And there's more where this came from !
……..Muskoka's climate in 2050

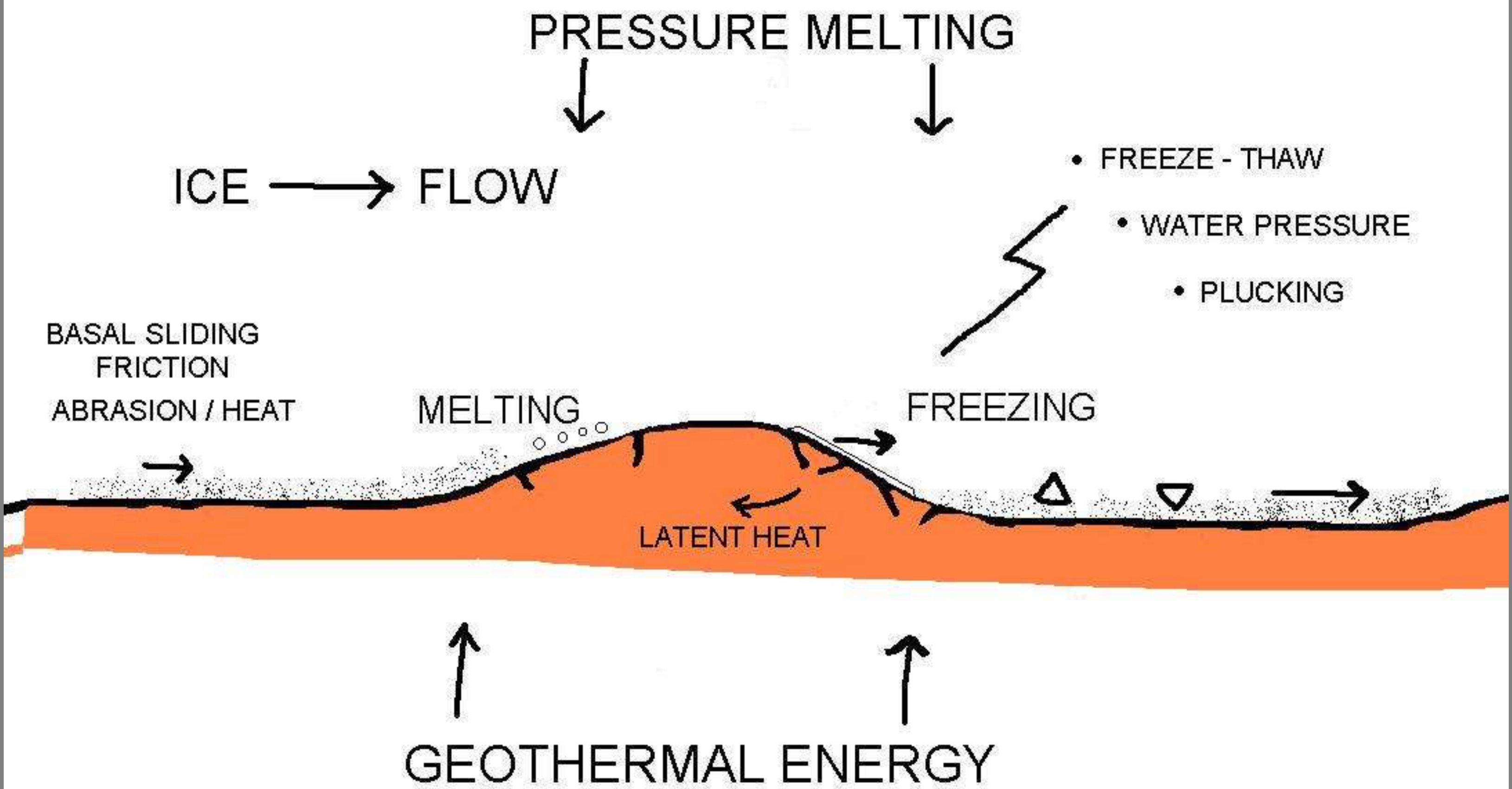
David Pearson
Laurentian University / Science North
and the
Ontario Panel on Climate Adaptation

24 April 2008

Muskoka News


Bracebridge 11,000 years ago

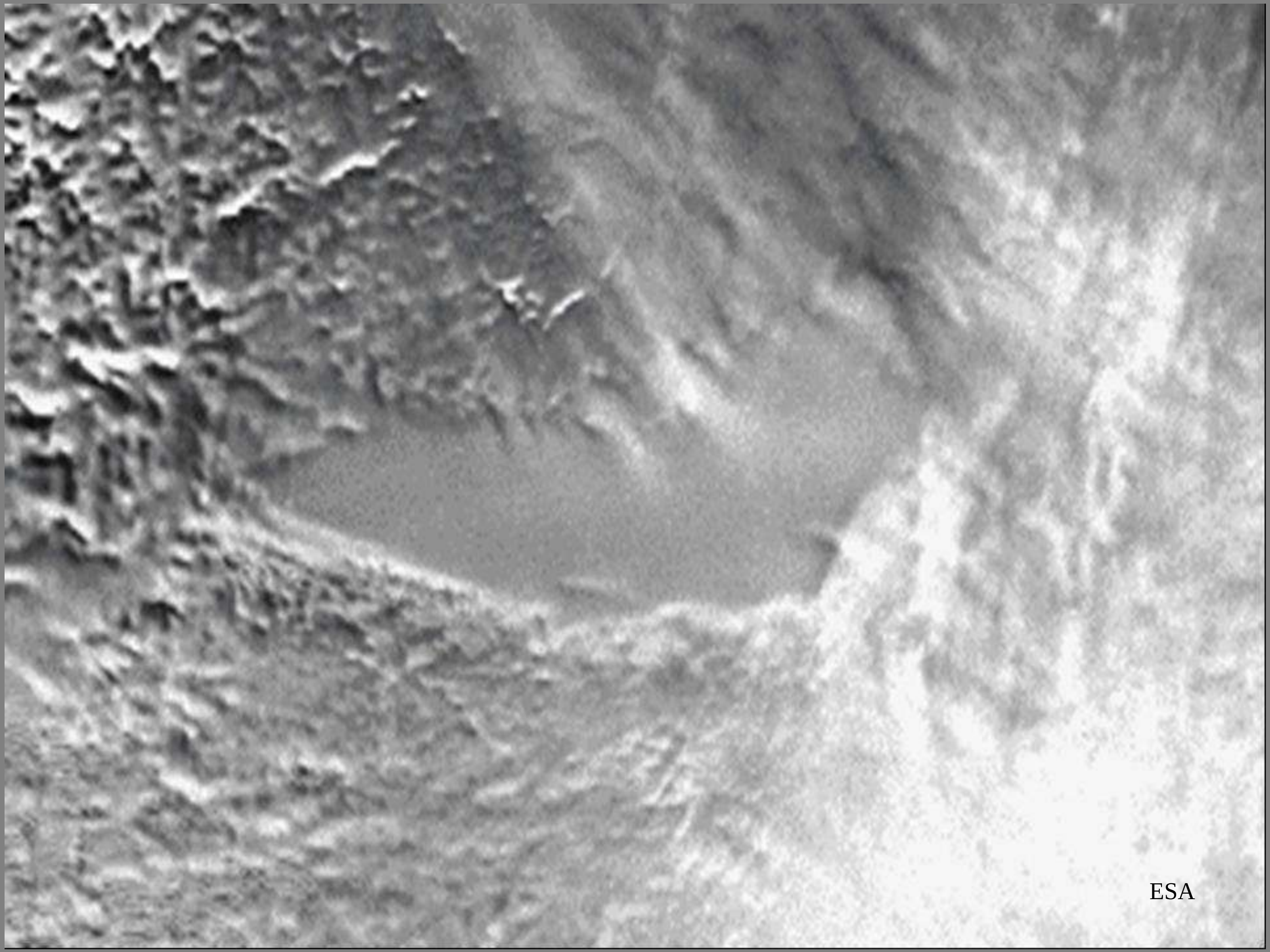

21,000 years ago
Russia
Bering land bridge
Greenland
Canada
United States
Univ. of Montana



(After Sugden & John, 1976)

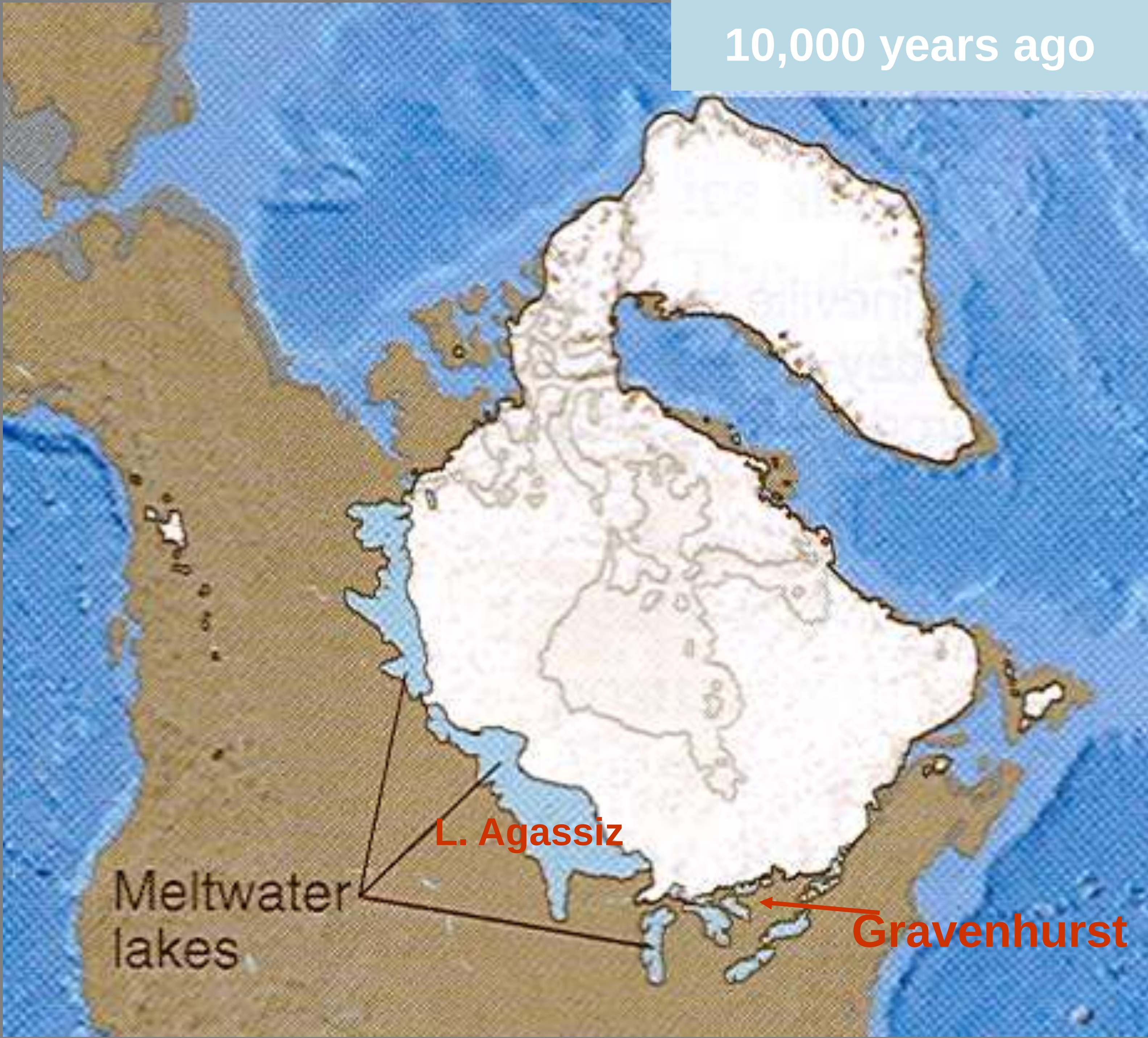
GSC

Under-ice lakes In Antarctica – might they have existed under the Laurentian ice sheet ?



