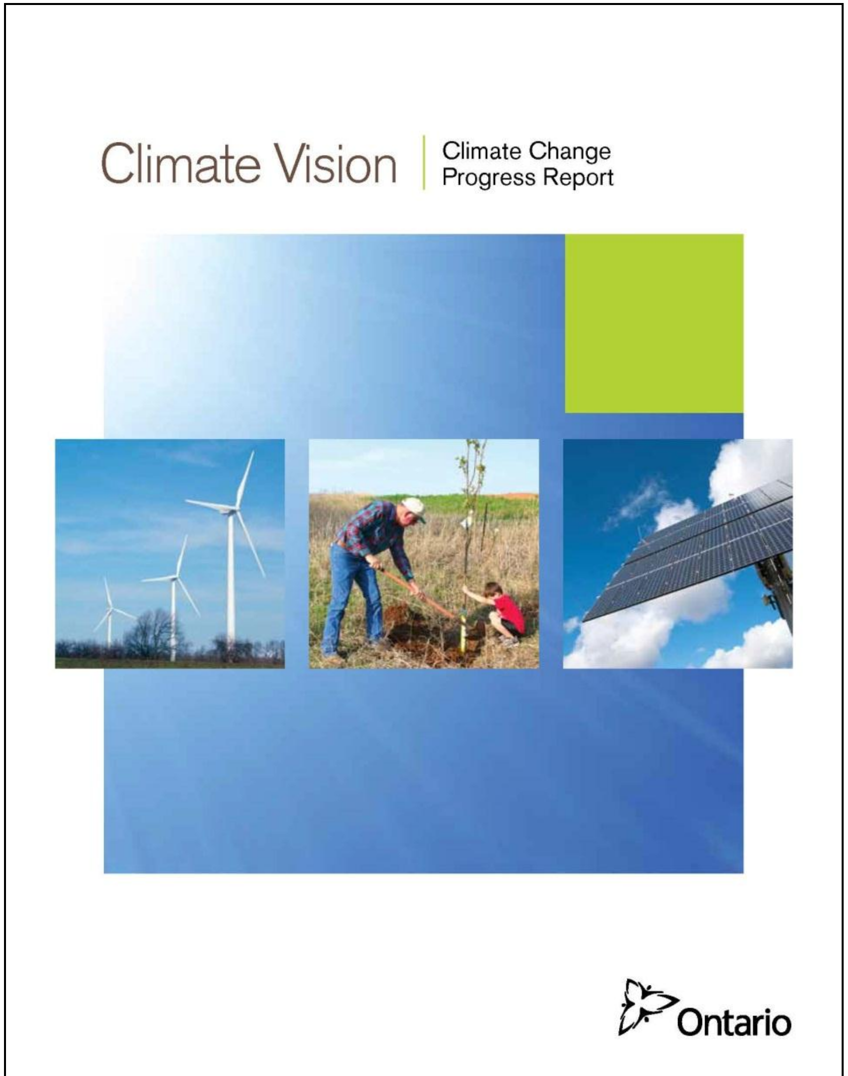
You may also find useful tools, data and information on the **Weather and Water Information Gatewa (WWIG)**, part of Land Information Ontario (LIO). The Gateway provides an open, searchable database with more technical information and datasets that may assist in adaptation planning.

23

Applications in Adaptation Assessment

Using This Downscaled Climate Data

Quoted by Government Climate Change Strategic Document



sectors such as winter tourism, agriculture, infrastructure and energy, we are undertaking a climate impact indicator study. The Province will identify trends and indicators to track direct economic, social and environmental impacts of climate change to help Ontarians better understand the scope of impacts that our province faces.

Reducing our exposure to risks and taking advantage of opportunities is the only prudent course of action to protect our families, our natural resources and the environment, and secure our business investments.

FIGURE 1
MEAN ANNUAL TEMPERATURE 2010 – 2099 FOR THREE TIME PERIODS
(A) 2010-2039, (B) 2040-2069, (C) 2070-2099[3]

3 University of Regina. July 2011. Regional Climate Modelling Over Ontario Using UK PRECIS. Study used the United Kingdom Providing Regional Climates for Impact Studies (PRECIS) model at 25-kilometer resolution and further downscaled to 10-kilometer results for the period 2010-2099. The Hadley Center global climate model (HadCM3O) results under scenario A1B was used to drive PRECIS.

36 Climate Vision

December 2012

University of Regina

Ontario

25

Helped Municipalities in Adaptation Assessments

Changes for the 2050-2060 period relative to the historical period (1979-2001) at Toronto (° C).

		Annual	summer	winter
WRF	T_{mean}	1-2	1-2	2-3
	T_{max}	1-2	2-3	2-3
	T_{min}	1-2	1-2	3-4
WRF+FLake	T_{mean}	2-3	2-3	3-4
	T_{max}	2-3	2-3	2-3
	T_{min}	2-3	2-3	4-5

Note: This data was provided to City of Toronto on request.

Used in Wind Energy Study

DILLON CONSULTING

Potential Impact of Climate Change on Wind Farm Performance in South-Western Ontario

Hong Liu[1](hongliu@dillon.ca), Jinliang Liu[2](Jinliang.Liu@Ontario.ca) , Greg Unrau[3](gunrau@live.ca),
Jon Fournier[4](jon.fournier@gdfsuezna.com), Gordon Huang[5](gordon.huang@uregina.ca) and Xiuquan Wang[5] (xiuquan.wang@gmail.com)
[1]Dillon Consulting Limited; [2]Ontario Ministry of the Environment; [3]Independent Reviewer, [4]International Power Canada Inc.; [5]University of Regina

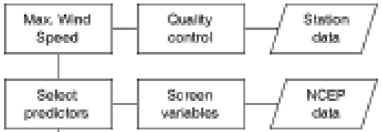
1. INTRODUCTION

Development of wind energy to meet future energy needs has been considered as a practical solution to combat climate change. It is therefore prudent to understand how climate change may impact both the viability and sustainability of the wind energy industry. One of the critical underlying parameters impacting the utilization potential of a wind turbine generator (WTG) is the wind speed. This parameter acts as the motive force (mean wind speed) and a potentially destructive force (extreme wind speed) to the WTGs. This presentation shows a novel approach to

the grid points used are shown in the Figure below) and followed by SD approaches. Average

2.2 Downscaling Extreme Wind Speed

The SDSM is a hybrid of stochastic weather generator and transfer function methods (Wilby et al, 2007), which facilitates the rapid development of multipl



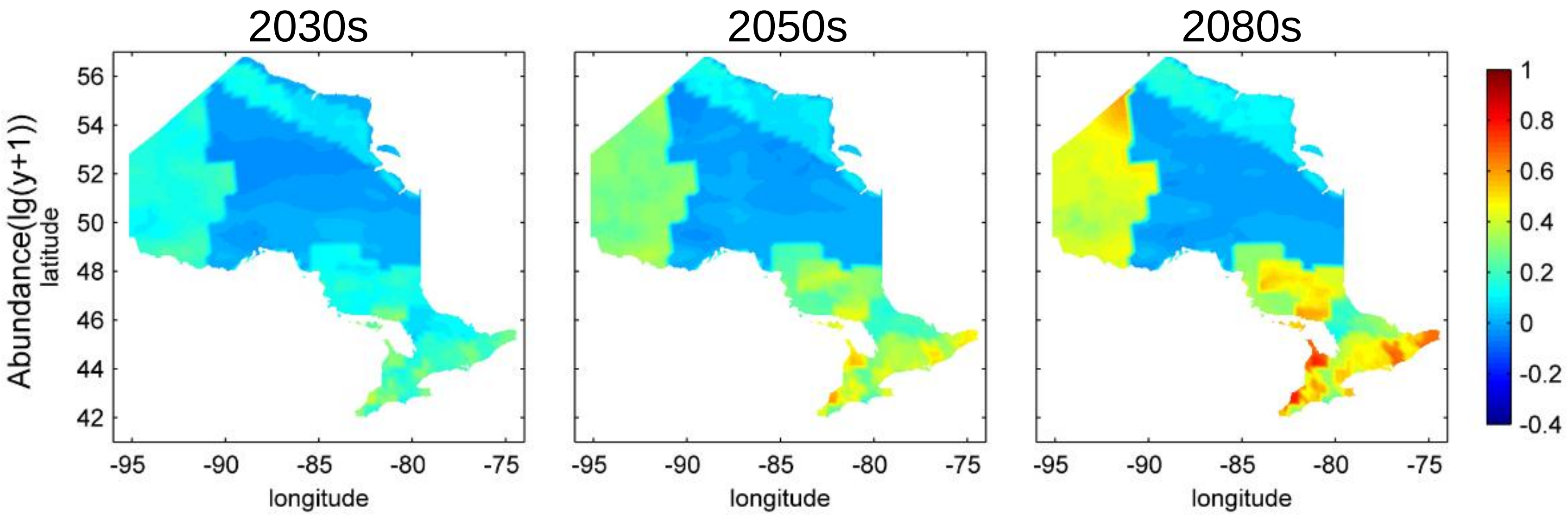
Projected Average Wind Speeds for 2040s decrease by ~3%

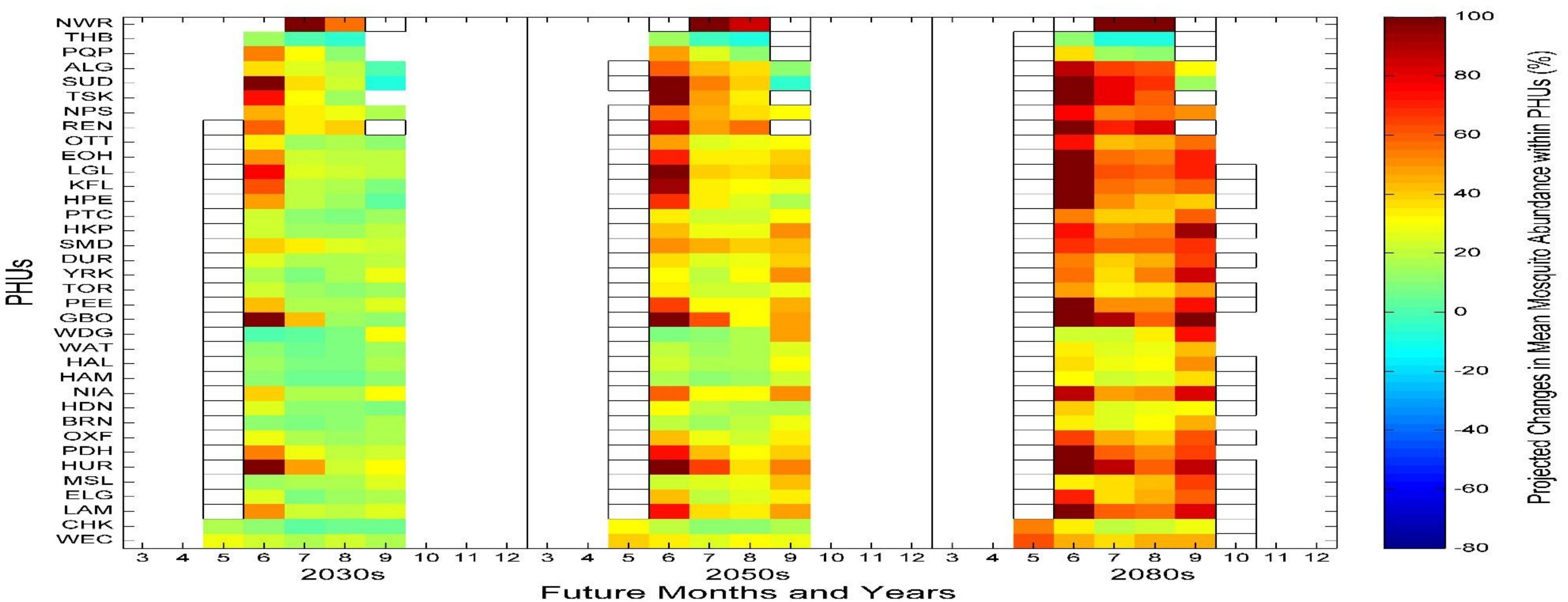
	Normalized Wind Speed
1994 - 2010 downscaled versus measured	100.2%
1980 – 2010 downscaled	100.0%
2011 – 2040 downscaled	97.6%

Projected Extreme Wind Speeds for 2040s increase by ~5%

	Normalized 50-Year Wind Speed
1994 - 2010 downscaled versus measured	95.9%
1980 – 2010 downscaled	100.0%
2011 – 2040 downscaled	104.8%

Projected Mosquito Abundance Changes over Ontario





This Just In: More Confirmed Applications

- **Trent University:** Lake Simcoe Ecosystem
- **University of Guelph:** Best Practice Management in Agriculture
- **Ontario Climate Consortium + York University:** agricultural and rural resilience
- **University of Toronto-Scarborough**
  - ✓ Extreme Cold Weather Alerts (Gough et al. 2014)
  - ✓ Fate of Ontario's Far North Palsas (Tam et al. 2014)
  - ✓ Growing Potatoes in Ontario's Far North
  - ✓ Agricultural Potential of the Great Clay Belt
  - ✓ Ontario Tourism – Provincial Parks & Metro Zoo (Hewer et al. 2014)
  - ✓ Risk to human health in Ontario (Partnership with MHLTC)

.....

Ontario

This Just In: OntarioCCDP Usage Statistics

Since its initial launch in January 2014, Ontario CCDP (as of Nov 26, 2014)

- has received about **15,000** downloading requests
- from over **60** registered users (academia, municipal and provincial agencies, non-government agencies, private sectors)

RWTH Aachen University (Germany)

University of Michigan (USA)

OCCIAR

City of London

QPC Consulting

SENES Consultants

University of Guelph

Dillon Consulting

University of Waterloo

Queen's University

Town of Oakville

York University

Green Analytics

Trent University

University of Toronto

Western University

Great Lakes and St. Lawrence Cities Initiative

YPDT-CAMC

MMM Group

Ontario Climate Consortium

City of Waterloo

Ontario Ministry of Agriculture and Food

Muskoka Watershed Council

Drainage Investment Group

Ministry of Transportation of Ontario

Town of BWG / Municipal Services Board

S.F. Pope Sustainability Consulting

On-going Projects (To be completed by April 2015)

York University	Updating the 45km x 45km Probabilistic Projections over Ontario Through Statistical Downscaling of IPCC AR5 GCM and updated NARCCAP RCM Projections
University of Regina	Updating the 25km x 25km Probabilistic Projections over Ontario by Dynamical Downscaling of IPCC's AR5 GCM Projections using UK PRECIS
York University	Ensemble Dynamic Downscaling Climate Projections over Ontario using the US Weather Research and Forecasting (WRF) Model
University of Toronto - Scarborough	Projecting Climate Change Impacts and Risks to Human Health in Ontario
York University	Projecting Climate Change Impacts on Hydrological Cycles over the Lake Simcoe Watershed
University of Toronto –St. George	Assessing Climate Change Impact on Carbon Cycles in the Ontario's Far North Ecosystems
York University	Assessing Climate Change Impacts on the James Bay Lowlands in the Far North of Ontario
University of Guelph	Assessing Climate Change Impacts on Water Quantity and Quality in an Agricultural Watershed in Southwestern Ontario

THANKS

Comment or Questions?

Email: Jinliang.Liu@Ontario.ca

Ontario

Downscaled Changes[1] in Ontario by 2050s[2]

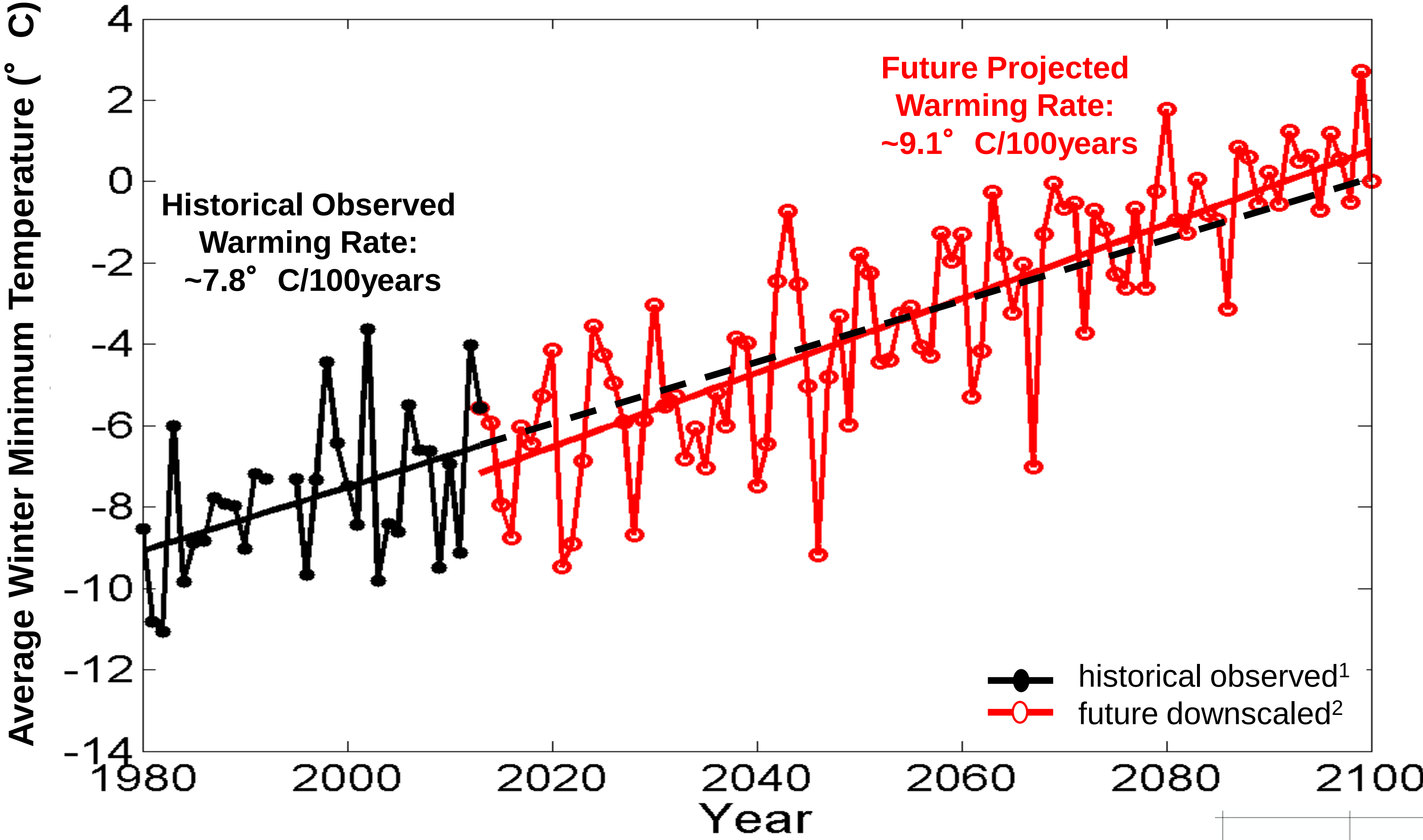
- **Average Climate Indicators**
  - **Temperature very likely to increase significantly**
    - Annual: by ~3.6 [1.3~6.9]° C
    - Winter: by ~5.3 [0.9~11.2]° C
    - Summer: by ~2.4 [-0.6~6.0] ° C
  - **Cooling degree day (CDD)**
    increases by ~177 [6 ~ 459]° C or ~167%
  - **Frost Days**
    decrease by ~31 [-38 ~ 12] days or 19%
  - **Precipitation likely to increase** (low confidence)
    - Annual: by ~11 [-13~34]%
    - Winter: by ~16 [-23~67]%
    - Summer: by ~12 [-37~65]%

- **Extreme Climate Indicators**
  - **Temperature-related**
    - warm-days increase ~59 [10~126] days or 164%
    - warm-nights increase ~70 [23~139] nights or 194%
    - Maximum single heat wave duration increase ~16 [1~50] days or 200%
  - **Precipitation –related** (low confidence)
    - Heavy precipitation days (>10mm/day) increase ~4 [-6~13] days or 17%
    - Very heavy precipitation days (>20mm/day) increase ~2 [-3~6] days or 33%
    - Very wet days (>95 percentile) increase ~2 [-3~8] days or 25%

1 Preliminary results from MOECC funded York University project, under the IPCC AR5 RCP8.5 business as usual projections.
2 2050s is defined as 2041-2070; all changes (except the following one in foot note 3) are calculated as the differences between the 2041-2070 and the averages of the end of last century, 1990s (1981-2010).

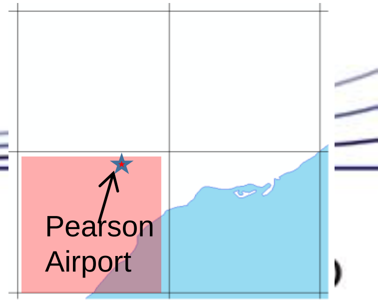
Ontario

Historical Observed and Future Projected Average Winter Minimum Temperature at Toronto Pearson Airport



1 Historical data read off from Dr. Pearson's plot.

2 Preliminary bias-corrected ensemble projection from a MOECC funded York University project, based on IPCC AR5 RCP8.5 business as usual projections. Plotted projections are for the ~32km x 32km grid cell (red shaded) in which the Pearson Airport ( ) is located. Generally, confidence level in 2050s vs 2080s projections is higher due to the relative importance of natural internal variability (i.e. the El Niño–La Niña cycle) and uncertainty in non-greenhouse gas forcing and response.



Climate change vulnerability and adaptation in ecosystems in Ontario

Jenny Gleeson

Senior Climate Change Program Advisor
Ministry of Natural Resources and Forestry

Ontario

Ministry of Natural Resources and Forestry

- MNRF is steward of Ontario’s vast Crown lands and waters, provincial parks, forests, fisheries, wildlife, aggregates and petroleum resources
- Nature is enormously complex
  - *Climate change magnifies those complexities and introduces additional uncertainties to sustainable natural resource management*

MNRF and climate change

Vision

- The Ministry integrates climate action across its mandate, strengthening the management of natural resources to ensure ecological resilience and contributing towards mitigation.

Approach

- Efforts include science and research, policy and implementation, monitoring, partnerships

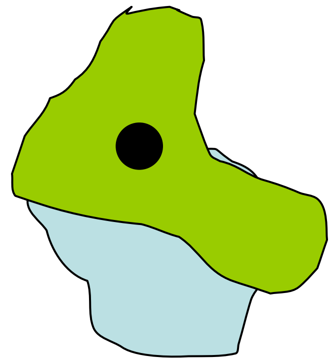
Presentation outline

- Observed and projected impacts on ecosystems and natural resources
- Vulnerability assessment methodologies
- Recent pilots in Ontario
- A view of ecosystem-based adaptation efforts in Ontario
- Great Lakes Basin vulnerability and adaptation project overview (COA)

Organism response to rapid climate change

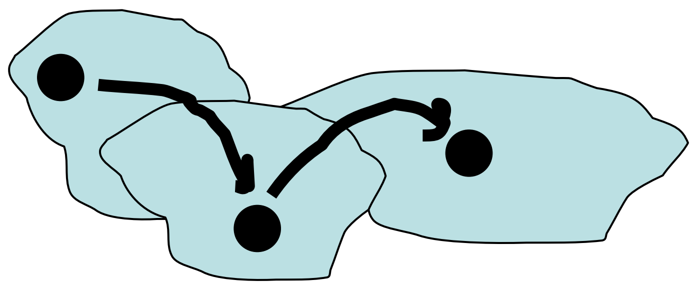
[Adapt, Move, or Die]

Adaptation / micro-evolution



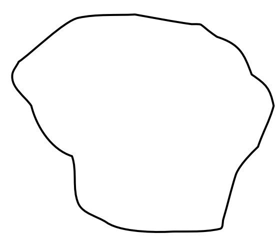
population shift in spawning time

Home range migration



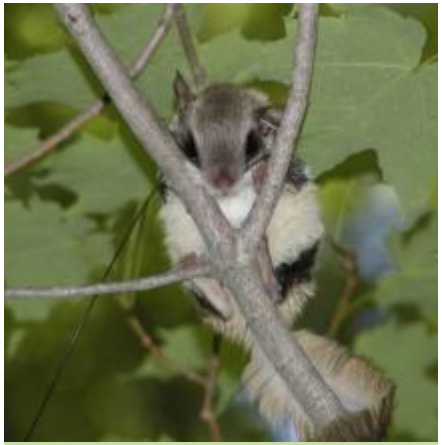
Virginia opossum northward range expansion

Extirpation/extinction



Potential extirpation in Ont due to climate change

Climate change is being observed in Ontario

Orchids

- Expanding north beyond historic range to Lake Superior shores
- High seed dispersal enables migration

Flying squirrels

- Southern species expanding range north; northern range contracting
- New interaction; hybridization

N. leopard frog & American toad

- Emerging and calling up to 37 days earlier

Wood warblers

- Uncoupling of timing with key prey
- Not advancing in breeding and migration

MNRF science

Catling, P.M., and Oldham, M.J. 2011. **Recent expansion of *Spiranthes cernua* (Orchidaceae) into northern Ontario due to climate change?** Canadian Field-Naturalist 125(1): 34–40

Garroway, C., J. Bowman, T. Cascaden, G. Holloway, C. Mahan, J. Malcolm, M. Steele, G. Turner, P. Wilson, 2010. **Climate Change Induced Hybridization in Flying Squirrels**. Global Change Biology. 16(1): 113-121.

Klaus, S. and S. Lougheed. 2013. **Changes in breeding phenology of eastern Ontario frogs over four decades.** Ecology and Evolution.

(4): 835–845.

Nituch, L. and J. Bowman. 2013. **Community-Level Effects of Climate Change on Ontario's Terrestrial Biodiversity.** CCRR-36. Ontario Ministry of Natural Resources.

Climate change is being observed in Ontario

Polar bear

- Hudson Bay ice melting 1 week / decade earlier
- Less sea ice makes seals available for shorter period

Boreal forest health

- Freezing damage due to spring temp. variability
- Bud damage affecting boreal species' survival and growth

Fish range shifts

- Fish shifted north by 12-17km /decade in last 30 years
- Coldwater species (e.g. brook trout, lk trout, walleye) most vulnerable

Less ice cover

- 40% decline in area of Lake Ontario covered in ice annually since 1970
- Earlier break-up, later freeze-up

MNRF science

Peacock, E., A.E. Derocher, N. Lunn and M.E. Obbard. 2010. **Polar Bear Ecology and Management in Hudson Bay in the Face of Climate Change.** Springer-Verlag, Berlin, Germany.

Man, R., G. Kayahara, S. Foley and C. Wiseman. 2013. **Survival and growth of eastern larch, balsam fir, and black spruce six years after winter browning in northeastern Ontario.** Forestry Chronicle 89(6): 777-782.

Alofs, K., D. Jackson and N. Lester. 2013. **Ontario freshwater fishes demonstrate differing range-boundary shifts in a warming climate.** Diversity and Distributions. 1–14.

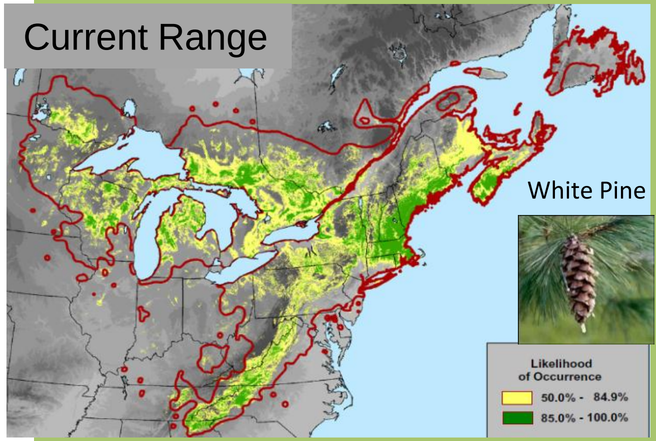
Ontario Biodiversity Council. 2010. **State of Ontario's Biodiversity 2010: A Report of the Ontario Biodiversity Council.** Peterborough, ON.

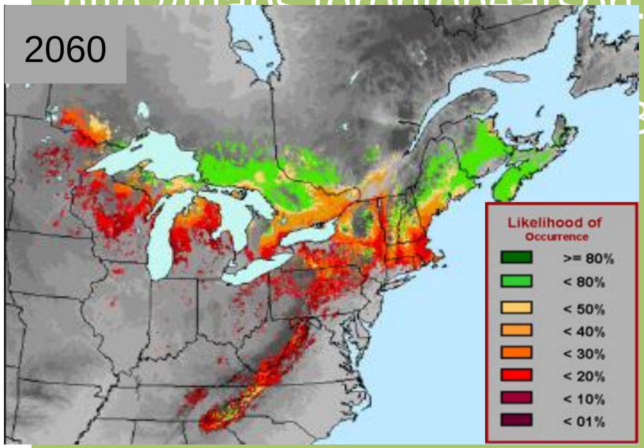
Shifting climatic conditions affecting biodiversity

- Climatic conditions drive ecosystem assembly and function.
  - Common pattern of shifting northward and dissipating
  - Affect amount of suitable habitat for plant and animal species, affecting biodiversity in unique and novel ways.

Forests in Ontario in 2050

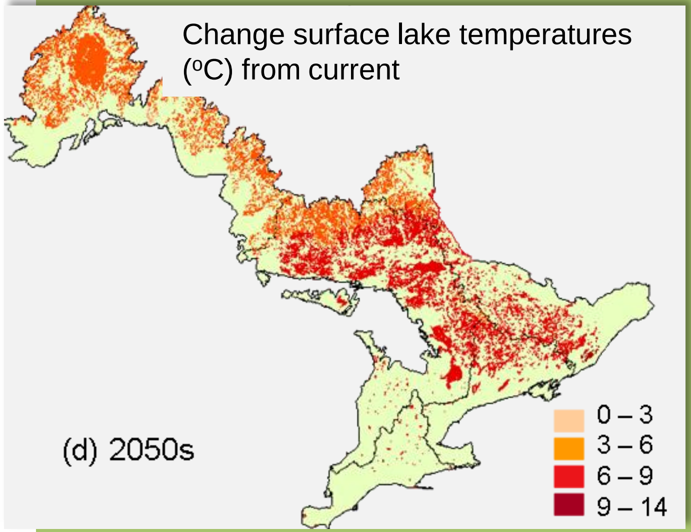
- Ontario's provincial tree (White Pine) is projected to experience widespread rapid recession
  - Entire southern ½ of current range at risk of extirpation.
  - High risk to populations in southern and eastern Ontario.
  - Some expansion of suitable habitat to the north and east of Great Lakes is projected.
- Productivity and composition of northeastern Clay Belt forests highly vulnerable to climate change
  - 80% tree productivity declines in Black Spruce; 40% in Jack Pine.
  - Changing forest composition with 100% increase in suitable climatic habitat for Great Lakes species such as Red Pine and Sugar Maple.
  - Significant decline of climatic habitat for Boreal species including 100% decline for Black Spruce and ~30% decline in Balsam Fir, Jack Pine.