10,000 years ago

Ice over Ontario is melting

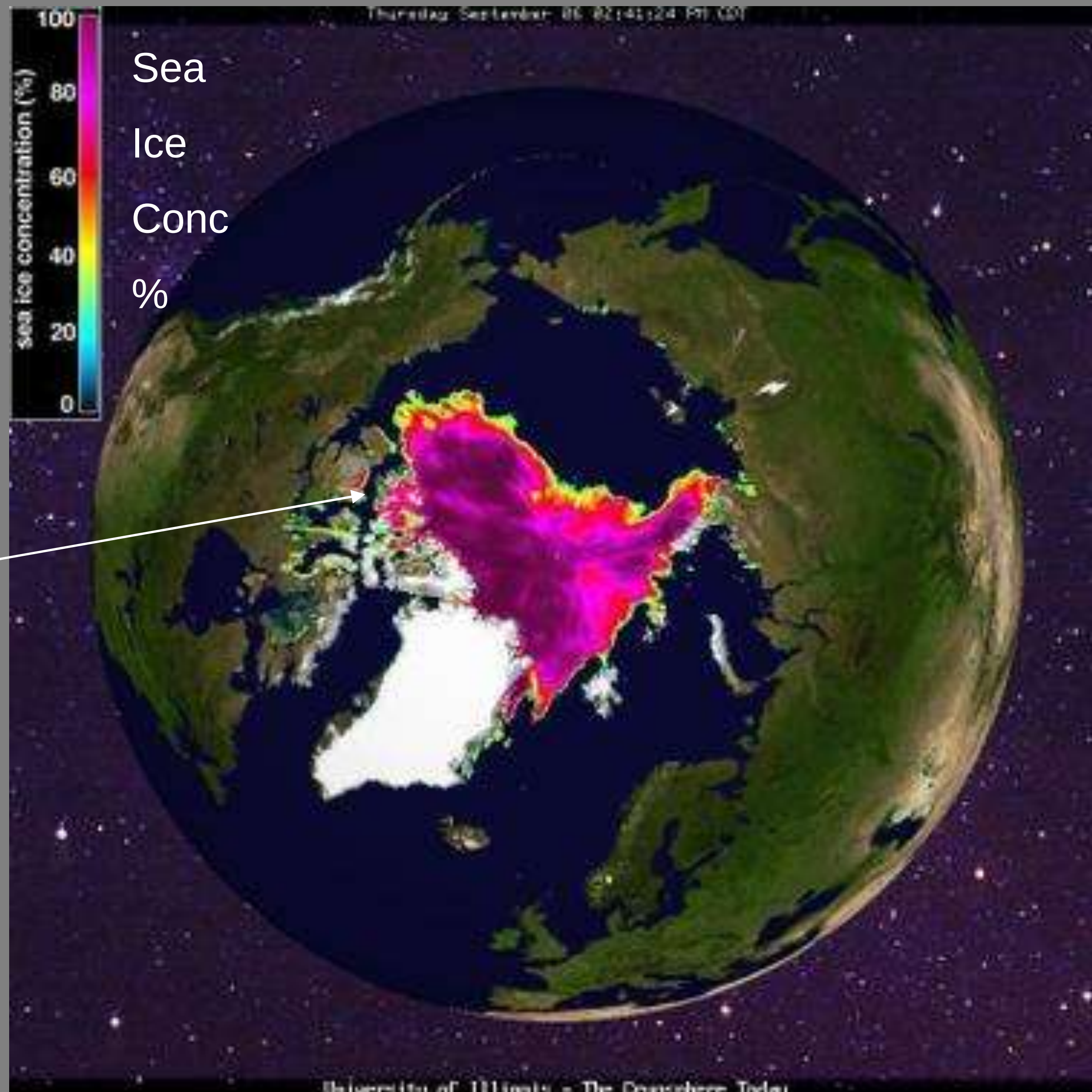



Jökullsarlón Lake, Iceland,
Simon Ho, ANU

9,500 years ago

After Teller 1987

The opening of the North West Passage 2007



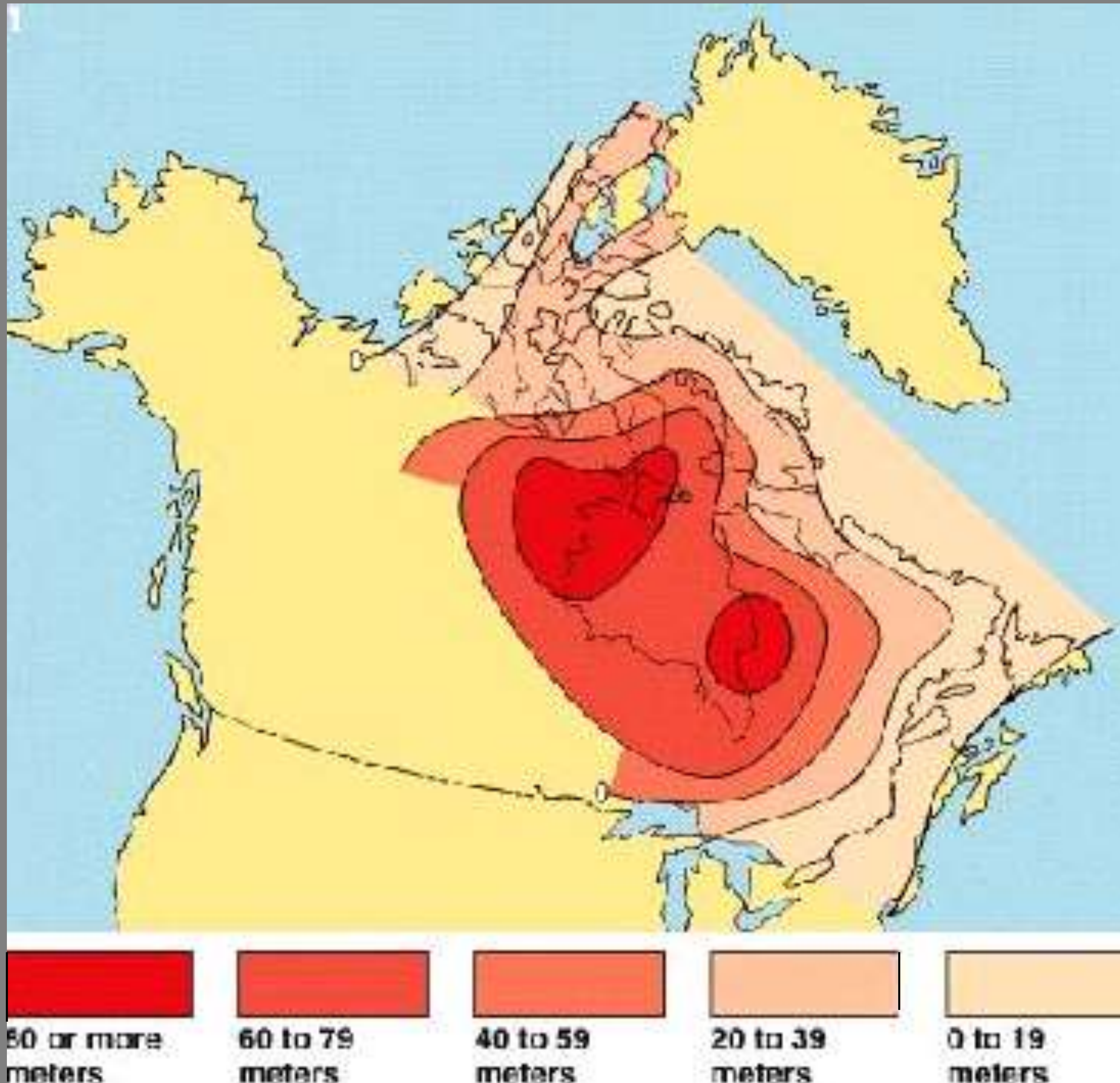
NW Passage

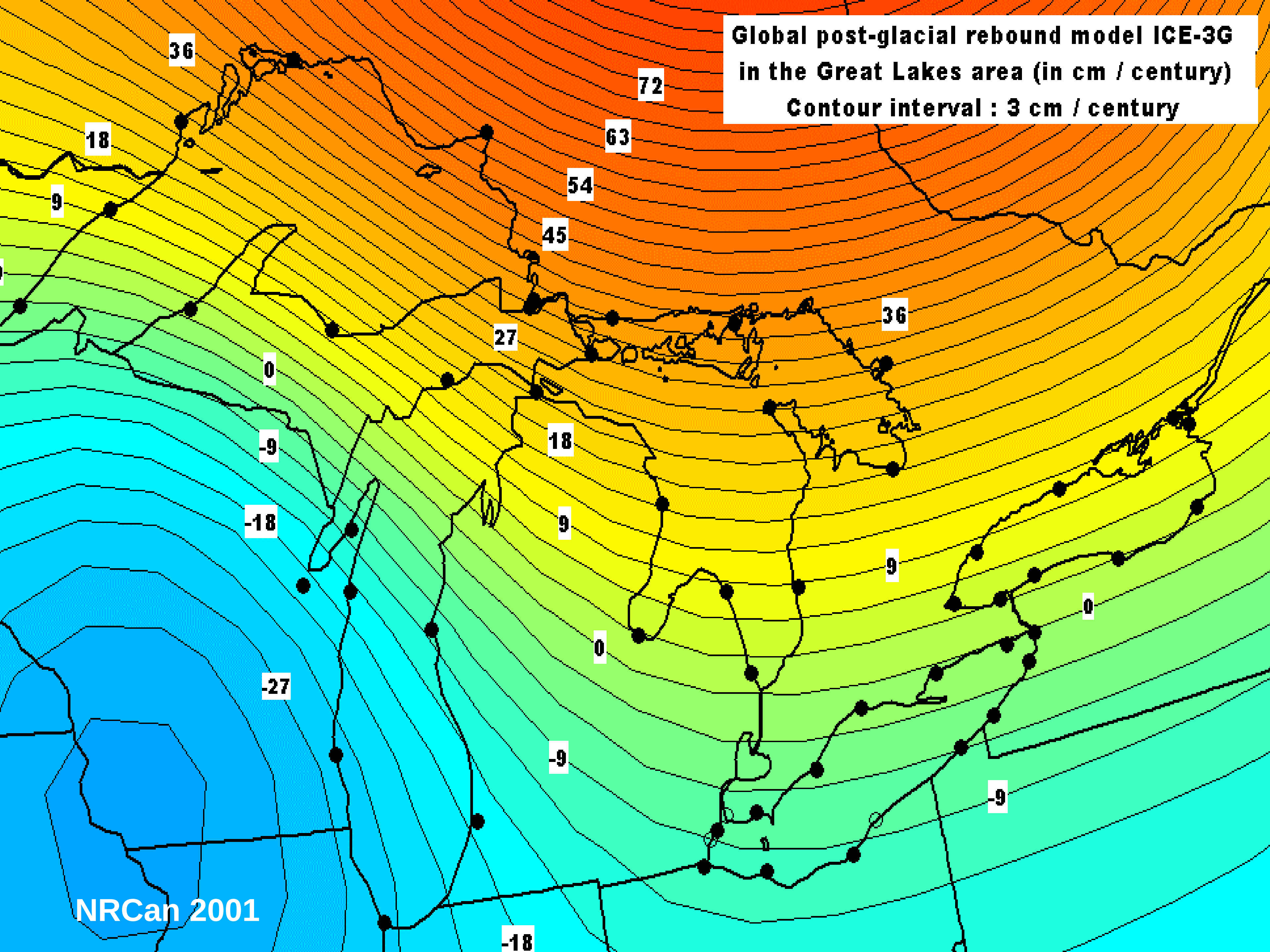
Post-glacial drainage

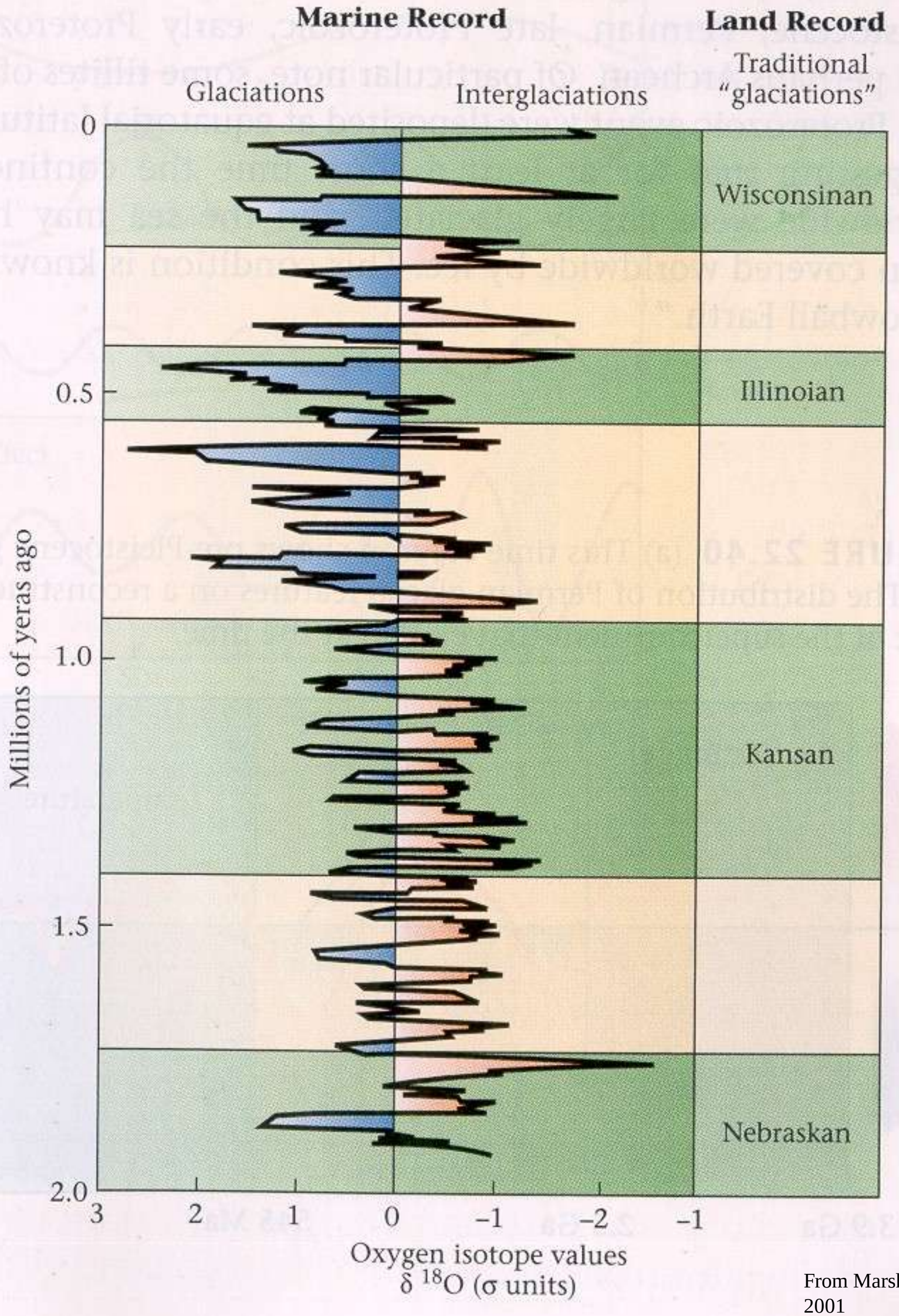
Pre-glacial drainage

Glacial Rebound

Sudbury has risen about 35 to 40 metres since the last ice sheet melted and is still rising at about 50 cm a century




Global post-glacial rebound model ICE-3G
in the Great Lakes area (in cm / century)
Contour interval : 3 cm / century
36
72
18
63
9
54
45
36
27
0
18
-9
9
-18
9
0
0
-27
-9
-9
-18
NRCan 2001



From Marshack 2001

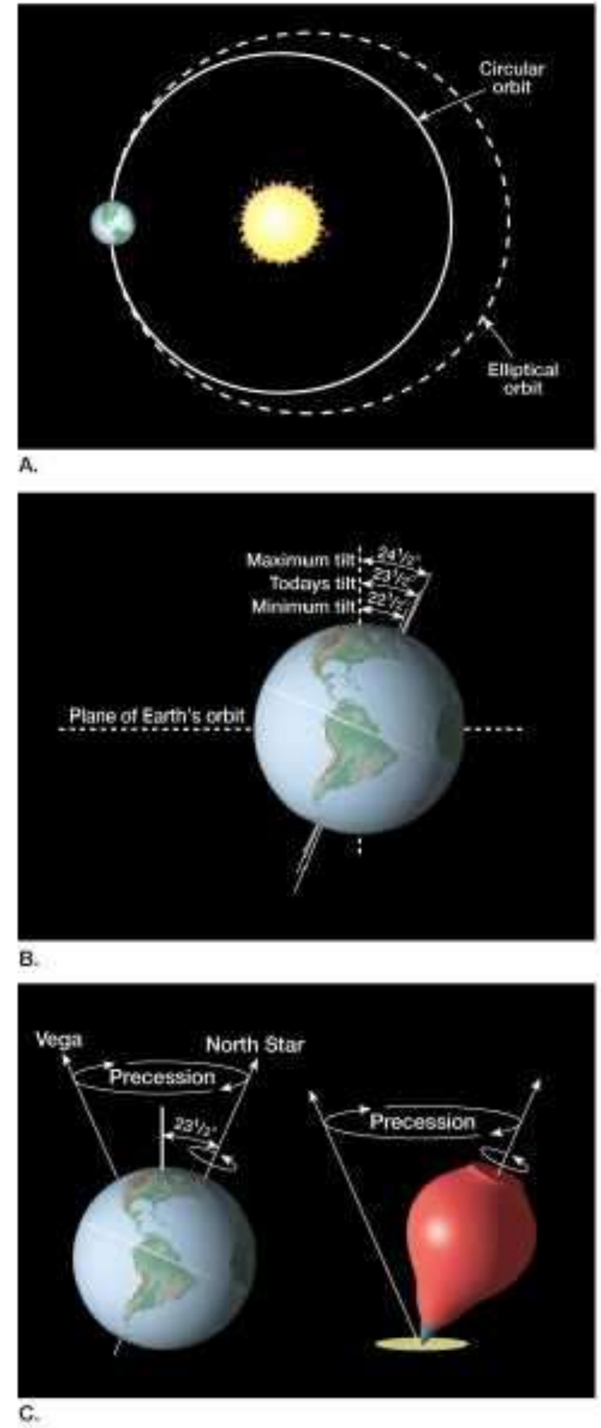
Geometry of Earth's orbit

Earth's orbit changes from nearly circular to elliptical and back over about 100,000 years. We are now about 5 million km (3%) closer to the Sun in January than in July

The tilt of the axis of rotation changes from 21.5º to 24.5º and back over 41,000 years. It is now 23.4º

The Earth's axis wobbles like a top over a cycle of 26,000 yrs, shifting the seasons around the orbit. Vega was the "North Star" 13,000 years ago.

More distant in summer + low tilt = cool = survival of snow at mid-north latitudes = advance of ice = Ice Age




Vostok

450,000 year record of CO2 and temp in an Antarctic ice core (Vostok)

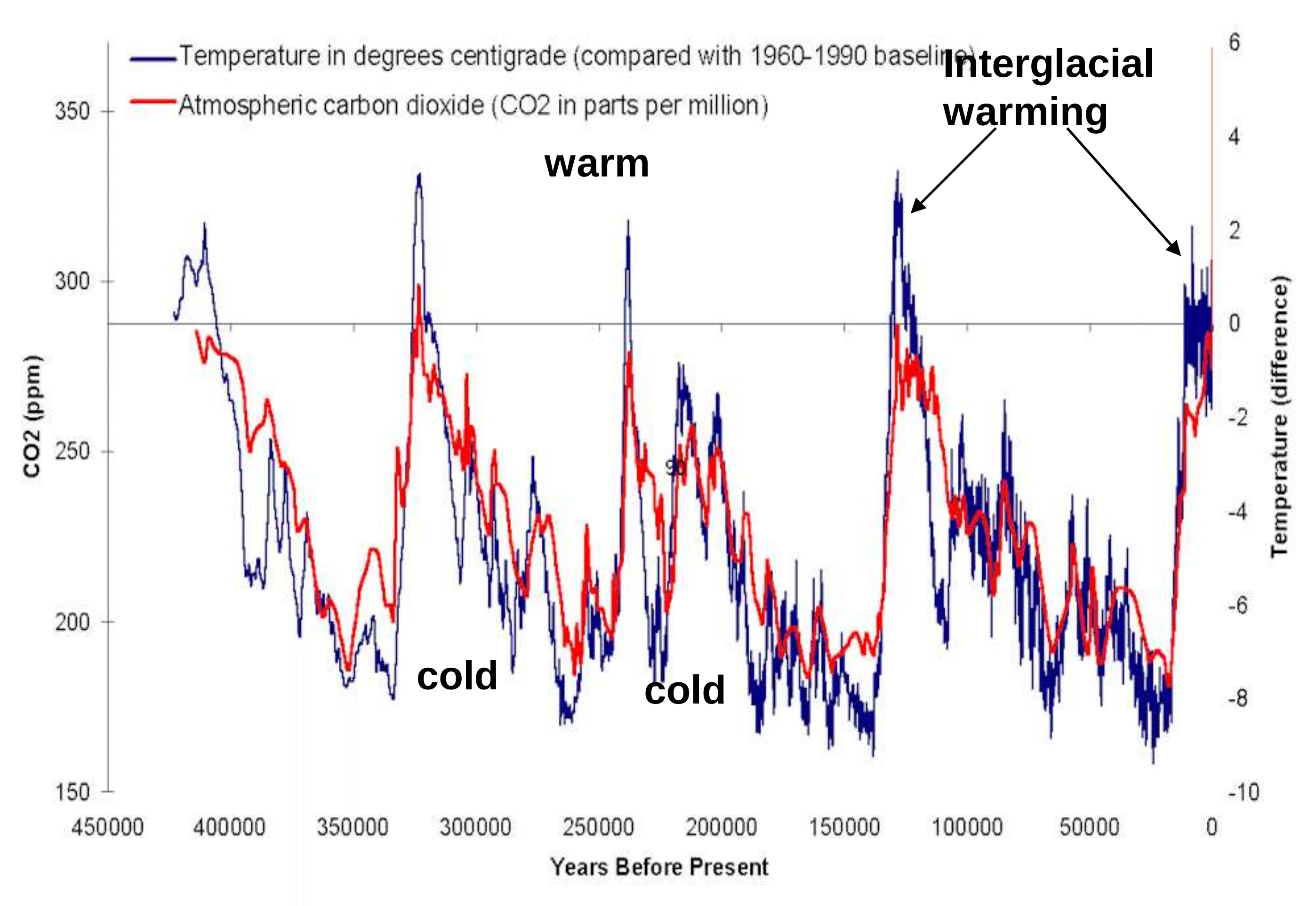
First rise in temp comes before CO2 increase until release of ocean CO2 drives warming about 800 yrs later

Interglacial warming because of

1. Changes in the geometry of Earth's orbit

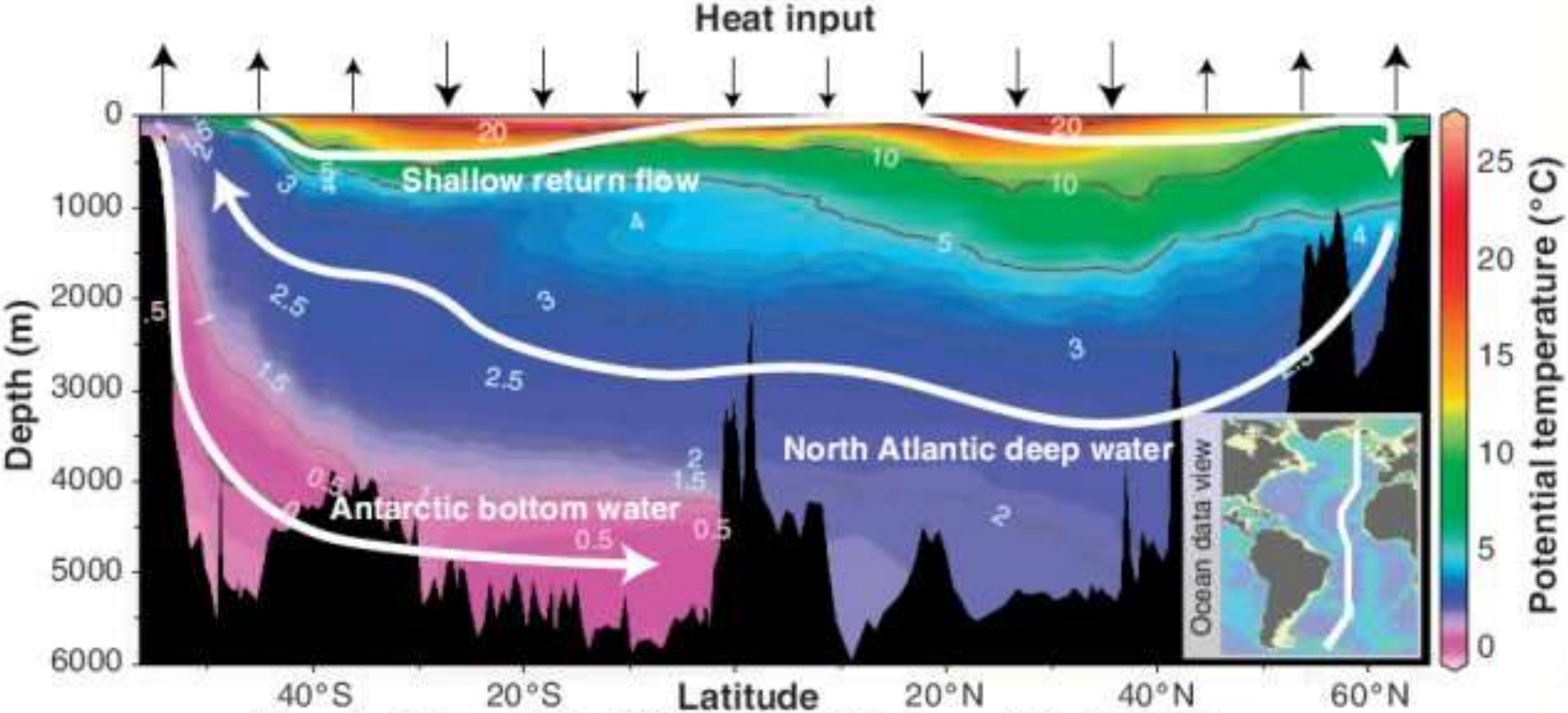
2. Loss of polar snow

3. Release of CO2 from ocean



Atlantic Ocean current system

- deep currents take 500 yrs to travel the length of the ocean
- cold deep water loses dissolved CO_2 at warm ocean surface



Hegerl, G.C. and Bindoff, N.L. 2005. Science 309: 245-255

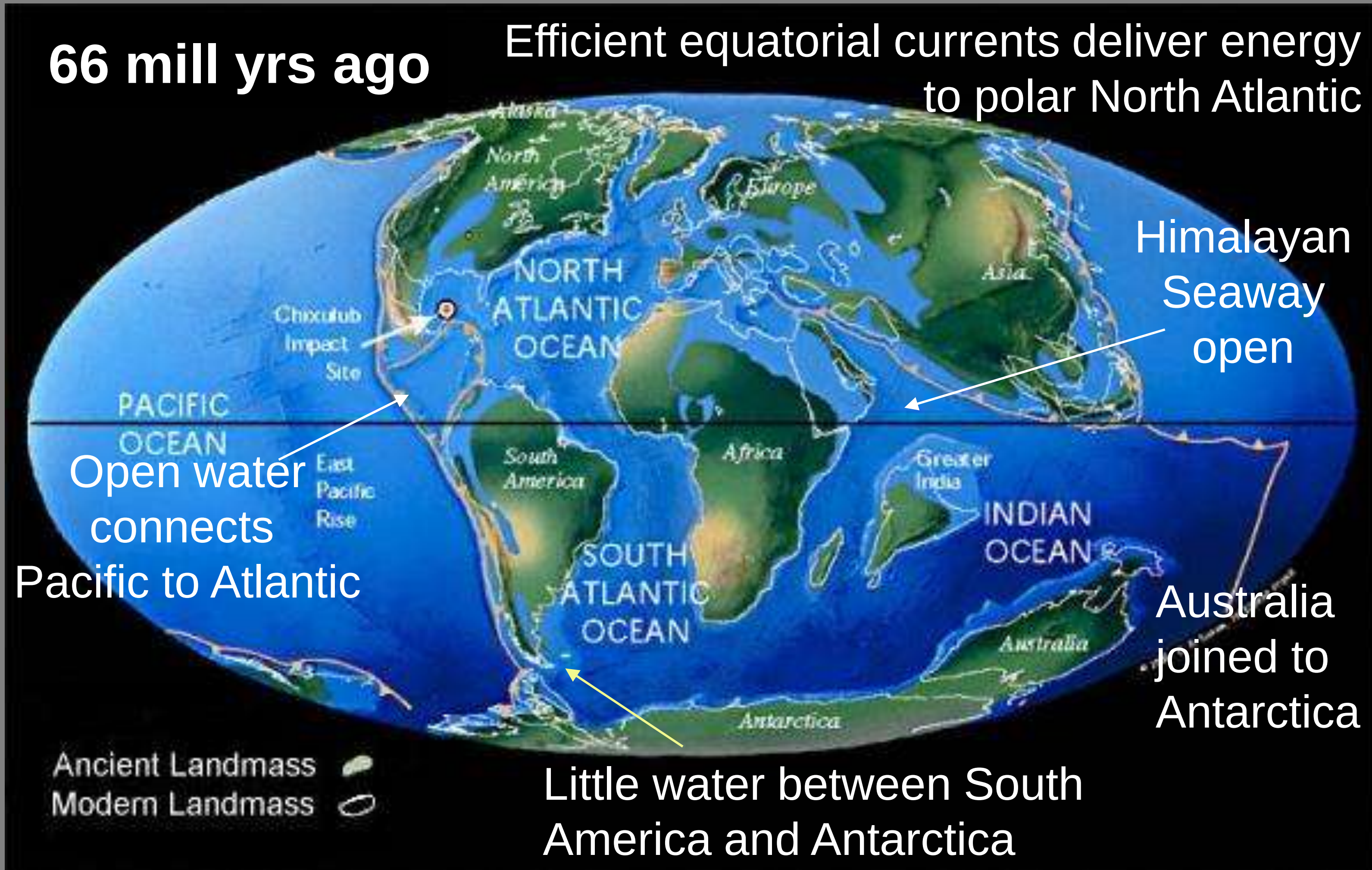
Climate responds to the pattern of oceans and continents …

70 million years ago

- Efficient tropical ocean circulation distributed heat to polar oceans
- No circum-Antarctic circulation therefore no global refrigerator
- Earth 9 – 12 ºC warmer
- Deep ocean 15 – 20º C warmer and much less effective sink for CO_2 therefore more in atmosphere
- Sea level much higher than today
- No ice at poles
- Dinosaur fossils found within 15 degrees of the South Pole at the time