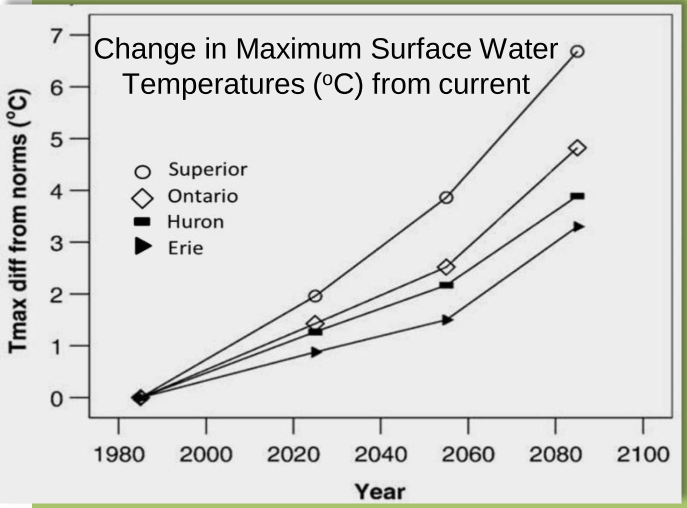




Fisheries & Aquatic Habitat in Ontario in 2050

- Commercial and recreational fish habitat will be altered as stream and lake temperatures warm
  - Across Ontario, the distribution of fish species (with different thermal preferences) will experience:
    - 49% decrease in Brook Trout (coldwater) habitat
    - 63% decrease in Artic Char (coldwater) habitat
    - 54% increase in Walleye (coolwater) habitat
    - 79% increase in Smallmouth Bass (warmwater) habitat
  - Water temperatures in the Great Lakes Basin will warm significantly:
    - Streams will increase 1.4 - 2.4 °C, decreasing coldwater habitat.
    - In-land lakes surface temperatures will increase by 3 - 6 °C.
  - Great Lakes surface water temperatures will warm significantly
    - Lake Huron: +2.2 °C with 37 more days above 4 °C
    - Lake Erie: + 1.5 °C with 36 more days above 4 °C
    - Lake Ontario: + 2.5 °C with 44 more days above 4 °C
    - Lake Superior: + 3.9°C with 52 more days above 4 °C

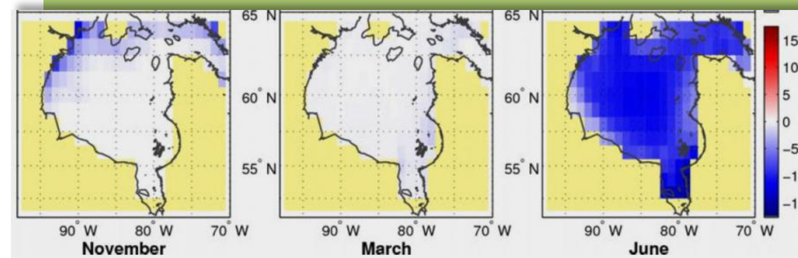




Far North in Ontario in 2050

- Reduction of the extent and duration of Hudson Bay sea ice
  - Will form later in the fall by ~ one month and melt earlier in spring by two months by 2050
  - Less ice make seals less available to polar bears
- Decrease in permafrost extent
  - Significant unknowns, requires further research
  - Will alter hydrology, vegetation composition, peatland carbon storage
- Changes to globally important peatland complex and unique 'two gas' role

% change in Hudson Bay sea ice in 2050



Movement of collared polar bears on ice

A vulnerability assessment approach

Vulnerability assessments

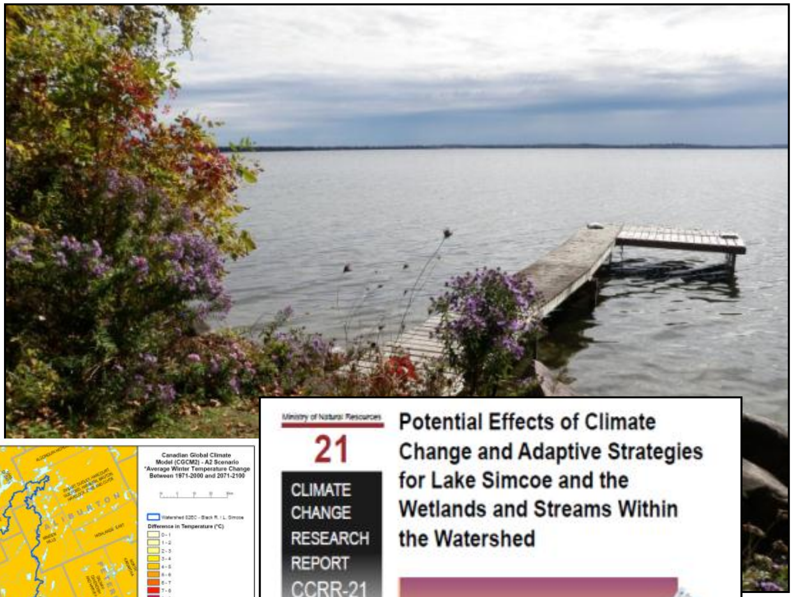
- Science-based activities (research, modeling, monitoring etc.); often multi-disciplinary
- Identify or evaluate the degree to which natural resources or other values are likely to be affected by climate change

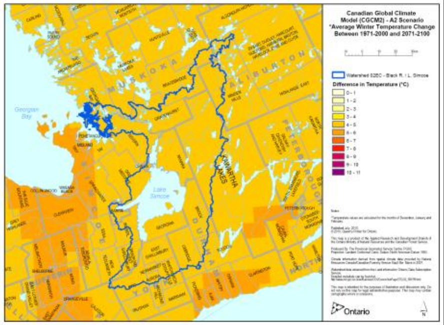
About guide

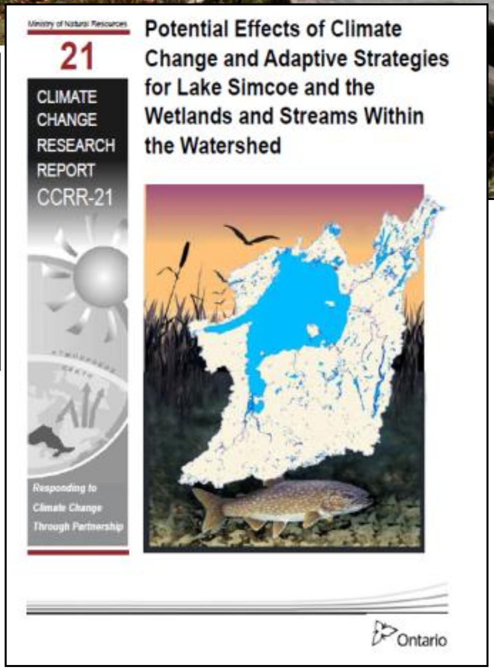
- Developed by MNRF and Ontario Centre for Climate Impacts and Adaptation Resources
- First Ontario-relevant resource available
- Being used by Conservation Authorities, municipalities, MNRF
- Interest in updating (V.2)

Lake Simcoe adaptation planning

- Lake Simcoe Protection Plan called for a watershed Adaptation Plan
- In 2011, MNRF and MOECC led a vulnerability assessment process to inform adaptation plan:
  - Wildlife
  - Hydrology
  - Aquatic habitat and wetlands
  - Forest cover
  - Parks and nature-based tourism
  - Species-at-risk etc.
- Vulnerability assessment results used to select adaptation options for Plan

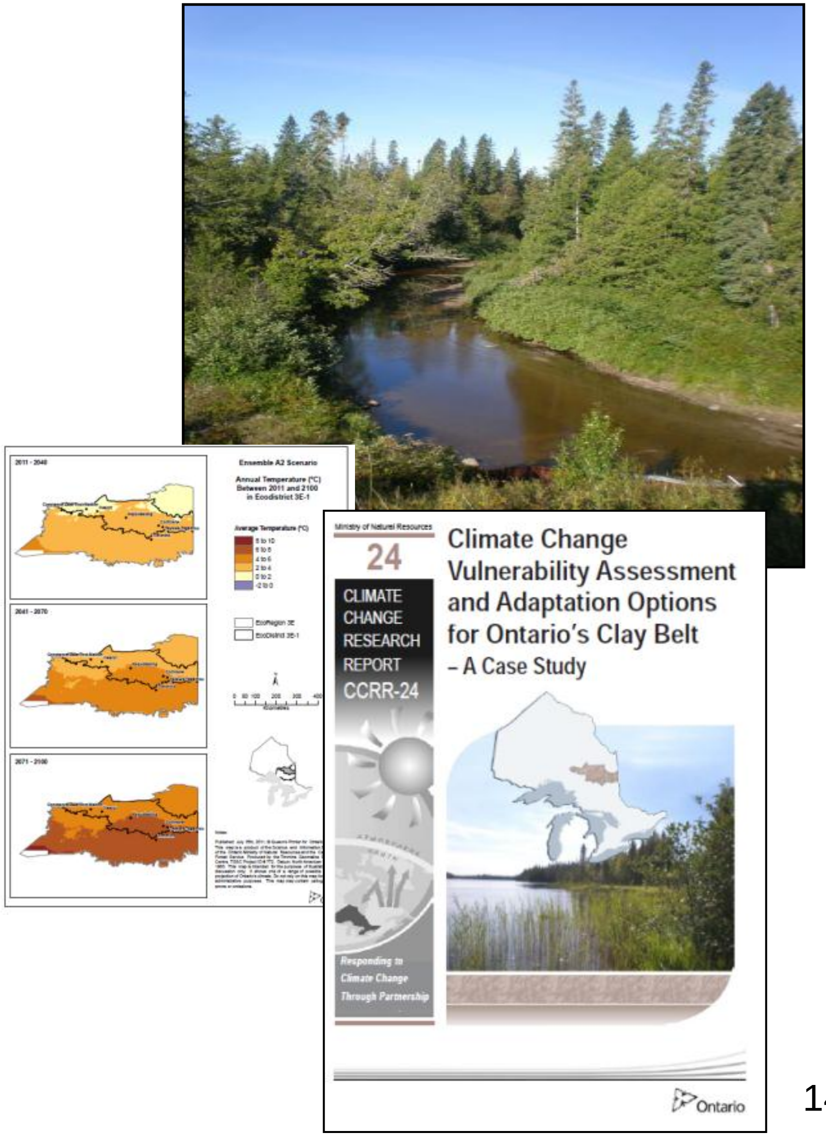




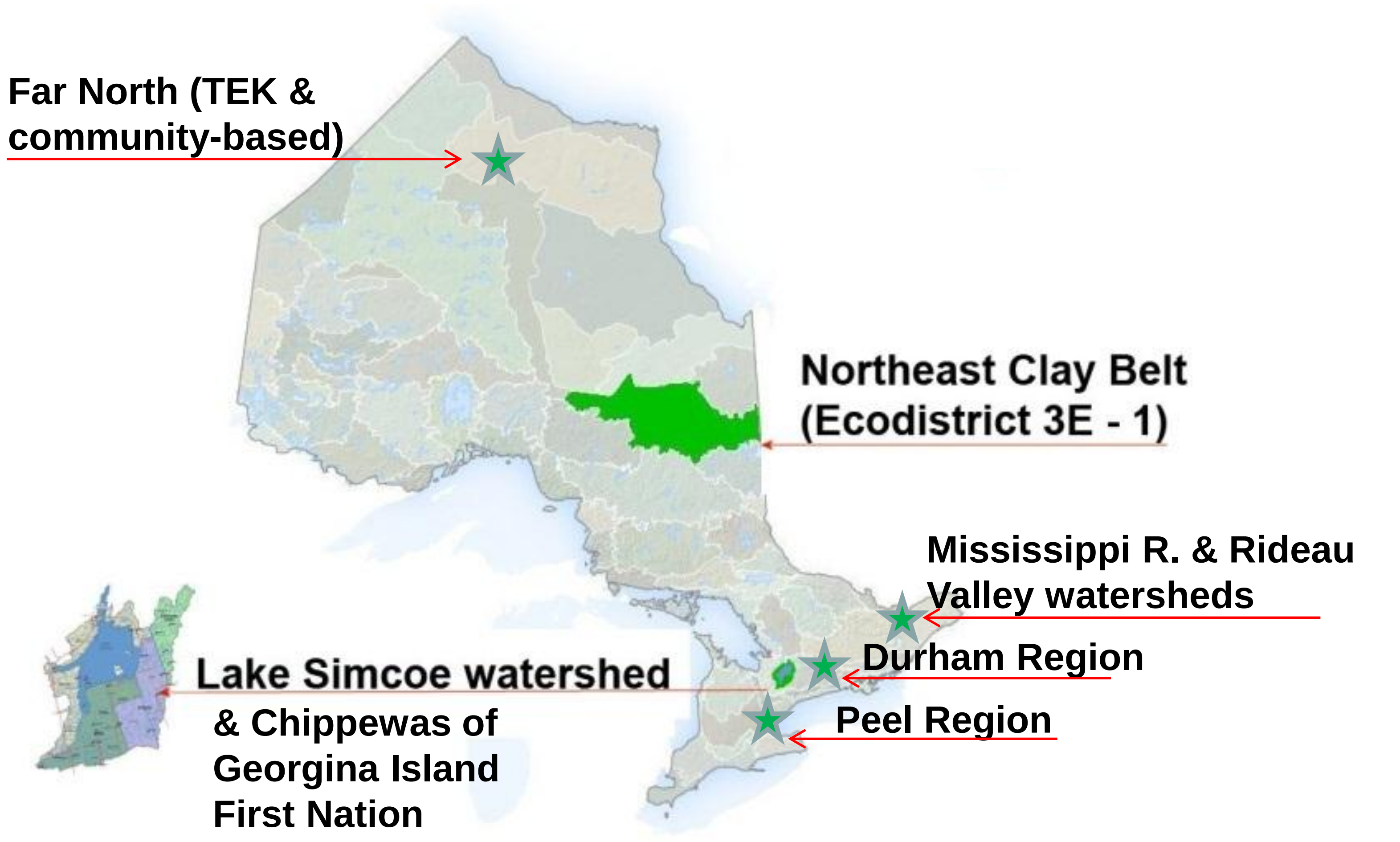


Northeast Clay Belt adaptation planning

- In 2012, MNRF applied same methodology
- Broadened out vulnerability assessment approach to include additional forest-related themes:
  - Forest fire
  - Forest blowdown
  - Forest composition and productivity
  - Ungulates
- Currently integrate results into Forest Management Planning
  - Hearst Forest Management Planning initiating next 10 year plan

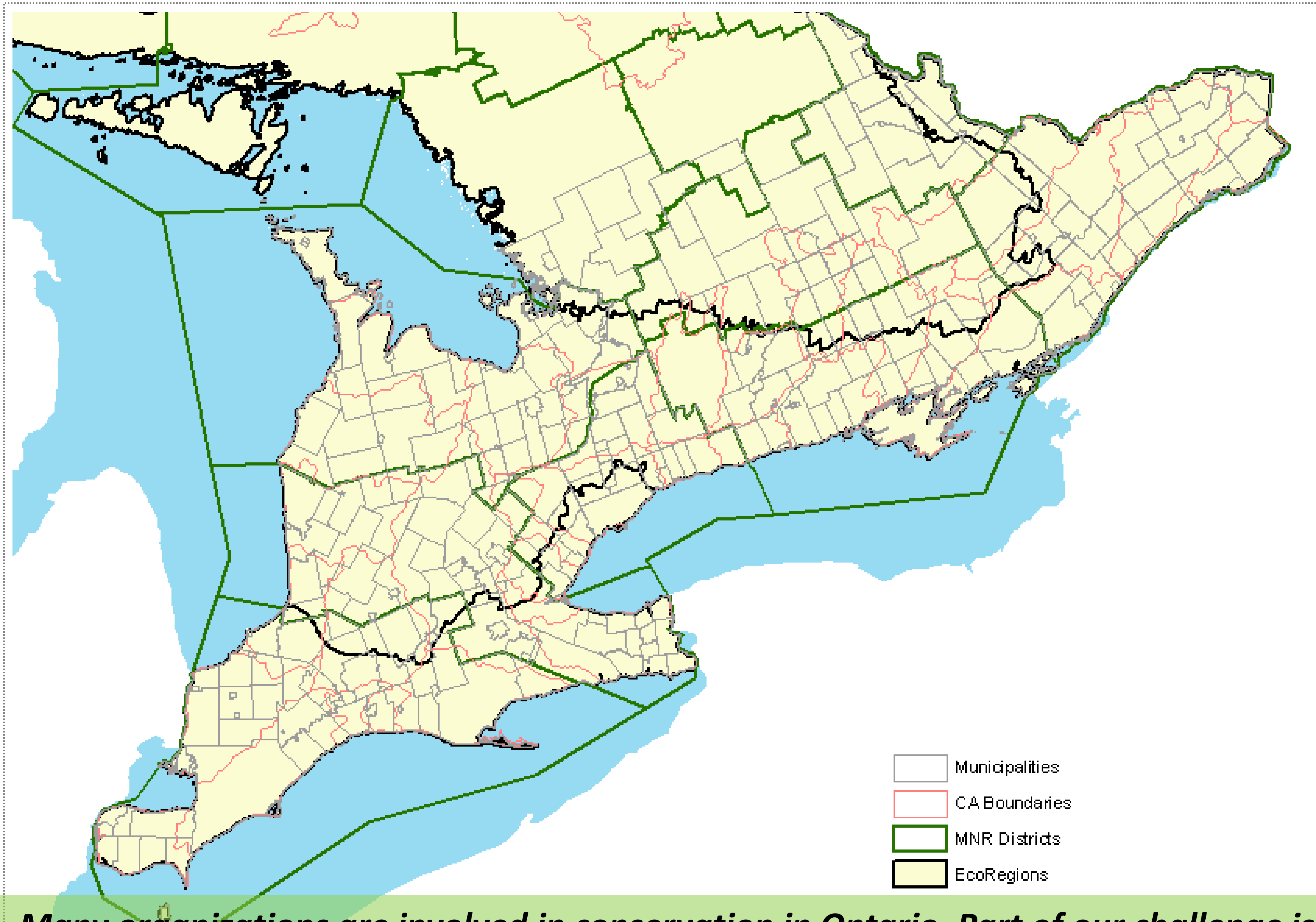


A view of ecosystem-based adaptation planning efforts in Ontario



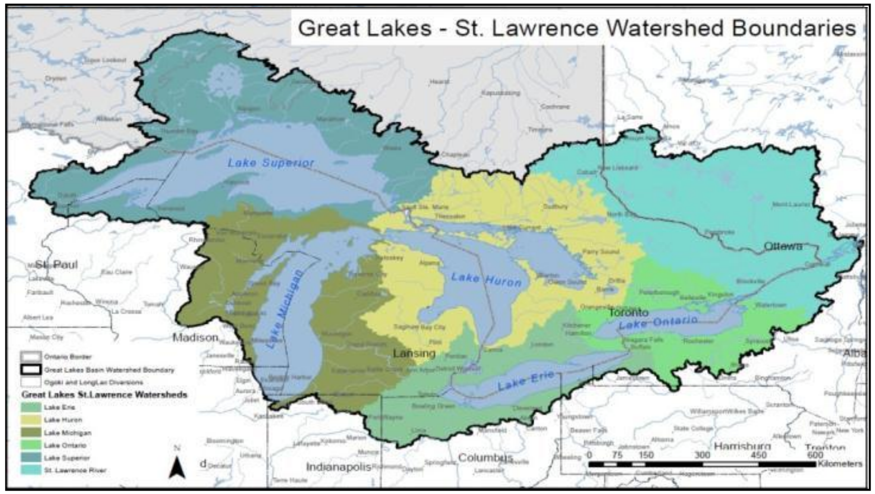
SCALE

COLLABORATION



Many organizations are involved in conservation in Ontario. Part of our challenge is to efficiently and effectively develop climate vulnerability information that is meaningful to a variety of jurisdictions and audiences.

Great Lakes Basin Vulnerability and Adaptation



MNR COA climate change commitments:

- Provide support for regional adaptive management initiatives and pilot projects
- Share climate change impact data and information with Great Lakes organizations and communities
- Communication ongoing developments in science
- Implement adaptation actions important to communities

State of Climate Change Science in the Great Lakes Basin

- Collaboration with Environment Canada and Ontario Climate Consortium
  - Explores use and outputs of climate modelling and research in the past 10 years
  - Identifies state of knowledge, knowledge gaps
- Physical and chemical effects
  - Temperature (Air and Water), Precipitation, Water Levels, Ice Dynamics, Groundwater, Extreme Events (Flooding, Drought, Wind, Ice Storms, Fire)
  - Acidity (pH), Oxygen, Phosphorus, Nitrogen, Mercury
- Aquatic and terrestrial biodiversity effects
  - Species Ranges and Ecosystem Shifts, Genetics Changes, Altered Phenology and Asynchrony, Habitat Loss and Fragmentation, Parasites and Pathogens, Invasive Species

	Theme	General projections	Trend	Data confidence
Physical Effects	Air temperature	• 1.5-7°C increase by the 2080s depending on climate scenario and model used. • Greater increases in the winter. • Increased frost-free period and growing season	↑	●
	Water temperature	• 0.9-6.7°C increase in surface water temperature by the 2080s. • 42-90 day increase in ice free season. • Increased period of stratification.	↑	●
	Precipitation	• 20% increase in annual precipitation across the Great Lakes Basin by 2080s under the highest emission scenario. • Increases in rainfall, decreases in snowfall. • Increased spring precipitation, decreased summer precipitation. • More frequent extreme rain events.	↑	●
	Water levels	• Water levels in the Great Lakes naturally fluctuate by up to 1.5m. • Long-term water levels in the Great Lakes peaked in the 1980s and have been decreasing since. • Projections of future lake water levels vary; however, they generally suggest fluctuations around lower mean water levels. • Lower water levels are due to a several factors including warmer air temperatures, increased evaporation and evapotranspiration, drought, and changes in precipitation patterns.	↑	◐
	Ice dynamics	• Projected decreases in ice cover duration, ice thickness, and ice extent. • Increased mid-winter thaws, changing river ice dynamics.	↓	●
	Groundwater	• Recharge rates will be greatest in the winter.		○

State of Climate Change Science in the Great Lakes Basin

- Captures research in a time stamped state of knowledge
- Integrates input from subject matter experts at Nov 25-26th symposium
- Will help to inform strategic investments in science

Water levels synthesis table

SOURCE	LOCATION	MEASURE	CLIMATE MODEL	SCENARIO										PROJECTED TREND		
				A2	A1Fi	A1B	B1	B2	$1xCO_2$	$2xCO_2$	$3xCO_2$	IS92a	IPCC	2020s	2050s	2080s
Angel and Kunkel 2010	Great Lakes	Water level (m)	AHPS	✓										decrease 0.05 to 0.1	decrease 0.07 to 0.2	decrease 0.12 to 0.41
Hayhoe et al. 2010	Great Lakes	Water level (m)	AHPS		✓									decrease 0.045 to 0.8	decrease 0.24 to 0.52	decrease 0.22 to 0.57
Lofgren et al. 2002	Great Lakes	Annual mean water level (m)	CGCM1							✓				increase 0.22 to 0.72	increase 0.31 to 1.01	increase 1.38 to 3.92
			HadCM2							✓				increase -0.01 to 0.05	increase -0.01 to 0.04	increase 0.01 to 0.35
MacKay and Seglenieks 2013	Great Lakes	Water level (m)	GLRCM	✓										decrease 0.3 to 0.6		
Moulton and Cuthbert 2000	Great Lakes Basin	Water level (m)	EC-GCM											decrease 0.4 to 1.2	decrease 0.45 to 1.5	

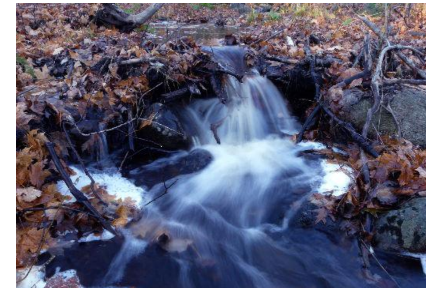
Great Lakes Basin Vulnerability and Adaptation

- **Purpose:** To provide integrated, state-of-the-art climate change science, information and outreach services to natural resource users and communities in the Great Lakes Basin in a strategic, collaborative and cost-effective way, enabling them to prepare for, cope with, and respond to the impacts of climate change.
- **Timeline:** 2014-2018 project planning horizon (current COA agreement)
- **Approach:** Vulnerability assessment methodology applied to basin-wide and lake drainage level research using common data sets where possible.

Great Lakes Basin Vulnerability and Adaptation

- Stream 1: Climate Change Vulnerability Assessments:
  - ✓ Aquatic habitat (Chu)
  - ✓ Aquatic invasive species (Johnson & Hunt)
  - ✓ Water balances (Metcalfe)
  - ✓ Forests (Parker and Lu)
  - ✓ Migratory and resident forest birds (Rempel)
  - ✓ Furbearers and landscape connectivity (Bowman)
  - ✓ Landscape connectivity (Bowman)
  - ✓ Biodiversity rapid assessment (Brinker)

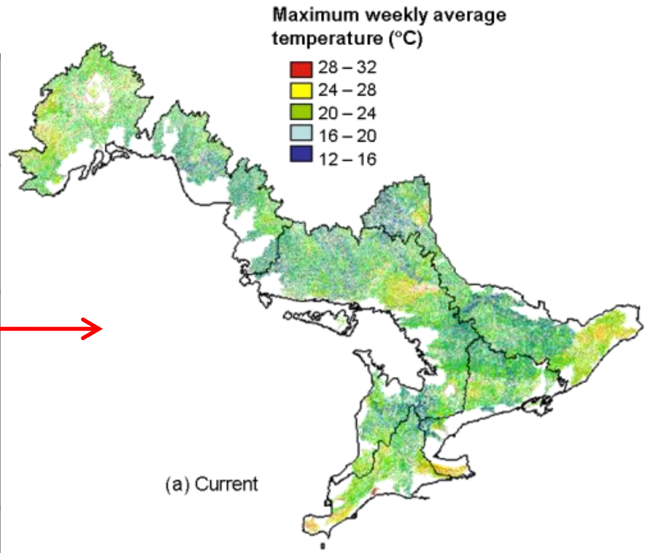
- Prioritization exercise for future themes to support

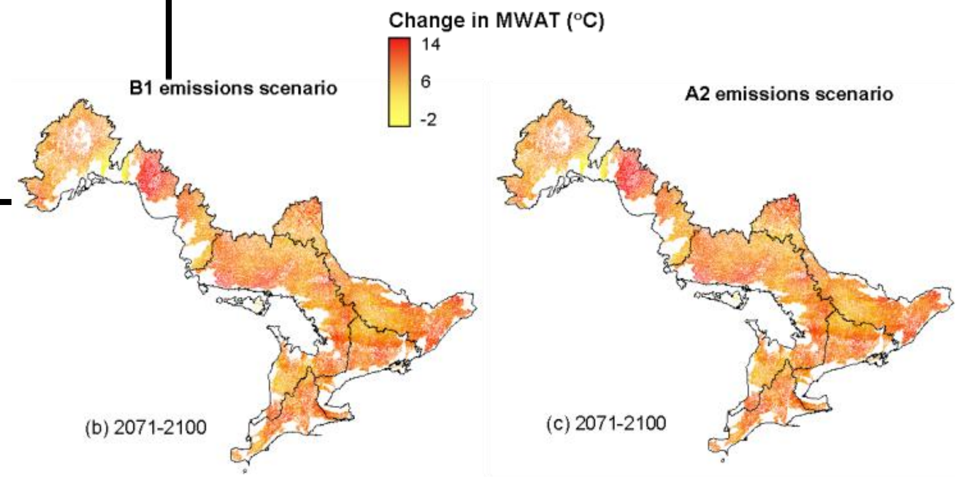


Research output example:

Aquatic Ecosystem Vulnerability Assessment

Aquatic Habitat	Climate Change Vulnerability Indicators
Wetlands	1. Wetland vulnerability (change in wetland extent) 2. Wetland-dependent bird species distributions
Streams	1. Maximum weekly stream temperatures 2. Indicator fish species thermal habitat availability 3. Quaternary watershed suitability for coldwater species
Lakes	1. Lake temperatures 2. Cold/cool/warm habitat 3. Walleye production 4. Smallmouth bass presence/absence based on surface water temperatures



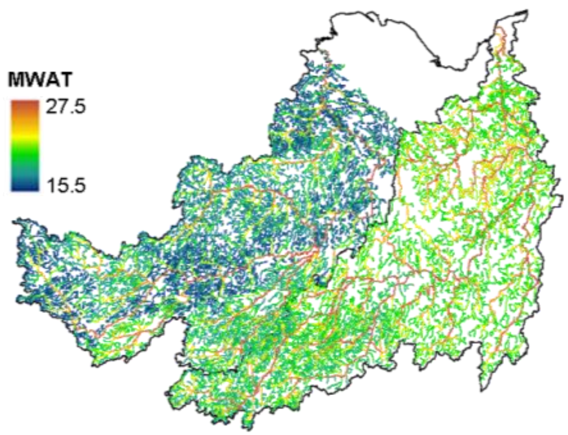


Source: Chu, C. In Press. Climate Change Vulnerability Assessment for Aquatic Ecosystems in the Great Lakes Basin

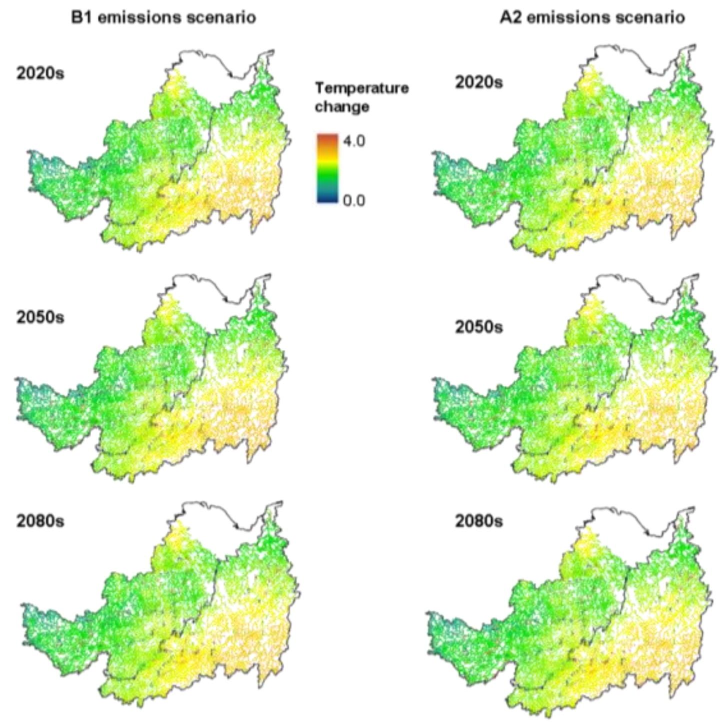
Potential to localize results for other practitioners

Where possible, build partnerships with local initiatives to feed in local data to inform & validate model and research

Example – local results for Mississippi River & Rideau Valley CAs



MWAT= Maximum Weekly Stream Temperature (oC)

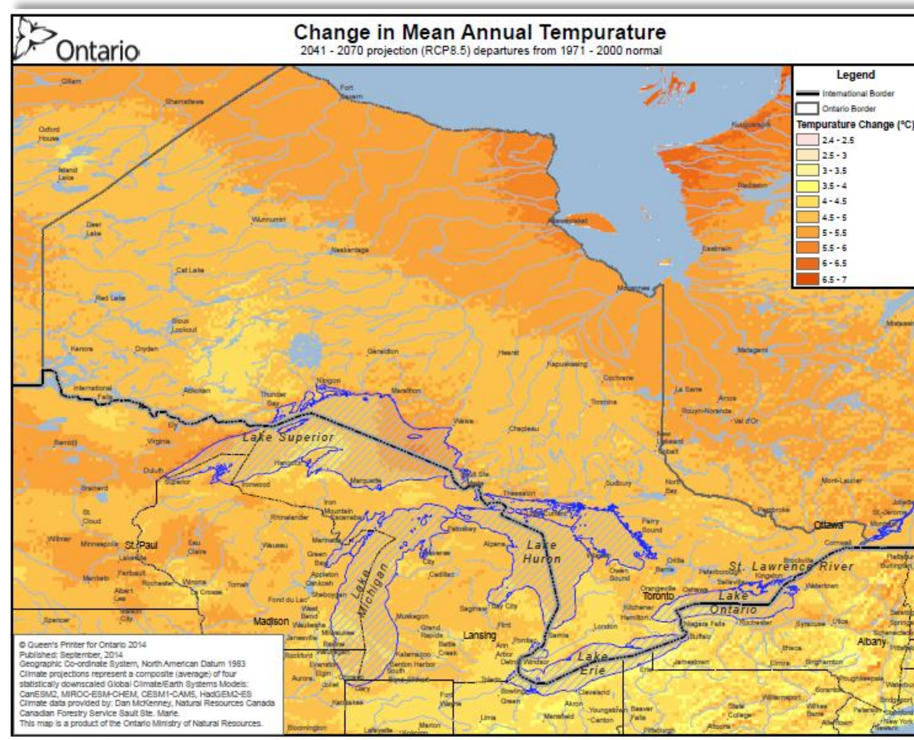


Source: Chu, C. In Press. Climate Change Vulnerability Assessment for Aquatic Ecosystems in the Great Lakes Basin

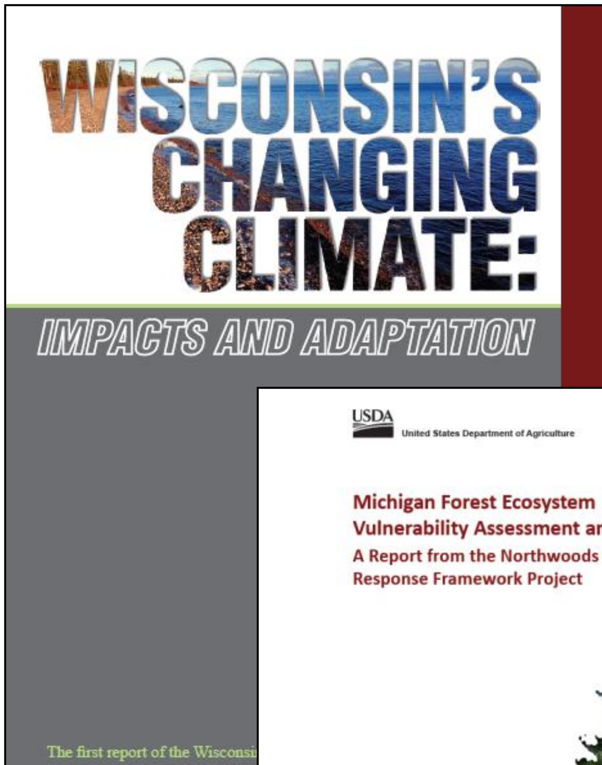
Great Lakes Basin Vulnerability and Adaptation

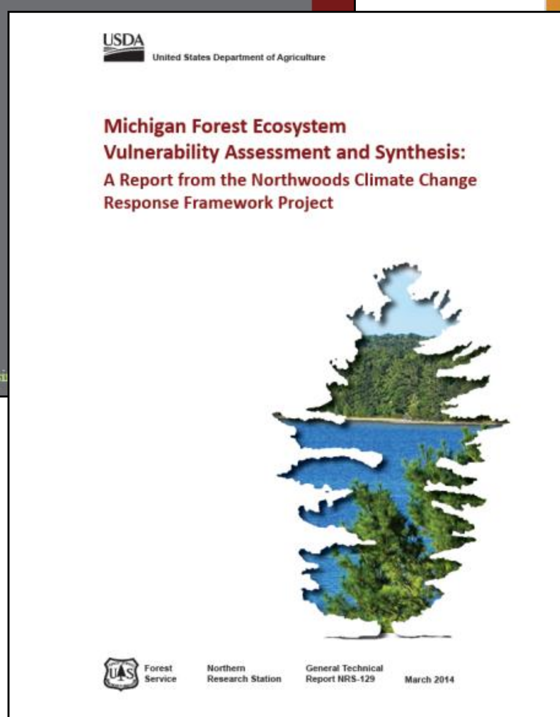
- Stream 2: Climate modeling
  - ✓ Removing significant barrier to public engagement by making climate science accessible to professional and lay audiences.
  - ✓ Climate modeling products (maps, accessible databases, Q&As)

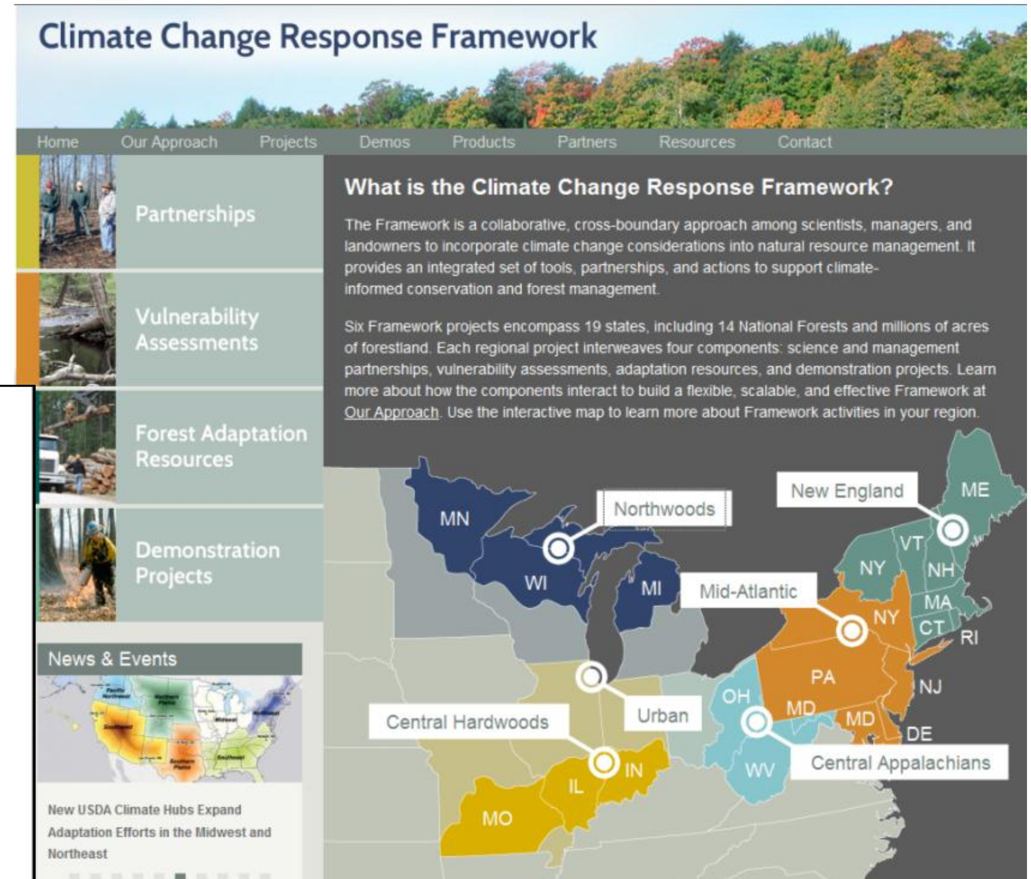
- Stream 3: Adaptation Planning
  - ✓ Working with partner organizations, resource users and communities to use vulnerability assessment information in adaptation planning efforts



Examples of integrated climate vulnerability results as platform for adaptation planning







Thanks!

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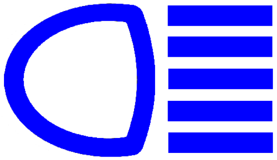
Climate Change Vulnerability and Adaptation in Agriculture Sector in Ontario

Presentation to: Best in Science Symposium
Climate Change Modelling and Impact Assessment
November 28, 2014

Alex Rosenberg
Ontario Ministry of Agriculture, Food and Rural Affairs

Content

- Setting the context- **“Realize”**:
  - Food: A unique class of commodity
  - Confluence of global stressors
  - Relevance of Ontario’s agri-food sector
- Broad implications to agriculture of a changing climate
- Selected examples of assessment and adaptive management work



Food: A Unique Class of Commodity

Unprecedented Confluence of Global Stressors

Climate Change
- Global weather events impacting food production system
- GHG emissions rise

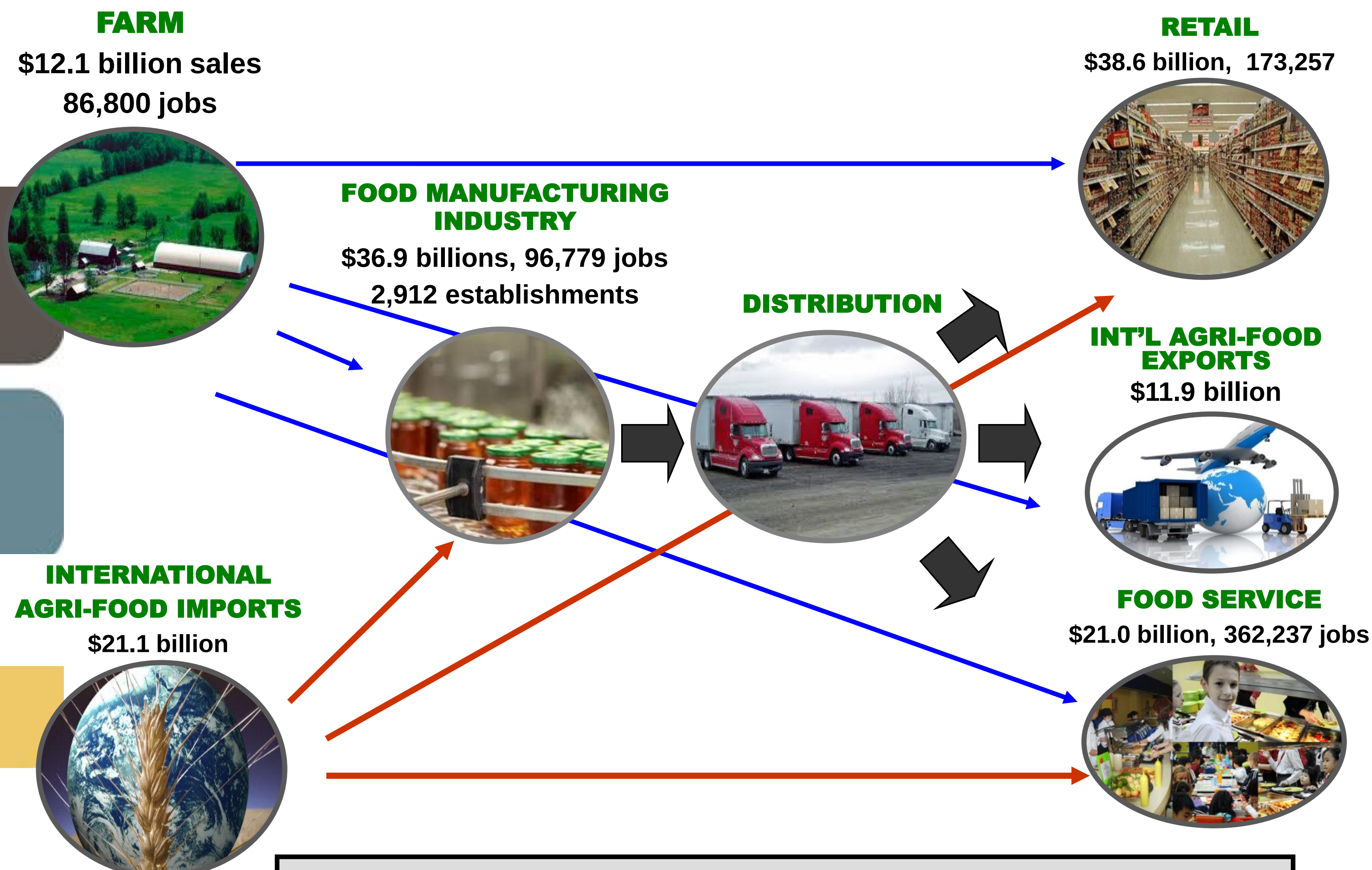
World Population Growth
- Increased demand for food
- New wealth generating new demand

Market and Consumer Demands
- Environmentally and socially responsible production practices

Resources Scarcity
- Soil health/ Water availability
- Peak phosphorus

Finite Land Base
- Pressure to feed an increasing global population
- Competing development pressures

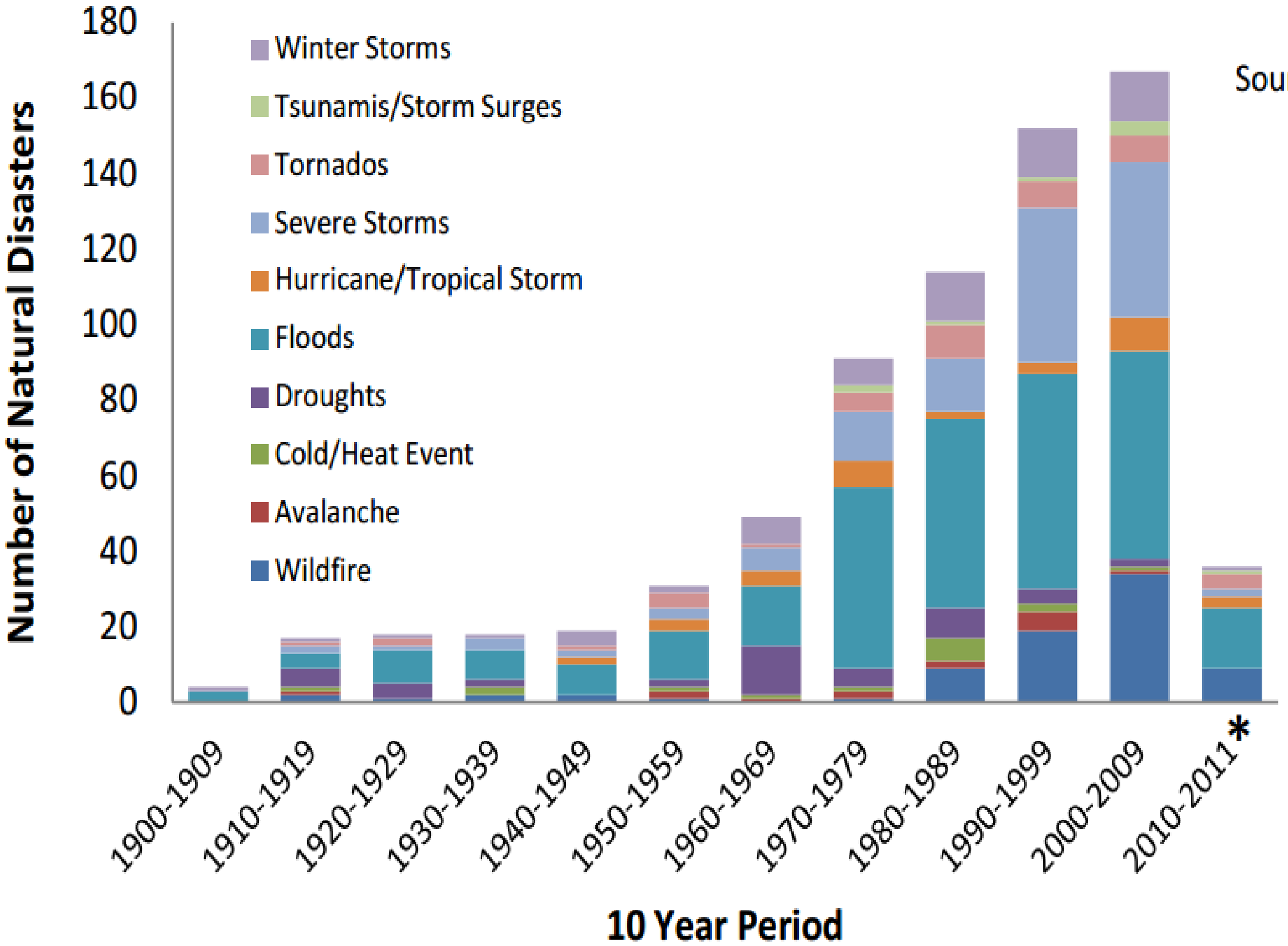
Ontario's Agri-Food Industry



- **Total jobs – 767,473, 11% of provincial employment**

Source: OMAFRA statistics 2013; [a] Food manufacturing revenue as of 2012

Intensity, Duration and Frequency of Weather Events Are Increasing



Source: Public Safety Canada (2012)

* Note: The final bar in the graph only covers the first two years of the decade.

Figure 1: Frequency of Natural Disasters in Canada (1900-2011).

With Greater Risks Come Higher Costs

In Aggregate, Economic Losses Cost

$ Billions

Spring Frost/Dry Summer

2012. Fruit trees crop losses estimated at $115 M
Forage production drop triggered $45 M in BRM payments

Tornadoes/Severe wind

2009. Vaughan and Grey County : $76 M in insured losses

2010. Leamington: $120 M

2011. Goderich: $110 M

Ice Storm

1998. Ontario/Quebec: $5 B in damages; over $1.6 B in insurance claims (CBC); settlements still ongoing: Sep 2013 $40M in QC

2013. Toronto $106 M

Flooding/ Thunderstorm

Water damage is now #1 source of household claims in ON

2005. Finch Avenue washed out: $500M in damages
2013. Toronto: $850 M –prelim. estimate of insured property damage

Climate Change Will Test Our Resilience and Open Opportunities

Climate trends will accentuate

- Milder winters
- More rain, less snow in winter
- More days above 30 degrees
- Increase in Heat Units
- Changes in freeze/thaw cycles
- Longer frost free period
- Increased volatility of severe weather events (intensity, frequency and duration)

Net impact is uncertain

- Complex interactions both positive and negative
- Ability to adapt is uneven:
  - by region
  - by sector

OMAFRA: Climate Change Research

- OMAFRA has extensive research programs that directly and indirectly address climate change

- Research to assess risk , vulnerability, and opportunity
  - E.g.; water availability, water quality impacts, invasive species, impact on crop yield, pest risk assessment, rural emergency preparedness and management capacity

- Enhanced approaches to build resilience and adaptability through:
  - better information- E.g., examining model capability; assessment of risk, vulnerability and resiliency

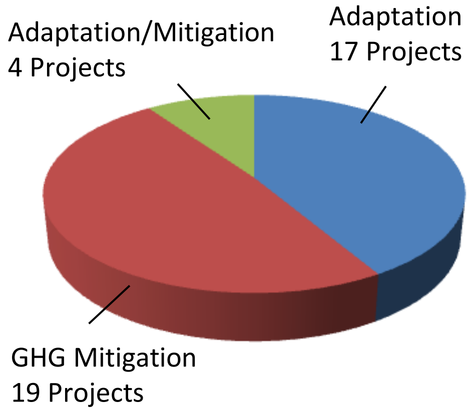
  - tools and practices for adaptation- E.g.; drought tolerant crops, irrigation efficiency, cover crops, tools to measure heat stress in animals and monitor pest

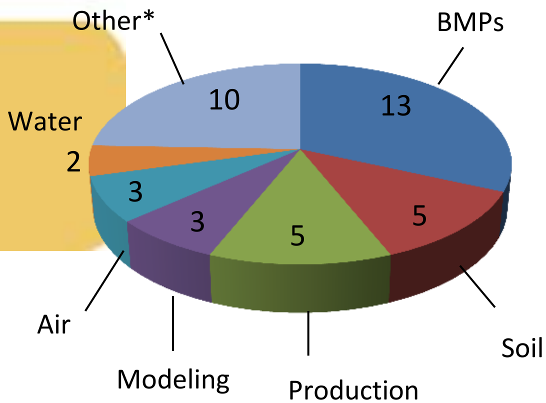
OMAFRA: Climate Change Research

Funding Overview (Since 2009)

- 41 projects
- $4.8M invested

Project Distribution





** Other = Energy, policy, economics, bioeconomy*

Research areas (selected example):

New Directions research program:

2013/14 call: Focus on research priorities that would inform policy and program development

Funded projects underway:

- "A coupled climate-groundwater-surface water modelling approach to assess agri-food sector sustainability in the Grand River watershed under future climate change"
- "Scenario-based risk assessment decision support modelling tools for regional climate change and climate extremes, impacts and adaptation in agricultural watersheds"
- "Identifying regions suitable for specialty crops by statistical analysis of climate and yield data"

Selected Examples

- Soil Erosion control: Application of Intensity-Duration and Frequency (IDF) curves
- Rural stormwater management: Lake Huron
- Agricultural Irrigation: Forecasts for Future Water Needs in the Grand River Watershed
- Grape and Wine Industry: building adaptive capacity

Case Study: Application of Intensity-Duration-Frequency (IDF) Data to Agriculture

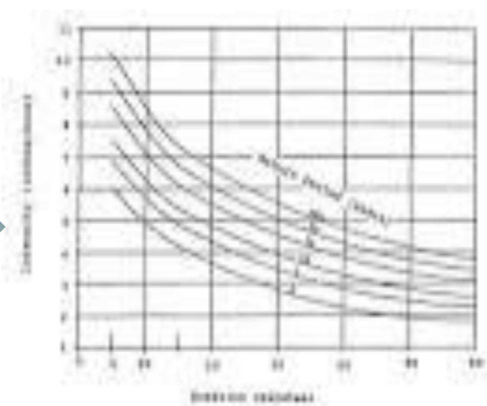
Climate Modelling
Acquire projections of future climate conditions

Climate Impacts
Translate into potential impacts at local/regional scale

Vulnerability Assessments
Assess specific vulnerabilities and risks

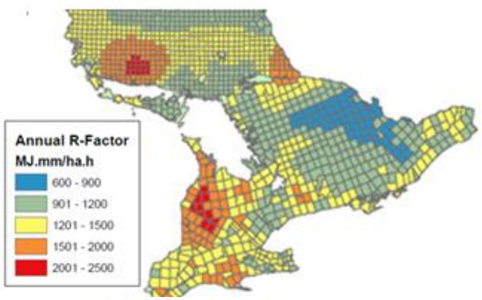
Adaptation Actions
Identify risk management strategies and adaptation actions

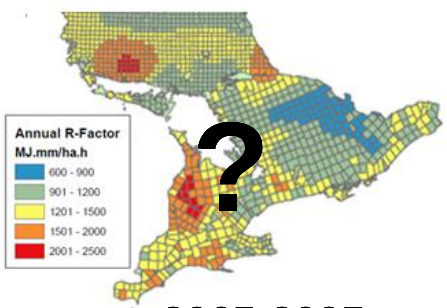
Precipitation projections are used to estimate IDF curves



IDF data is key input to calculate and map local values for rainfall erosivity ("R") factor

R-factor 1951-2005





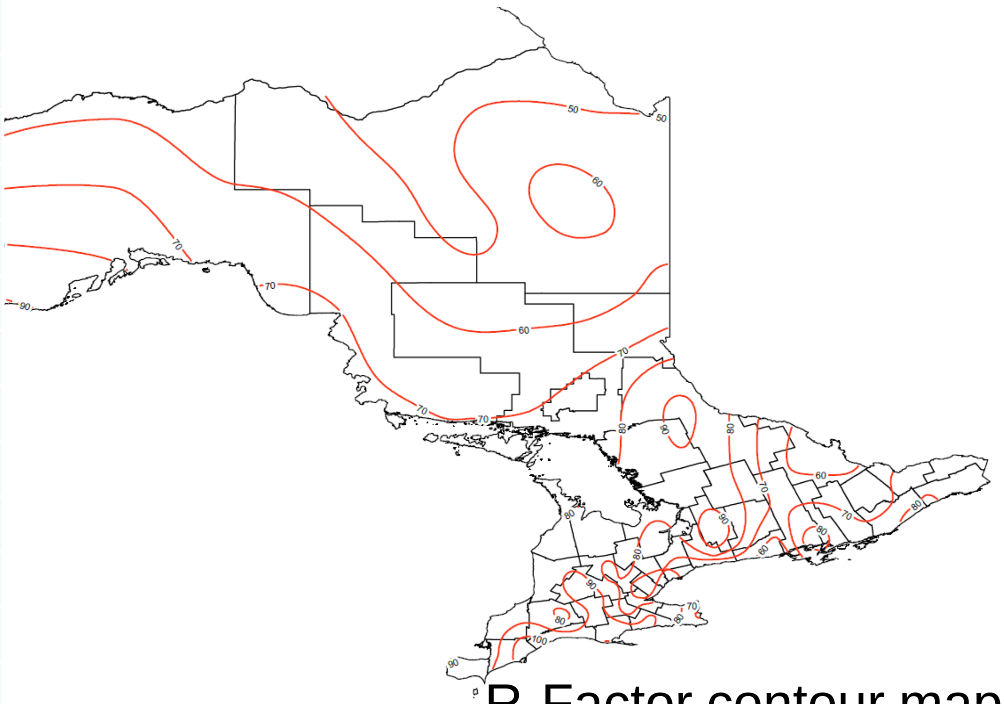
2065-2095

RUSLE2 is Climate Ready but ….

Projected Climate Input for RUSLE2 - London Grid (43.0685 lat, 278.8143 long) Period 2065 - 2095 (20% percentile)			
Month	Ave Temp.	Monthly Precipitation	Monthly R
	°C	mm	MJ mm ha^{-1} hr^{-1}
January	-0.75	79.0	?
February	0.81	89.0	?
March	4.72	101.0	?
April	10.44	110.0	?
May	15.97	103.0	?
June	21.33	48.0	?
July	25.36	43.0	?
August	25.31	47.0	?
September	20.70	54.0	?
October	13.34	73.0	?
November	6.14	99.0	?
December	1.16	80.0	?
Annual	12.04	926.0	1797

Additional future projections needed to estimate Monthly R values

- 2 year, 6 hour storm amount by month (IDF)
- Precipitation amount as rain vs snow ;
- Days Max T <=0, Days Max T >0
- Days with rain; Days with snow;
- Mean melt runoff volume (mm/month)

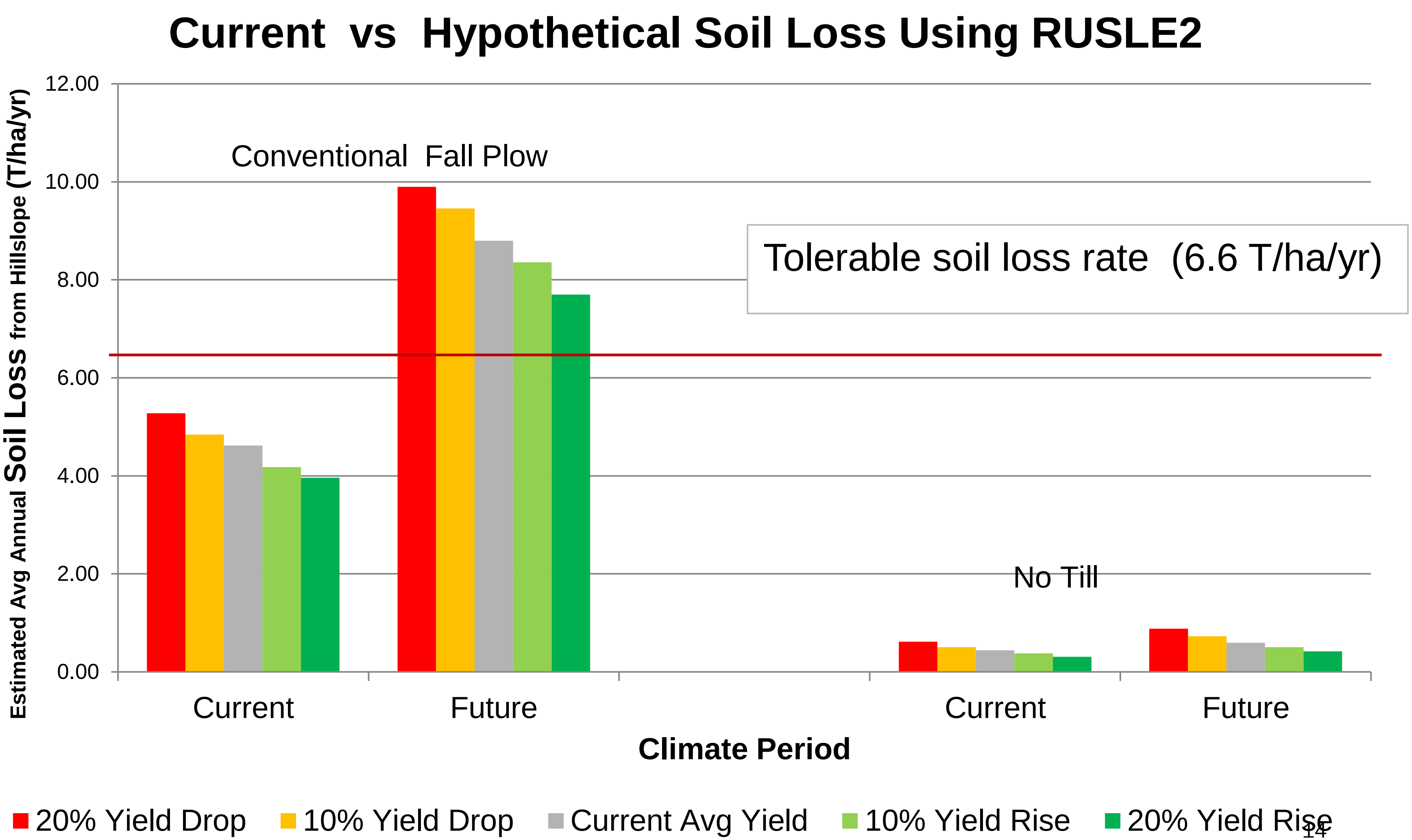


R-Factor contour map

RUSLE2 in Action

Example using **re-created** future monthly R values

- Corn-soybean-winter wheat rotation on Bryanston silt loam and 3% hillslope

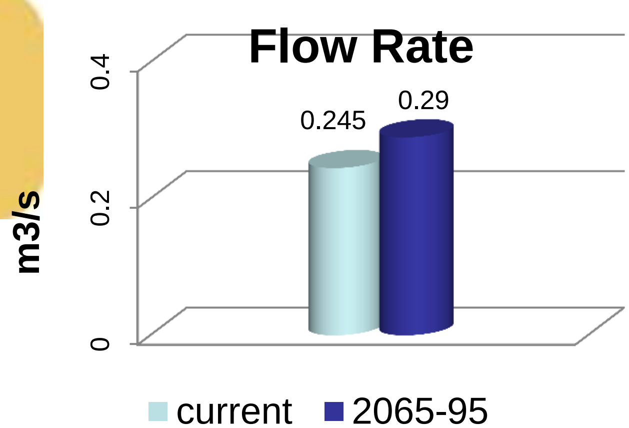


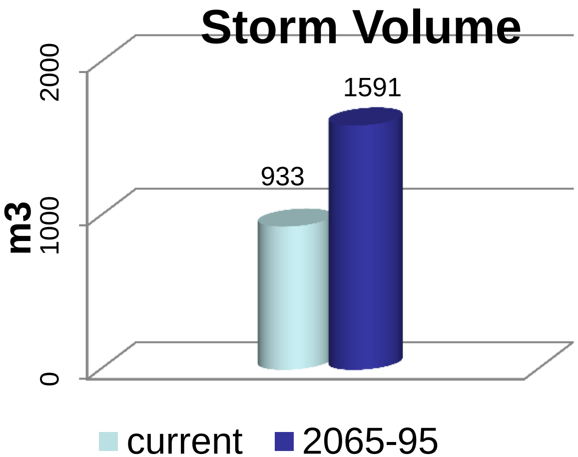
AgErosion Software: Design of Agricultural Erosion Control Structures