45 million years ago

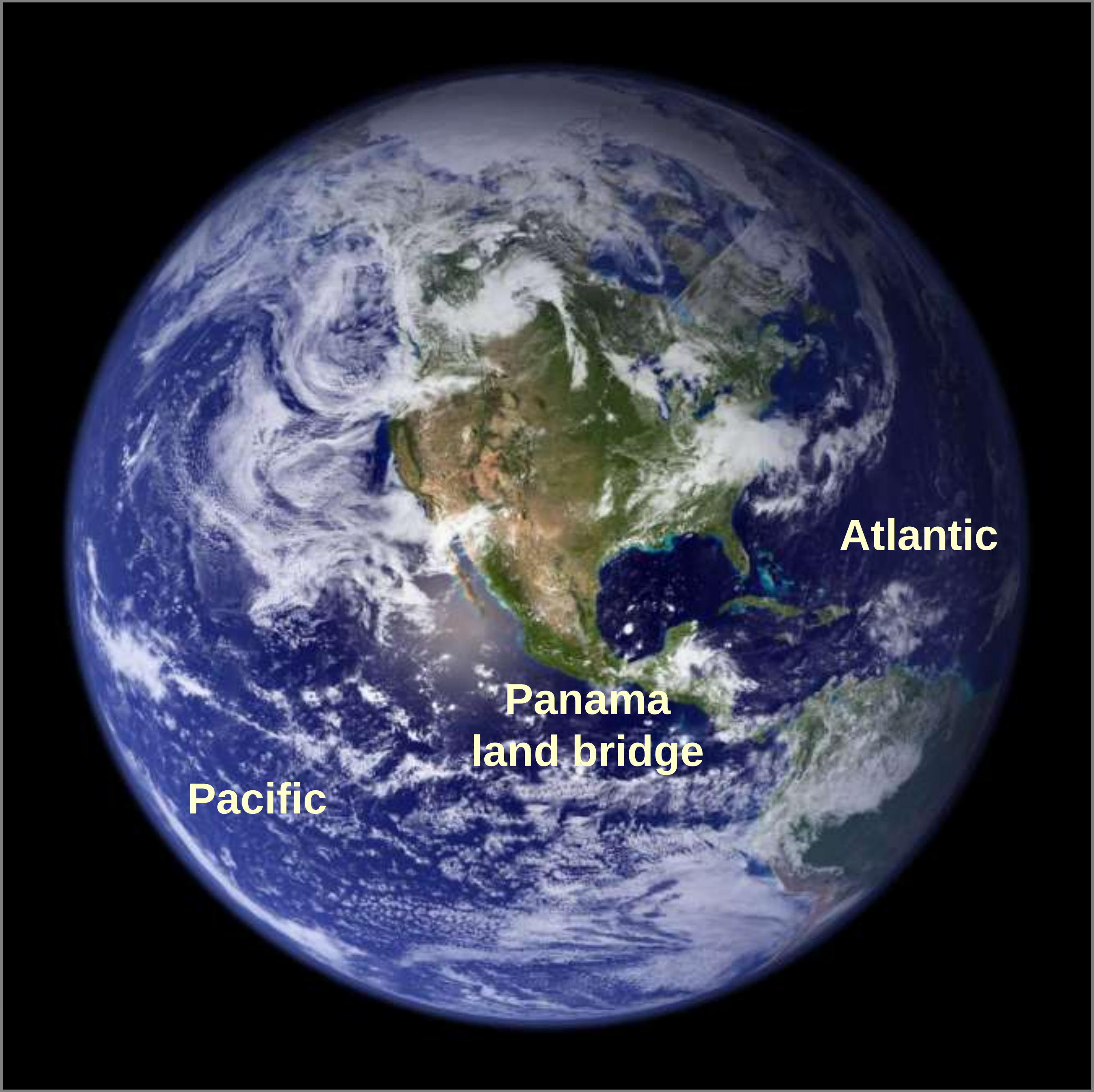
- Redwood forests in the Arctic

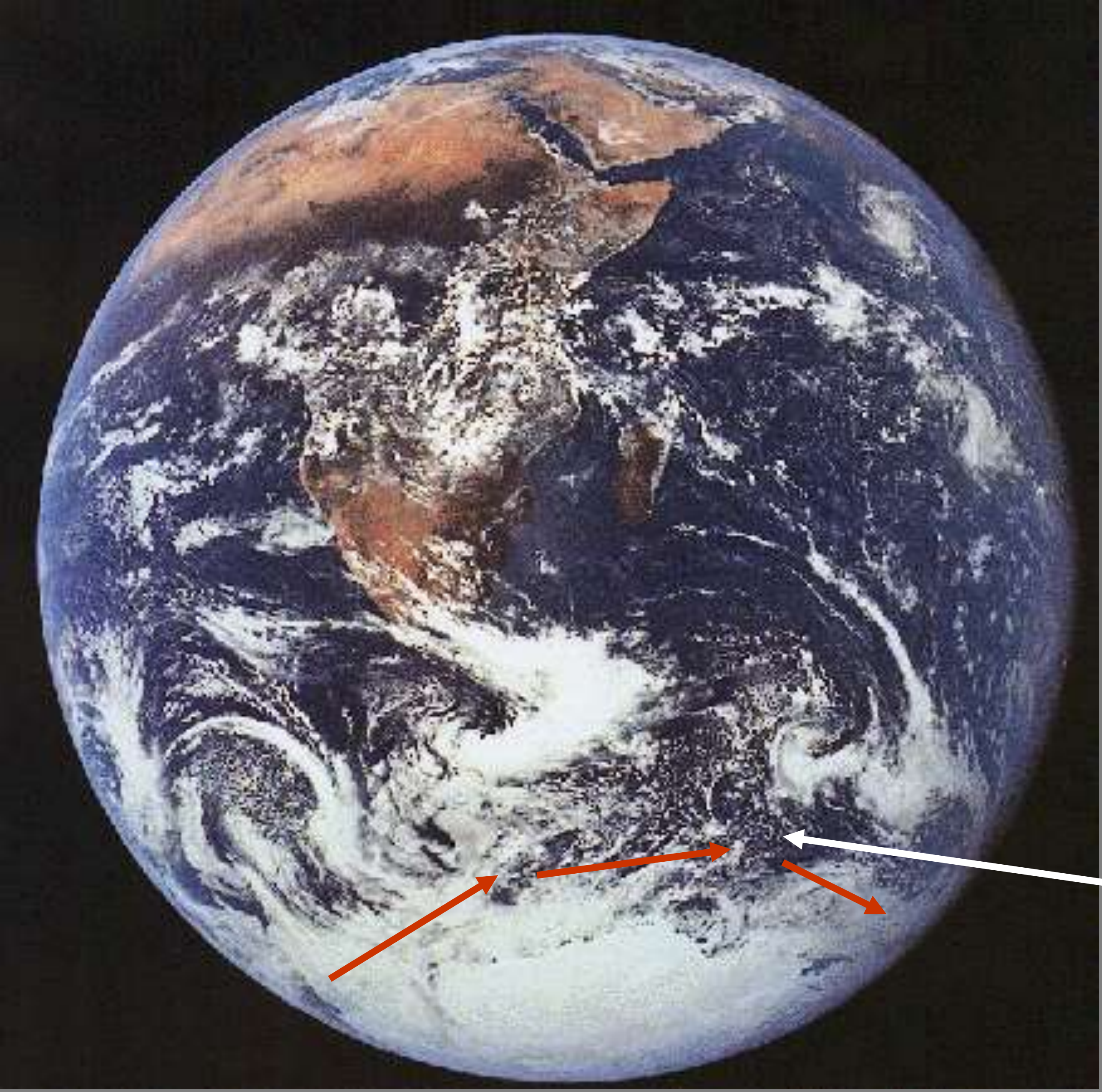


Global geography in the geological past

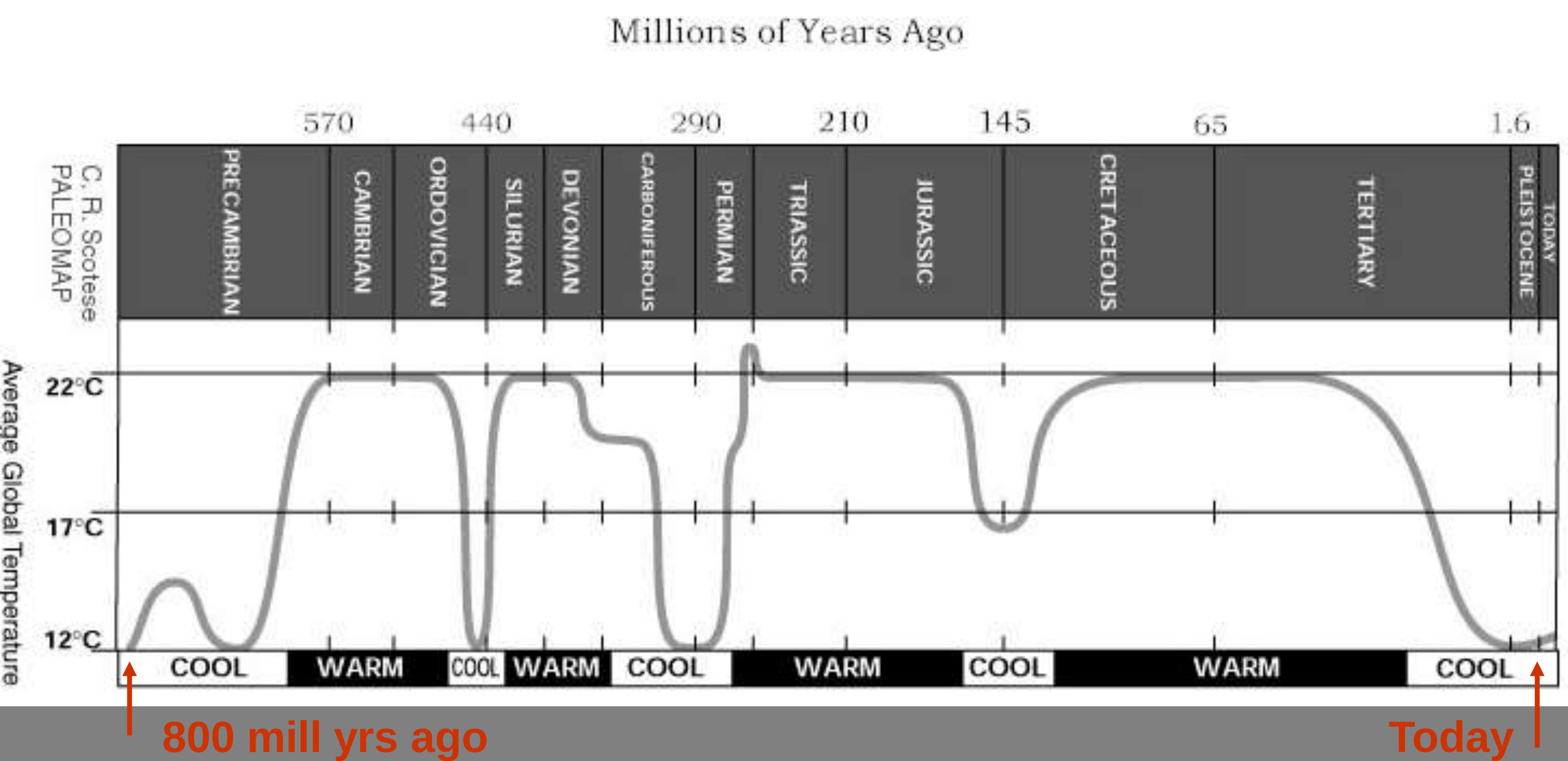
The Panama land bridge formed from a chain of volcanoes 3 million yrs ago cutting equatorial circulation between the Atlantic and Pacific.

Ice caps formed in the N. Hemisphere 2 million yrs ago



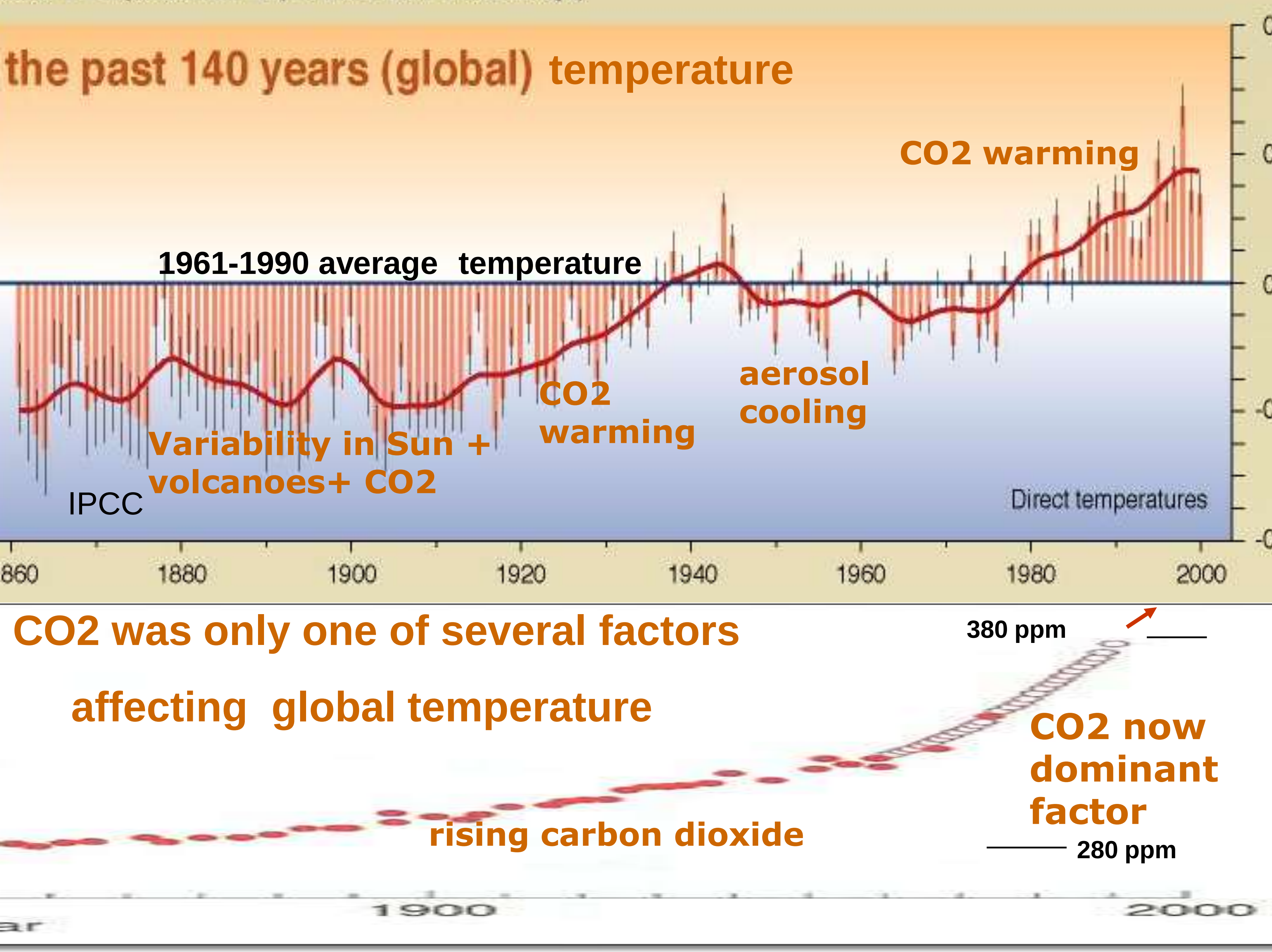


Circum Antarctic
current -
Earth’s refrigerator

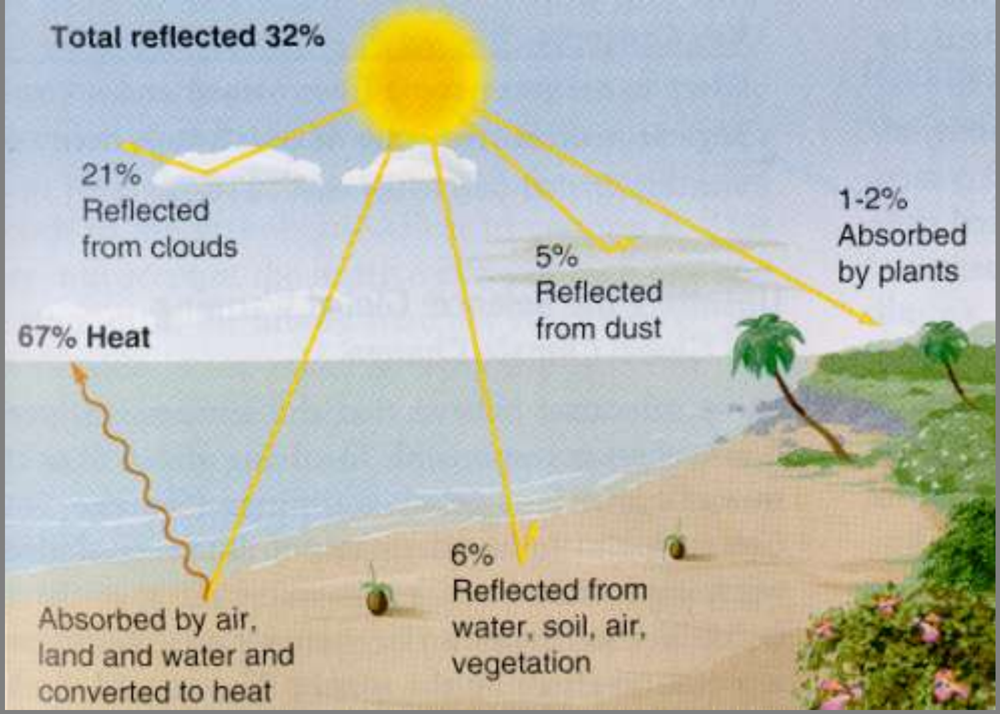


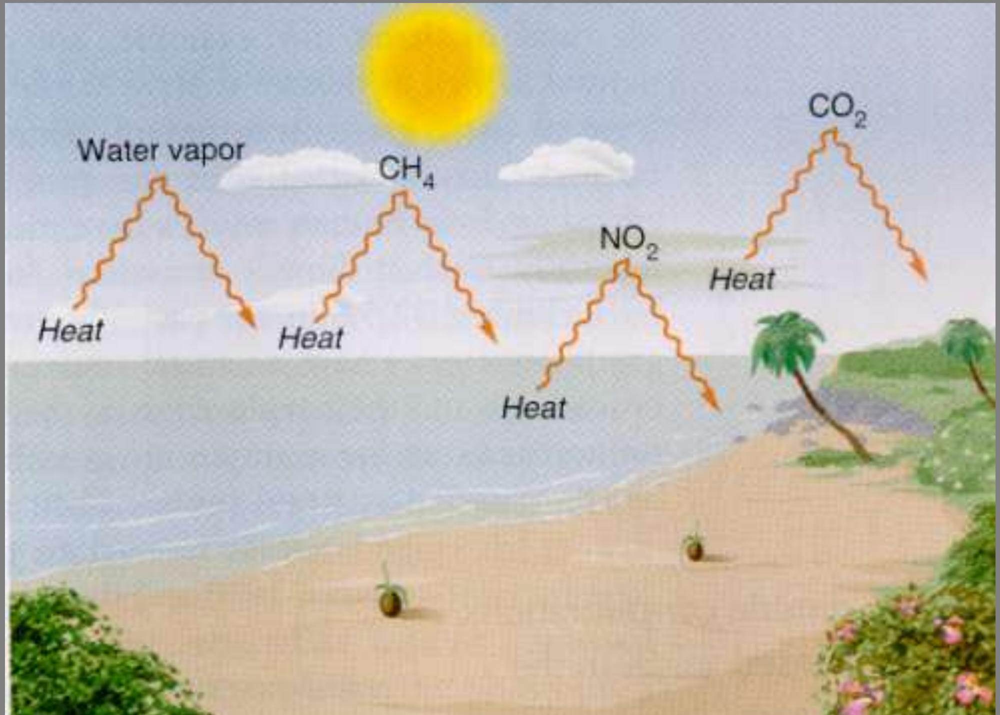
Millions of Years Ago
570
440
290
210
145
65
1.6
C. R. Scotese
PALEOMAP
PRECAMBRIAN
CAMBRIAN
ORDOVICIAN
SILURIAN
DEVONIAN
CARBONIFEROUS
PERMIAN
TRIASSIC
JURASSIC
CRETACEOUS
TERTIARY
PLEISTOCENE
TODAY
Average Global Temperature
22°C
17°C
12°C
COOL
WARM
COOL
WARM
COOL
WARM
COOL
WARM
COOL
800 mill yrs ago
Today

C. Scotese



the past 140 years (global) temperature
CO2 warming
1961-1990 average temperature
CO2 warming
aerosol cooling
Variability in Sun + volcanoes+ CO2
IPCC
Direct temperatures
860
1880
1900
1920
1940
1960
1980
2000
CO2 was only one of several factors
affecting global temperature
380 ppm
CO2 now dominant factor
rising carbon dioxide
280 ppm
1900
2000