Use of IDF data to estimate design for peak flows and runoff volumes

Hypothetical example:

- London, ON
- IDF Future: 2065-95; 20% percentile
- Storm return period: 10 years
- Watershed size : 8ha
- Land use: row crops





Agricultural Erosion Control Structures

Grassed Waterways

Water and Sediment Control Basins (WASCoBs)

Case Study: Understanding and Managing Rural Stormwater

Rural Stormwater Management Model Project

ruralstormwater.com

▲ TYPICAL CONDITIONS

▲ DURING AN EVENT

When it comes to water quality, storm events are *the* issue

As we experience more weather extremes, we need to understand what is happening on the landscape and know how to better manage runoff

ACTion BMPs and the Treatment Train

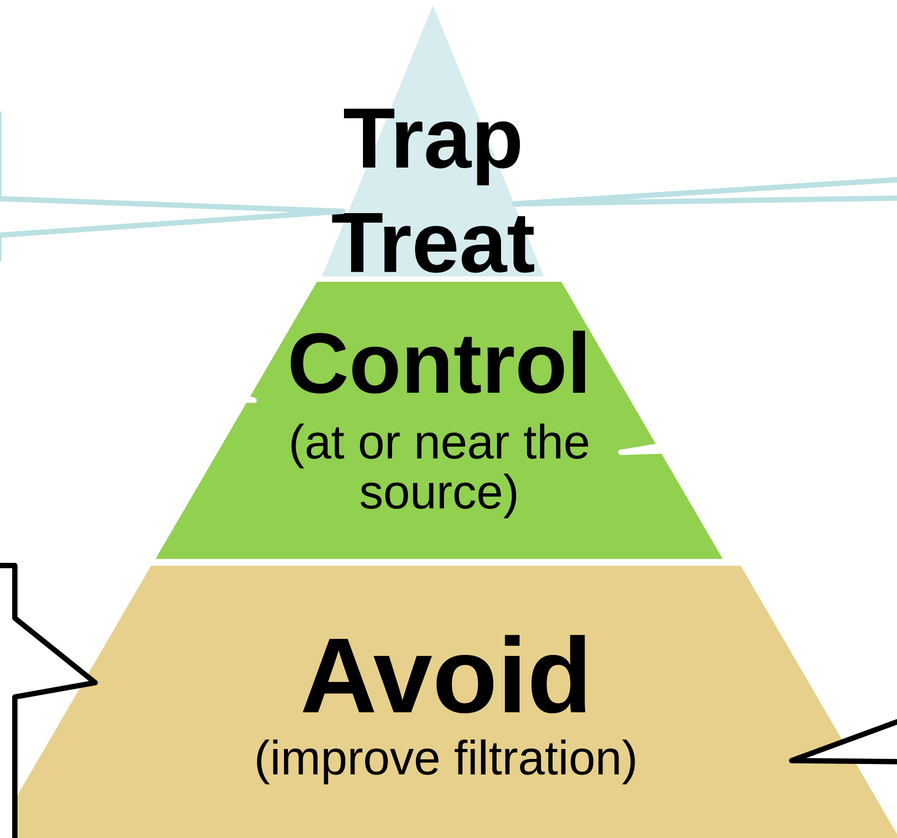
(**ACT** = **A**void, **C**ontrol, **T**rap/**T**reat)

Rural BMPs

- Buffers
- Two-stage ditches

- Controlled drainage
- Grassed waterways
- Berms
- Wetlands

- No till/minimum till
- Cover crops
- Nutrient/manure management
- Natural cover



Urban BMPs

- Stormwater Ponds

- Rain gardens
- Rain barrels
- Bioswales

- Less pavement
- Permeable pavement
- Natural cover

Based on Tomer *et al*. 2013 and Kroger *et al.* 2012

AUSABLE BAYFIELD CONSERVATION
CREATING AWARENESS | TAKING ACTION

Crops and Creeks Huron
A Watershed-Based Best Management Practices Evaluation (WBBE) Project

Healthy Lake Huron
Clean Water, Clean Beaches

Rural Stormwater Management Model Project
ruralstormwater.com

Evaluation of Best Management Practices

Crops and Creeks Huron
– A WBBE (Watershed-Based Best Management Practices Evaluation) Project

Evaluated:

- Cover crop
- Nutrient management
- Conservation tillage
- Water and sediment control basin (WASCoB)
- Grassy ditch

Findings:

- **Soil and Water Assessment Tool (SWAT)** model found land management BMPs are more effective than the WASCoBs at the watershed scale for reducing phosphorus
- Within-field practices such as a WASCoB and edge-of field practices (grassy ditch) are more easy to verify than the effectiveness of cover crops, nutrient management, and conservation tillage
- To evaluate the effectiveness of BMPs we need to monitor water quality during storm events

AUSABLE BAYFIELD CONSERVATION
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ruralstormwater.com

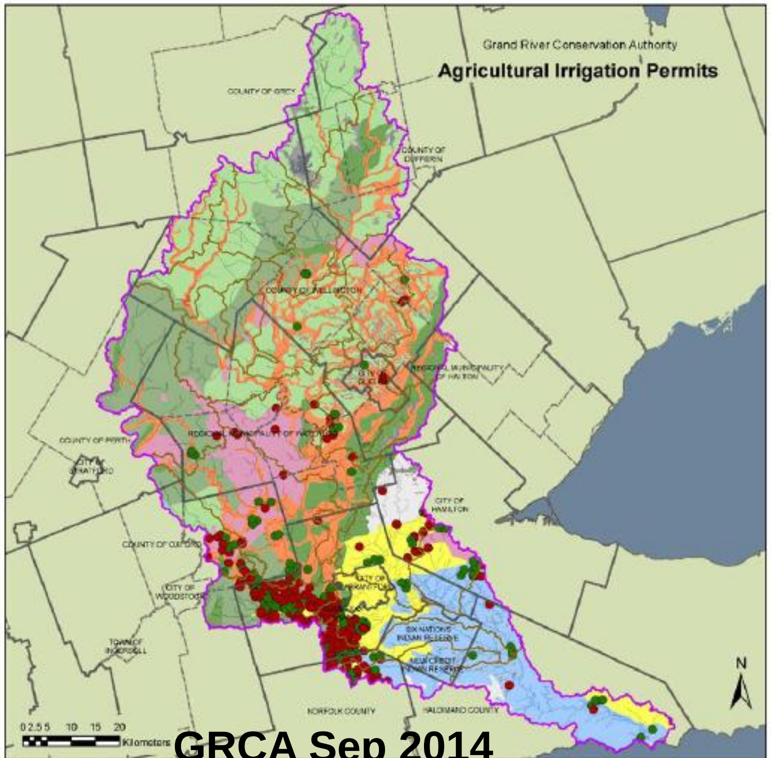
Agricultural Irrigation: Forecasts for Future Water Needs in the Grand River Watershed

Annually, irrigation is estimated to be the third highest water use in the Grand River watershed, following municipal and dewatering (Wong, 2011)

Grand River Watershed
Water Management Plan update:

Assess current and future water needs for agricultural irrigation to:

- Ensure that the future water needs can be sustainably met
- Identify areas that, on sub-watershed basis, have potential for conflict or water use constraint (now or in the future) as a result of the combined water demands of all watershed users



GRCA Sep 2014

Scenarios

- 2 set of scenarios
- Scenarios are fairly extreme but helpful in quantifying possible future situations

A. Irrigation increase by increase in area	
1. Low Water Use	Irrigation similar to current
2. Moderate Water Use	2a. Irrigation area expanded by 10% 2b. Irrigation area expanded by 25%
3 High Water Use	3a. 10% of cropland in sandy soils irrigated 3b. 5% of all cropland irrigated

B. Intensity scenario driven by climate	Time Period	Average number of irrigation events
Baseline	1960-1990	8
Moderate-worse case	2050	11

Assessment Findings

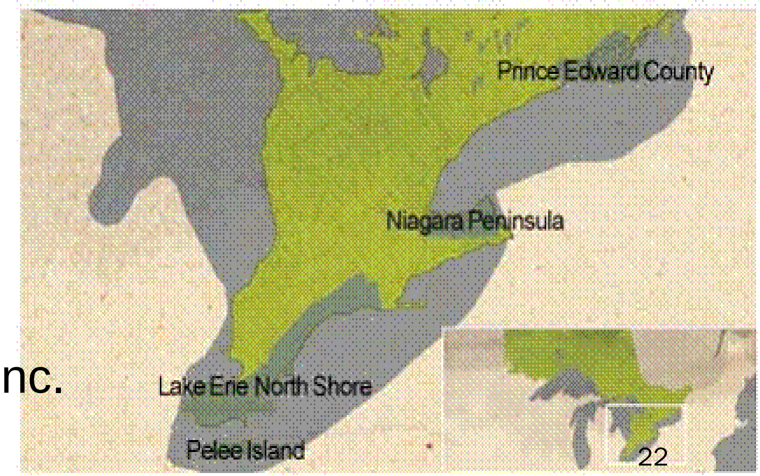
- Future water needs for crop irrigation can be sustainably met at the sub-watershed scale, particularly if irrigation is sourced from groundwater and/or storage and not taken directly from surface water
- Projections show “Low” water use for most sub-watersheds despite significant increase in irrigated area and increase in irrigation intensity because of climate change

Table: water use relative to groundwater supplies

Assessment Areas	Groundwater Availability Parameters (L/s) (Using Supply from Climate Change Scenario 34)		Future Water Demand with Climate Change									
			Scenario 1: Similar to Current Demands		Scenario 2a: 10% increase in irrigation		Scenario 2b: 25% increase in irrigation		Scenario 3a: 10% of all Sandy Soils		Scenario 3b: 5% of all Cropland	
	Supply	Reserve	Average Monthly	Max Monthly	Average Monthly	Max Monthly	Average Monthly	Max Monthly	Average Monthly	Max Monthly	Average Monthly	Max Monthly
Nith Above Grand to New Hamburg	3,999	302	8%	12%	8%	12%	8%	12%	8%	13%	8%	13%
Whitemans Creek	2,640	206	4%	17%	4%	17%	5%	18%	6%	22%	8%	25%
Grand Above York to Brantford	1,186	150	22%	38%	22%	38%	22%	39%	23%	43%	25%	45%
Fairchild Creek	1,697	147	6%	7%	6%	8%	6%	8%	7%	10%	8%	11%
Mckenzie Creek	1,003	77	5%	21%	5%	22%	6%	23%	9%	30%	11%	35%

Case Study: Grape & Wine Industry

- Since 2009, Ontario committed to long term whole-of-government grape and wine strategy focused on high quality Ontario grown product
- Ontario Research Fund: Research Excellence Program –
  - *"Innovation, Integration, Adaptation: A winning response to climate change for the Ontario grape and wine industry"*
  - $10 M over five years (2010-2015); provincial share $2.86 M
  - Partnering Institutions:
    - Cool Climate Oenology & Viticulture Institute (lead) - (Brock University)
    - Niagara College
    - Vineland Research and Innovation Centre
    - University of Guelph
    - Environment Canada
  - Contributing Industry Partners:
    - Grape Growers of Ontario
    - Vintners Quality Alliance Ontario
    - Ontario Grape and Wine Research Inc.
    - 5 wineries, 4 grape growers



Climatic Indices Relevant for Grapes for Wine

Vinifera growing conditions:

- No winter extremes below -20° C
- Frost free period above 165 days
- Moderate temperature (20-30° C) during growing season
- Minimum rainfall between ripening and harvest
- 1000 chill units to be fruitful
- Most critical period: winter

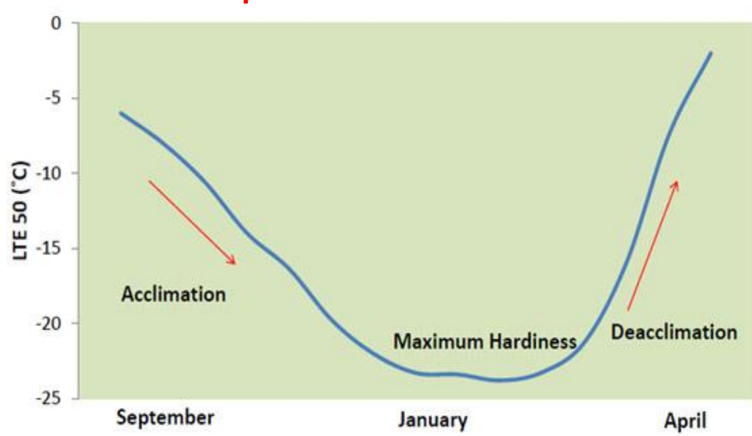


Figure 1. Profile of bud cold hardiness during the dormant season

Government has committed to long term strategy focused on high quality Ontario grown product

OMAFRA committed to provide assistance for grape grower transition

- improve grape quality to support the production of VQA wine and align grape production with winery demand

Future Climatic Suitability for Grapes for Wine

Potential changes in future climate

- Projections of critical changes in temperature but not in overall precipitation levels:
  - Increase in number of heat units
  - Longer frost free period (>180 days)
  - Reduction in winter severity but potential for freeze damage from increased variability in freeze/thaw cycles
  - Extreme temperature >30ºC during growing season
  - Potentially wetter in Sep/Oct (harvest)

Potential implications

- Earlier maturity: shift of optimal conditions for early-season varieties -Chardonnay- while benefitting red varieties -Cabernet
- Winter variability and summer extremes affecting yield/quality & survivability
- New areas could become suitable for growing grapes

Program Highlights: Short Term Strategies

Viticulture

- Optimize grapevine winter hardiness for vines currently in production
  - Measure grapevines' acclimation and deacclimation processes
  - Measure peak hardiness of vines in Ontario's designated viticultural areas
  - Groundwork on grapevine molecular biology to identify genes to breed for winter hardiness
  - Development of management practices guide for growers

Oenology

- Development of new wine styles to exploit cool, less optimal years when grapes do not fully ripen
  - Sparkling wine production
  - Appassimento-style wines, ripening of grapes off-vine
  - Removal of green characteristics in wine due to under-ripe grapes and/or Asian Lady beetles

Program Highlights: Long Term Strategies

- Modelling to assess impact of climate change on Ontario’s wine regions
  - Examine ranges of probable future climate, including extreme weather events
    - Downscaled regional climatic modelling to assess climate change impacts on Ontario’s wine regions
    - Use a vineyard simulation model (e.g. Vine LOGIC) to assess impacts on grapevine phenology
- Develop adaptive strategies with respect to:
  - Grape varieties that thrive under future environmental conditions
  - Viticulture practices: advances in technology, water management, factors that affect cold hardiness
  - Potential new wine production regions
  - Consideration to changes in wine styles as conditions change

Moving Forward

To ensure the food system's long-term sustainability, we must:

- Plan and invest based on the evidence we have
- Continue to gather new evidence to support continuous improvement
- Optimize our resiliency/flexibility to prepare for unknowns and capitalize opportunities

Information and Knowledge Gaps

- Improved projections on probabilities of extremes to inform regional vulnerability assessments
- Comprehensive economic assessment of the impacts of climate change on agriculture and agri-food sectors both, provincially and at the regional level
- Updated state/quality of our natural resources e.g. soil health, soil mapping, soil erosion, water availability
- Improved communications and tools to influence stakeholders' behaviour and assist them on business risk management as well as capturing opportunities

Thanks

Thoughts and Questions

Vulnerability and Risk Assessment in the Infrastructure Sector to Adapt to Climate in Ontario

David Lapp, FEC, P.Eng.
Practice Lead – Engineering and Public Policy

Ontario Ministry of Environment and Climate Change
Best in Science Symposium
Climate Change Modelling and Impact Assessment

November 28, 2014
Toronto, ON

What is Engineers Canada?

STRUCTURE

- National organization for the engineering profession in Canada
- Members - 12 constituent associations that regulate the practice of engineering e.g. Professional Engineers Ontario (PEO)
- Over 270,000 professional engineers in Canada

FUNCTIONS

- Common approaches for professional qualifications, professional practice and ethical conduct
- Accredits all undergraduate engineering programs in Canada– 271 programs in 43 universities
- National and international voice of the profession
- Climate change work since 2001

Guiding Principles for this Presentation

- The climate is changing
- Climate change threatens the ability of engineers to safely and effectively design **resilient** infrastructure to meet the needs of Canadians
  - Design, operation and maintenance practices must adapt
  - Growing liability concerns for profession
- Climate change engineering vulnerability assessment contributes to adaptation process
- Updated and improved codes, standards and practices needed

Civil Infrastructure

The services provided by civil infrastructure works support society in many ways…

Services

Shelter

Safety and security

Aesthetics

Heat, Light and Power

Mobility for people, goods and services

Health and recreation

Wealth creation

Categories

Homes & Buildings

Transportation networks

Energy networks

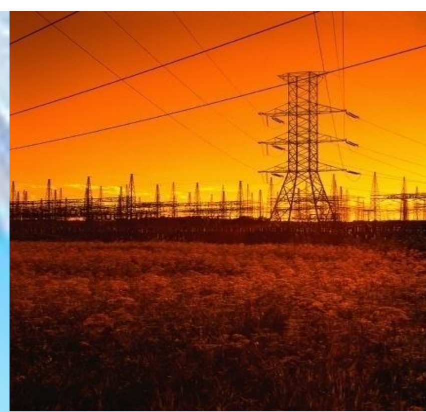
Water, Waste, & Storm water networks

Industrial structures

Communications networks

Landfills and waste depots

Culture and recreational facilities



Flexible adaptation options working with *Infrastructure Lifecycle Timeframes*

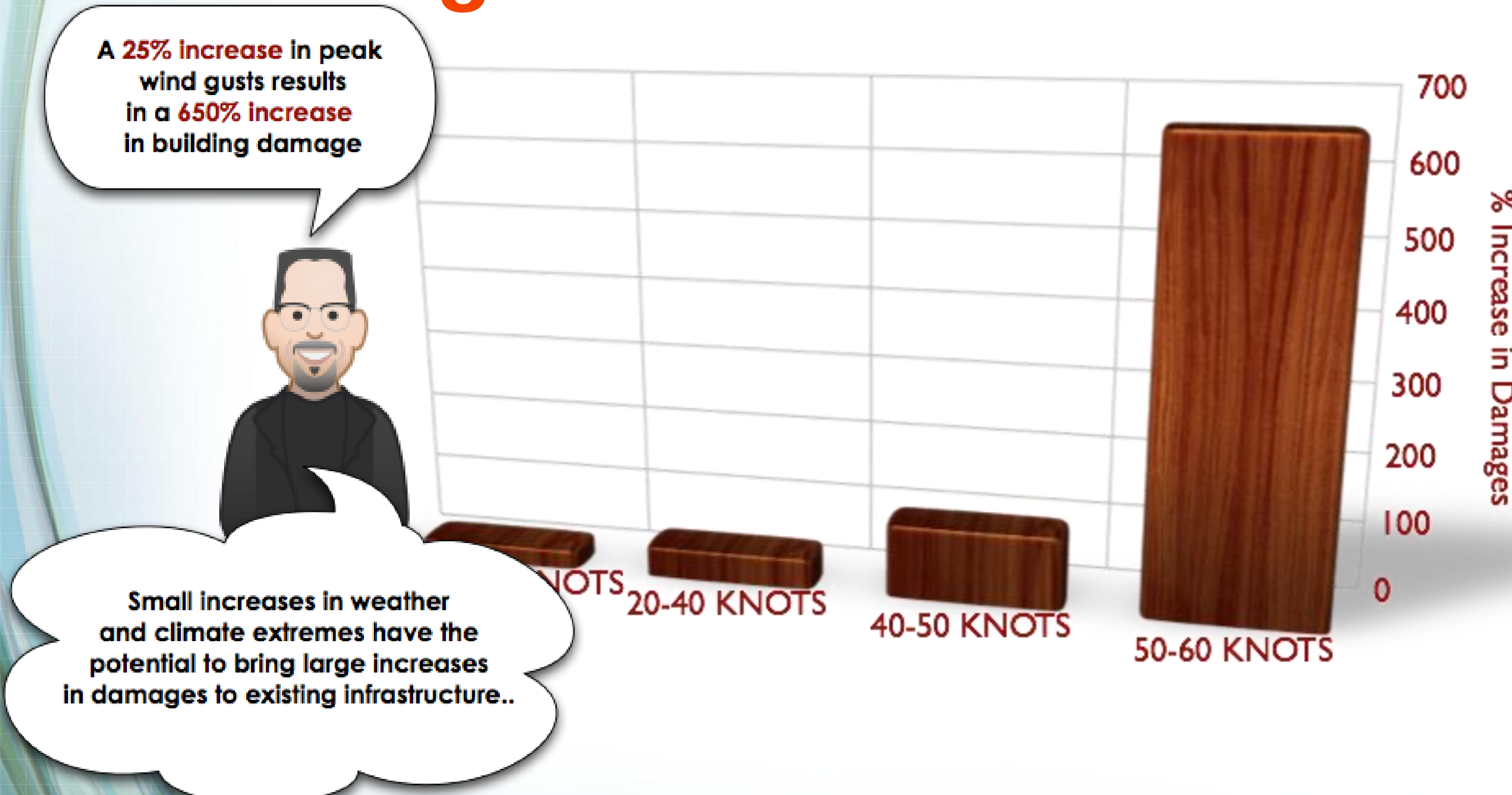
Structures	Expected Lifecycle
Houses/Buildings	Retrofit/alterations 15-20 yrs Demolition 50-100 yrs
Sewer	Major upgrade 50 yr
Dams/Water Supply	Refurbishment 20-30 yrs Reconstruction 50 yrs
Bridges	Maintenance annually Resurface concrete 20-25 yrs Reconstruction 50-100 yrs

Improves Asset management

Risks to Various Infrastructure Types from Increasing Climate/Weather Extremes (Frequencies/Intensities)

STRUCTURES	Ice Storms and Wet Snow	Rainfall Intensity & Accum.	Extreme Winds	Summer Storms & Tornadoes	Extreme Snow
Power Lines & Transmission Structures	FAILURE ice + wind	ADDITIVE	FAILURE	FAILURE	SOME
Communication	FAILURE ice + wind	ADDITIVE	FAILURE	FAILURE	SOME
Buildings	SEVERE ICING & WET SNOW	DRAINAGE & FAILURE	FAILURE	FAILURE	FAILURE
Roads, Bridges	OPERATION RISKS	DRAINAGE & EROSION	OPERATION & RISKS	FAILURE RISK	OPERATION
Stormwater & Wastewater	POWER FAILURES	TOTAL FAILURE	POWER FAILURES	FAILURE	RISKS
Water Supply & Distribution	POWER FAILURES	LACK OF - DROUGHT	POWER FAILURE	POWER FAILURE	RISKS

Small Increases Lead to Escalating Infrastructure Damage



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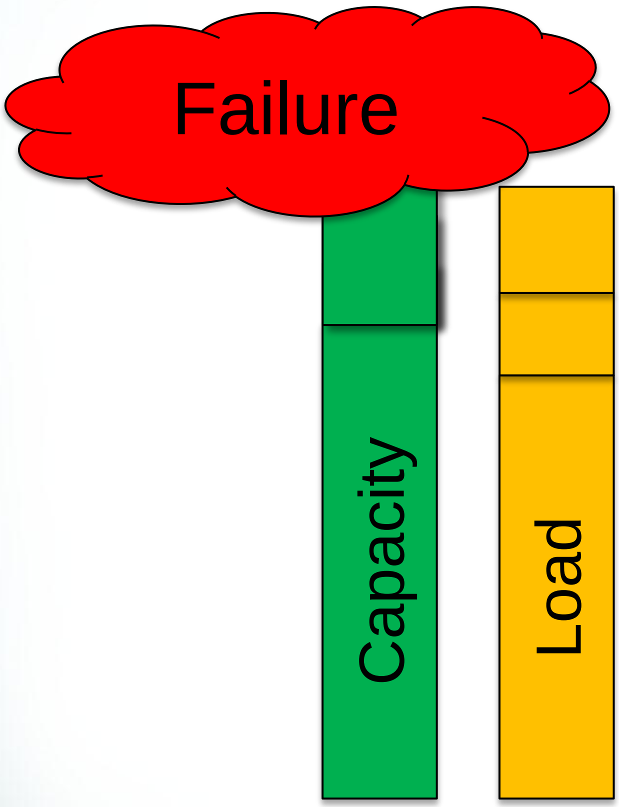
How do Small Changes Lead to Catastrophic Failure?



- Design Capacity
- Safety Factor
- Impact of age on structure
- Impact of unforeseen weathering

- Design Load
- Change of use over time
  - e.g. population growth
- Severe climate event

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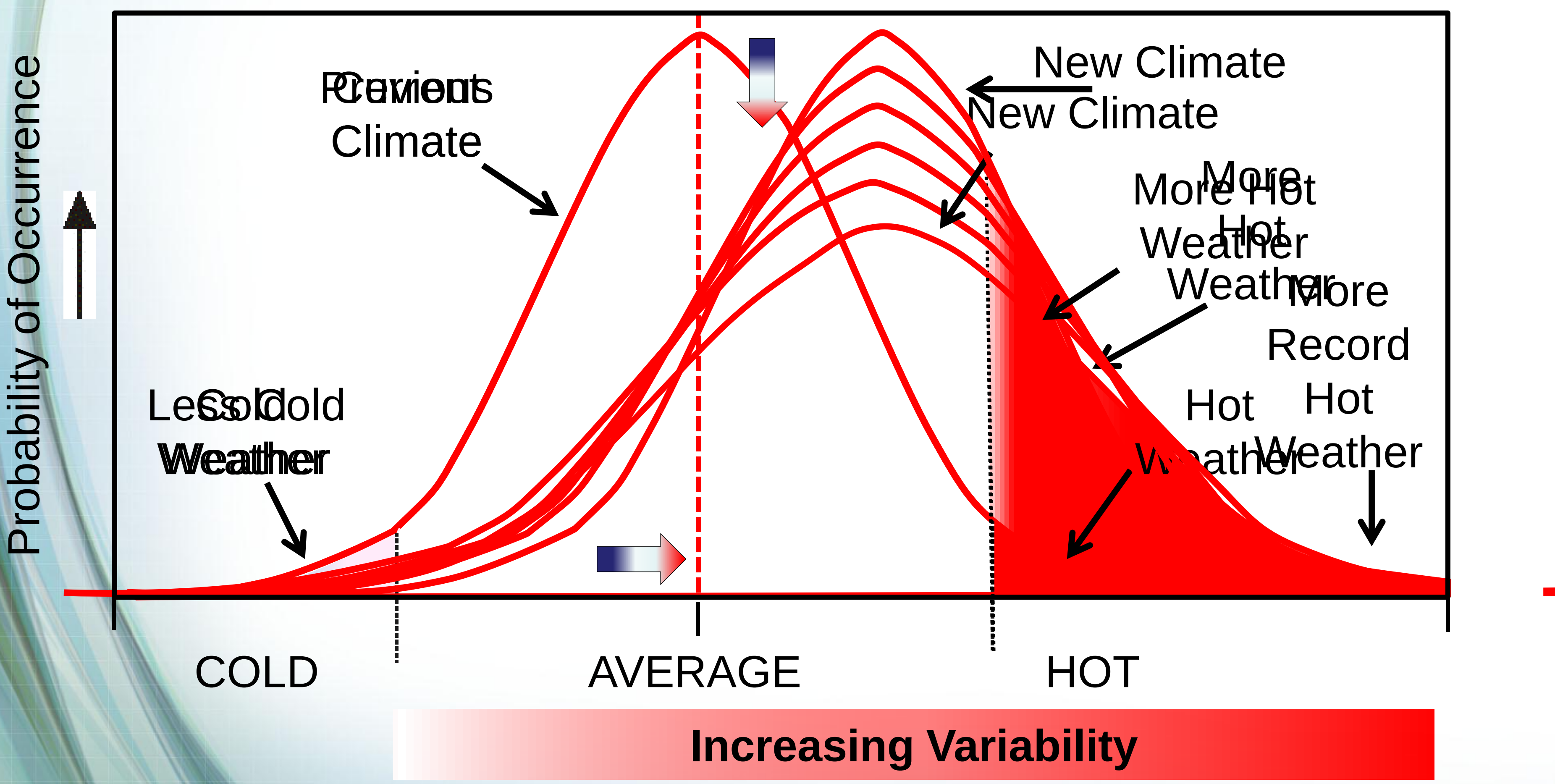
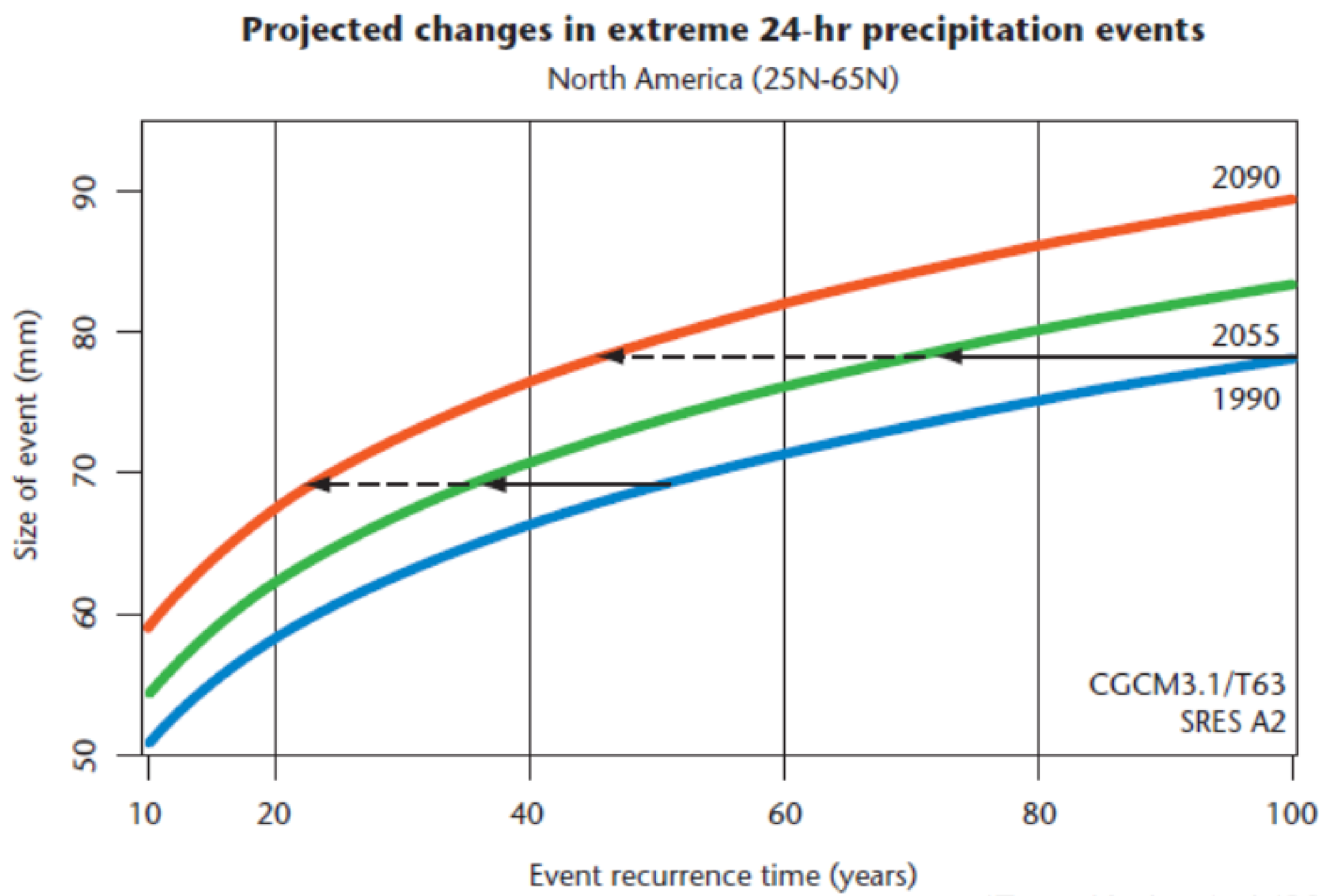
The probability of extremes changes in a warmer climate

INCREASES IN MEAN and VARIANCE





(From Karin et al (2007))

Projected changes in extreme 24-hour precipitation amounts and return periods for mid to late 21st century compared to 1990 values (SRES A2)

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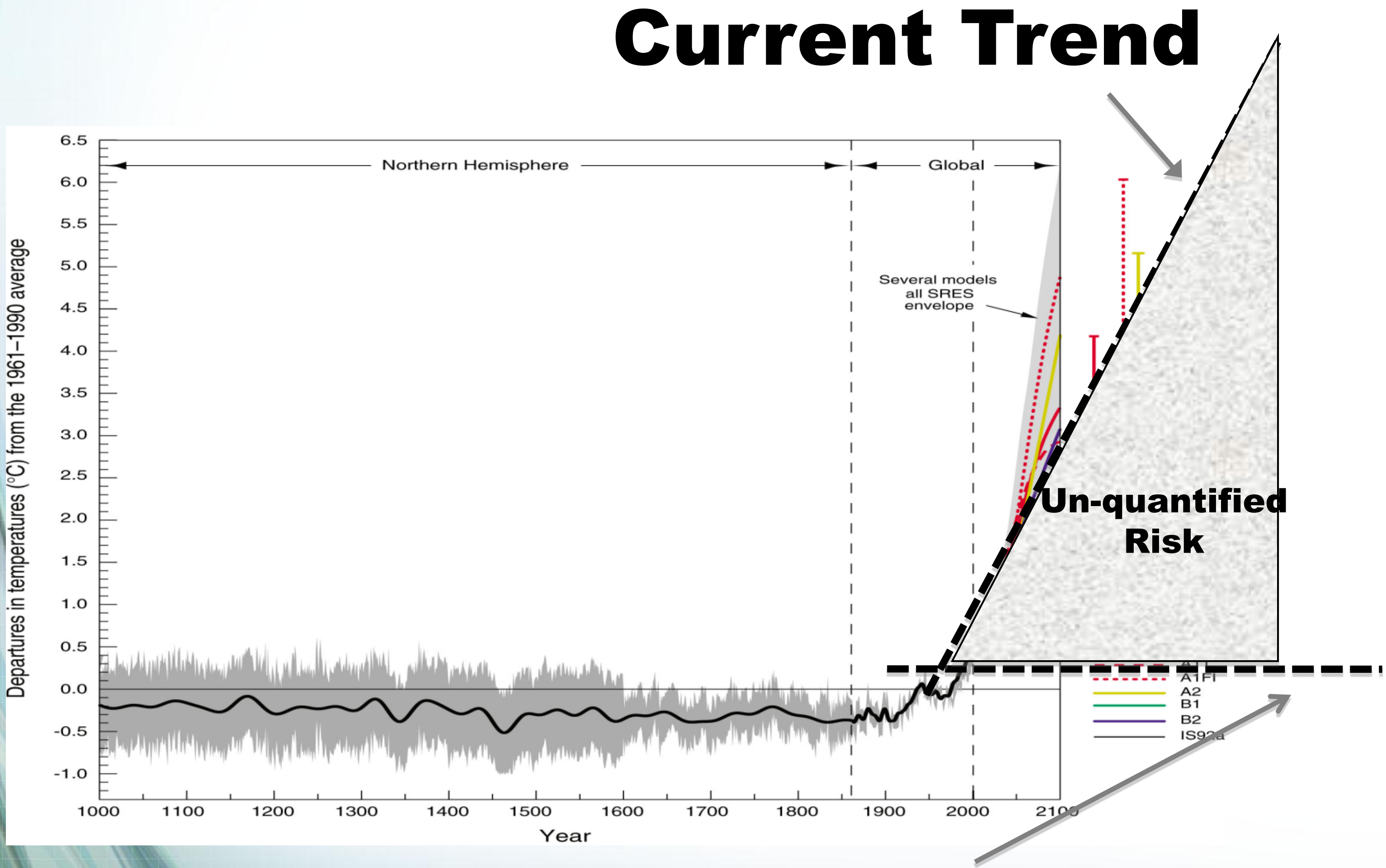
The Past IS NOT the Future



The Past is the Future

Why Address Infrastructure Risks?

- Minimize service disruptions
- Protect people, property and the environment
- Optimize service
  - Manage lifecycle
  - Manage operations
  - Avoid surprises
  - Reduce costs
- First step in planning adaptation

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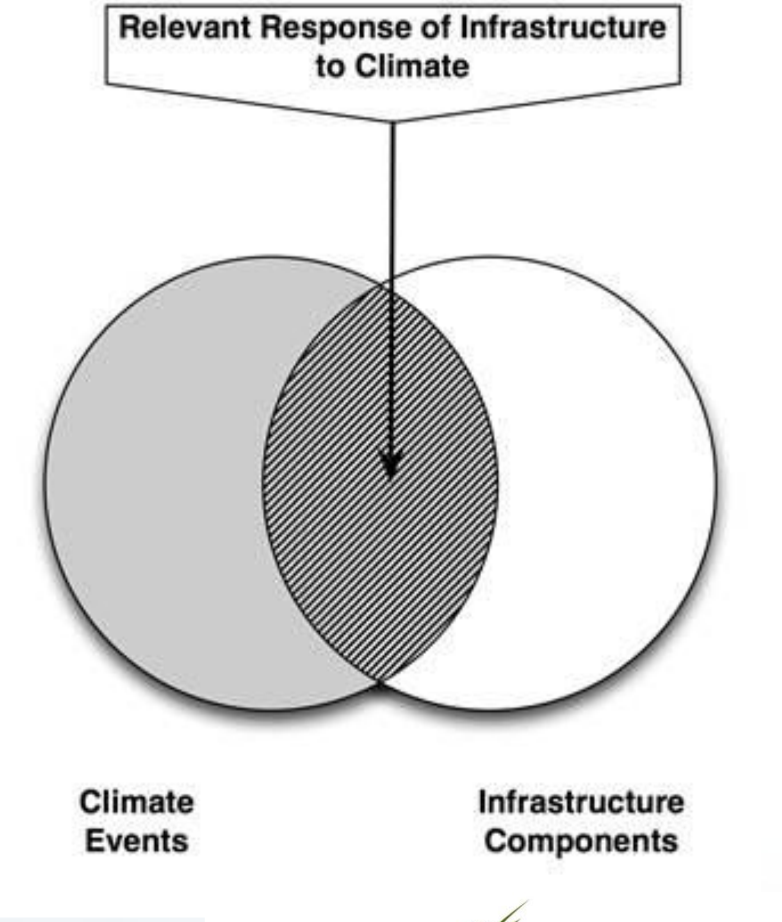
… and furthermore

Building infrastructure today without considering future climate impacts is incorporating vulnerabilities that will later cause service disruptions and failures thus increasing costs to government, the private sector and users.

PIEVC Engineering Protocol: a risk screening tool

- Five step evaluation process
- A tool derived from standard risk management methodologies
- Intended for use by qualified engineering professionals
- Requires contributions from those with pertinent local knowledge and experience
- Focused on the principles of vulnerability and resiliency



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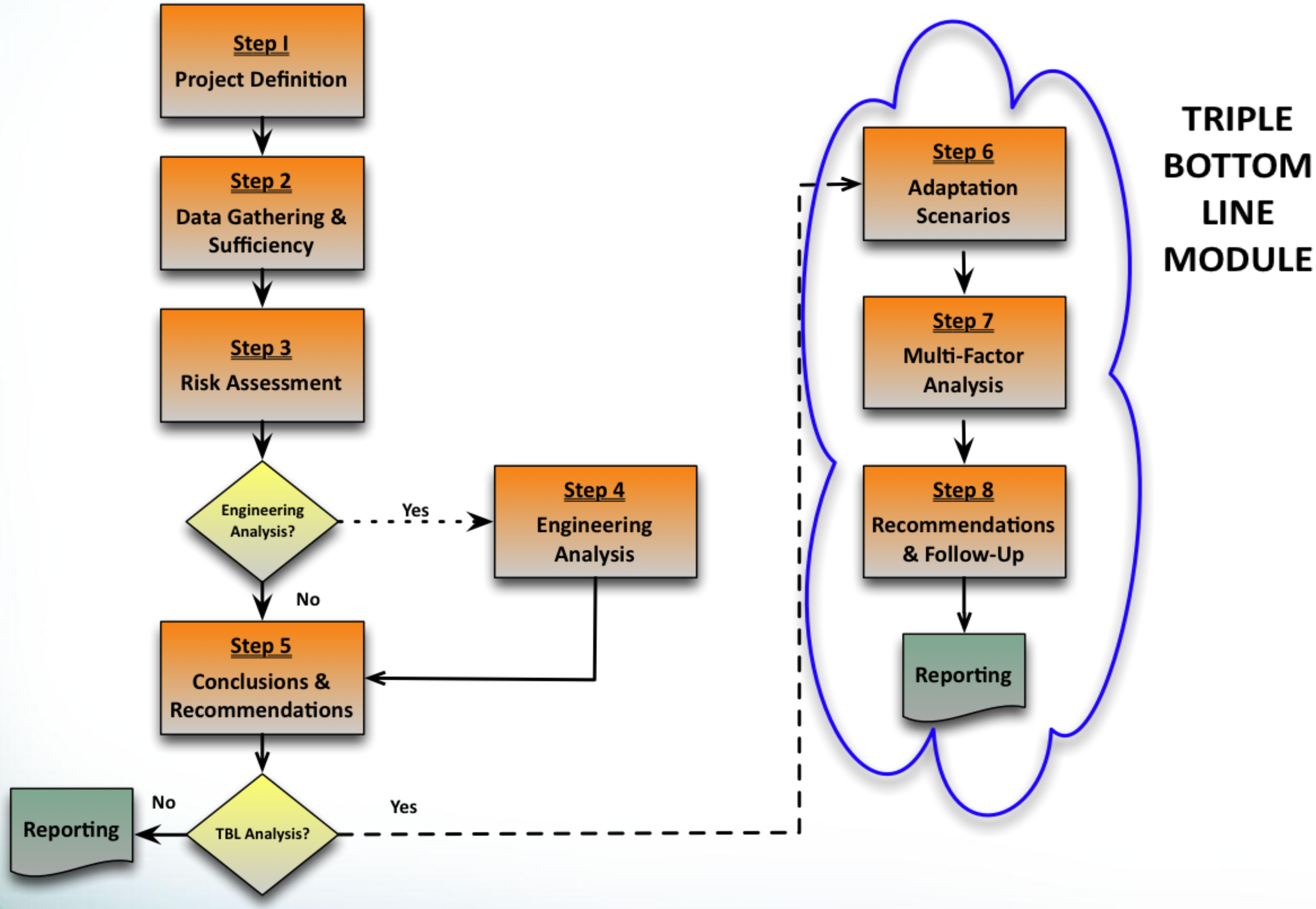
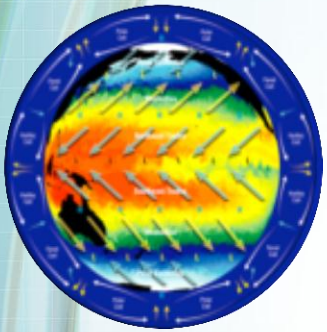
5 Steps plus an Optional TBL Module



Public Infrastructure Vulnerability Process



Climatic Conditions

Character, magnitude and rate of change in climate conditions for exposed infrastructure

Sensitivities of Infrastructure

How sensitive is the infrastructure to climatic changes?

Built-in Capacity of Infrastructure

What level of built-in capacity of infrastructure exists to absorb consequences of a changing climatic?

Vulnerability Assessment needs to consider all 3 elements!

Climate Change Risk Mitigation Through Adaptation

Flood
CLIMATE CHANGE
Flood
ADAPTATION
Flood

7	SEVERITY	Catastrophic 0.800	0	[illegible]	[illegible]	[illegible]	[illegible]	35	[illegible]	49
6		Hazardous 0.400	[illegible]	[illegible]	12	18	24	[illegible]	[illegible]	42
5		Serious 0.200	0	5	10	15	20	25	[illegible]	35
4		Major 0.100	0	4	8	12	16	20	[illegible]	28
3		Moderate 0.050	0	3	6	9	12	15	[illegible]	21
2		Minor 0.025	0	2	4	6	8	10	[illegible]	14
1		Measurable 0.0125	0	1	2	3	4	5	6	7
0		No Effect	0	0	0	0	0	[illegible]	[illegible]	0
			negligible or not applicable	improbable 1:1 000 000	remote 1:100 000	occasional 1:10 000	moderate 1:1 000	probable 1:100	frequent 1:10	continuous 1:1
			PROBABILITY							
			0	1	2	3	4	5	6	7

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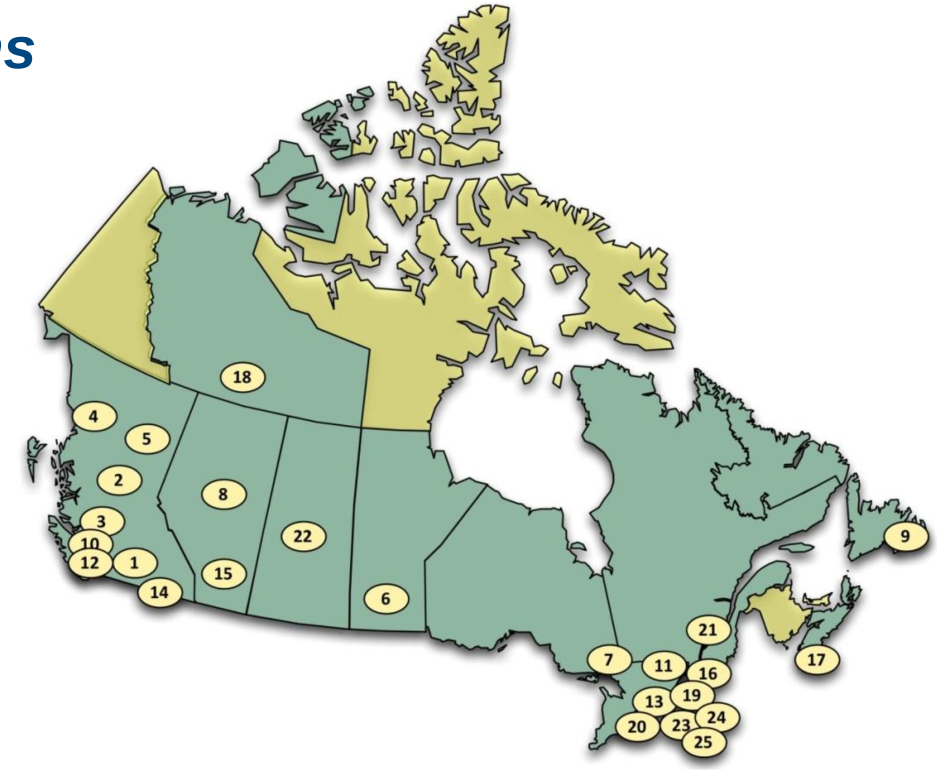
Applied to 40+ Projects and Counting …

- *Water resource systems*
- *Storm & waste water systems*
- *Roads & bridges*
- *Buildings*
- *Transportation infrastructure*
- *Energy Infrastructure*



PIEVC Water Infrastructure Climate Risk Assessments

ONTARIO

- Union Water Supply System (Leamington ON)
- City of Welland – Stormwater and wastewater infrastructure
- Town of Prescott - Stormwater management infrastructure

NATIONAL

- Cities of Castlegar and Nelson, BC – Stormwater management
- City of Calgary – Potable water supply
- Town of Shelburne NS – New sewage treatment plant
- Metro Vancouver – Stormwater and wastewater systems

PIEVC Transport Related Assessments

- BC MOTI – Coquihalla and Yellowhead Highways
- BC MOTI – Hwy 20 (Bella Coola), Hwy 37A (Stewart Region), Hwy 97 (Pine Pass Region)
- City of Toronto –Three Large Culverts
- City of Edmonton – Quesnell Bridge Upgrade
- City of Sudbury – City-wide assessment of roads, bridges and culverts
- City of Miramichi NB – two highways
- GNWT Department of Transportation – Highway 3 West of Yellowknife
- Greater Toronto Airport Authority – Runway Culvert and De-Icing System
- Placentia NL – Local road and coastal structures

Lessons Learned from Infrastructure Climate Risk Assessments

Several common issues:

- **Intensity** – short duration precipitation is almost always a concern
- Infrastructure systems are **almost always vulnerable to interruptions in power supply**
  - Severe weather events can disrupt power supply and have significant impact on the serviceability of your infrastructure
- **Combinations of events can have more impact than discrete events**
  - Rain on snow
  - High snowfall followed by rapid thaw

Highway 404 in Toronto, Ontario July 27, 2014
Image: Global News

Lessons Learned from Infrastructure Climate Risk Assessments

- Meteorological **data used in design can often be very dated**
  - IDF curves based on 1960s precipitation data
- **Regional climate expertise** is always better
  - Climate specialists from distant locations may not be conversant with local weather phenomena
- **Multidisciplinary teams are very important.** Teams should comprise:
  - Fundamental **understanding of risk and risk assessment processes**
  - Directly **relevant engineering knowledge of the infrastructure**
  - **Climatic and meteorological expertise** relevant to the region
  - Hands-on **operation experience** with the infrastructure
  - Hands-on **management knowledge** with infrastructure
  - **Local knowledge** and history

Lessons Learned from Infrastructure Climate Risk Assessments

- Climate change projections should be based on **ensembles of model outputs**
  - There is always a temptation to use only one set of data
- Understanding your **baseline climate is critical**
  - How infrastructure has responded to historical weather events informs judgment on how it will likely respond to future, more extreme, events
- It is important to **monitor and maintain**
  - Good records of weather events
  - The impact they had on your infrastructure
  - How you responded

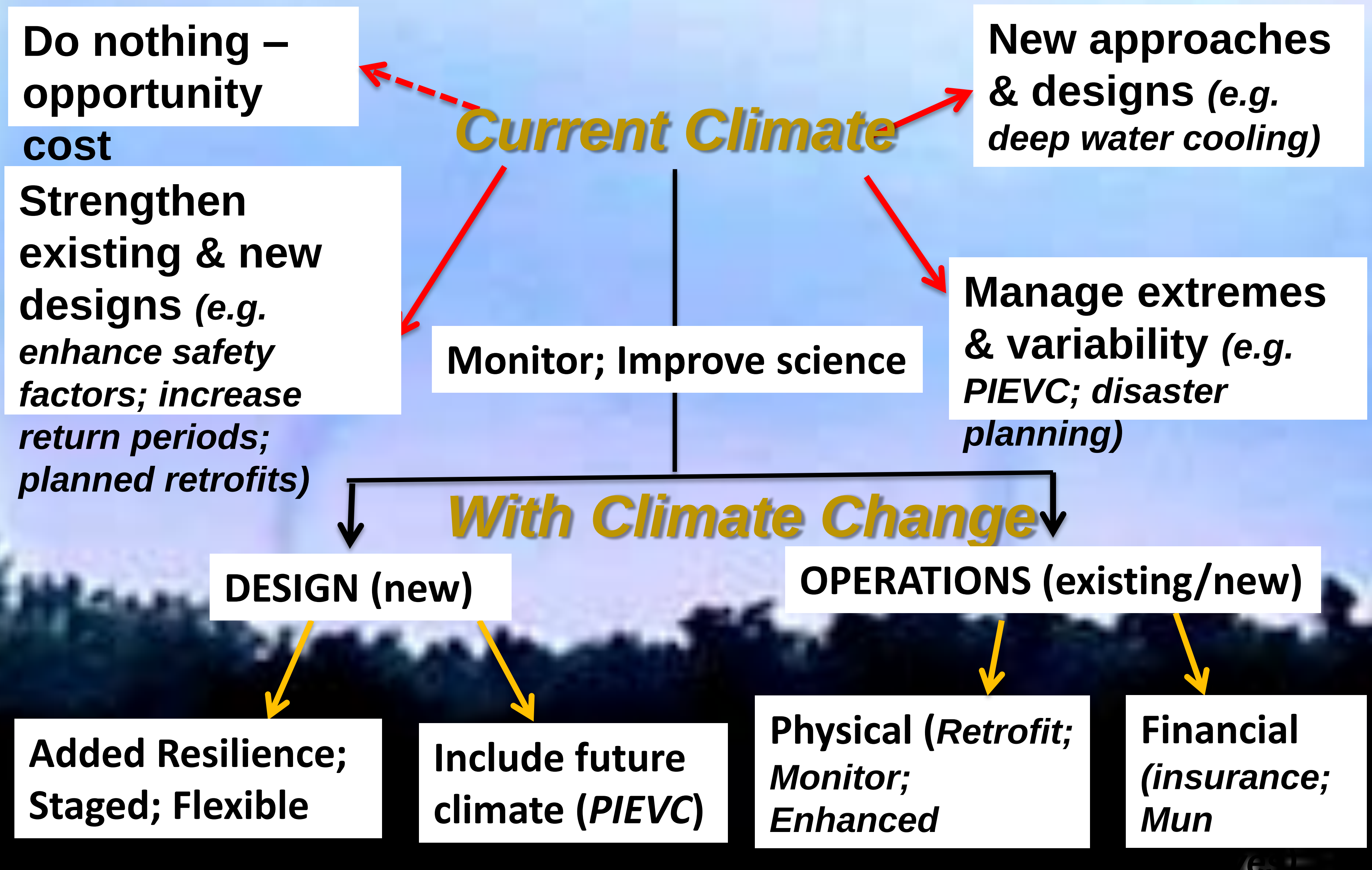
Benefits of Infrastructure Climate Risk Assessment

- Identify nature and severity of risks to components
- Optimize more detailed engineering analysis
- Quick identification of most obvious vulnerabilities
- Structured, documented approach ensures consistency and accountability – **due diligence**
- Adjustments to design, operations and maintenance
- Application to new designs, retrofitting, rehabilitation and operations and maintenance
- Reviews and adjustments of codes, standards and engineering practices

The Interdependence of Climate Experts and Engineering Design

- An inseparable link
- Cannot work without each other
- With Climate Change, working closely together is critical for safeguarding public well-being:
  - *Reduce uncertainty on how future climate will deviate from regional historic climate*

Adaptation Choices for Climate & Weather Resilience



Thank you!

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What the profession is doing

- Raising awareness among engineers, other professions and decision-makers
- Continuing professional development – climate change syllabus (e.g. Climate Resilient Systems Training; http://climateresilientsystems.com/)
- Assessment of climate risks (e.g. PIEVC)
- Developing (best) practice guidelines – Model Guide on Principles of Climate Change Adaptation for Engineers
- Constituent associations – practice guidelines for specific infrastructure categories

What the profession is doing

- Encouraging integration of climate change into undergraduate curriculum
- Encouraging incorporation of climate risk into asset management
- Joining other professions to urge government action – regulatory and procurement policies
- Contributing reviews of design, construction and operations codes, standards, procedures and policies

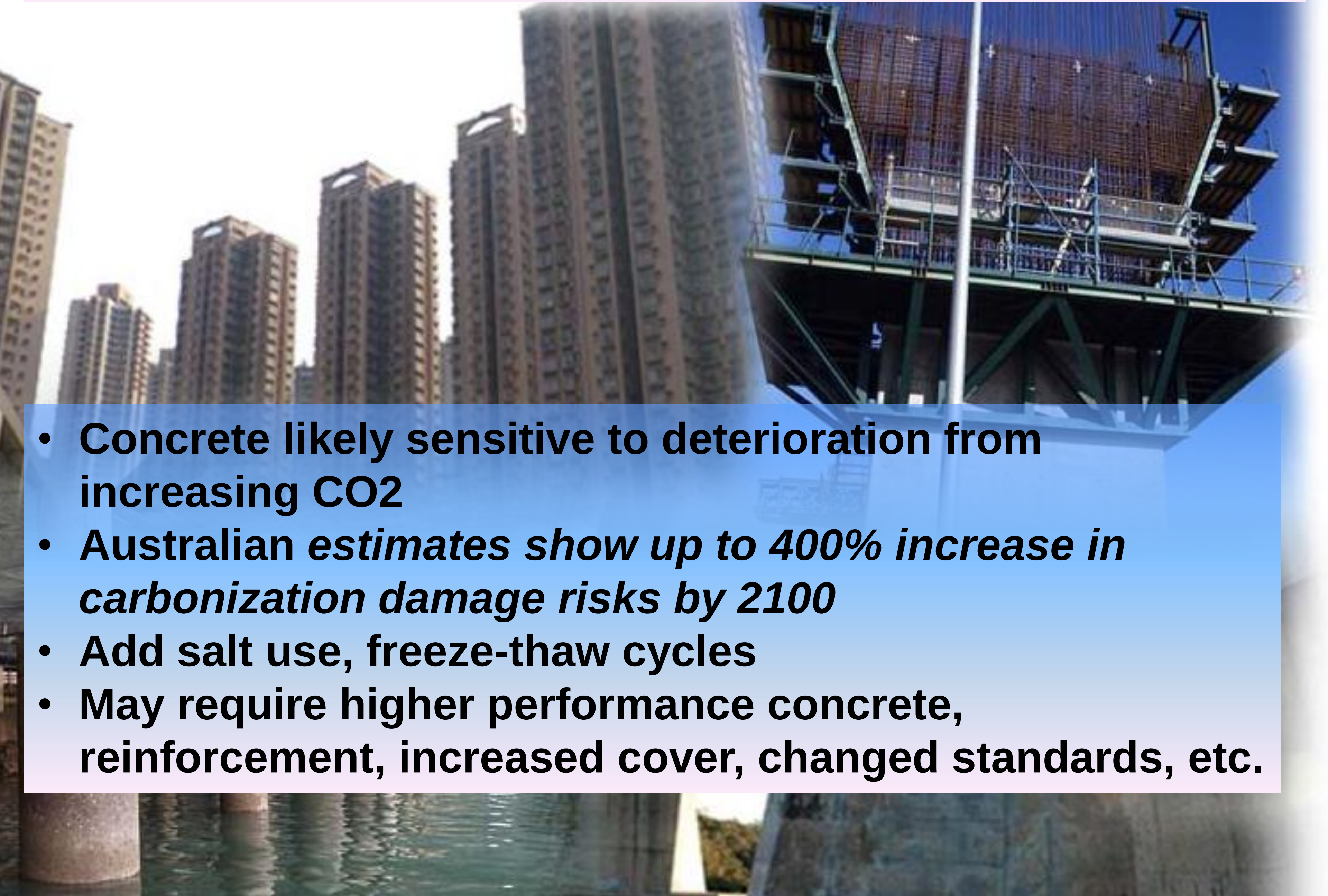
National Building Codes and Standards – climate design information today

Climate information is included in building codes and standards for design of safe and economical infrastructure

National Building Code of Canada (NBCC) climate data needed:

- ***Extreme winds and gusts***
- ***Extreme snow loads/weights***
- ***Extreme rainfall amounts – 15 min, 24 hour, etc.***
- ***Heating Degree Days, Cold & Hot Design Temperatures, Humidities***
- ***Weathering data – DRWP, Annual Precipitation, Rainfall***
- ***NOW, climate change risks (2015 NBCC)***

Premature weathering of concrete under CC?