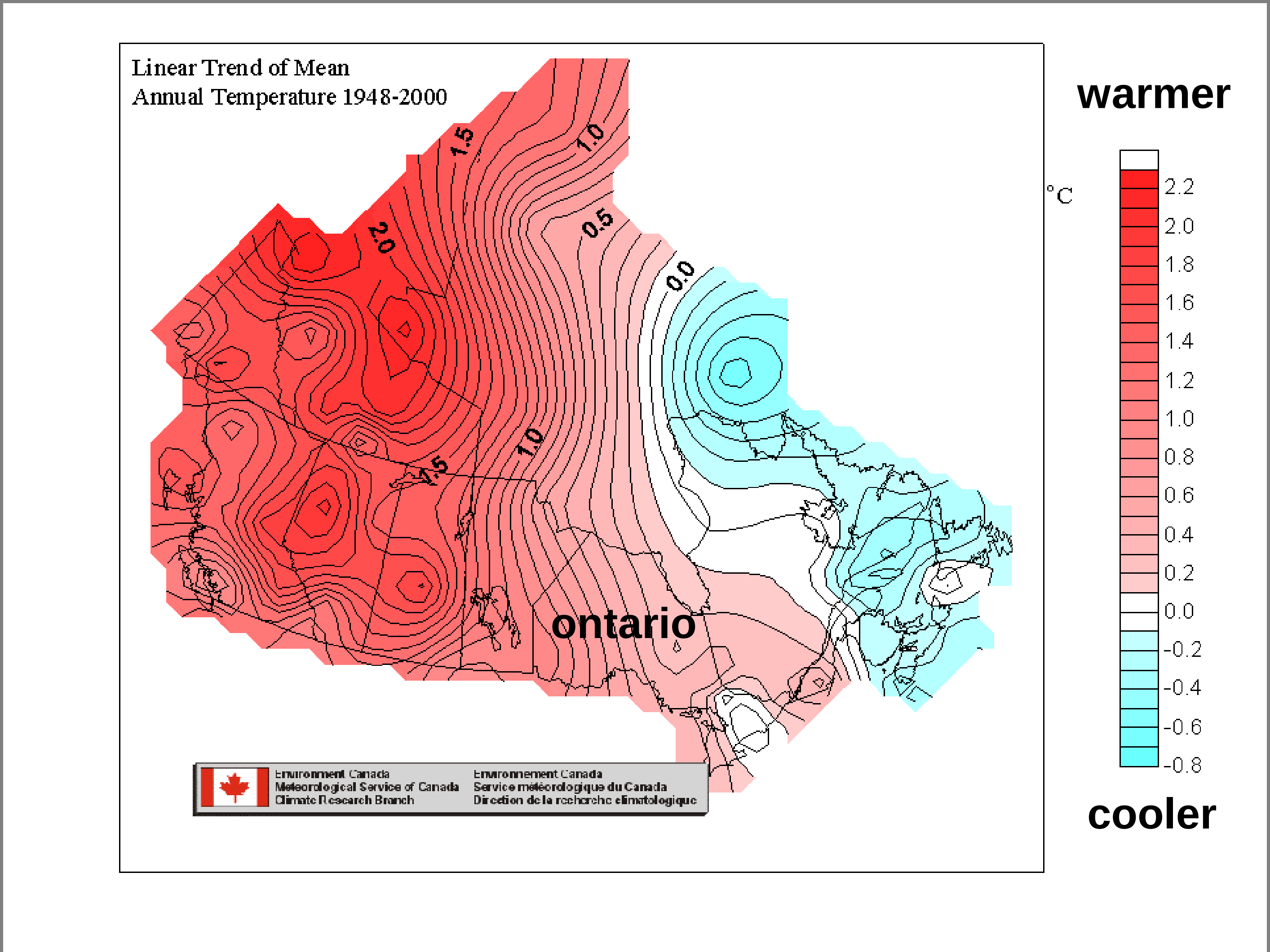

Total reflected 32%
21%
Reflected
from clouds
5%
Reflected
from dust
1-2%
Absorbed
by plants
67% Heat
6%
Reflected from
water, soil, air,
vegetation
Absorbed by air,
land and water and
converted to heat

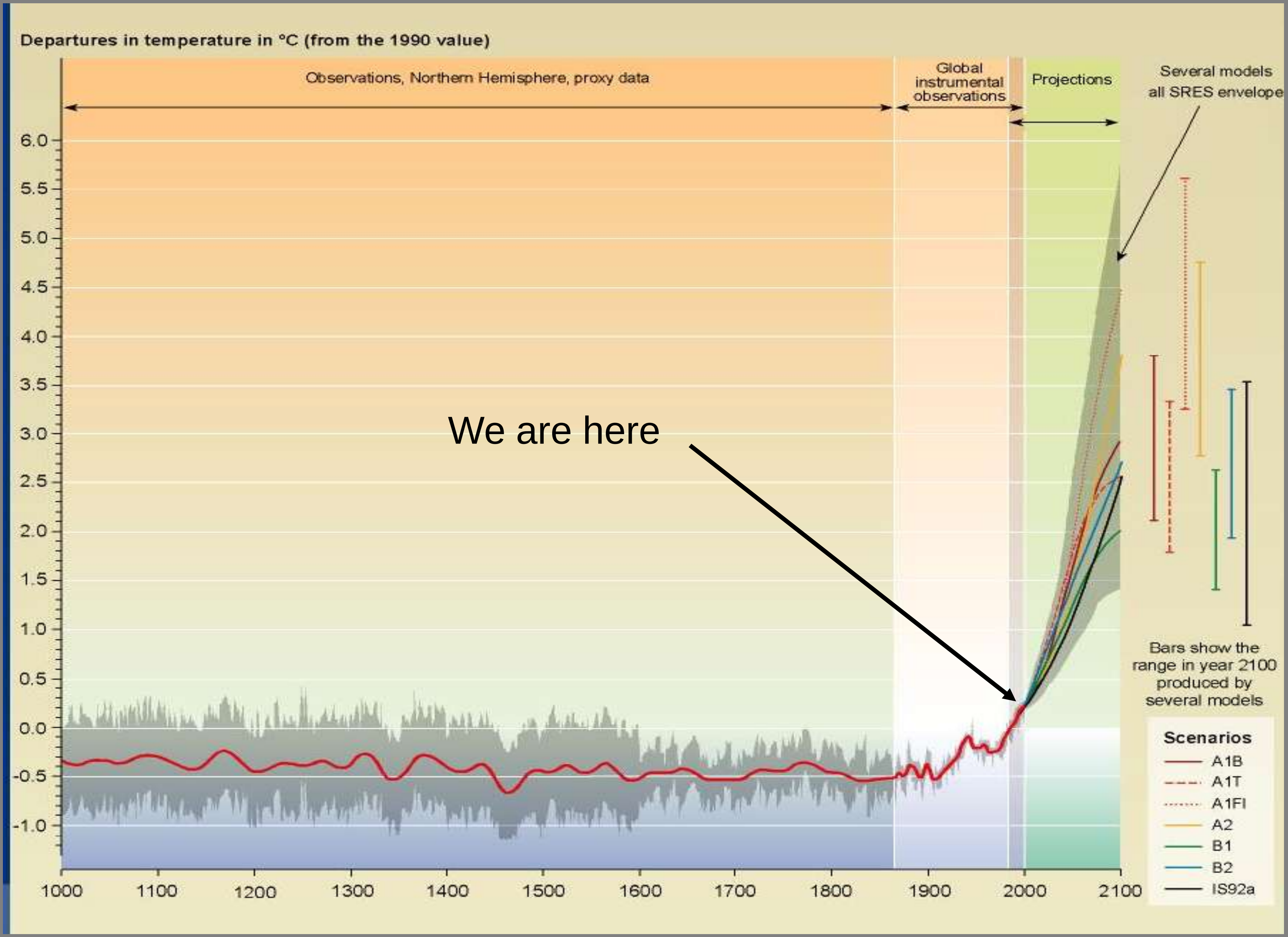

Water vapor
CH_4
NO_2
CO_2
Heat
Heat
Heat
Heat

Chiras, 2001

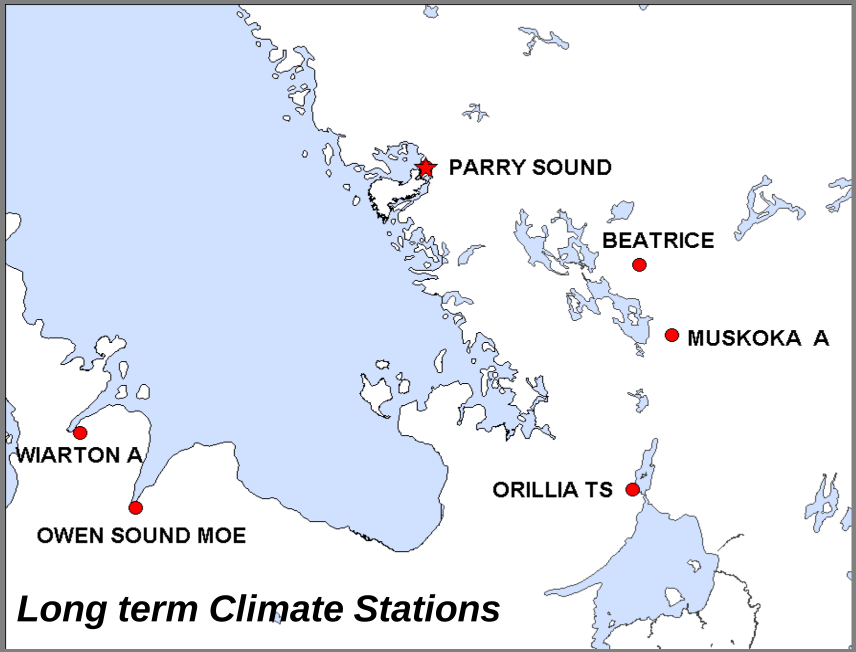
Communicating the science ….

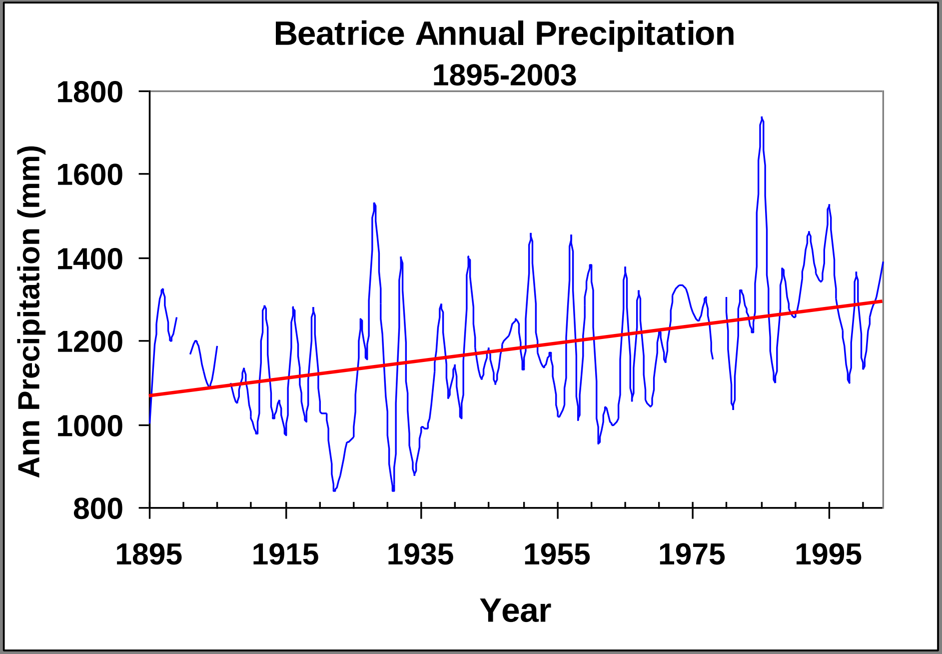
Ontario is already warmer than in the 1960s

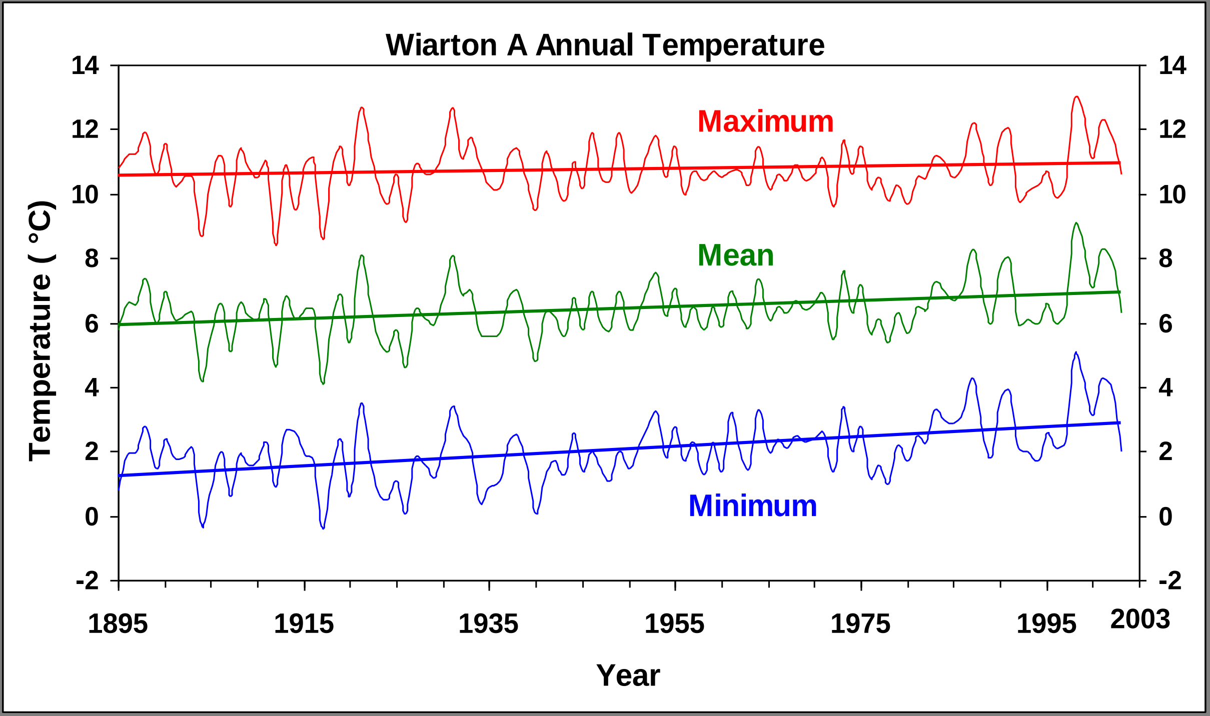




Departures in temperature in °C (from the 1990 value)
Observations, Northern Hemisphere, proxy data
Global instrumental observations
Projections
Several models all SRES envelope
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
We are here
Bars show the range in year 2100 produced by several models
Scenarios
A1B
A1T
A1FI
A2
B1
B2
IS92a







<u>Since 1895…</u>

Annual Temperature has warmed ~ 0.5-1.0 °C (Min Temps up to 2 °C)

Annual Precipitation has increased up to 20%

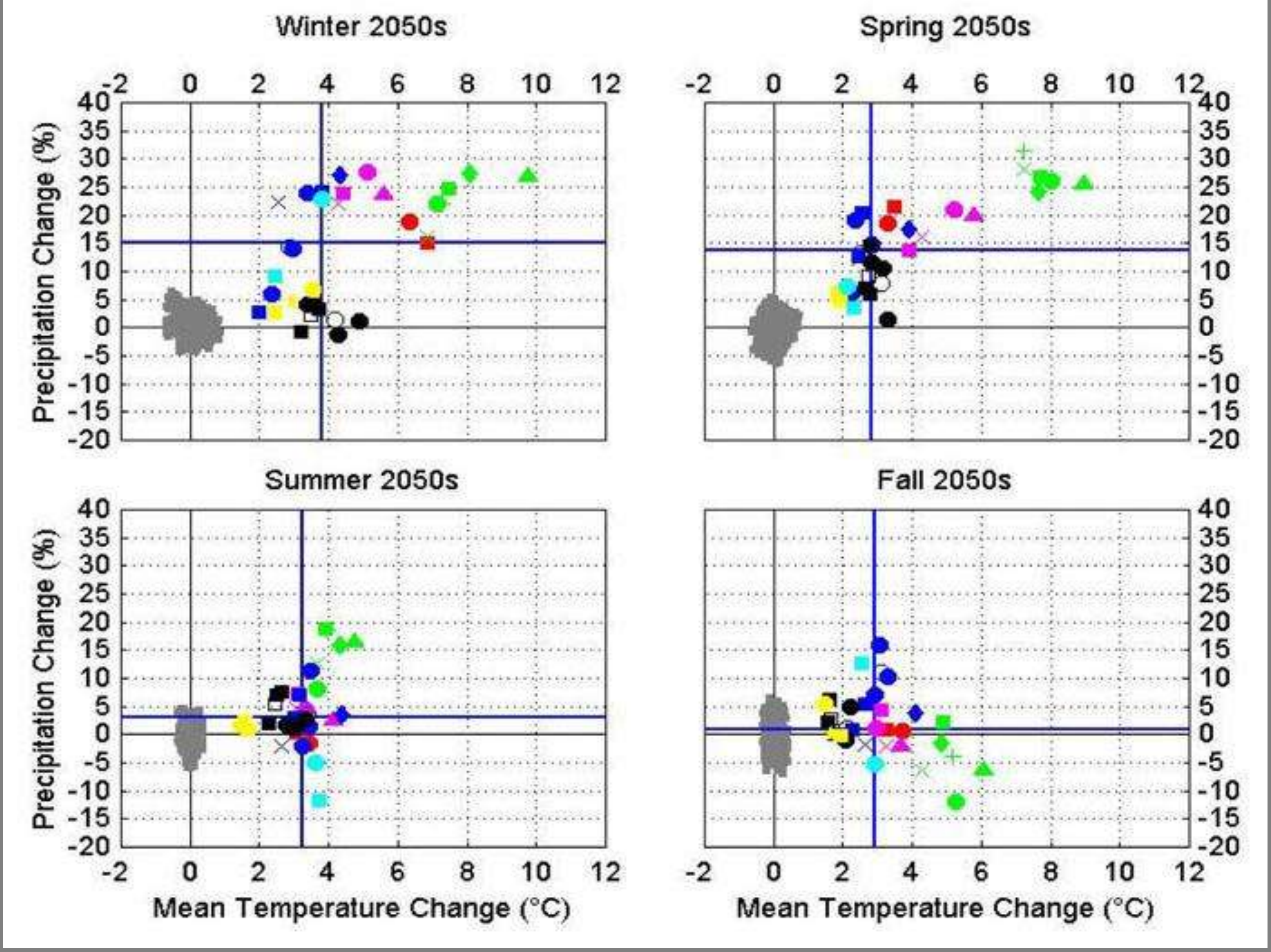
Modeled pptn and temp for the Great Lakes Basin in 2050 compared to 1961-90 average

Averaging models and scenarios shows …

• 10 to15 % increase in precipitation in Winter and Spring

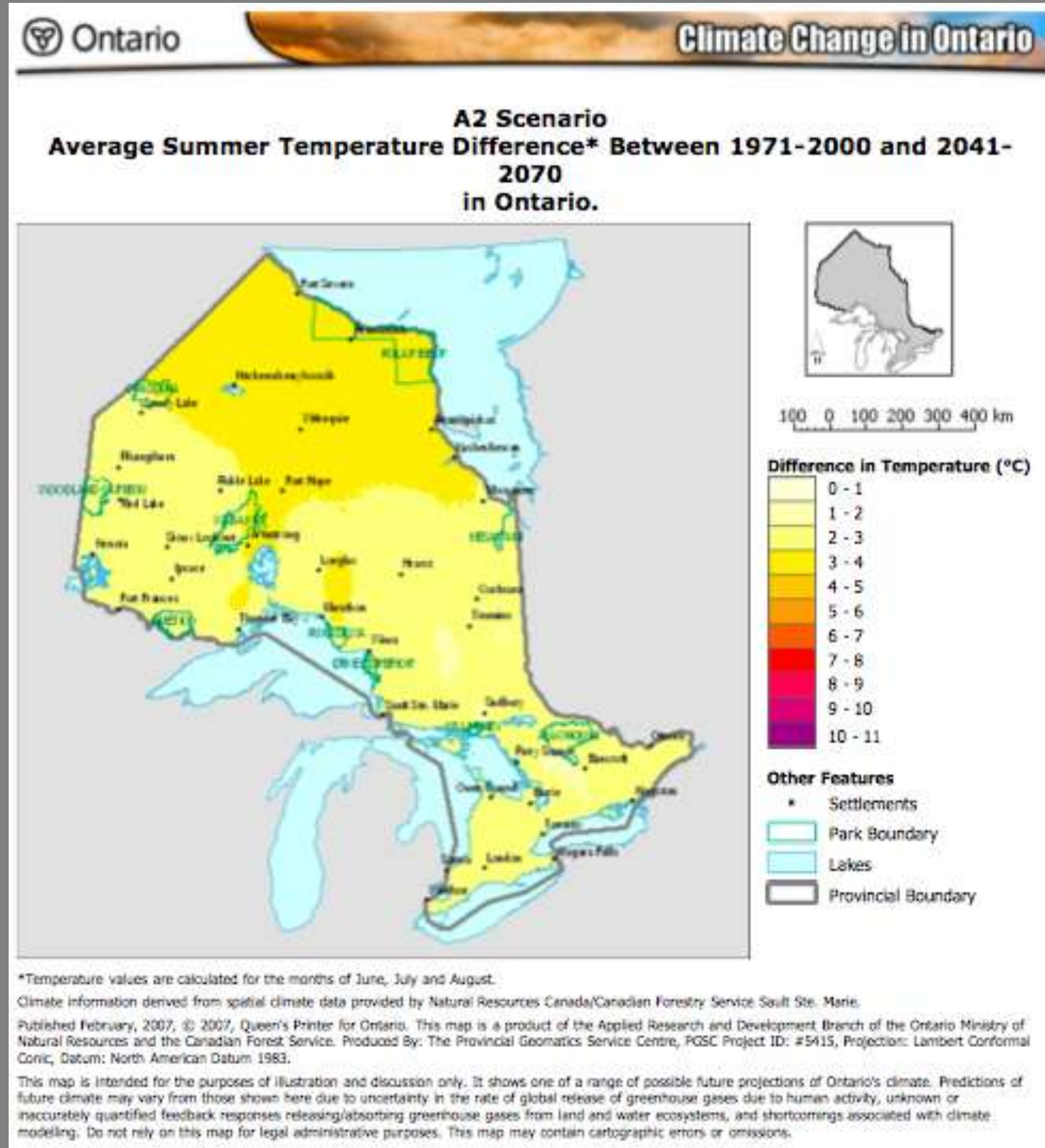
• 3 to 4 degree increase in temp especially in Winter

Courtesy Joan Klaassen Env. Canada



Average Summer Temp difference between 1971 - 2000 baseline and 2041 – 2070

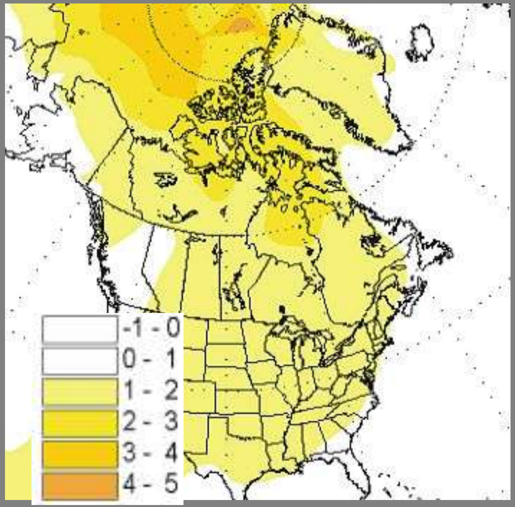
(A2 emission scenario assumes 15 billion population by 2100 = 1320 ppm CO2 in atmosphere by 2100)



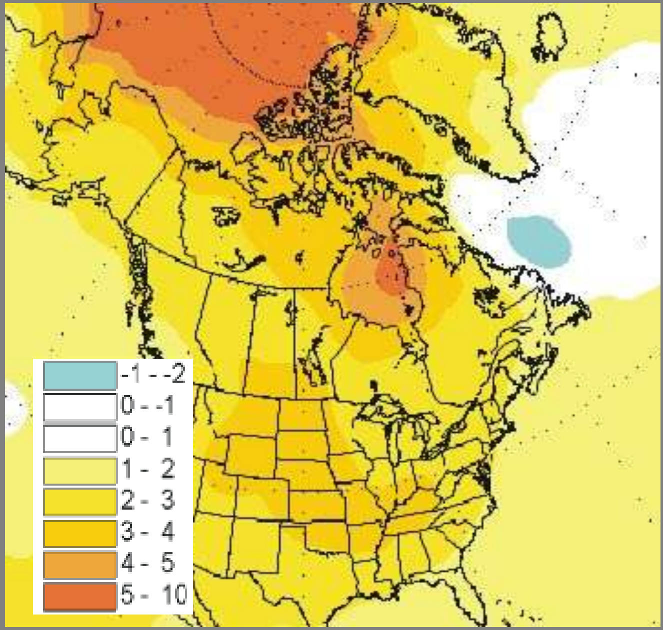
Long Term Temperature Changes

Average Temperature - using the Canadian model = double CO_2 by 2060 [scenario IS92a]
(Meteorological Service of Canada, Environment Canada)

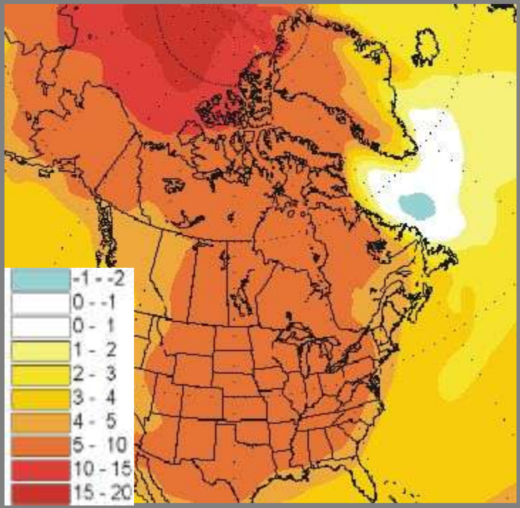
2010-2030 with respect to **1975-1995**



2040-2060 with respect to **1975-1995**



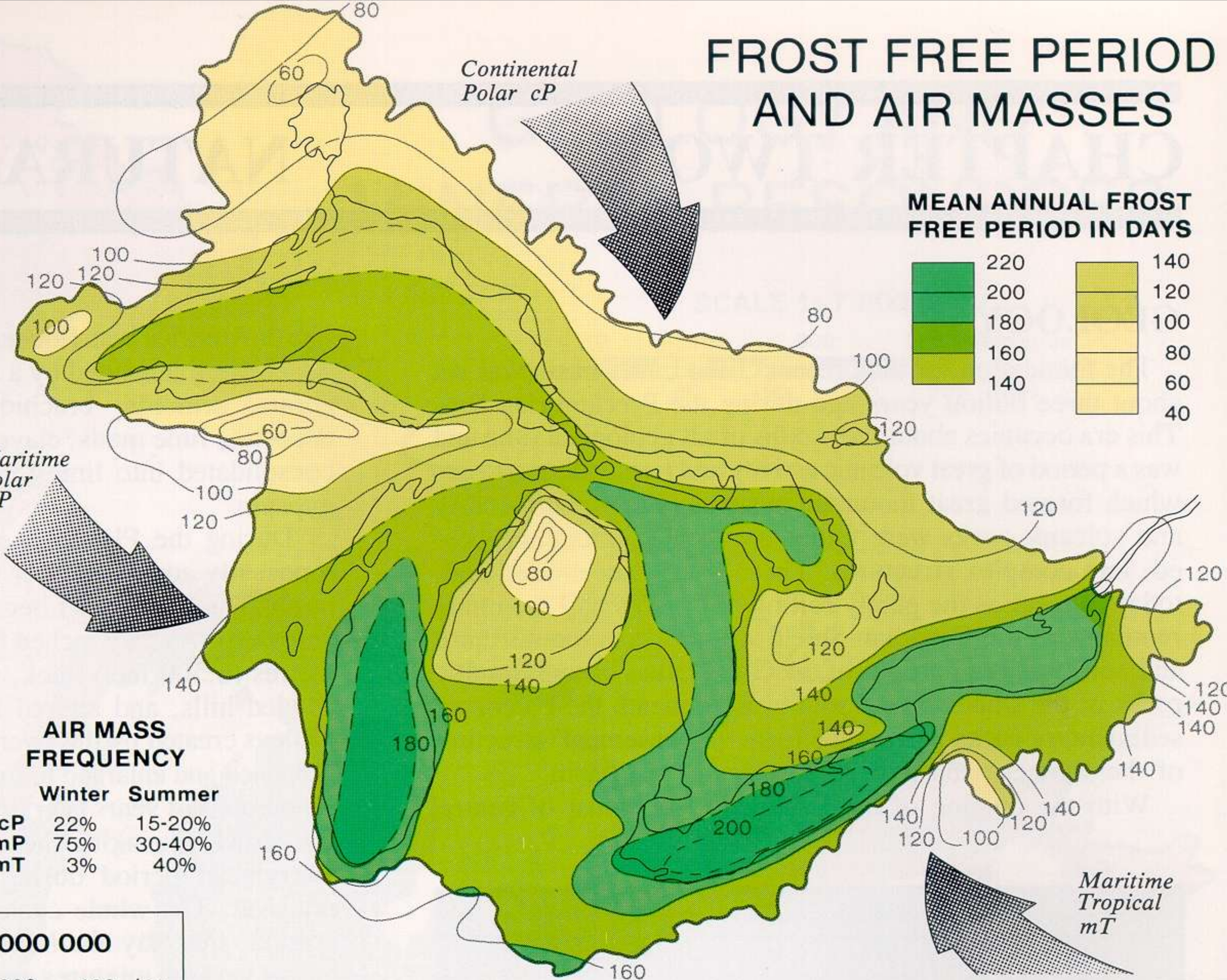
2080-2100 with respect to **1975-1995**



Sudbury to experience additional 2 to 4 degree average temp increase by 2050 esp. in Winter (3-5 degrees)

OURANOS

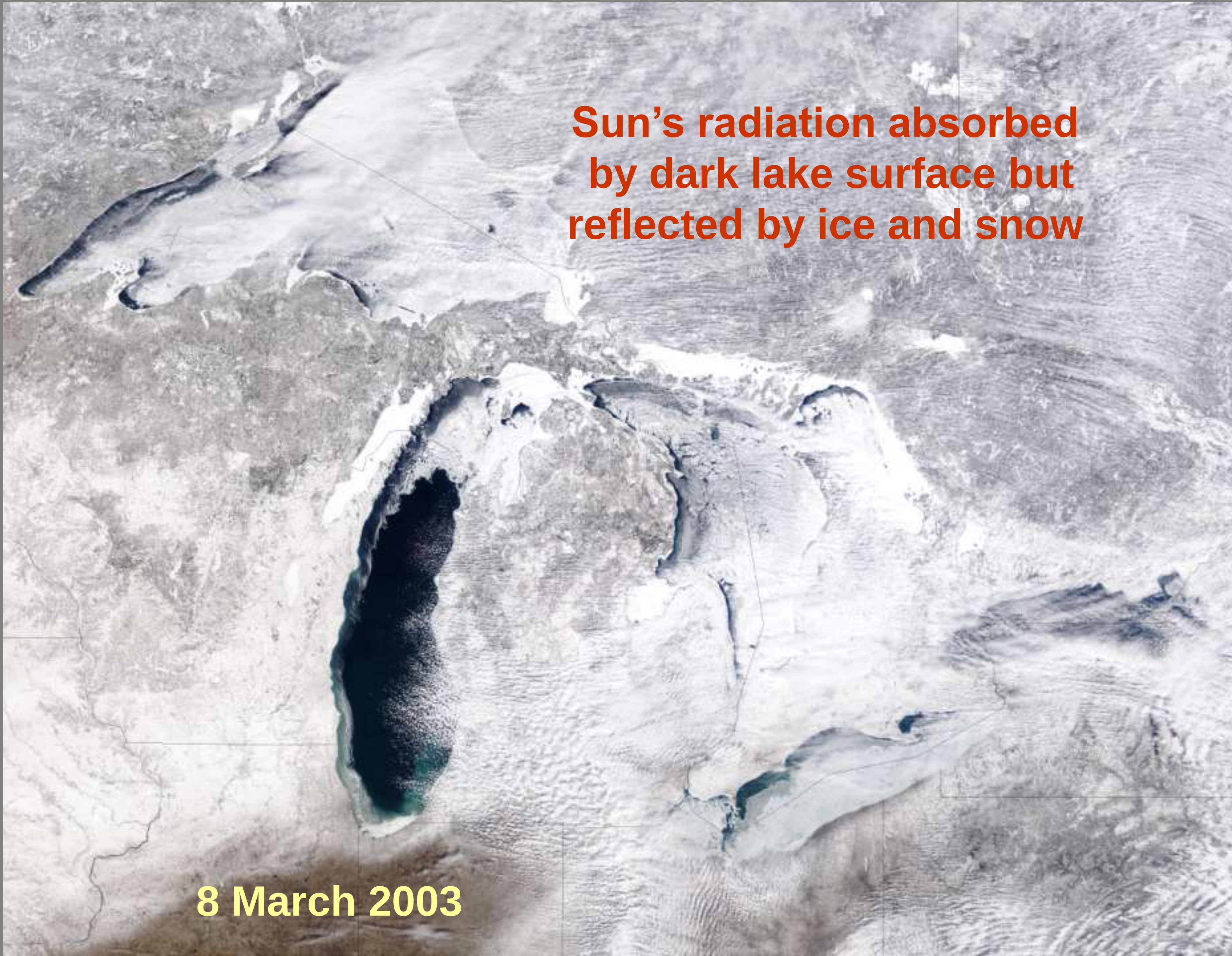
FROST FREE PERIOD AND AIR MASSES



AIR MASS FREQUENCY

	Winter	Summer
cP	22%	15-20%
mP	75%	30-40%
mT	3%	40%

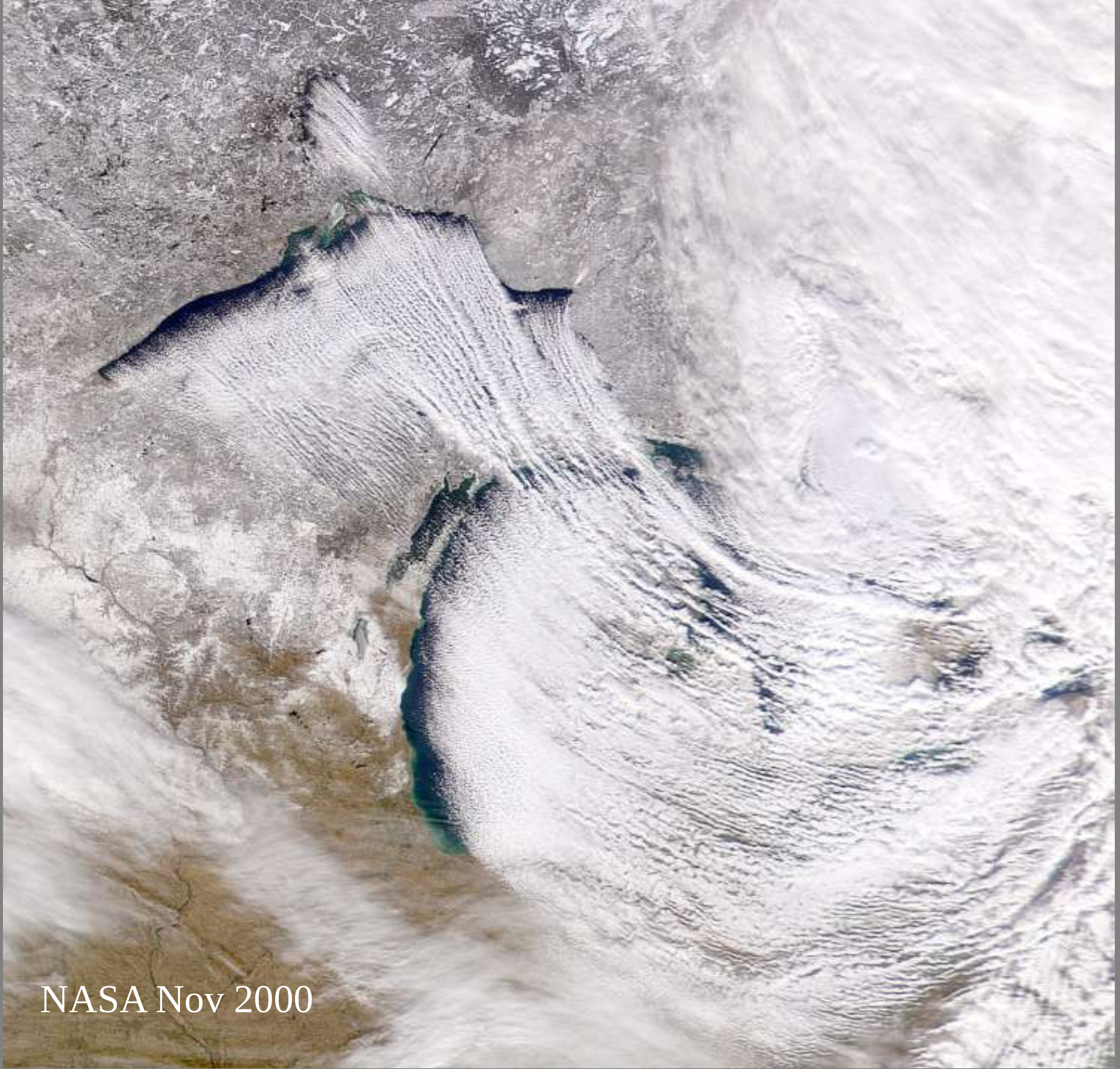
0 000 000

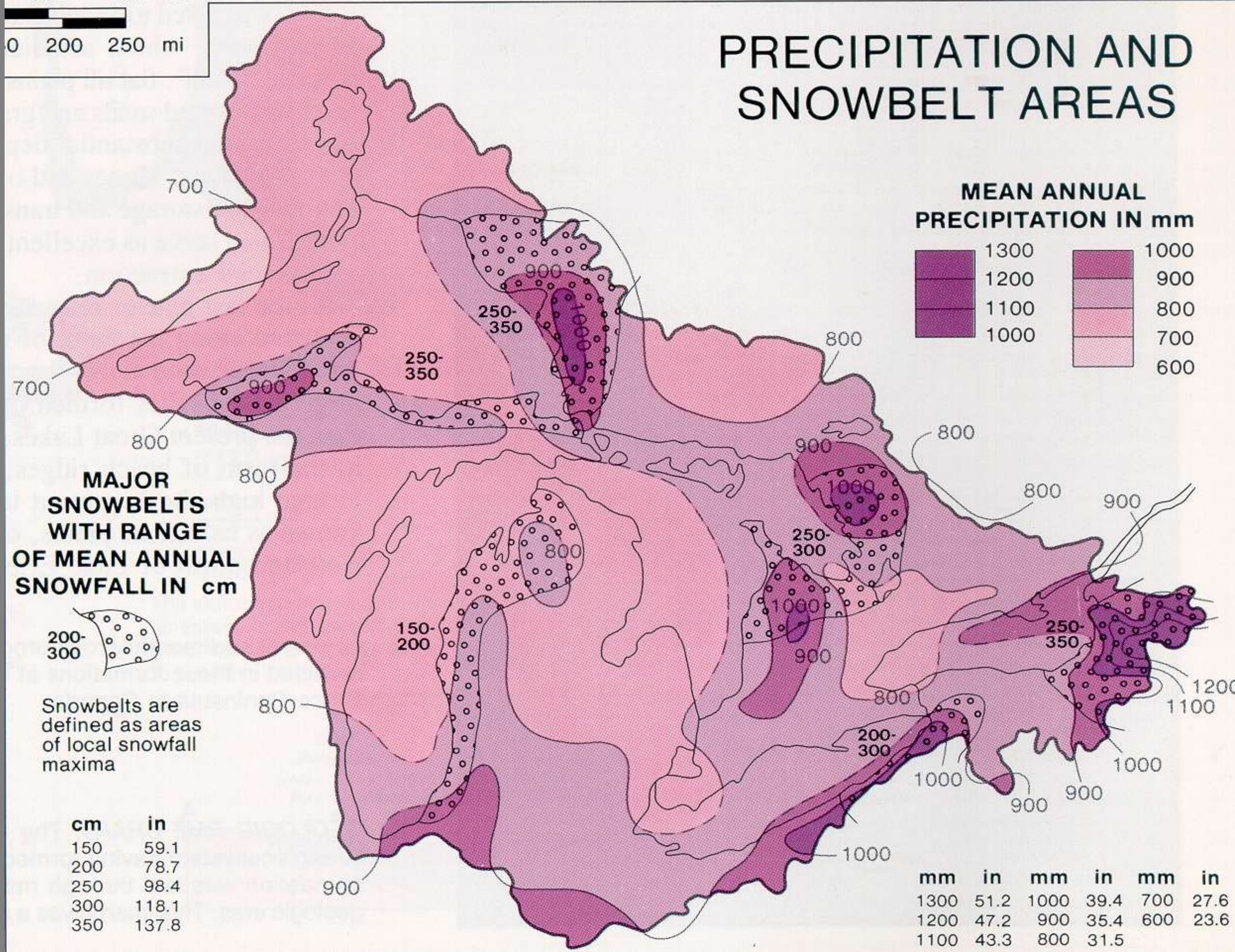

Sun’s radiation absorbed by dark lake surface but reflected by ice and snow
8 March 2003

Lake effect snow = evaporation from open water

Longer open water season = more evaporation

More evaporation = potentially lower lake level





0 200 250 mi
PRECIPITATION AND SNOWBELT AREAS
MEAN ANNUAL PRECIPITATION IN mm
1300
1200
1100
1000
1000
900
800
700
600
MAJOR SNOWBELTS WITH RANGE OF MEAN ANNUAL SNOWFALL IN cm
200-300
Snowbelts are defined as areas of local snowfall maxima
cm in
150 59.1
200 78.7
250 98.4
300 118.1
350 137.8
mm in mm in mm in
1300 51.2 1000 39.4 700 27.6
1200 47.2 900 35.4 600 23.6
1100 43.3 800 31.5
700
700
800
800
800
800
800
800
900
900
900
900
900
900
900
900
900
1000
1000
1000
1000
1000
1000
1000
1100
1200
250-350
250-350
250-350
250-300
150-200
200-300

Changes in average conditions ….

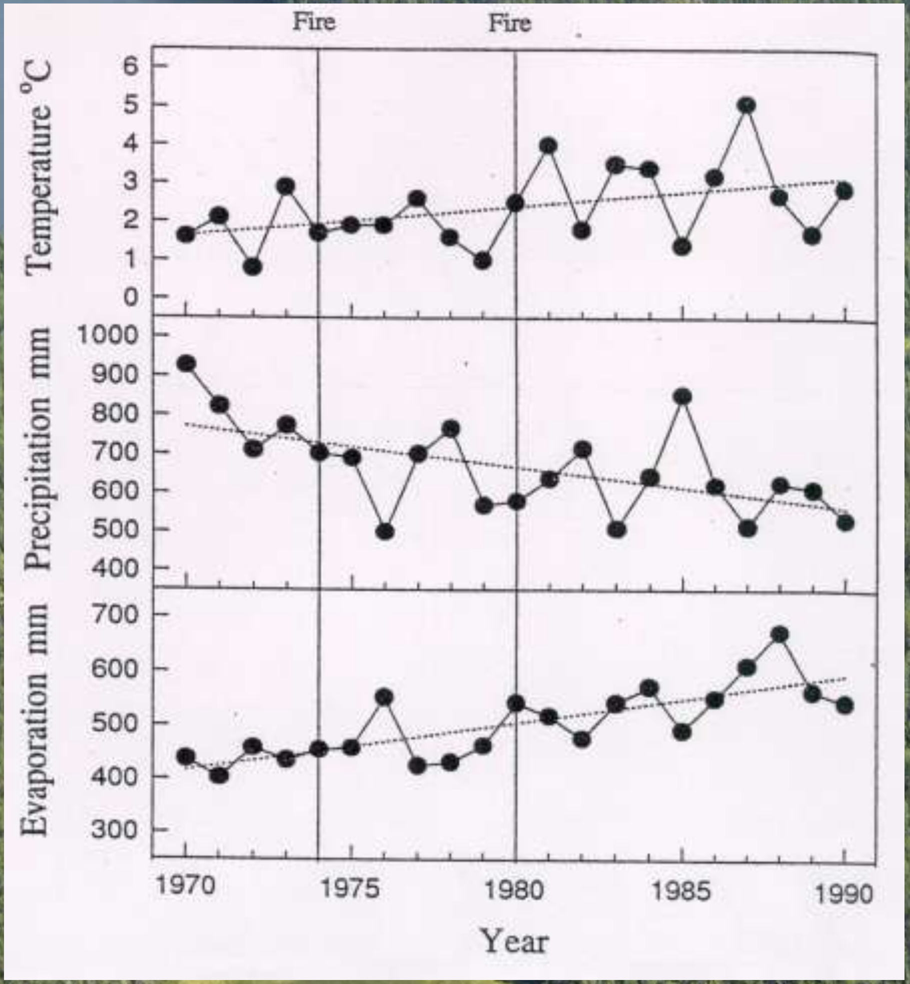
Increase of 1.4 degrees C in average temperature led to 30% increase in evaporation between 1970 and 1990

(Exp. Lakes Area, NW Ont.)