- **Concrete likely sensitive to deterioration from increasing CO2**
- **Australian *estimates show up to 400% increase in carbonization damage risks by 2100***
- **Add salt use, freeze-thaw cycles**
- **May require higher performance concrete, reinforcement, increased cover, changed standards, etc.**

Importance of Forensic Analyses in Increasing Resilience

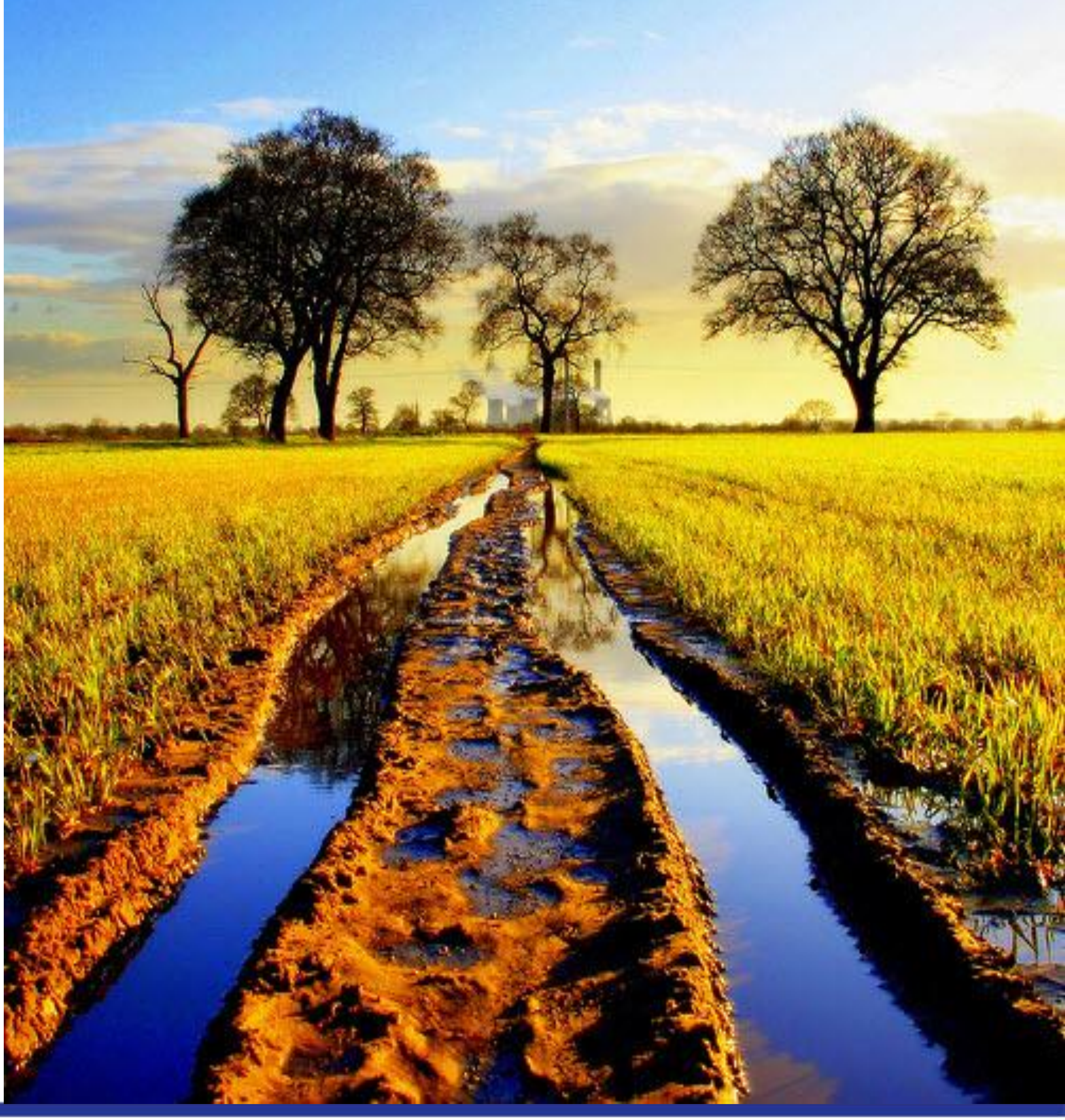
- Learning through past climate-related failures
- Part of "due diligence"
- Evidence for improvements to codes and standards
- Supports improved practices and adaptation solutions
- Proactive - Reduces legal liabilities into future
- Multi-disciplinary: engineering, climate, operations, policy, codes and standards, financial decision-makers, etc
- e.g. Prototype - Climate and Infrastructure Forensic Analyses System (CIFAS)

Increasing Climate Resilience through new and updated Codes and Standards

- Climatic design values very outdated in many codes and standards (*e.g. Highway and Bridge Code*)
- NBCC 2015 added option to include climate change adaptation – given scientific evidence
- Several new Northern CSA standards – snow loads, drainage, permafrost maintenance, thermosyphons, IDFs for Water Practitioners PLUS 4013, Permafrost Foundations PLUS 4011
- Changes to all Codes and Standards based on "**evidence**" – often forensic analyses
- Canada a leader globally in climate change, codes, standard

An Environmental Health Climate Change Framework for Action for Ontario

Vidya Anderson

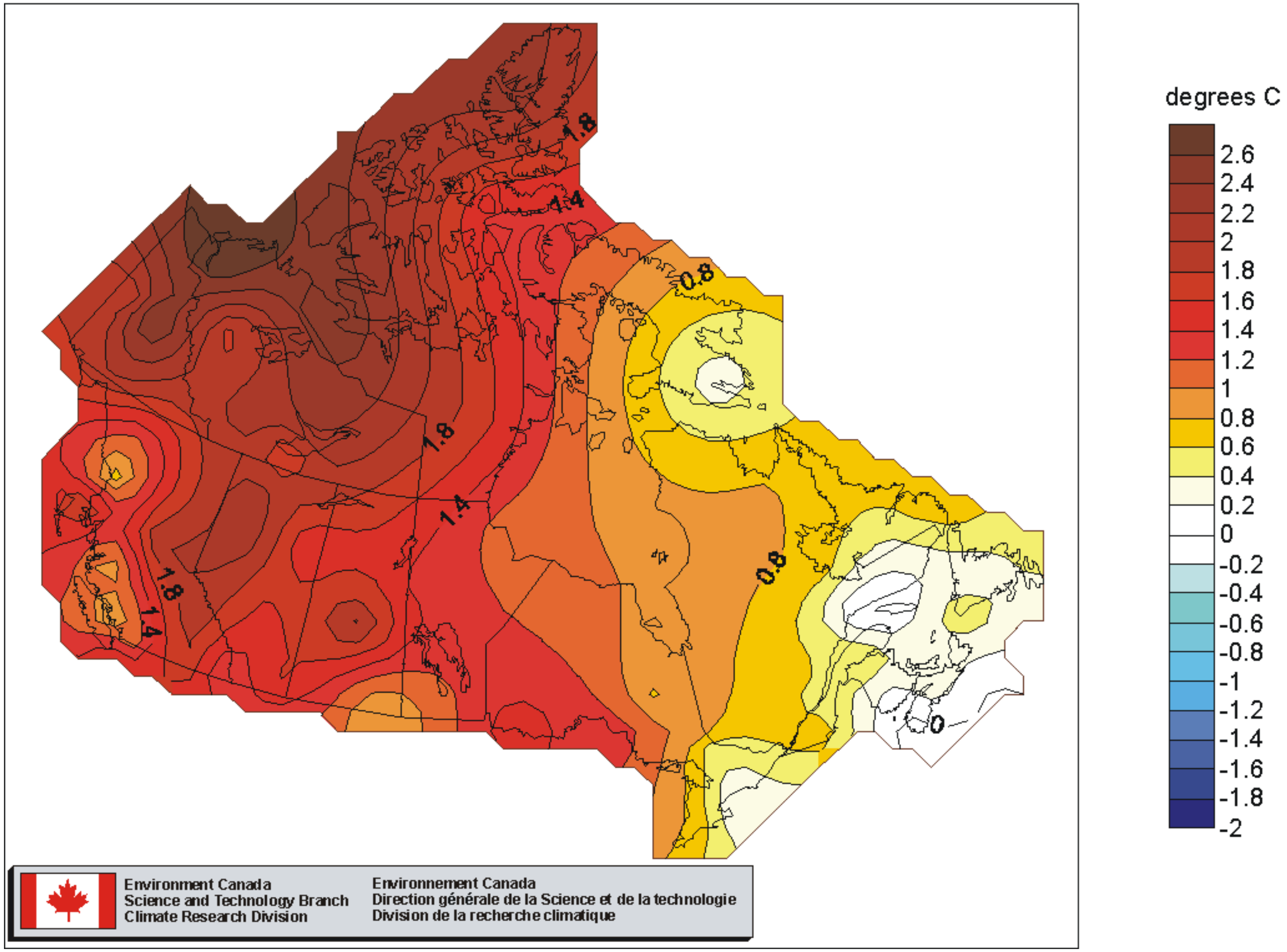


Ontario

Ministry of Health and Long-Term Care

Context: Ontario's Changing Climate

Annual Temperature Trend, 1948-2008



Ontario

Climate Change Impacts: Low Water Levels

BEFORE (1994) **AFTER (2013)**

Honey Harbour, Georgian Bay

Ontario

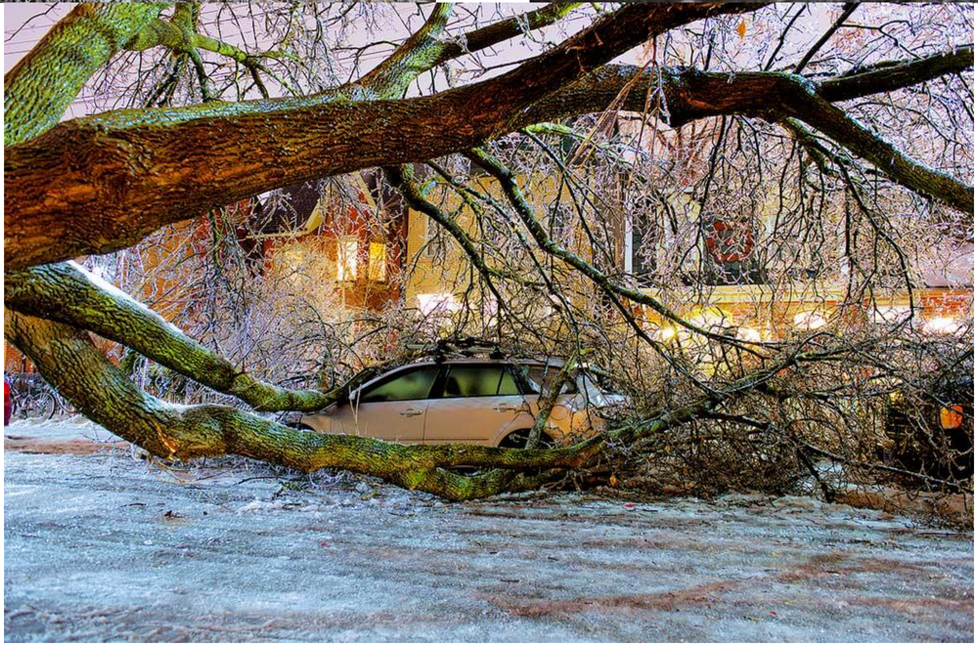
Climate Change Impacts: Severe Storms

Photo: Tornado damage in Vaughan, 2009

Ontario

Climate Change Impacts: Flooding July 8, 2013

Climate Change Impacts: Ice Storm - December 2013



Ontario

Context: Human Health Impacts

Climate change is more than an environmental phenomenon. Humans are directly exposed to climate change and its related health hazards through changes in weather patterns. Humans are also at risk of adverse health outcomes from the impacts of climate change.

Rising Temperatures

- Increased incidence of heat-stress related illness
- Increased risk of diseases transmitted by mosquitoes, ticks and other vectors
- Drought

Air Quality

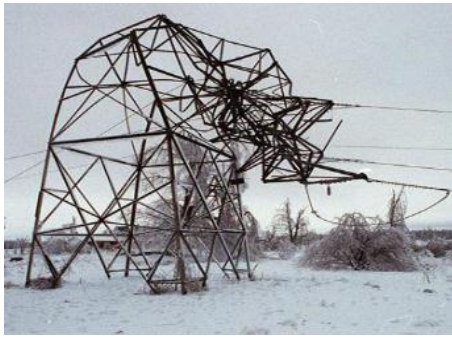
- Increased incidence of respiratory and cardiovascular disorders

Extended Warm Weather Season

- Aggravation of allergy symptoms and respiratory conditions
- Increased incidence of sunstroke, eye damage and other related conditions

Extreme Weather Events

- Flooding, wind damage and severe winter storm damage
- Increased risk of food and waterborne illnesses
- Increased risk of injury, illness or loss of life due to damage and weakening of infrastructure



Ontario

Ontario's Climate Change Efforts

2007 – Expert Panel on Climate Change Adaptation

2008 – Climate change identified as a key priority

2009 – Expert Panel releases *Adapting to Climate Change in Ontario*

Ontario is addressing climate change adaptation in different ways:

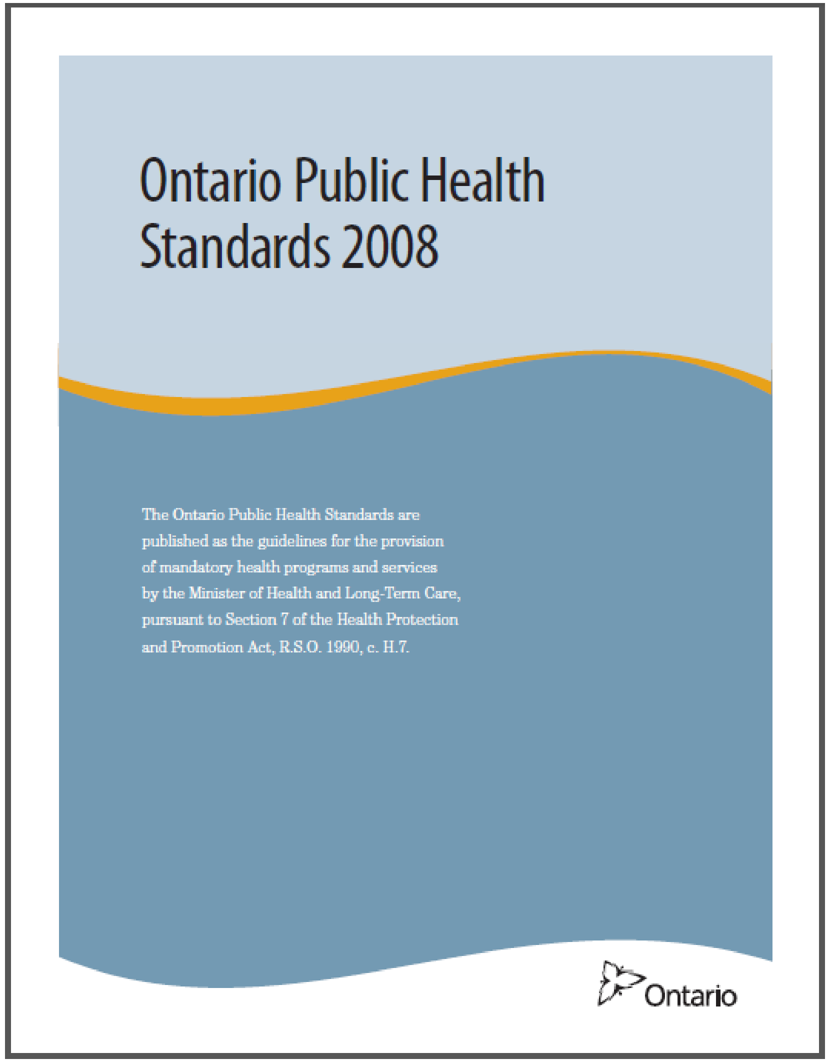
- *Climate Ready*, the Ontario government's climate change adaptation strategy and action plan
- *Great Lakes Strategy*, the Ontario government's road map to restore and protect the Great Lakes
- *Biodiversity: It's In Our Nature (BIION)*, the Ontario government's biodiversity implementation plan
- *Ontario's Action Plan for Healthcare*, the government's plan to make Ontario the healthiest place in North America to grow up and grow old

Ontario

Legislative Mandate

Health Hazard Prevention and Management Standard

- Increase public awareness of health hazards including climate change and emerging health issues associated with extreme weather

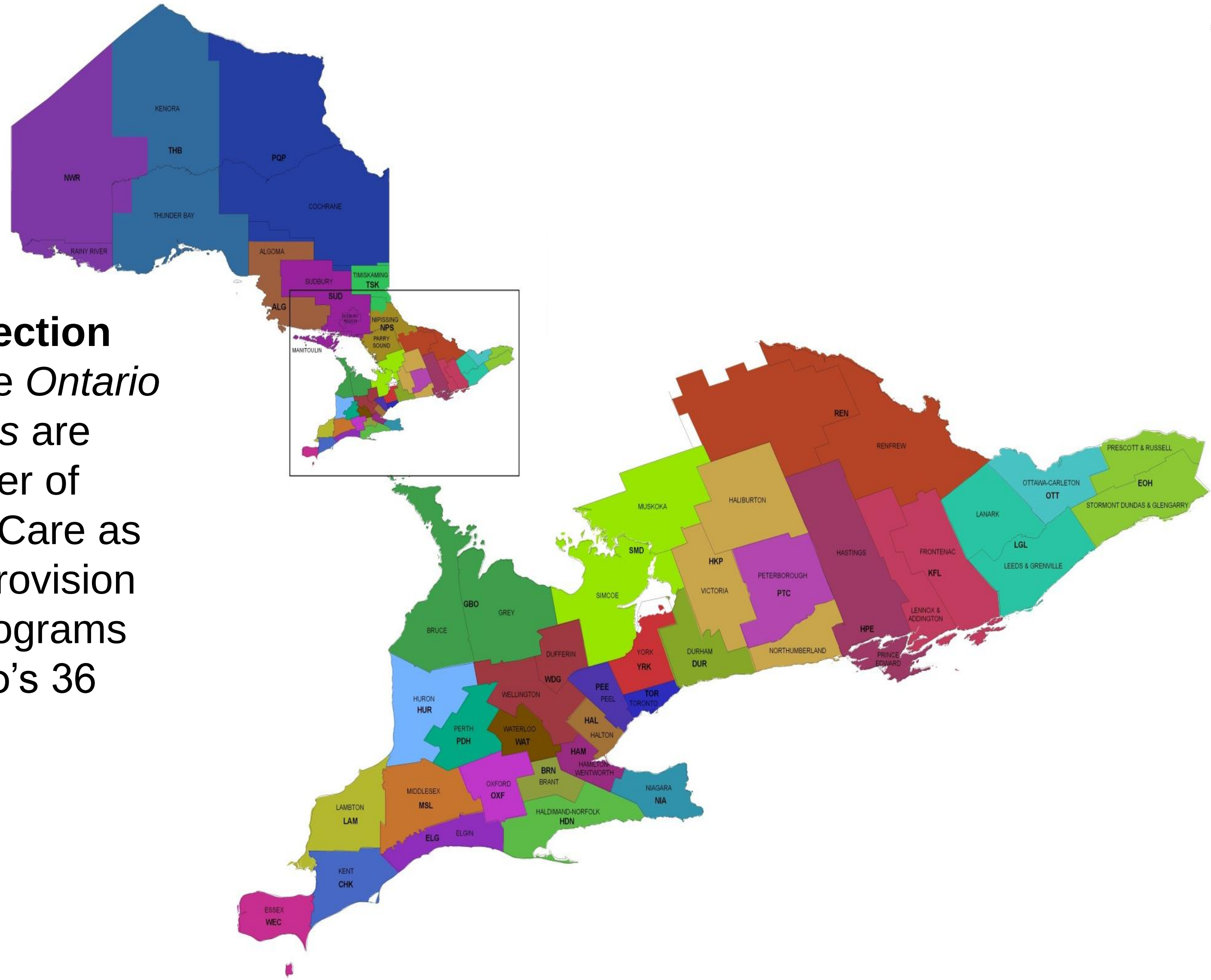


Identification, Investigation and Management of Health Hazards Protocol

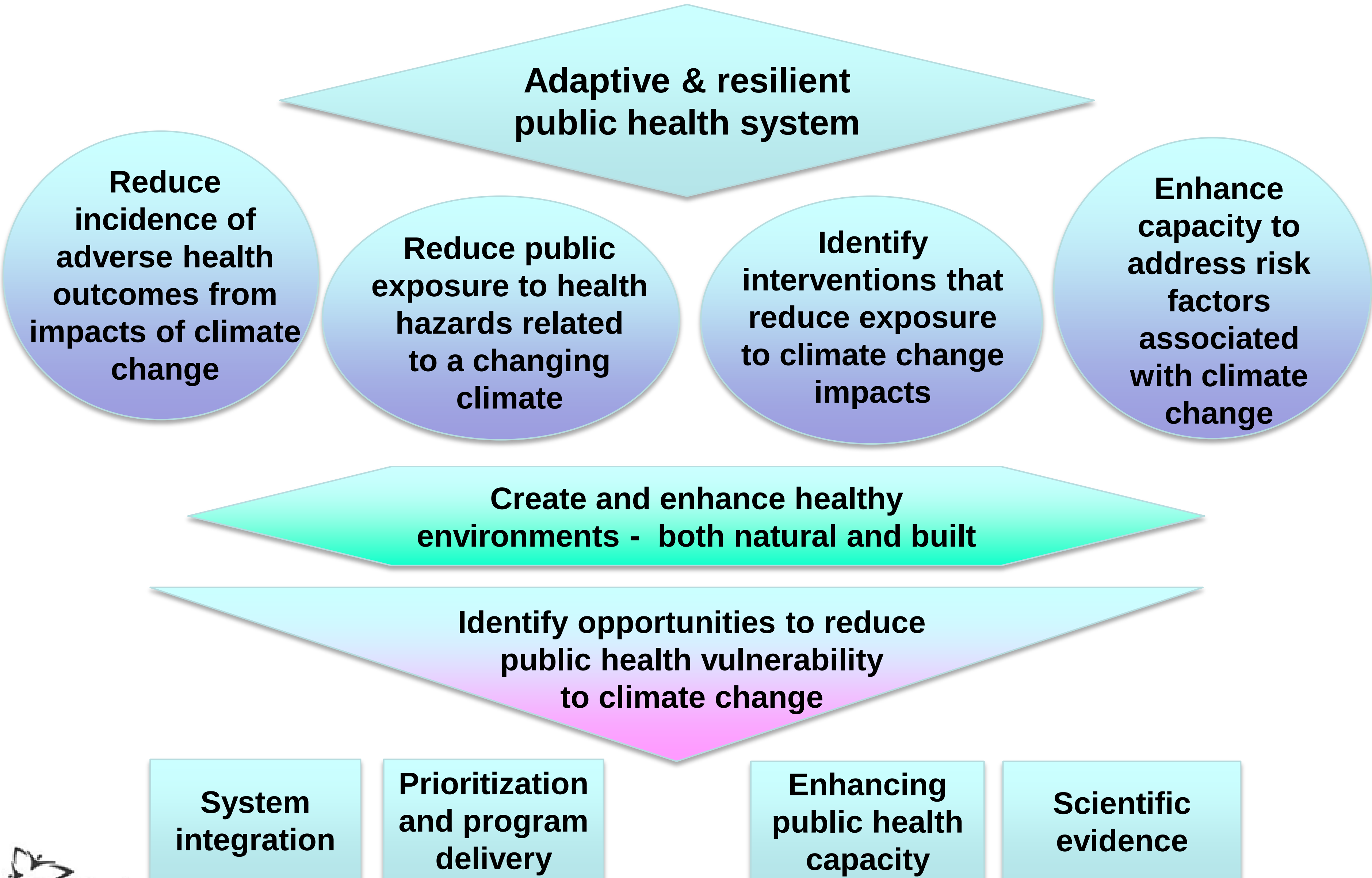
- Develop policies related to reducing health hazards
- Implement control measures to prevent or reduce exposure to health hazards
- Respond to and manage health hazards in the environment

Legislative Framework

Under the **Health Protection and Promotion Act** the *Ontario Public Health Standards* are published by the Minister of Health and Long-Term Care as the guidelines for the provision of mandatory health programs and services by Ontario's 36 Public Health Units

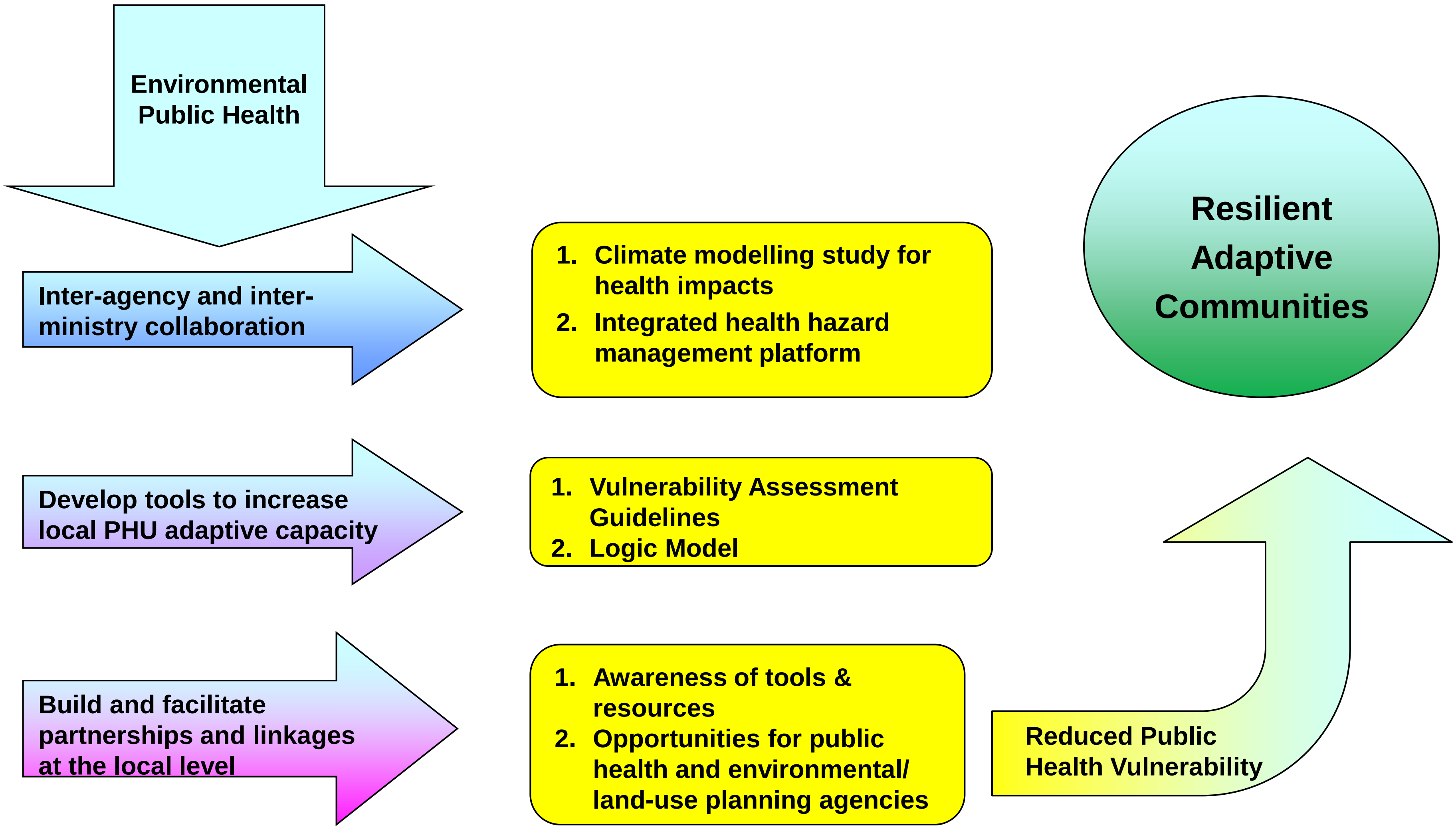


Framework for Action



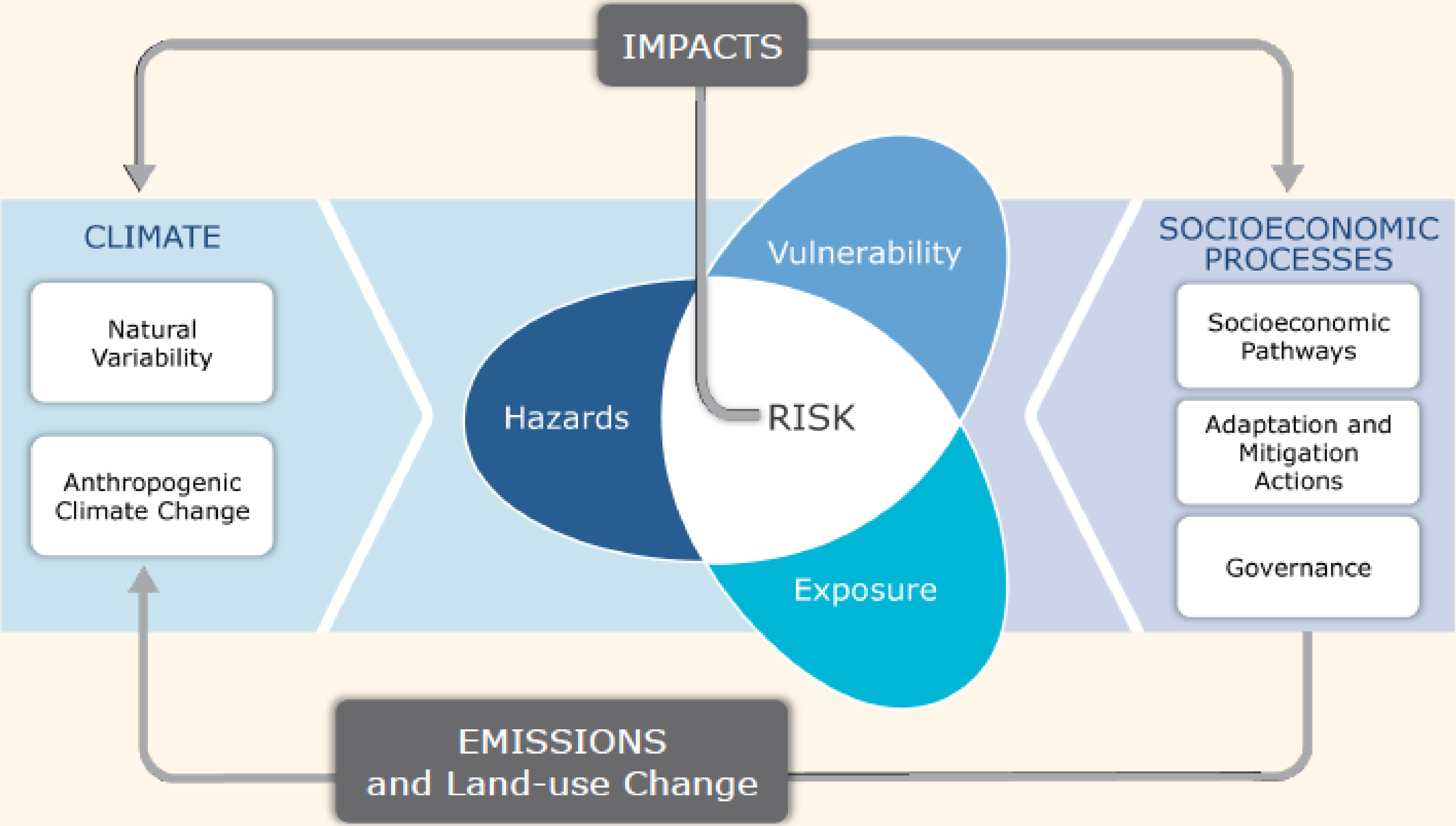
Ontario

Framework for Action



Ontario

Framework of Risks of Climate Variability & Change



Source: IPCC

Vulnerability & Adaptation Assessment Guidelines

Developed for Ontario PHUs to:

- Improve evidence and understanding between climate and health outcomes
- Provide information on severity and pattern of current and future health risks
- Identify opportunities to incorporate climate change concerns into existing policies and programs
- Provide a baseline analysis for future change
- Facilitate cross-sectoral collaboration to improve health outcomes

Climate Modelling Study

- Assess the impacts of climate change on human health and forecast key health risks across Ontario including:
  - ✓ *Heat stress*
  - ✓ *Waterborne illness*
  - ✓ *UV exposure*
  - ✓ *Vectorborne disease*
  - ✓ *Foodborne illness*
  - ✓ *Air pollution*

- Identify climate related health variables, required for the health models

- Generate projection scenarios for the 2020s, 2050s and 2080s for each of the 36 public health unit areas

- Provide graphical representation to illustrate the spatial distribution of health risks

Climate Change Impact Assessment (CCIA)

Key objectives:

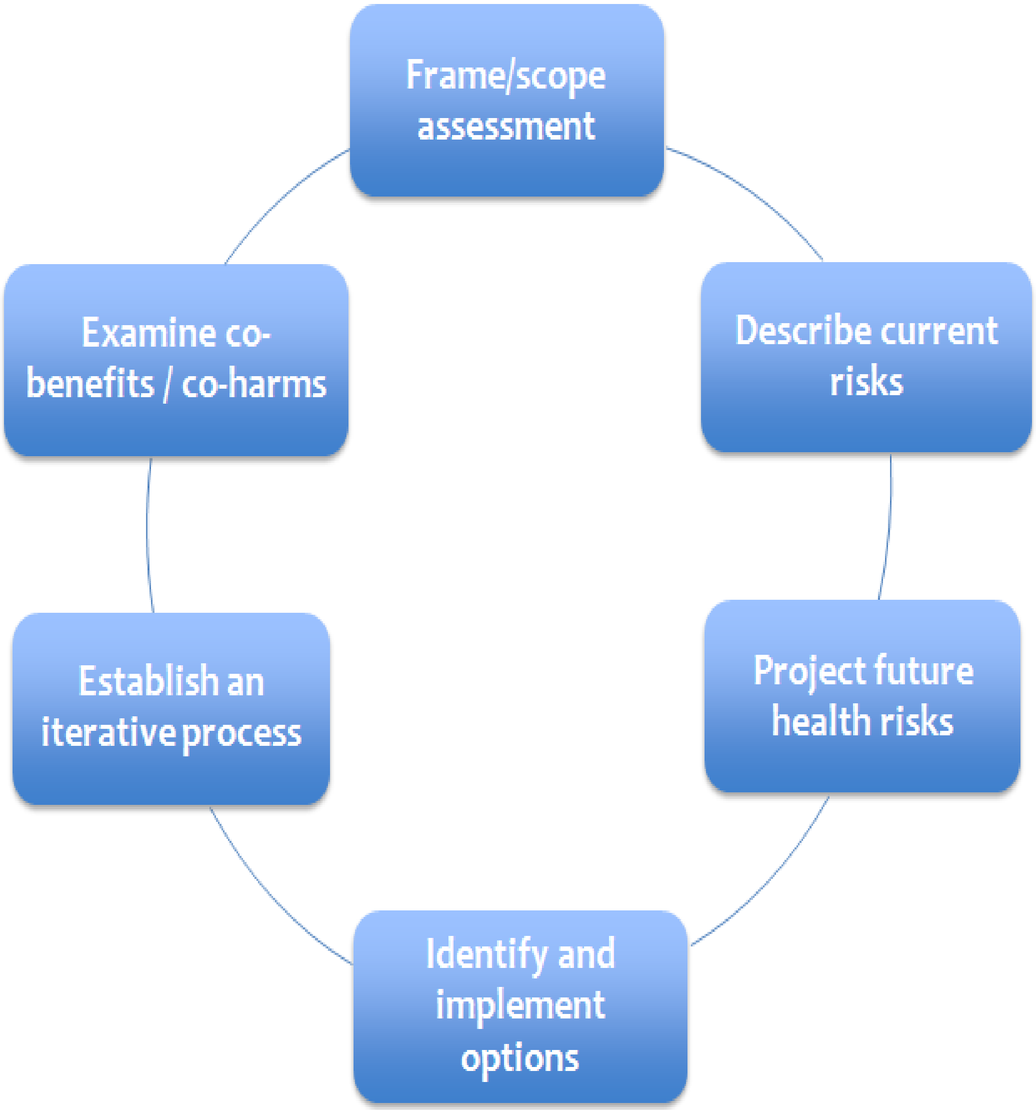
- Assess climate change impacts and adaptation in a scientific manner
- Provide mode of analysis that will enable policy/decision makers to choose among a set of adaptation options
- Develop a suitable strategy of responses that combines adaptation and mitigation measures

Seven steps of climate change impact assessment	
1	Define problem
2	Select method
3	Test method/sensitivity
4	Select scenarios
5	Assess biophysical impacts/ Assess socio-economic impacts
6	Assess autonomous adjustments
7	Evaluate adaptation strategies

Ontario

Vulnerability & Adaptation Assessment Steps

1. Frame and scope the assessment
2. Describe current risks, including vulnerabilities and capacities
3. Project future health risks
4. Identify and prioritize policies and programs to manage the additional health risks associated with a changing climate
5. Establish an iterative process for managing and monitoring health risks
6. Examine the potential health benefits and co-harms of adaptation; and mitigation options implemented in other sectors



Ontario

Resilient Community Outcomes

Ontario

Resilient Community Outcomes

Ontario

For more information:

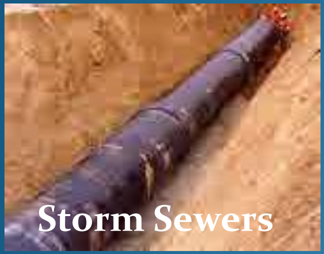
Vidya Anderson
(416) 326-0720
Vidya.Anderson@ontario.ca

Ministry of Health and Long-Term Care
Public Health Policy & Programs Branch
Environmental Health Section

Ontario

Ministry of
Transportation

Preliminary Assessment of Highway Drainage Infrastructure Resilience to Climate Change



Best in Science Symposium
27-28 November 2014

Hani Farghaly, PhD., P.Eng.
Ontario Ministry of Transportation
Design and Contracts Standards Office

Focus of the MTO Study

- The main focus of the MTO study is on the design procedures and standards of highway drainage infrastructure and if they provide some resilience to possible impact of climate change
- It also looked at possible adaptive measures in the management of existing and future drainage infrastructure assets and if they can be used to address future vulnerabilities

Objective of the Study

- The objective of the study was to conduct a practical review of the impact of flow increases as predicted by currently available climate change models for Ontario on MTO drainage infrastructure

- A practical review means following current design standards and procedures using actual design project in assessing the impact of flow increase scenarios

Note: There can be a general expectation that larger flows require larger infrastructure. This concept needed to be investigated to establish real design outcomes rather than generalized assumptions

Components of the Study

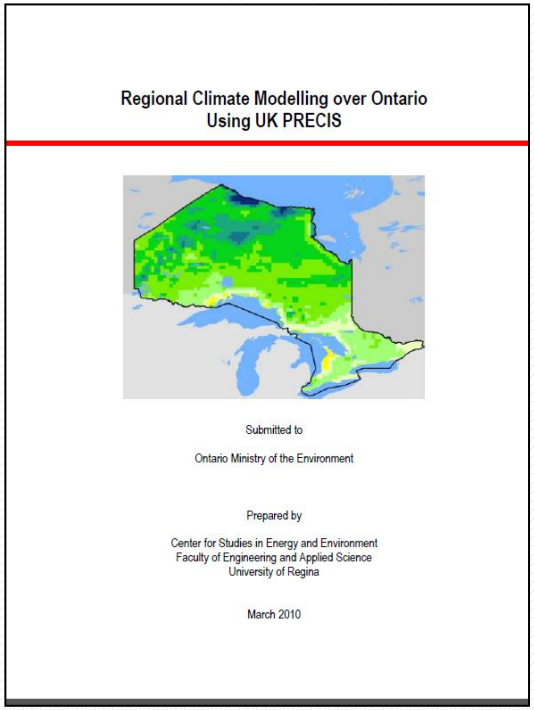
1. Review climate change (CC) studies for Ontario to determine reasonable climate change scenarios of rainfall to investigate
2. Assessment of the resilience of highway drainage infrastructure for different the identified climate change scenarios
3. Identify possible climate change adaptation measures for highway drainage infrastructure

Definition of Resilience

- The term “Resilience” can have many definitions depending on the investigation being conducted.
- In this study “Resilience” means “Hydraulic Resilience” and is defined as follows:

Hydraulic Resilience: The ability of a structure to maintain its hydraulic performance for a specific flow rate or design frequency in excess of the design value or frequency, without exceeding set threshold for structural and stream stability or road function

Main CC Studies Reviewed


Regional Climate Modelling over Ontario
Using UK PRECIS

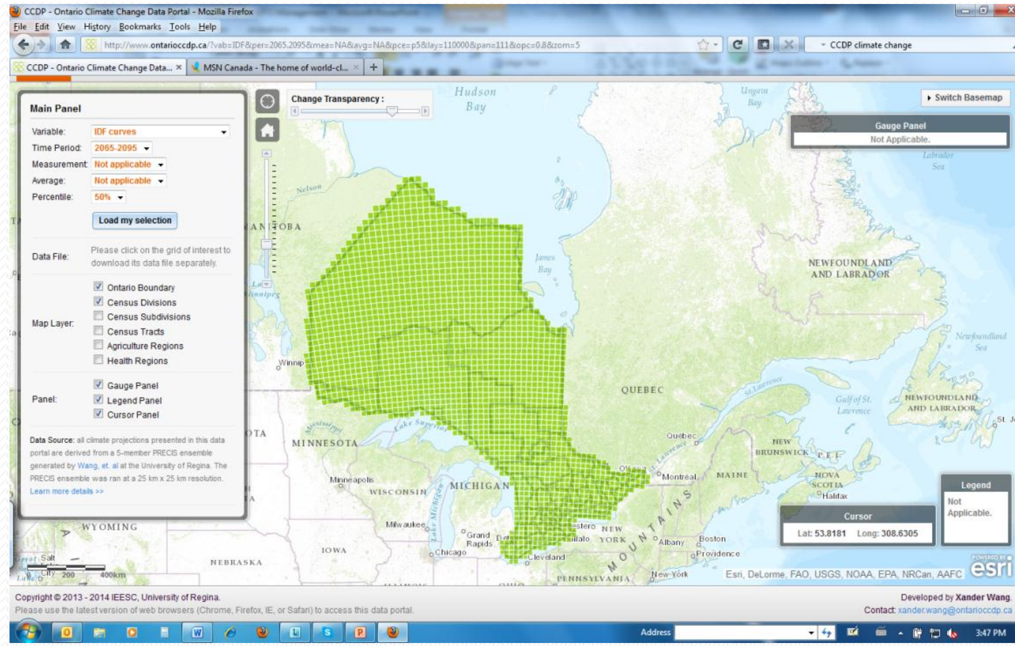
Submitted to

Ontario Ministry of the Environment

Prepared by

Center for Studies in Energy and Environment
Faculty of Engineering and Applied Science
University of Regina

March 2010



Regional Climate Modelling over Ontario
Using UK PRECIS
2010
Presented IDF curves for 12 stations (6 in Northern and 6 in Southern Ontario)

Climate Change Data Portal using 5-member PRECIS ensemble generated at the University of Regina. The PRECIS ensemble were ran at 25 km x 25 km resolution

2014
Presented IDF curves for 2000 grid points across Ontario

Climate Change Scenarios

- The three flow rate increase scenarios were identified based on the results of the MOE models :
  - 10% increase over the base condition (2007)
  - 20% increase over the base condition
  - 30% increase over the base condition

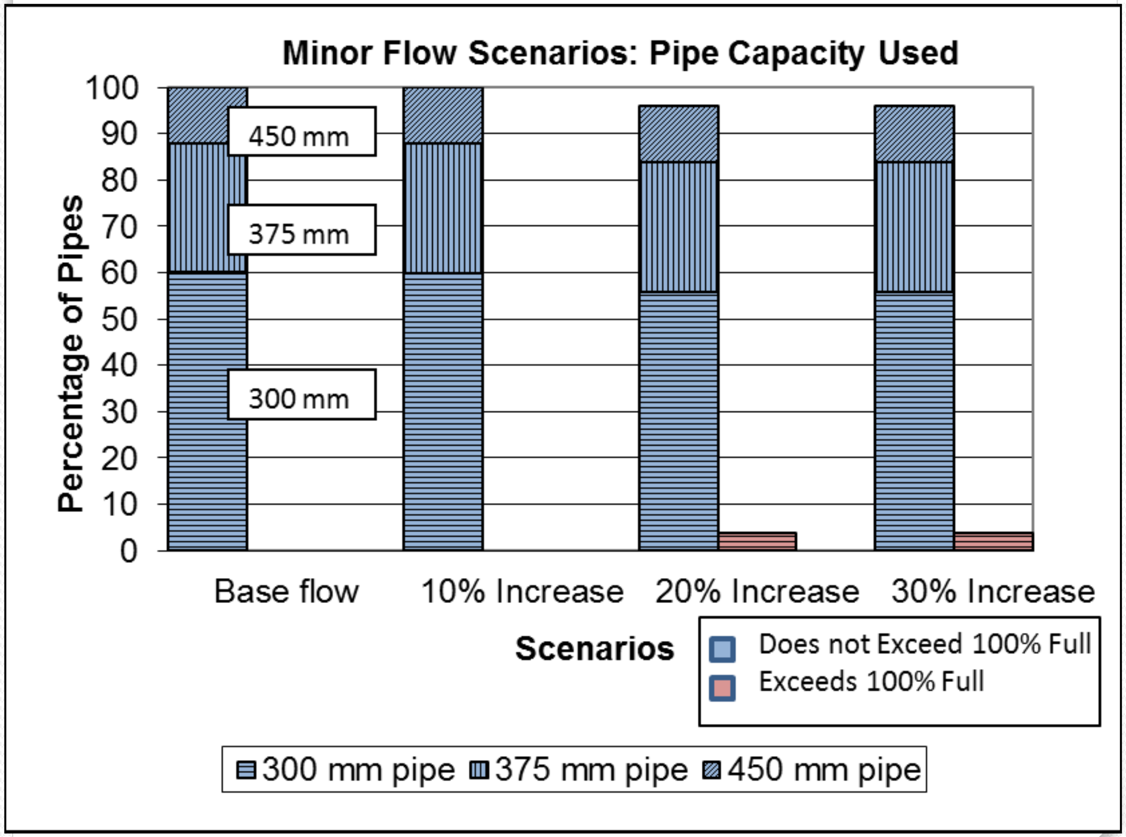
- These values only provided guidance for the assessment of the potential impact on the highway drainage infrastructure analysis

Finding for Storm Sewers Capacity

Network 1: (Highway 37)

Test Criteria:

Pipe Capacity exceeding 100% full

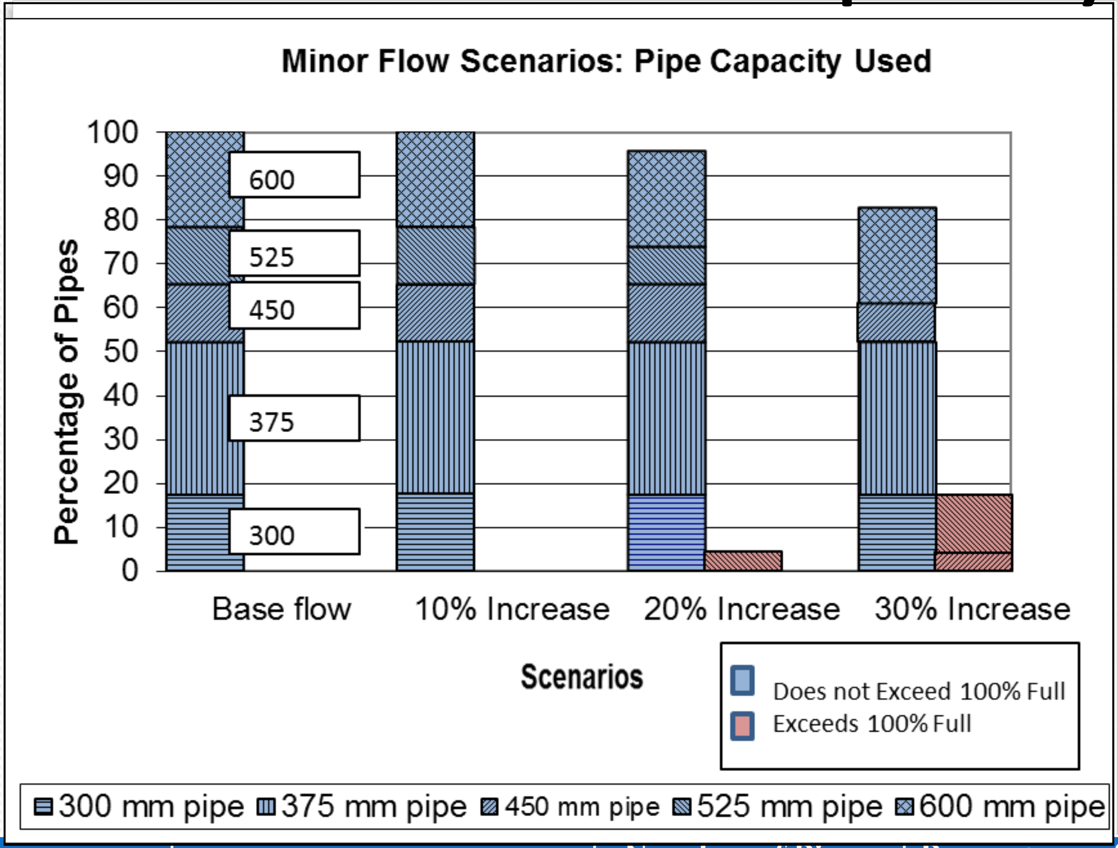


Scenario	Number of Pipes Not Exceeding Design Capacity of 100% Full	Percentage of Pipes Not Exceeding Design Capacity of 100% Full	Number of Pipes Exceeding Design Capacity of 100% Full	Percentage of Pipes Exceeding Design Capacity of 100% Full
10% Increase	25	100%	0	0%
20% Increase	24	96%	1	4%
30% Increase	24	96%	1	4%

Finding for Storm Sewers Capacity

Network 2: (Highway 417)

Test Criteria: Pipe Capacity exceeding 100% full for the different CC scenarios



Scenario	Number of Pipes Not Exceeding Design Capacity of 100% Full	Percentage of Pipes Not Exceeding Design Capacity of 100% Full	Number of Pipes Exceeding Design Capacity of 100% Full	Percentage of Pipes Exceeding Design Capacity of 100% Full
10% Increase	23	100%	0	0%
20% Increase	22	96%	1	4%
30% Increase	19	83%	4	17%

Finding for Spread on Roadway

	Base Case	10% Increase	20% Increase	30% Increase
Average Spread	1.12	1.14	1.18	1.22
Maximum Spread	2.34	2.43	2.51	2.59
Minimum Spread	0.33	0.34	0.35	0.36

Spread at Major Flow for Different Scenarios (Hwy 37)

	Base Case	10% Increase	20% Increase	30% Increa
Average Spread	1.48	1.54	1.59	1.73
Maximum Spread	2.26	2.34	2.42	2.49
Minimum Spread	0.63	0.65	0.67	0.92

Spread at Major Flow for Different Scenarios (Hwy 417)

Finding for Culverts

- 46 new or recently rehabilitated concrete and steel culverts
- The culvert sizes ranged from 450 mm diameter circular culverts up to 6100 x 2720 mm box culverts

Flow		Base Flow	10% Increase in Flow	20% Increase in Flow	30% Increase in Flow
Number of Culverts meeting Standard	(HW/D<1.5)	40	39	37	35
Number of Culverts Exceeding Standard	(HW/D≥1.5)	6	7	9	11
Percentage of Culverts not Meeting the Head Water Criteria		13%	15%	20%	24%
Percent Change in Number of Culverts not Meeting the Head Water Standard		0%	2%	7%	11%

Culvert Analysis Summary (Head Water Ration HW/D)

Finding for Culverts

Flow		Base Flow	10% Increase in Flow	20% Increase in Flow	30% Increase in Flow
Number of Culverts meeting Criteria	(V < 2m/s)	27	25	25	22
Number of Culverts Exceeding the Criteria	(V ≥ 2m/s)	19	21	21	24
Percentage of Culverts not meeting the Velocity Criteria		41%	46%	46%	52%
Percent Change in Number of Culverts Exceeding the Velocity Criteria		0%	4%	4%	11%

Culvert Analysis Summary (Exit Flow Velocity)

Bridges Analysis

- Each water crossing is unique and it is a challenge to develop an overall determination of how all bridges will perform under future climate change conditions
- Nevertheless, an investigation to determine the response of generalized bridge configurations can provide some insight into the possible response to increased flows.

Additional Design Considerations

- Bridges can have inherent resilience due to:
  - being on navigable waterways with clearances than required for hydraulic performance
  - having wider bridge spans to accommodate stream meanders or even straddling the entire stream valley

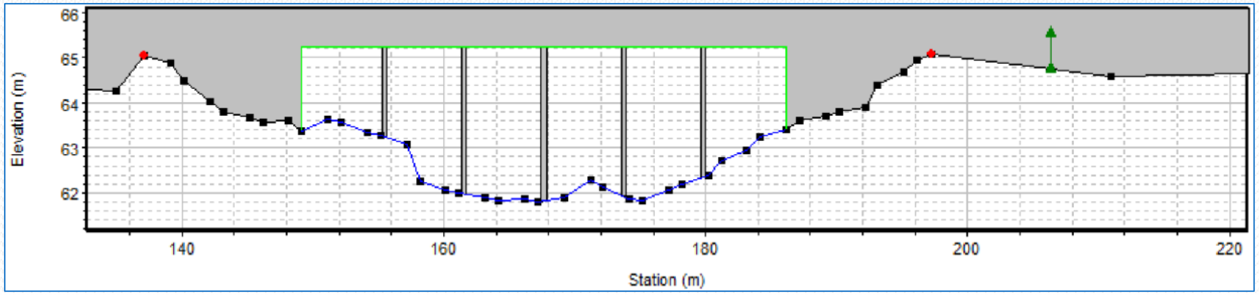
MTO Design Standard for Bridges

- Current MTO Drainage Design standards for bridges require the assessment and mitigation of the impact of the regulatory storm (*Hurricane Hazel, Timmins Storm or 100-year storm depending on location*) on the structure and surrounding lands and buildings.

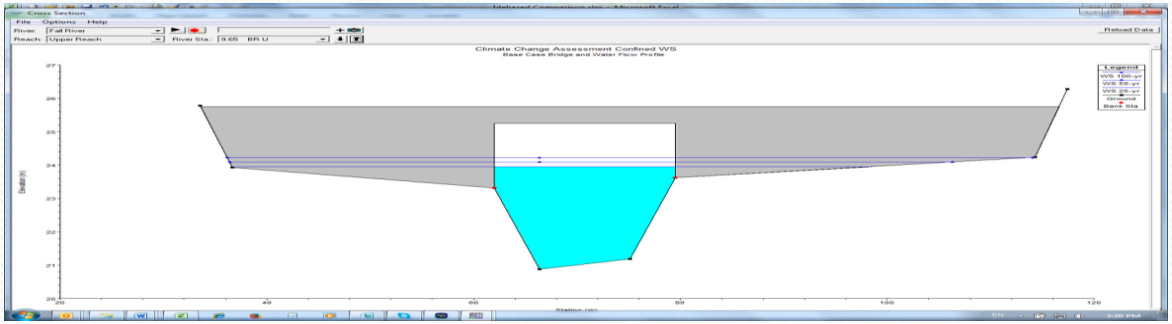
  (Regulatory storms are established by MNR)

- These storms are generally in excess of the design storm used in determining the size of the structure opening and erosion protection measures.

Types of Bridges Investigated



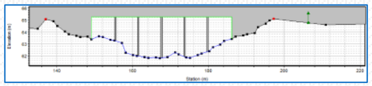
Bridge Structure 1



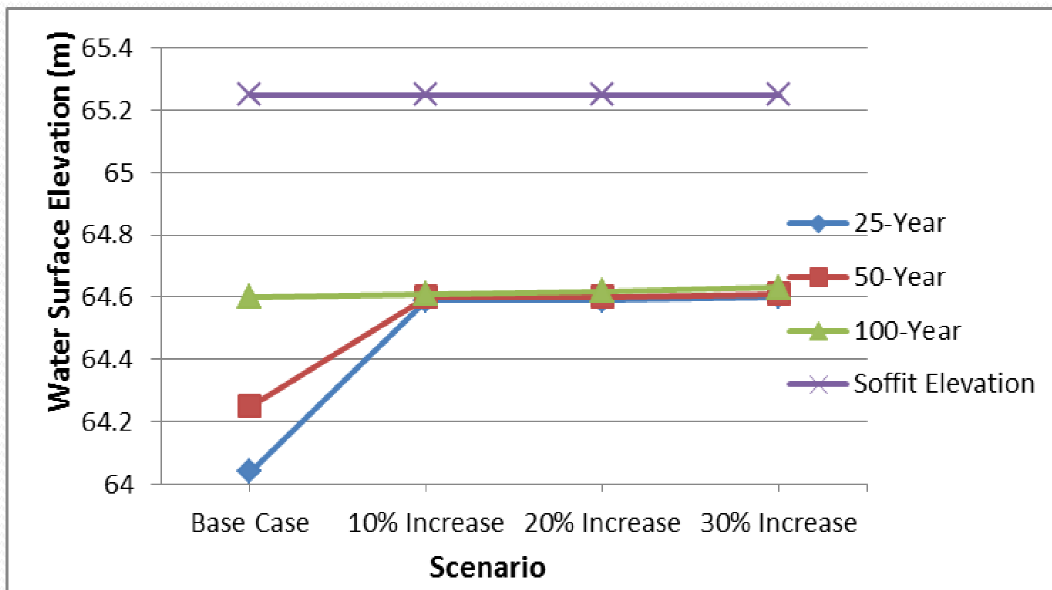
Two types of structures were investigated:

- a multi span bridge was selected that represents a standard bridge design with a floodplain that allows water to spread unimpeded
- a single span bridge that represents a standard bridge design with a restricted flood plain that does not allow water to spread unimpeded

Result for Bridge Structure 1



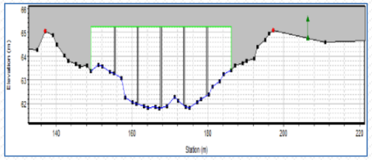
Return Period	Climate Change Scenario	H.W. Elevation (m)	Clearance (m)	Change in Clearance (m)
50	Base Case	64.25	1.02	0.00
50	10% Increase	64.6	0.67	0.35
50	20% Increase	64.6	0.67	0.35
50	30% Increase	64.61	0.66	0.36
100	Base Case	64.6	0.67	0.35

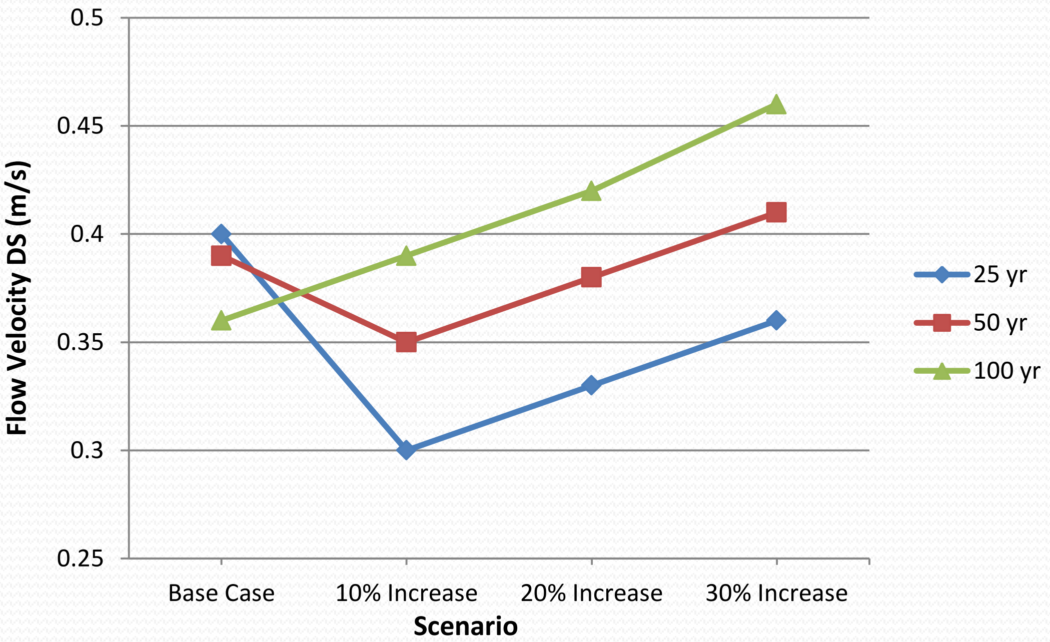


Water Surface Elevation at the Upstream Section of the Bridge

Result for Bridge Structure 1

Profile	Q Total	Flow Velocity
	m3/s	m/s
50-year Base Case	28.75	0.39
50-year 10% Increase	31.6	0.35
50-year 20% Increase	34.5	0.38
50 -year 30% Increase	37.4	0.41
100-year Base Case	32.5	0.36

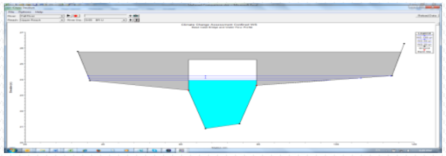


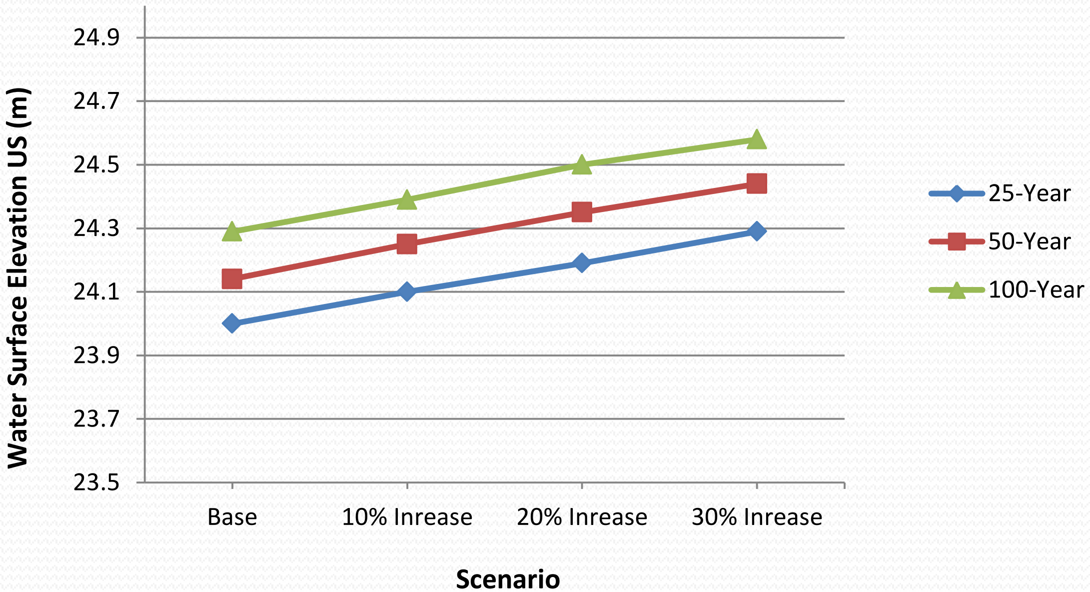


Flow Velocity at the Downstream Section of the Bridge

Result for Bridge Structure 2

Return Period	Climate Change Scenario	H.W. Elevation (m)	Clearance (m)	Change in Clearance (m)
50	Base Case	24.14	1.06	0
50	10% Increase	24.25	0.95	0.11
50	20% Increase	24.35	0.85	0.21
50	30% Increase	24.44	0.76	0.30
100	Base Case	24.21	0.99	0.07