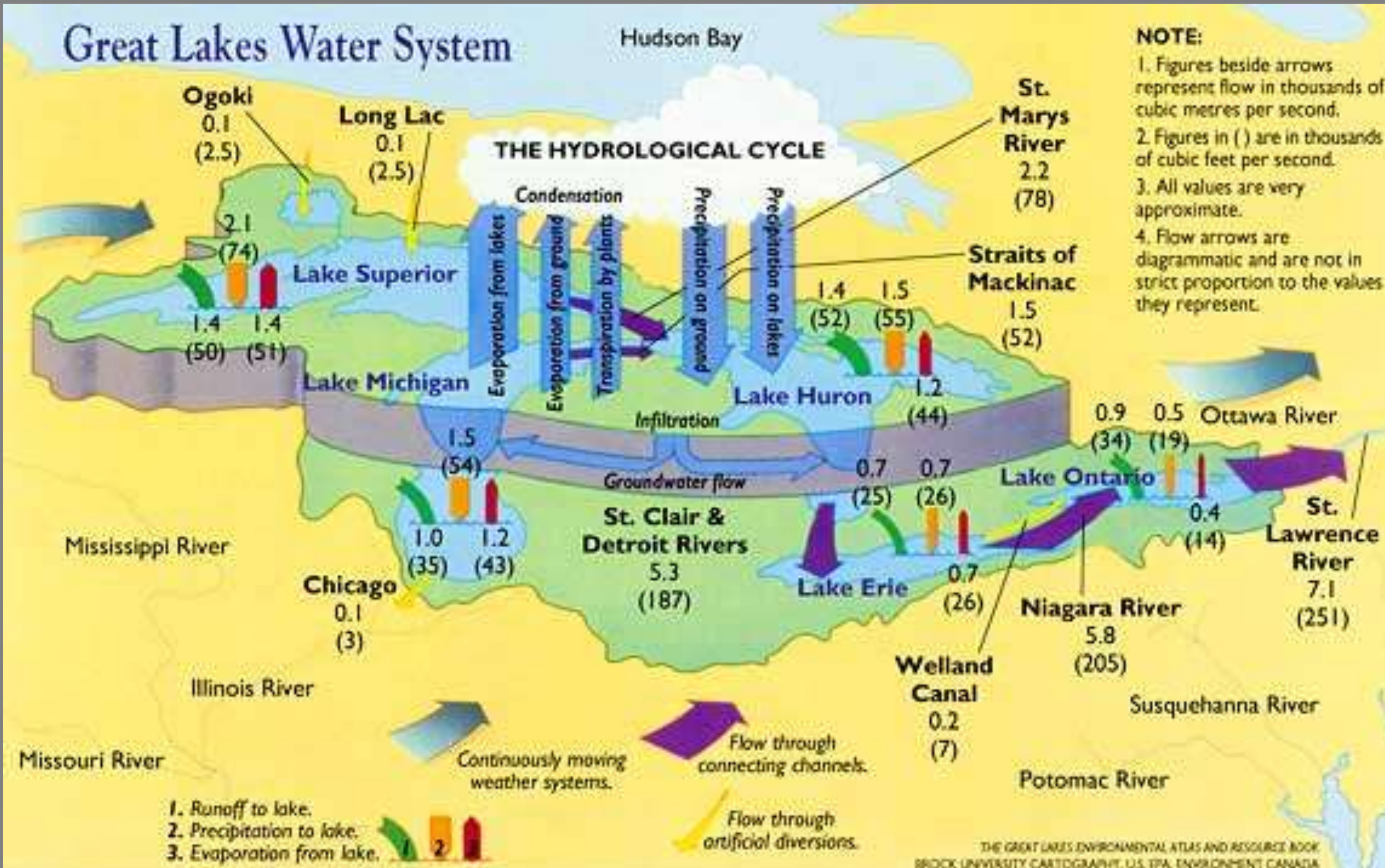
Temp

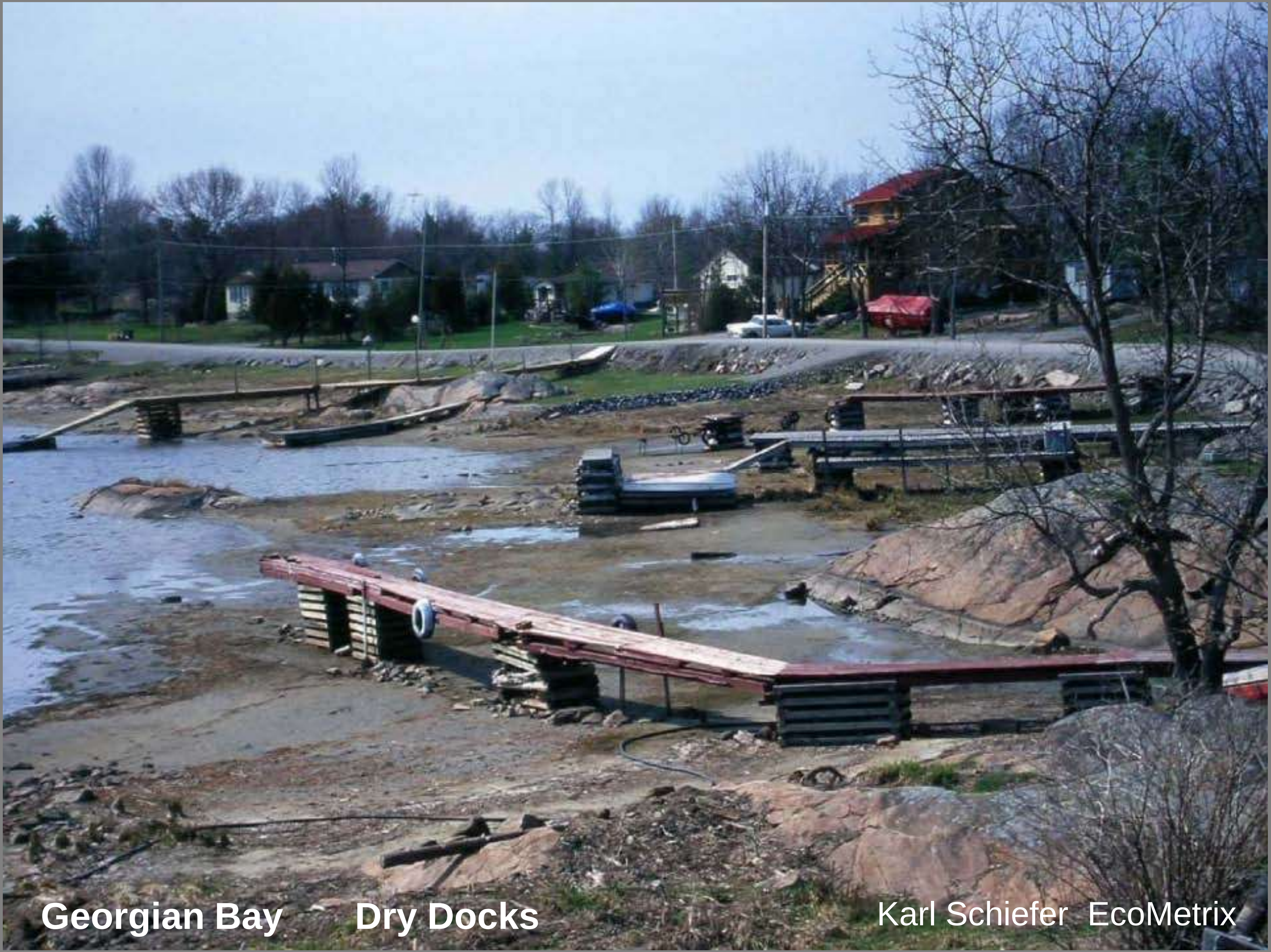
Precip

Evap



Schindler et al


Great Lakes Water System
Hudson Bay
NOTE:
1. Figures beside arrows represent flow in thousands of cubic metres per second.
2. Figures in ( ) are in thousands of cubic feet per second.
3. All values are very approximate.
4. Flow arrows are diagrammatic and are not in strict proportion to the values they represent.
Ogoki 0.1 (2.5)
Long Lac 0.1 (2.5)
THE HYDROLOGICAL CYCLE
Condensation
Evaporation from lakes
Evaporation from ground
Transpiration by plants
Precipitation on ground
Precipitation on lakes
St. Marys River 2.2 (78)
Straits of Mackinac 1.5 (52)
2.1 (74)
Lake Superior
1.4 (50) 1.4 (51)
Lake Michigan
1.4 (52) 1.5 (55)
Lake Huron
1.2 (44)
Infiltration
1.5 (54)
Groundwater flow
1.0 (35) 1.2 (43)
St. Clair & Detroit Rivers 5.3 (187)
0.7 (25) 0.7 (26)
Lake Erie
0.7 (26)
0.9 (34) 0.5 (19)
Ottawa River
Lake Ontario
0.4 (14)
St. Lawrence River 7.1 (251)
Niagara River 5.8 (205)
Welland Canal 0.2 (7)
Mississippi River
Chicago 0.1 (3)
Illinois River
Missouri River
Susquehanna River
Potomac River
Continuously moving weather systems.
Flow through connecting channels.
Flow through artificial diversions.
1. Runoff to lake.
2. Precipitation to lake.
3. Evaporation from lake.
THE GREAT LAKES ENVIRONMENTAL ATLAS AND RESOURCE BOOK
BROCK UNIVERSITY CARTOGRAPHY, U.S. EPA, ENVIRONMENT CANADA

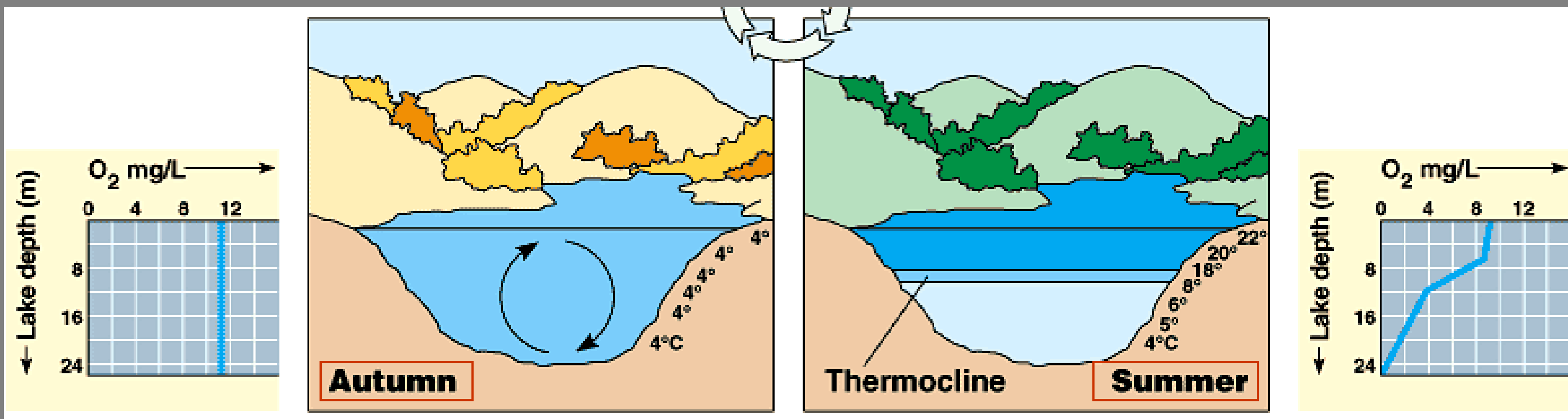

Georgian Bay
Dry Docks
Karl Schiefer EcoMetrix

• **Warmer Winters = more Winter rain, less snow**

• **Less and gradual Spring run-off = less effective flushing of phosphorus released into bottom water in winter = more algal growth in nutrient rich water**

(Similar effect may occur In bays of Great Lakes when water level drops and less water is available to dilute incoming nutrients from lawns and field beds)

Simon Lake July 2007



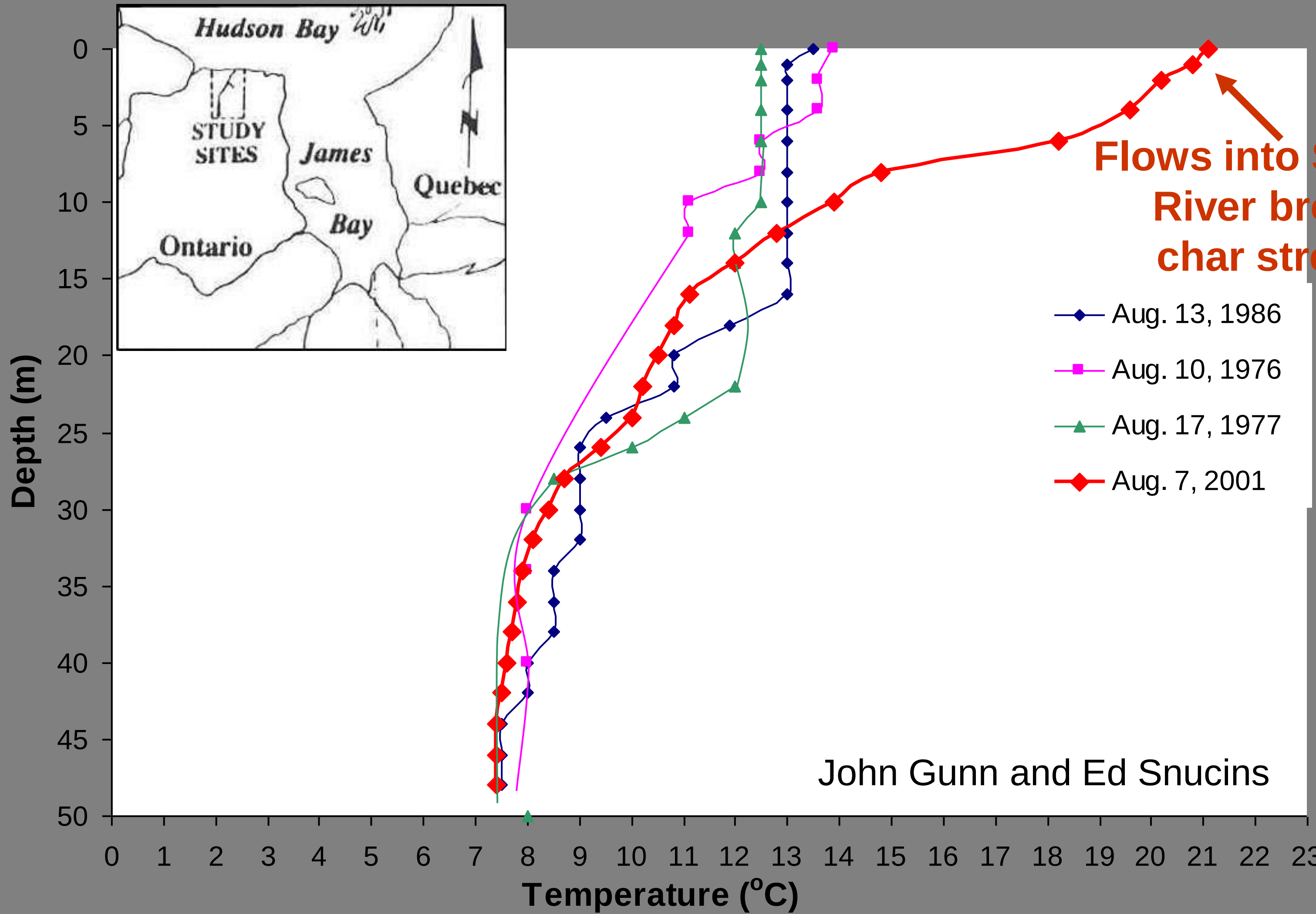
- Turnover in the Fall mixes oxygen through the water column

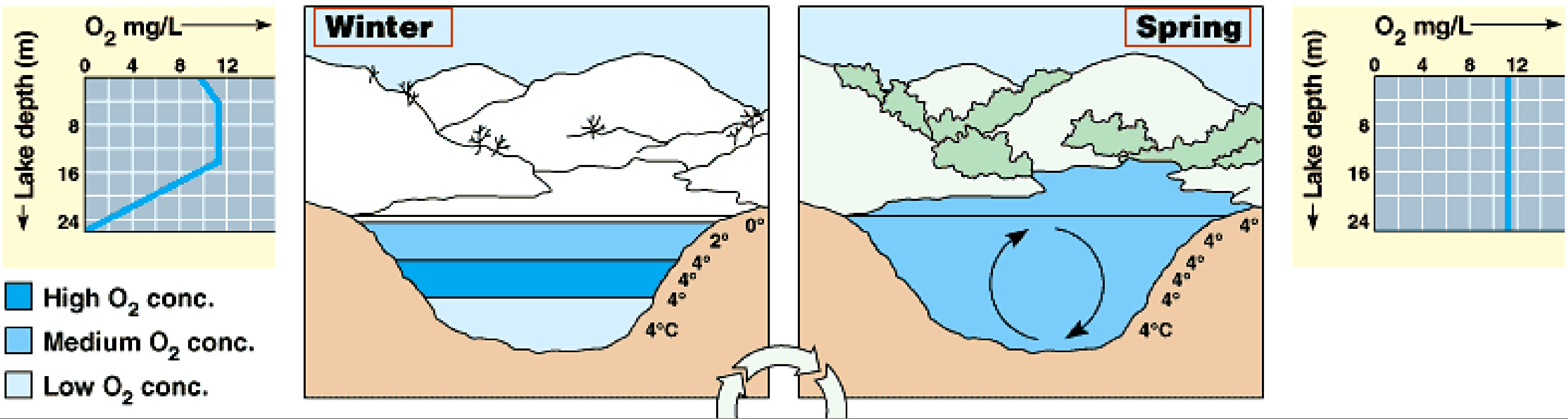
- Warm surface water traps cold bottom water = lake trout habitat *CC causing this to happen earlier and surface water becomes warmer*

- bottom water loses oxygen as decay of organic matter occurs *Possibly affecting lake trout health*


Chris Morey

Warming of Hawley Lake in the Hudson Bay Lowlands



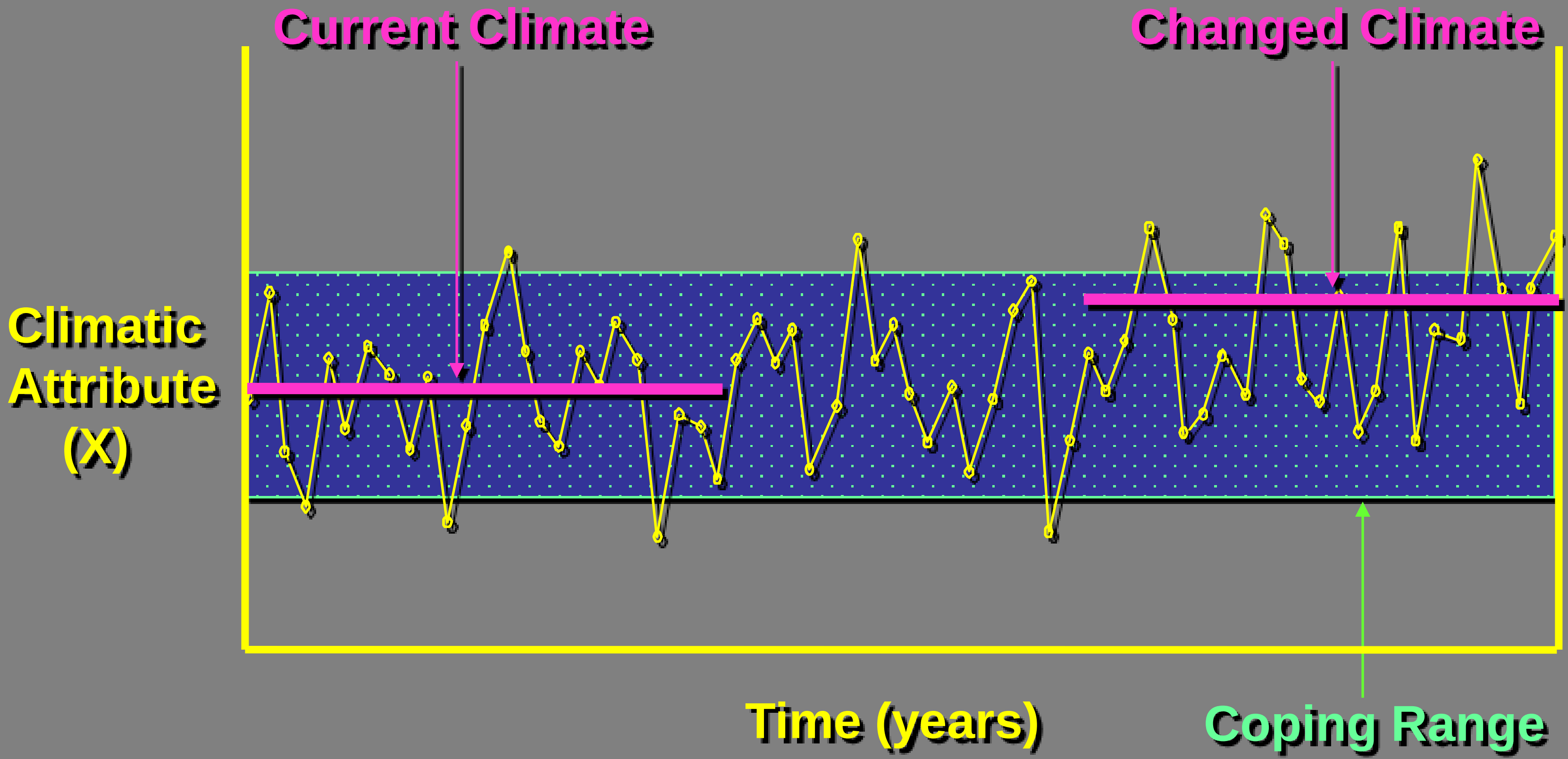


- Under ice cover lake divides into layers with dense 4^0 C water at the bottom.
- Rotting organic matter consumes oxygen in the bottom water
- Phosphorus is released from organic matter into the oxygen-poor bottom water

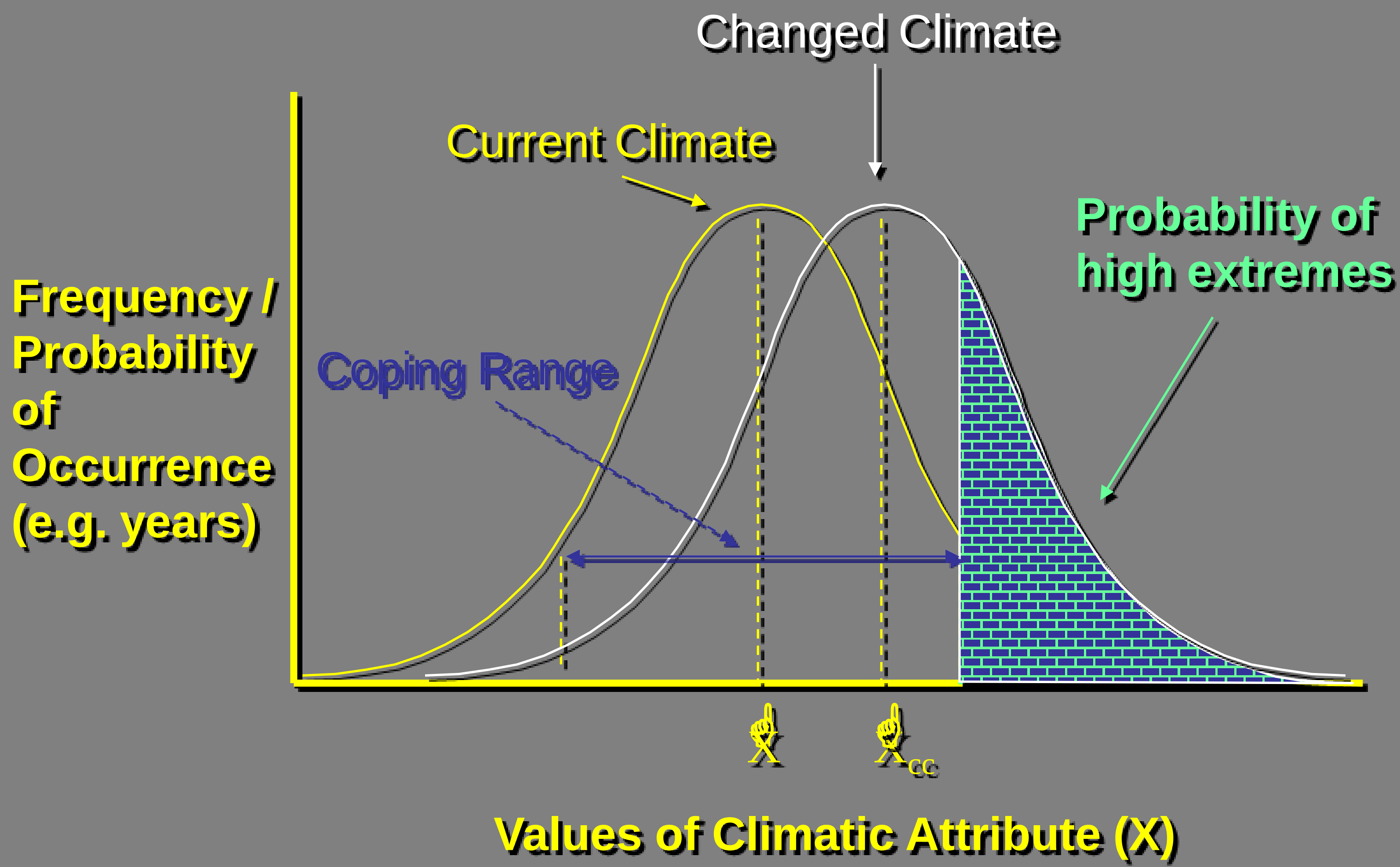
- Spring turnover occurs when surface water warms to 4^0 C
- Dissolved oxygen is mixed into the lake replenishing the winter loss.
- nutrients like phosphorus are mixed into the lake increasing biological activity

If climate change shortens the winter season will that reduce the cycling of nutrients back to the lake from the sediment ?

Climate Change Extremes and Coping Range



Barry Smit Bonn 2001



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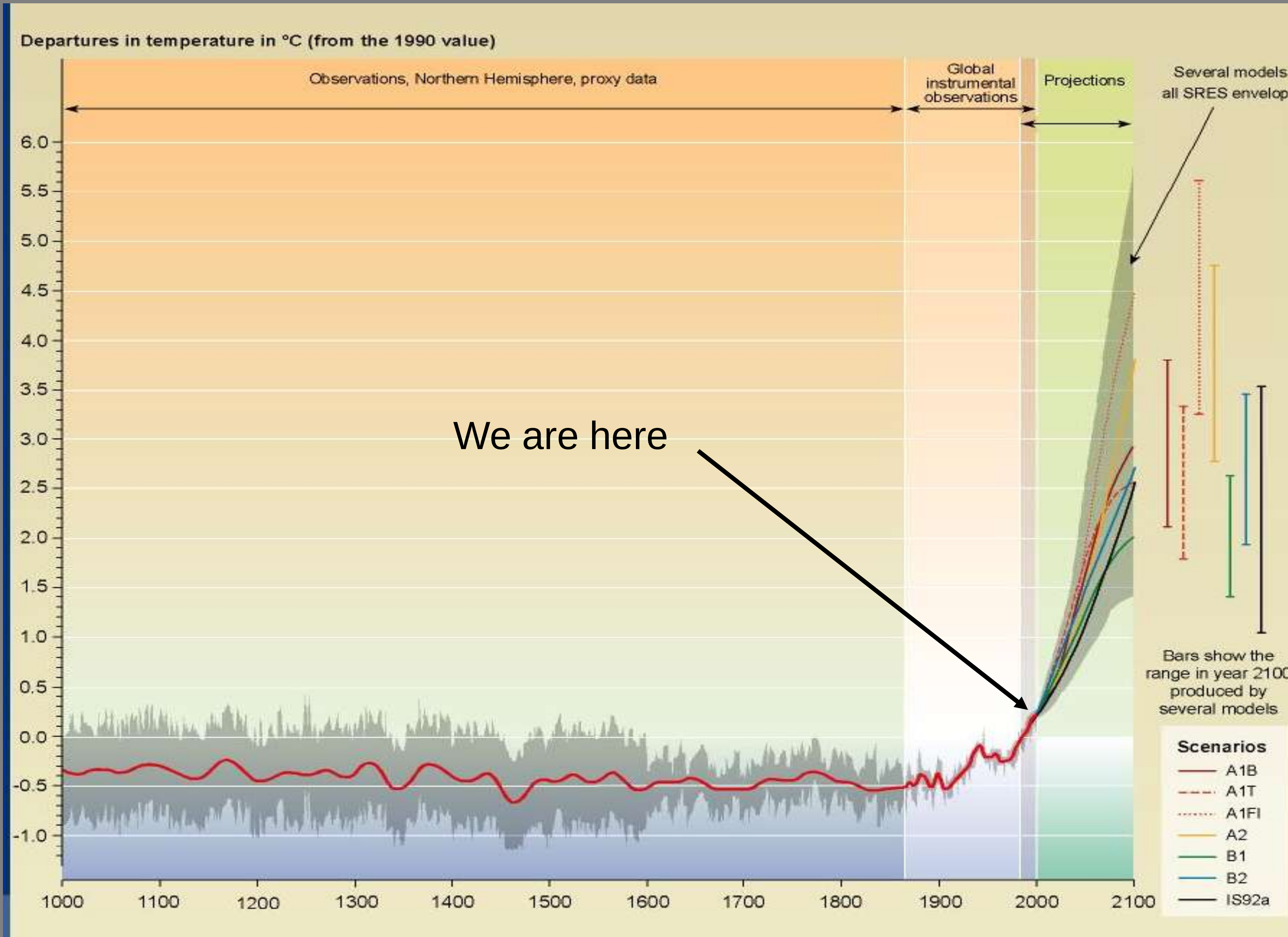

Departures in temperature in °C (from the 1990 value)
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A1B
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6.0
5.5
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4.5
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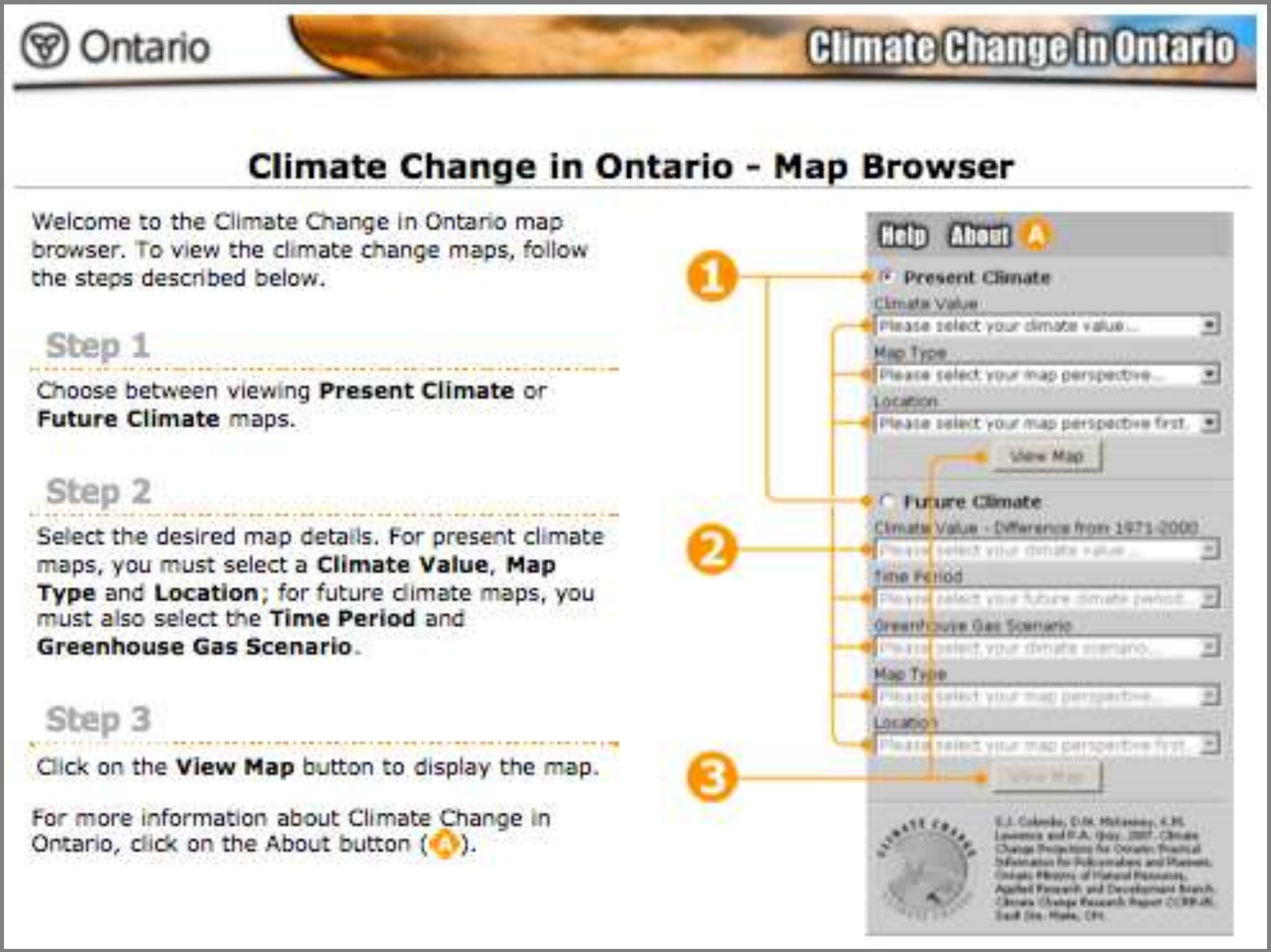
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100

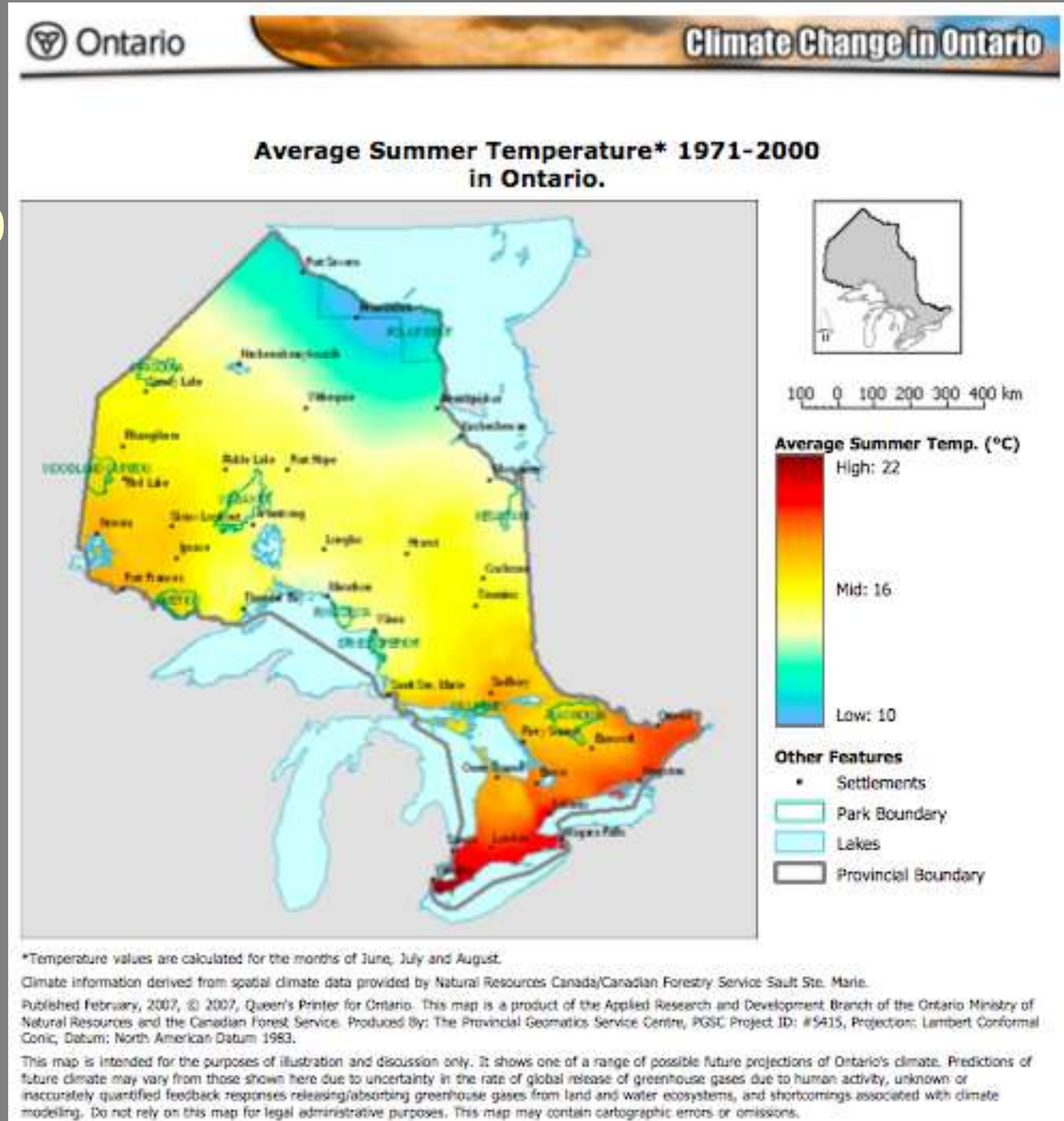
Thank you !

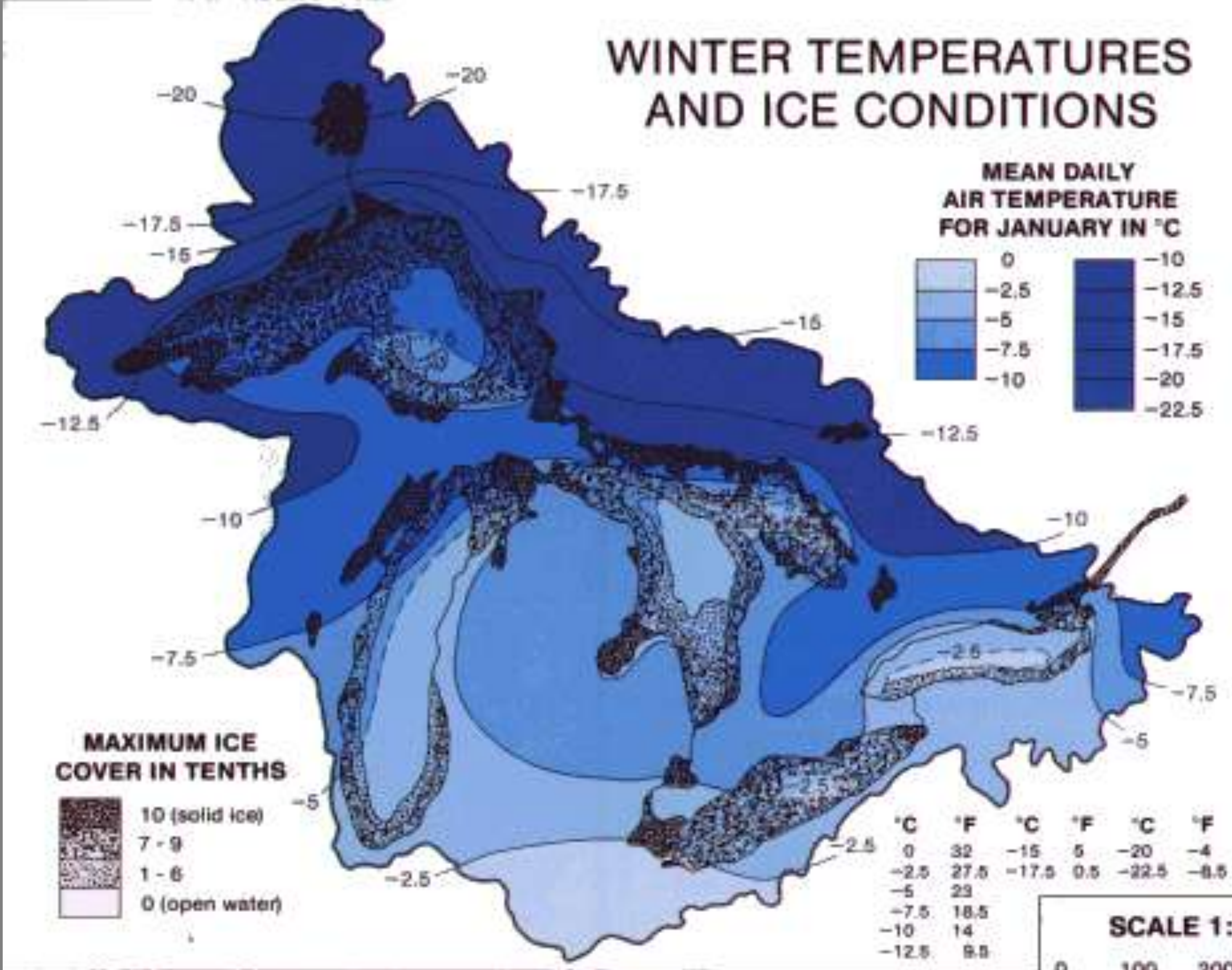
Future climate scenarios – GoGreenOntario site



Average Summer Temp 1971 – 2000

Baseline for "Future Climate" scenarios

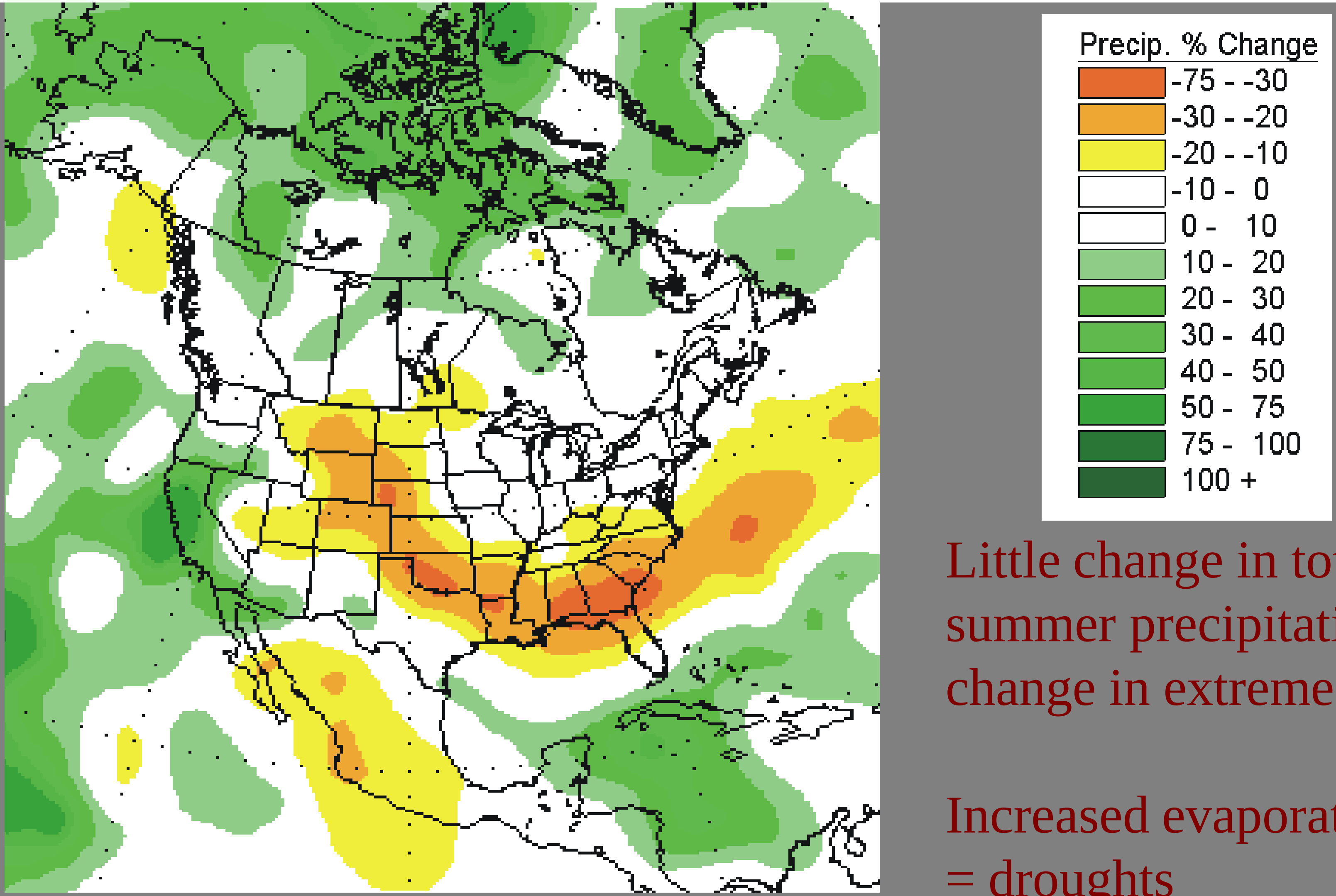




WINTER TEMPERATURES
AND ICE CONDITIONS
MEAN DAILY
AIR TEMPERATURE
FOR JANUARY IN °C
0
−2.5
−5
−7.5
−10
−10
−12.5
−15
−17.5
−20
−22.5
MAXIMUM ICE
COVER IN TENTHS
10 (solid ice)
7 - 9
1 - 6
0 (open water)
−20
−20
−17.5
−17.5
−15
−15
−12.5
−12.5
−10
−10
−7.5
−7.5
−5
−5
−2.5
−2.5
−2.5
−2.5
−2.5
°C °F °C °F °C °F
0 32 −15 5 −20 −4
−2.5 27.5 −17.5 0.5 −22.5 −8.5
−5 23
−7.5 18.5
−10 14
−12.5 9.5
SCALE 1:
0 100 200