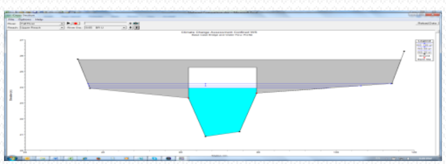


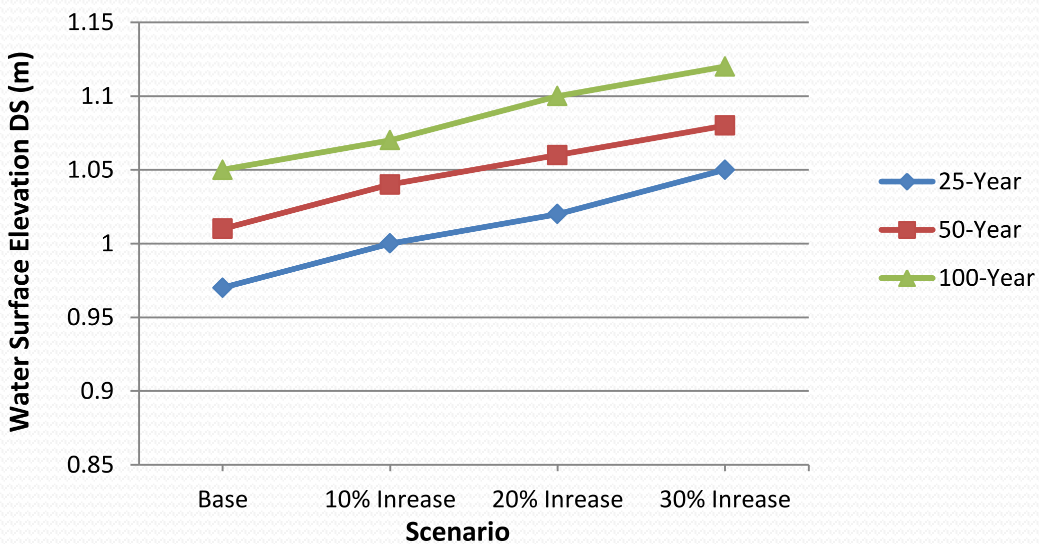


Water Surface Elevation Immediately Upstream of The Bridge

Result for Bridge Structure 2

Return Period	Climate Change Scenario	Flow Velocity Upstream (m/s)	Flow Velocity Downstream (m/s)	Change in Flow Velocity Upstream of Bridge (m/s)	Change in Flow Velocity Downstream of Bridge (m/s)
50 Years	Base	1.02	1.01	-	-
50 Years	10% Increase	1.05	1.04	0.03	0.03
50 Years	20% Increase	1.07	1.06	0.05	0.05
50 Years	30% Increase	1.08	1.08	0.07	0.07





Flow Velocity Immediately Downstream of Bridge

Conclusions

For the design cases and climate change scenarios investigated the following can be concluded:

- There appears to be significant resilience in storm sewer hydraulic capacity considering current design standards and methods
- Similarly for culverts, a significant percentage of culverts have resilience to the flow increases. Adaptive measures can address cases where flow capacity is an issue
- For bridges, current design practice provides sufficient capacity to handle increased flow. However, this only reflects the requirement for the stability of the structure.
- Impacts on surrounding land has to be assessed on a case by case basis
- There are general consideration that can be set to identify the more vulnerable structures.
- Changes in extreme events from the current regulatory storms applied in Ontario may cause significant impacts. These scenarios are not dealt with through changes in IDF curves and there are no current predictions provided in climate change studies.

Questions

Factor Affecting Bridges Resilience

Factors to be considered in determining the level of hydraulic resilience/vulnerability of a bridge structure to climate change. These include

- Whether or not the structure meets current design standards
- The span of the structure and how much the structure interferes with the stream channel
- Existing soffit clearances and freeboard at the approach. This includes clearances provided for navigation
- The characteristics of the watershed and availability of storage in the flood plain
- Location of buildings and structures and the possible impacts to lands within the zone of influence of the bridge due to increases in water level
- Existing bed material types and erosion measures protecting piers , abutments and footings
- History of flooding, debris flows and damage to the structure due to historic weather events, extreme or otherwise

Climate Change Vulnerability: Northern Ontario and the Mining Industry

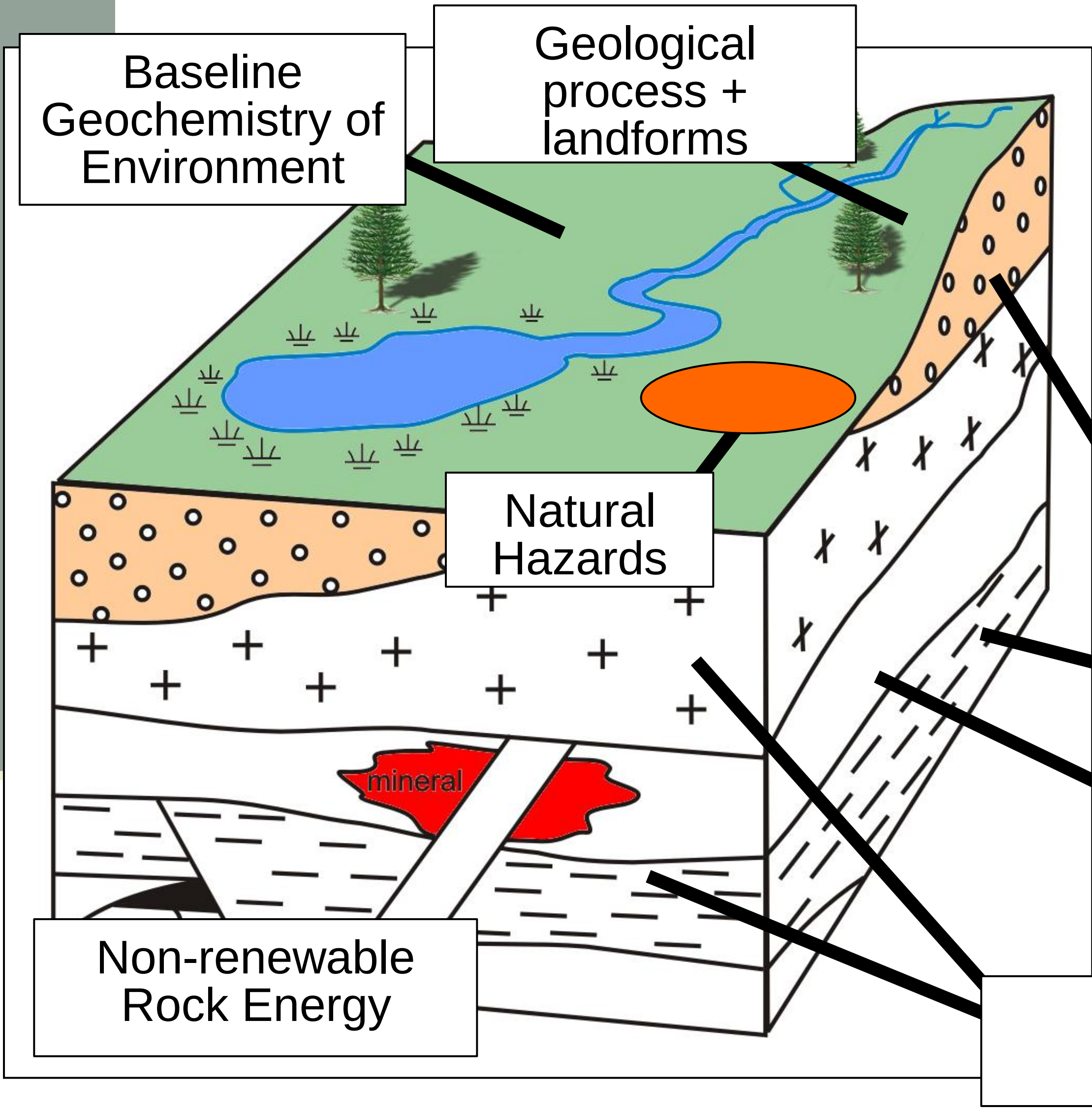
Ministry of Northern Development and Mines
Government of Ontario, Canada

A presentation to the
MOECC "Best in Science" Climate Change Symposium,
November 28, 2014

Outline

- MNDM geoscience data in support of Climate Change impact and mitigation models.
- Anticipated Impacts of Climate Change on Northern Ontario.
- Potential issues for Northern Ontario and the Mining Industry.

Ontario Geological Survey provides geoscience knowledge to support decision-making by Governments, civil-society, and industry



Application:
Mineral, aggregate, energy resources.
Water: surface + groundwater.
Climate change mitigation + adaption.
Waste management.
Natural geological hazards.
Public health and safety.
Land-use planning.
Infrastructure planning.

Ontario Geological Survey (OGS)

Application of geological data, information, and knowledge held by MNDM's Ontario Geological Survey (OGS), can help inform climate change impacts:

- Geological record of climate change and paleoclimate,
- Geological hazards,
- Groundwater,
- Physical infrastructure,
- Methane gas release,
- Metals in the environment,
- Green-house gas sequestration,
- Carbon reduction, and
- Soils and agriculture.

Geoscience Application: Climate Change Ontario Projections

Geological record of climate change and paleoclimate:

- Provide a geological context for global to local (Ontario) climate change rates based on geological record (i.e. isotopic records in deep seas sediment cores, ice cores; dating and paleoecological study of buried organic deposits).

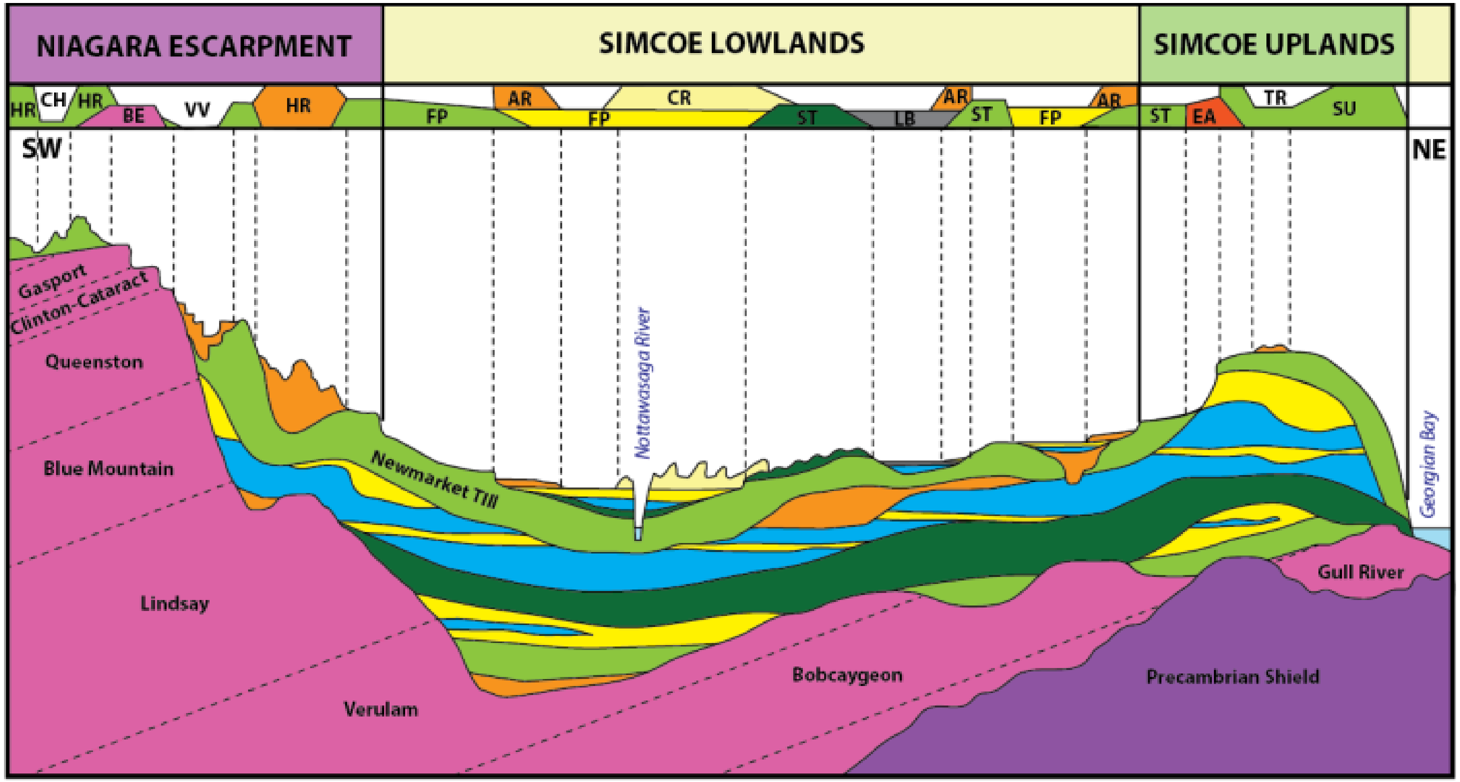
Geological hazards:

- Infer areas where increased frequency of landslides may be due to melting permafrost and coastal erosion.

Geoscience Application: Climate Change Ontario Projections

Groundwater:

- OGS maps aquifers across southern Ontario. The geological models can be applied to model climate change impact on old and young groundwater systems, including impacts on source water potential.



Geoscience Application: Climate Change Ontario Projections

Physical infrastructure:

- Identify areas where increased risk to all-season and winter roads are likely due to climate change.

Geological implications for physical infrastructure

Methane release:

- Identify geological conditions and areas of probable release of natural gas from gas hydrates, rocks, and soils.

Forest Rings: natural gas seep

Geoscience Application: Climate Change Ontario Projections

Metals in the Environment:

- Identify areas where potentially hazardous metals may be released into the environment due to changes in stability of the environment.

Alternate renewable heat sources

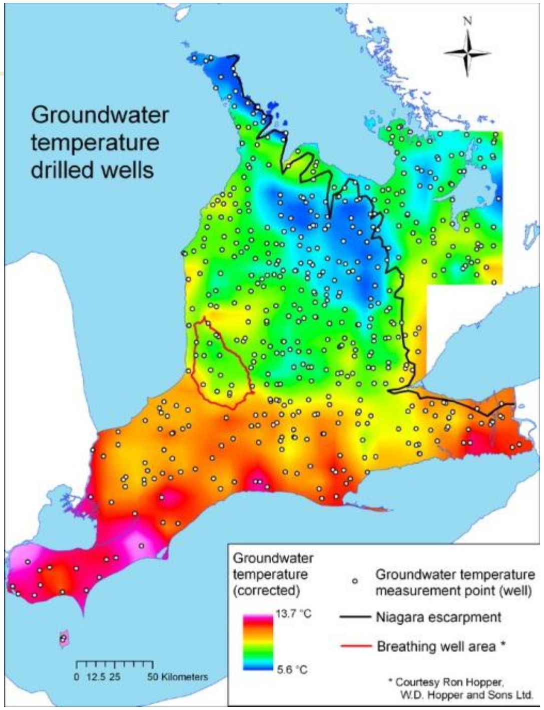
- Renewable ground heat.

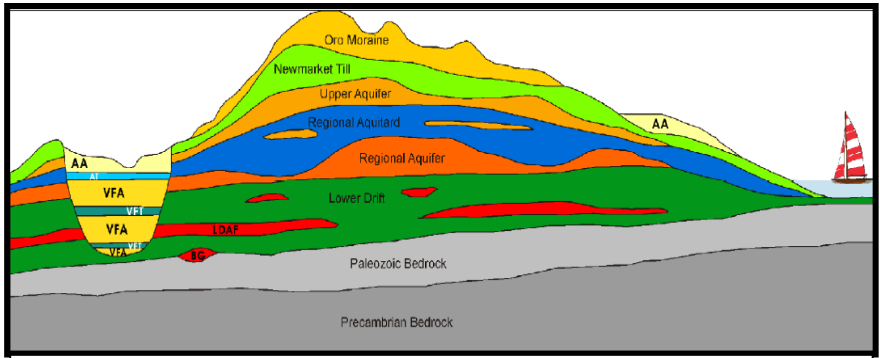
Green-house gas sequestration:

- OGS bedrock geology maps can help identify possible carbon-capture and storage (CCS) geological receptacles if CCS were to be considered in the future.

Soils and agriculture:

- Drought potential related to ground-water budget and CC and alternate agriculture areas.

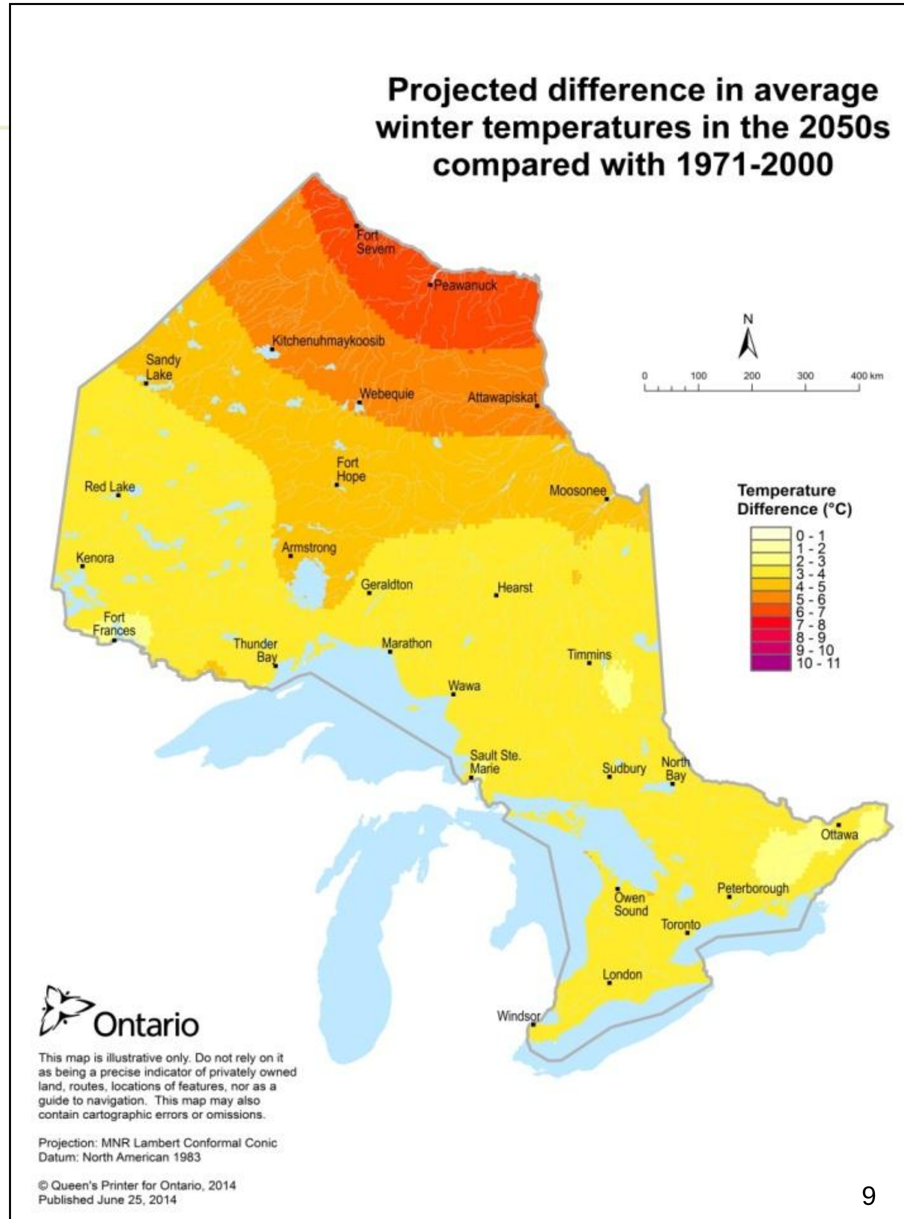




Aquifer models applied to drought management

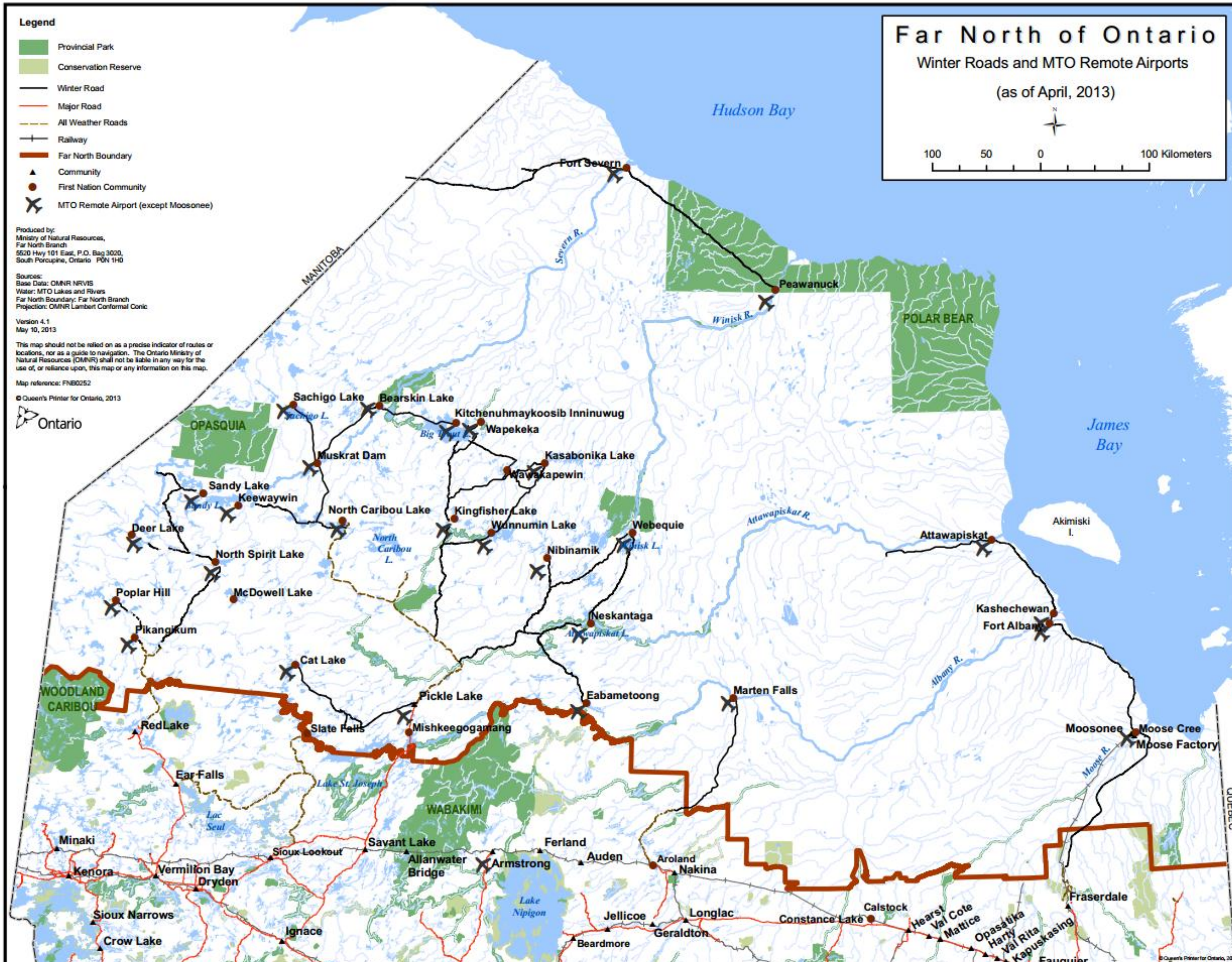
Anticipated Climate Change Impacts on Northern Ontario

- Rising Temperature
- Extreme weather events
- Changing water levels and precipitation
- Ecosystem stress
- Human health impacts



Geography and Population of Northern Ontario

- Northern Ontario covers 800,000 km^2, almost 90% of Ontario's land mass. By virtue of its geography and climate, the North has a dependence on resource-based industries.
- In 2013, Northern Ontario's population was estimated at 803,320, 5.9% of the provincial population.
- The "Far North", the portion of the province north of commercially licenced forestlands (above the red line in the map to the right) is considered one of Canada's most remote regions.
- The Far North is home to 24,000 people living in 34 communities, 31 of which are First Nation communities. First Nation people make up over 90% of the Far North's population.
- Far North communities rely on "winter roads", ice roads that allow temporary transport to areas with no permanent road access, and are re-built each year.


Far North of Ontario
Winter Roads and MTO Remote Airports
(as of April, 2013)
100 50 0 100 Kilometers
Legend
Provincial Park
Conservation Reserve
Winter Road
Major Road
All Weather Roads
Railway
Far North Boundary
Community
First Nation Community
MTO Remote Airport (except Moosonee)
Produced by:
Ministry of Natural Resources,
Far North Branch
5520 Hwy 101 East, P.O. Bag 3020,
South Porcupine, Ontario P0N 1H0
Sources:
Base Data: OMNR NRVIS
Water: MTO Lakes and Rivers
Far North Boundary: Far North Branch
Projection: OMNR Lambert Conformal Conic
Version 4.1
May 10, 2013
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Map reference: FNB0252
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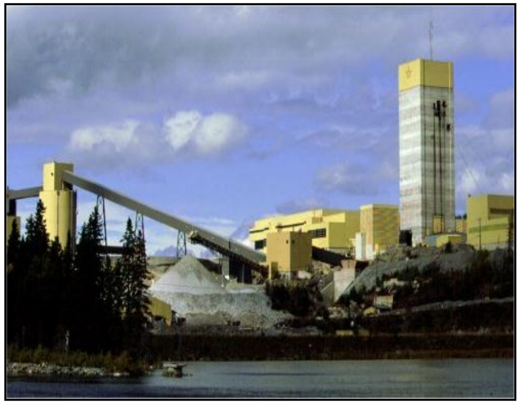
Ontario
Hudson Bay
James Bay
MANITOBA
QUEBEC
Fort Severn
Severn R.
Peawanuck
Winisk R.
POLAR BEAR
Akimiski I.
Sachigo Lake
Bearskin Lake
Kitchenuhmaykoosib Inninuwug
Wapekeka
OPASQUIA
Muskrat Dam
Kasabonika Lake
Wawakapewin
Sandy Lake
Keewaywin
North Caribou Lake
Kingfisher Lake
Wunnumin Lake
Webequie
Attawapiskat R.
Attawapiskat
Deer Lake
North Spirit Lake
Nibinamik
Poplar Hill
McDowell Lake
Kashechewan
Fort Albany
Pikangikum
Neskantaga
Albany R.
Cat Lake
Pickle Lake
Eabametoong
Marten Falls
WOODLAND CARIBOU
Red Lake
Slate Falls
Mishkeegogamang
Moosonee
Moose Cree
Moose Factory
Moose R.
Ear Falls
Lake St. Joseph
Lac Seul
WABAKIMI
Minaki
Sioux Lookout
Savant Lake
Ferland
Auden
Aroland
Nakina
Kenora
Vermilion Bay
Dryden
Allanwater Bridge
Armstrong
Lake Nipigon
Sioux Narrows
Crow Lake
Ignace
Jellicoe
Beardmore
Longlac
Geraldton
Calstock
Constance Lake
Hearst
Val Cote
Mattice
Opasatika
Harty
Val Rita
Kapuskasing
Fraserdale
Fauquier

Potential Issues for Northern Ontario

Ontario – A Leading Mining Jurisdiction

Victor Mine, Northern Ontario

Ontario – A Leading Mining Jurisdiction



- Ontario's mineral resource base is one of the richest in the world, and we lead Canada in the production of nickel, gold, cobalt, copper, platinum group metals, salt as well as sand and gravel.
- Much of Ontario's mining activity is located in Northern Ontario; however approximately 30% of mineral production comes from southern Ontario.
- The value of mineral production in 2013 was $9.8 billion from 42 industrial and metallic mines, equivalent to 22% of Canada's overall production.
- Employment from mining is significant (as of 2013):
  - Direct jobs in mineral production - 26,000
  - Mineral Processing - 50,000 direct and indirect
  - Mining Equipment and Services - 25,000
- In 2013, exploration expenditures remained over the $600 million mark

The Mining Sequence

Exploration

- Acquire land by claim staking and undertake exploration activities
- Potential activities includes further prospecting, airborne and ground-based geophysical surveys, claim staking, line cutting, stripping, drilling, road/trail building, bulk sampling

Mine Operations

- If exploration results look promising, a company may intensify its efforts or move on to advanced exploration, construction of a mine and operation of a mine.
- Potential activities during this stage includes mine design and construction, stripping/storing of overburden of soil and vegetation, ore extraction, crushing/ grinding of ore, flotation or chemical concentration of ore, mine and surface water treatment, storage of waste rock and tailings.

Mine Closure

- A company must rehabilitate and have a closure and reclamation plan for its mine and set aside financial assurance for the total estimated reclamation costs before the start of mining.
- Potential activities during this stage includes: recontouring of pit walls/waste rock piles, covering of reactive tailings ponds, decommissioning of roads, dismantling of buildings, re-seeding/planting of disturbed areas, ongoing monitoring and possible water quality treatment

Potential Issues for the Mining Industry

- More frequent and intense natural disasters may damage mine, transportation, and energy infrastructure and equipment.
- Increased physical and nonphysical risks will make project financing more difficult to secure.
- Increased spending on environmental management will be required/longer term monitoring to ensure effectiveness of reclamation measures.
- Permafrost thaw, leading to deterioration of infrastructure including building foundations, pipelines, roads, dams, bridges and the melting of impermeable permafrost beds of mine-tailing ponds and landfill sites

Conclusion

- Geoscience offers not only historical insight to rates of past climate changes that affected the Earth, but geological data is also an important consideration in the mitigation and adaptation of future changes that will affect the Earth.

“The past is the key to the future”.