Projected Summer Precipitation Change Between 1975-1995 and 2080-2100

Combined Effects of Projected Greenhouse Gas and Sulphate Aerosol Increases - Canadian Model

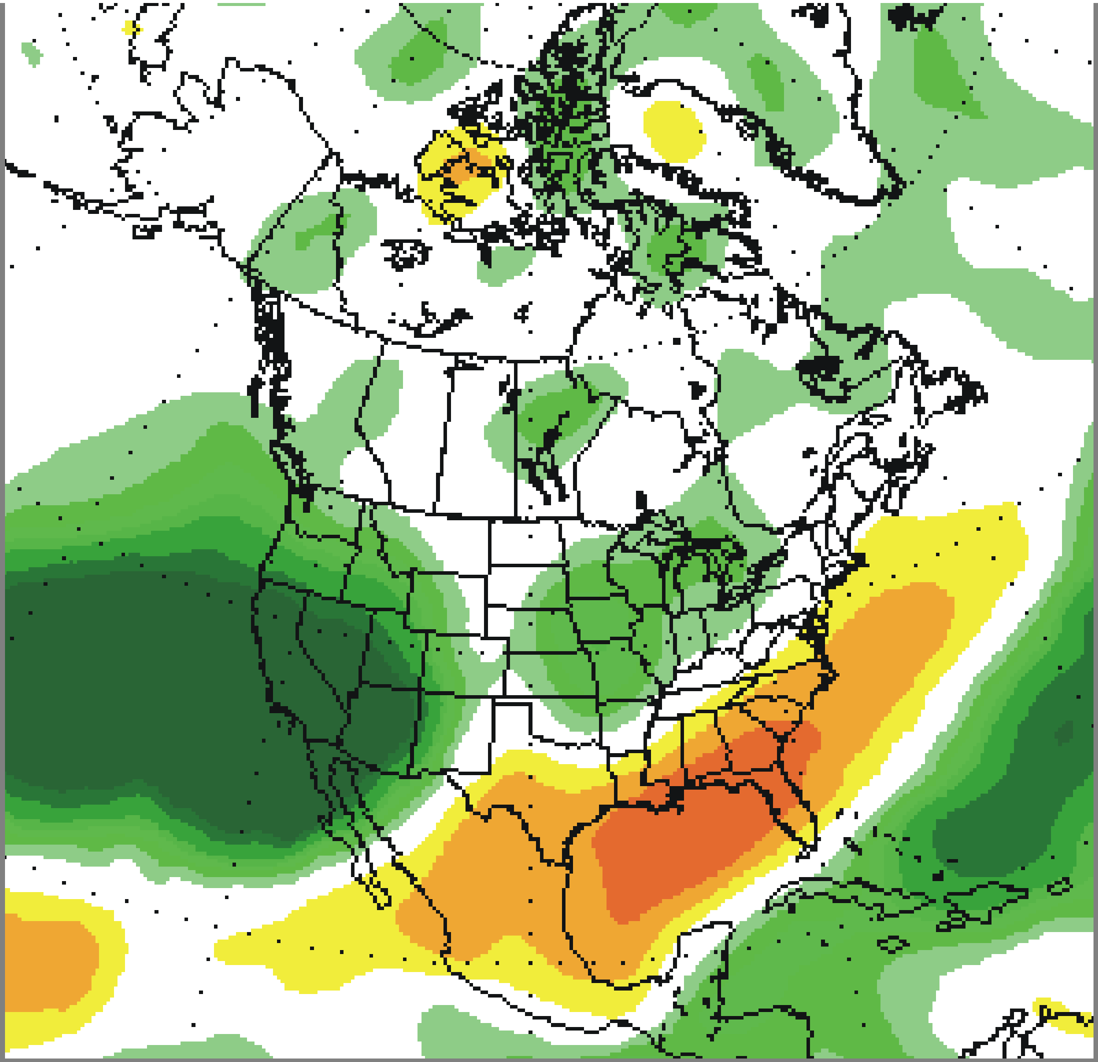


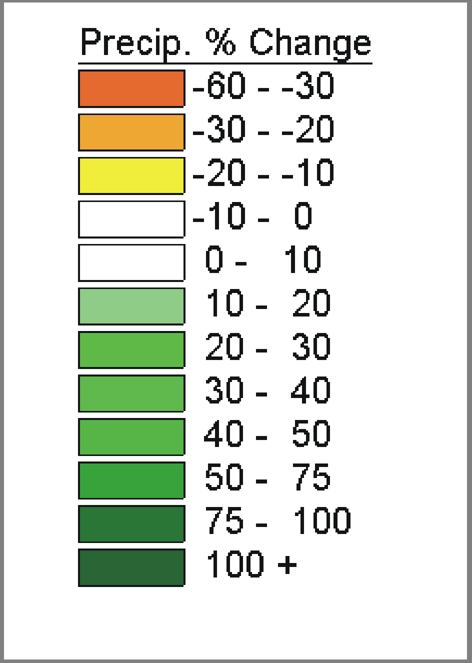
Little change in total summer precipitation; change in extremes ?

Increased evaporation = droughts

Projected Winter Precipitation Change Between 1975-1995 and 2010-2030

Combined Effects of Projected Greenhouse Gas and Sulphate Aerosol Increases - Canadian Model





Some increased winter precipitation over Ontario

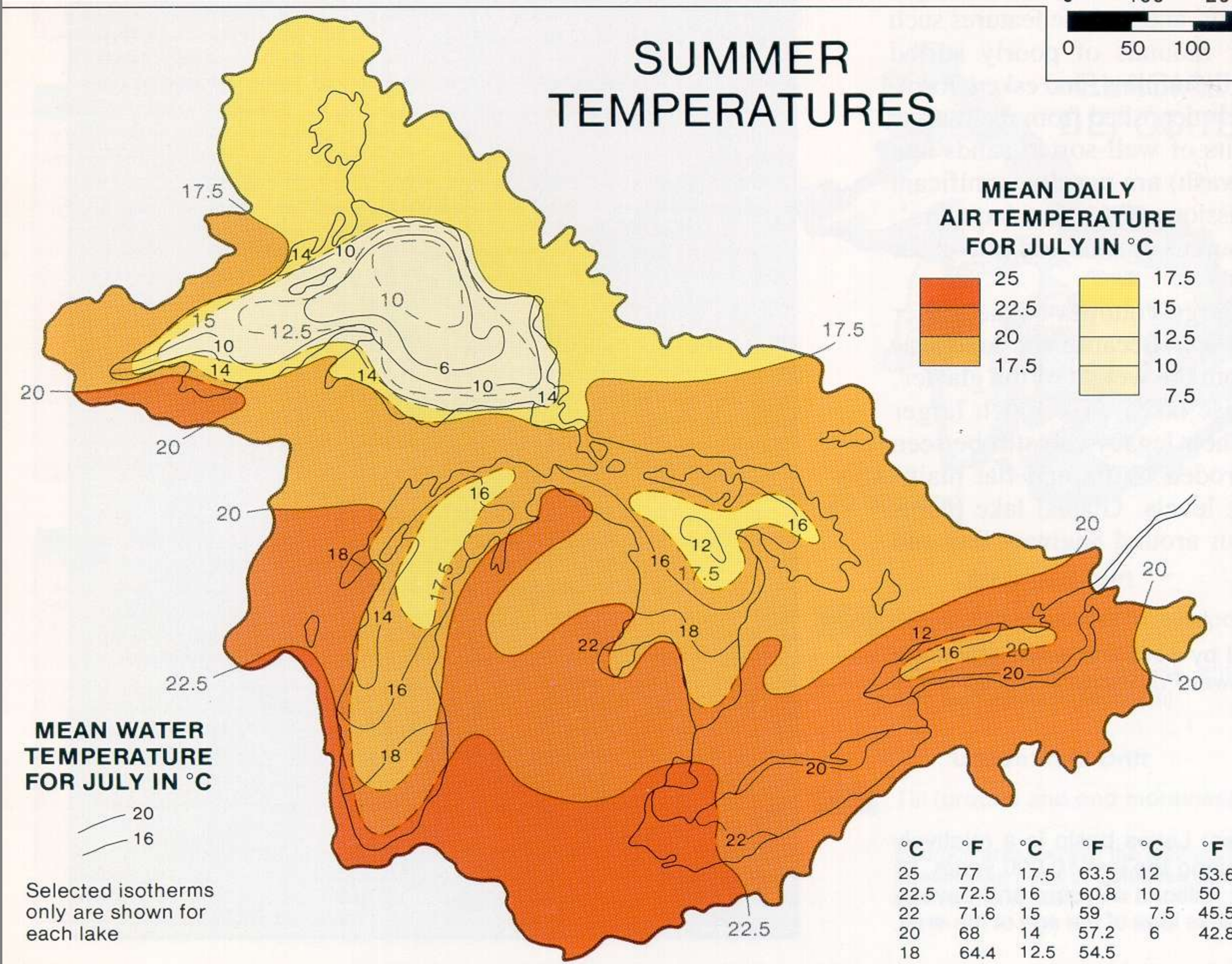
More rain – less snow

Since 1979 the temperature of Lake Superior has increased by 2.5 ^{0} C = twice the increase in air temperature (Jay Austen in press)

21,000 years ago

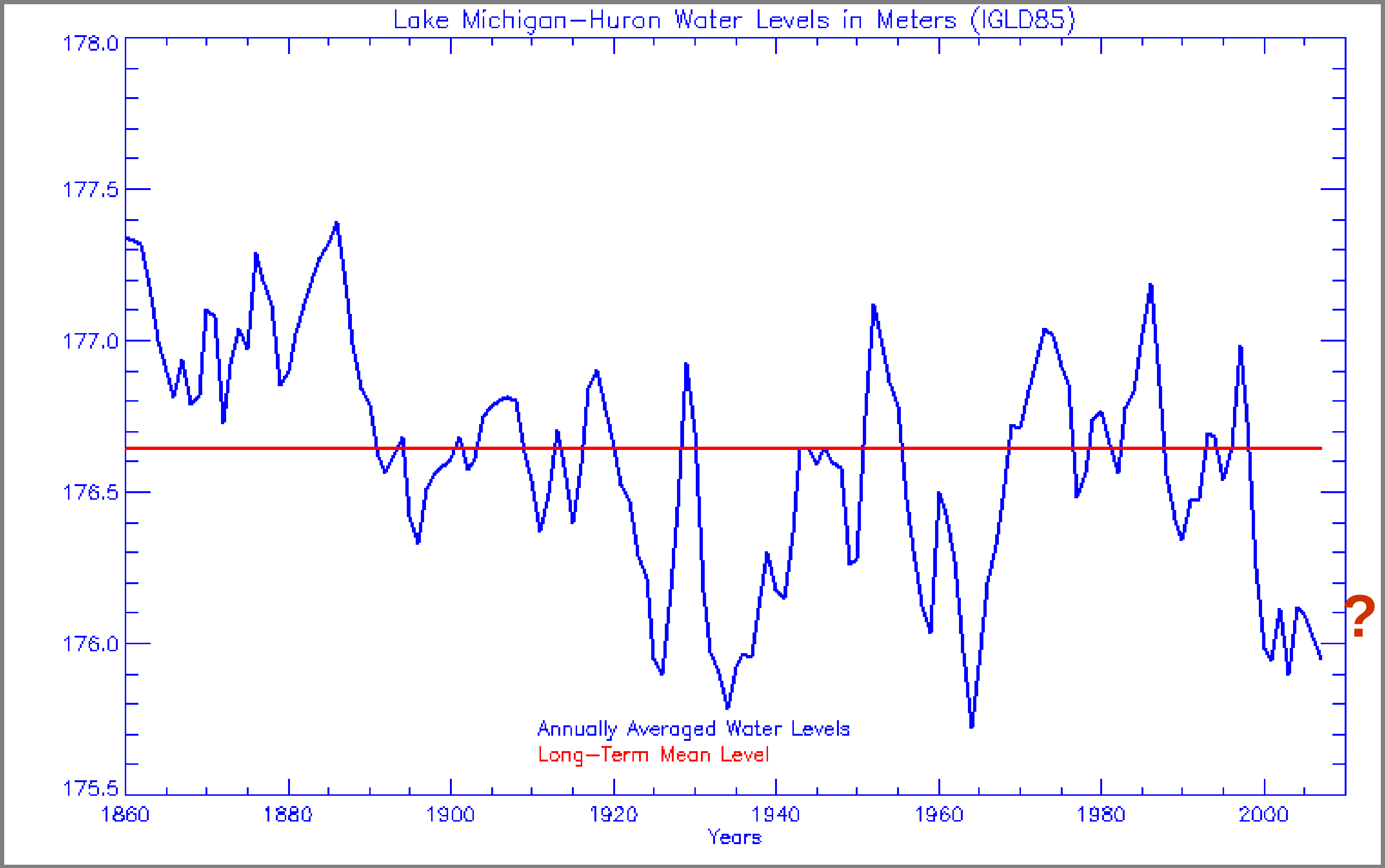
Univ. of Montana

SUMMER TEMPERATURES



°C	°F	°C	°F	°C	°F
25	77	17.5	63.5	12	53.6
22.5	72.5	16	60.8	10	50
22	71.6	15	59	7.5	45.5
20	68	14	57.2	6	42.8
18	64.4	12.5	54.5		

The future of GL water levels depends on how much increase in precipitation occurs and whether it balances increased evaporation because of higher temperatures and less ice cover



The Canadian model shows A decline of 1.38m by 2090 But the Hadley (UK) model Shows an Increase of 0.35m

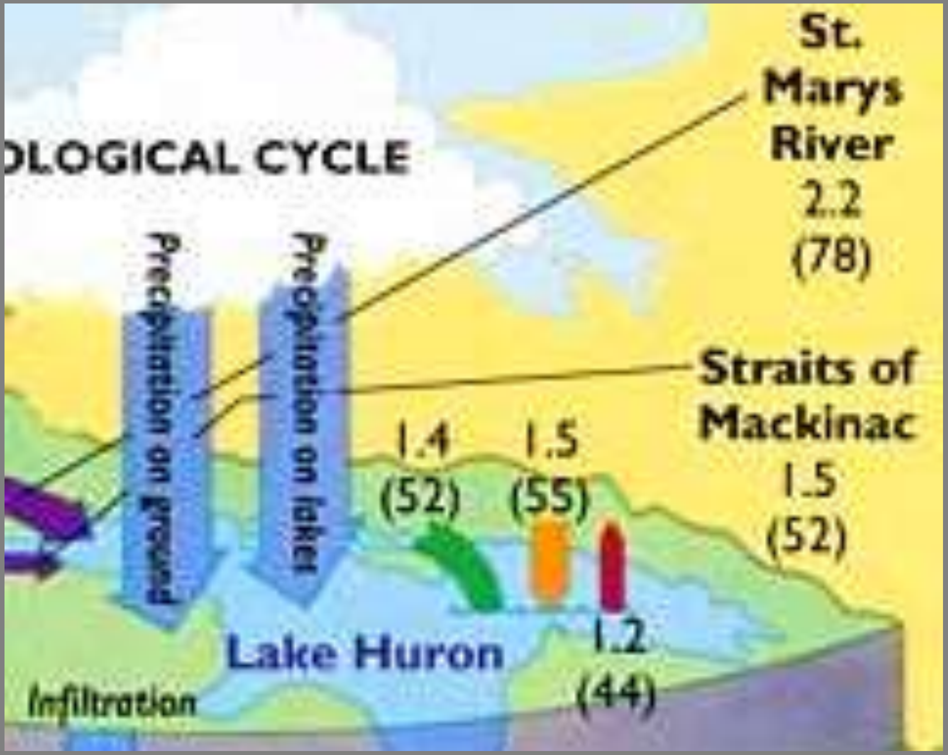
NOAA GLERL

Future climate suggests an increase in the ice free period for Lake Ramsey of

9 days - 2020
17 days - 2050
29 days - 2080

(Bill Keller 2007)

If evaporation from Lake Ramsey is roughly 30 to 50% of the rate of Lake Huron that would amount to an average of 6 to 8mm per day (approximately equivalent to 3 or 4 Olympic size Swimming pools a day)



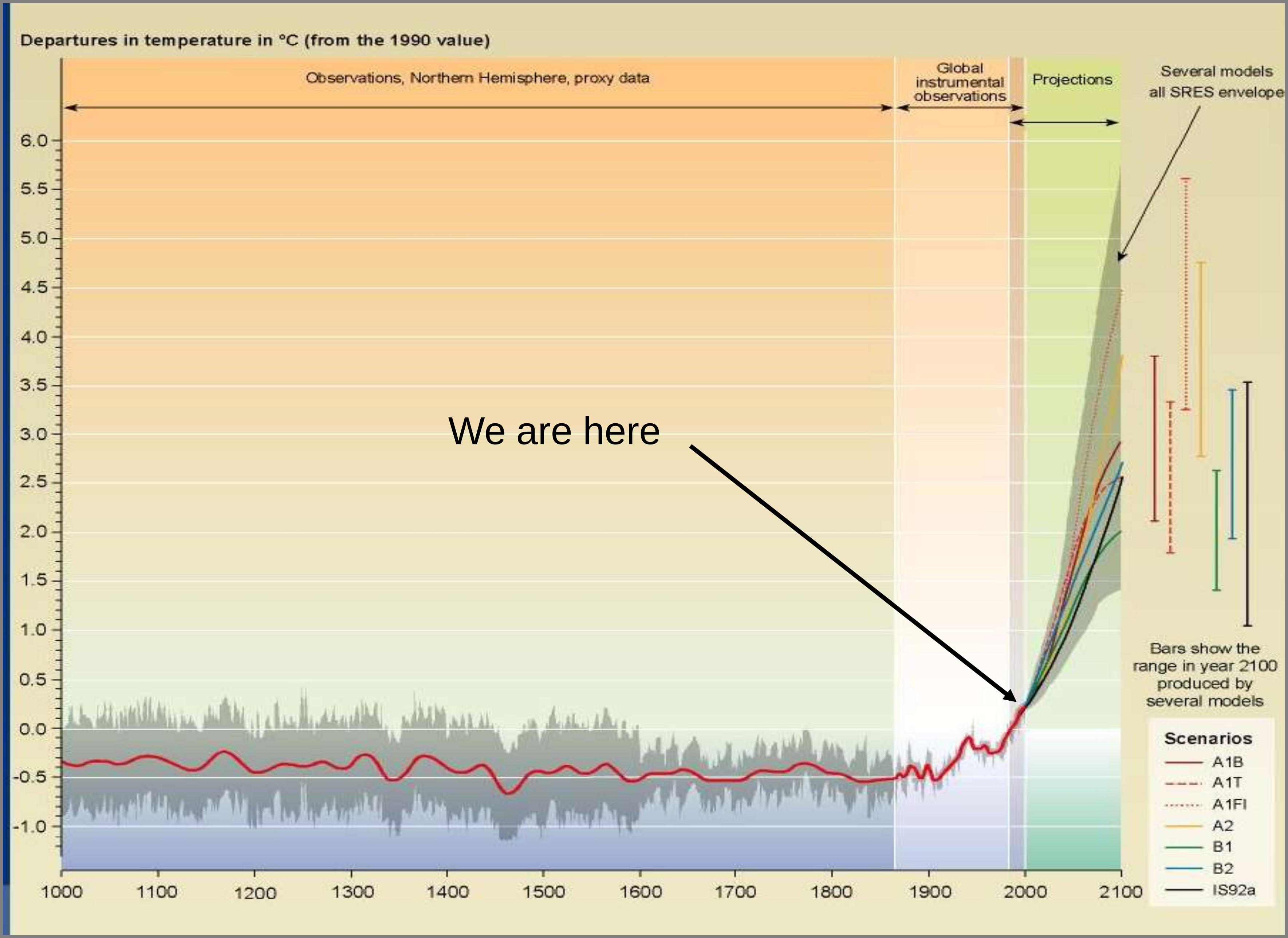
Stream and river flows into Lake Huron from the surrounding watershed total 1,400 cubic metres a second.

Precipitation onto the lake totals 1,500 cubic metres a second.

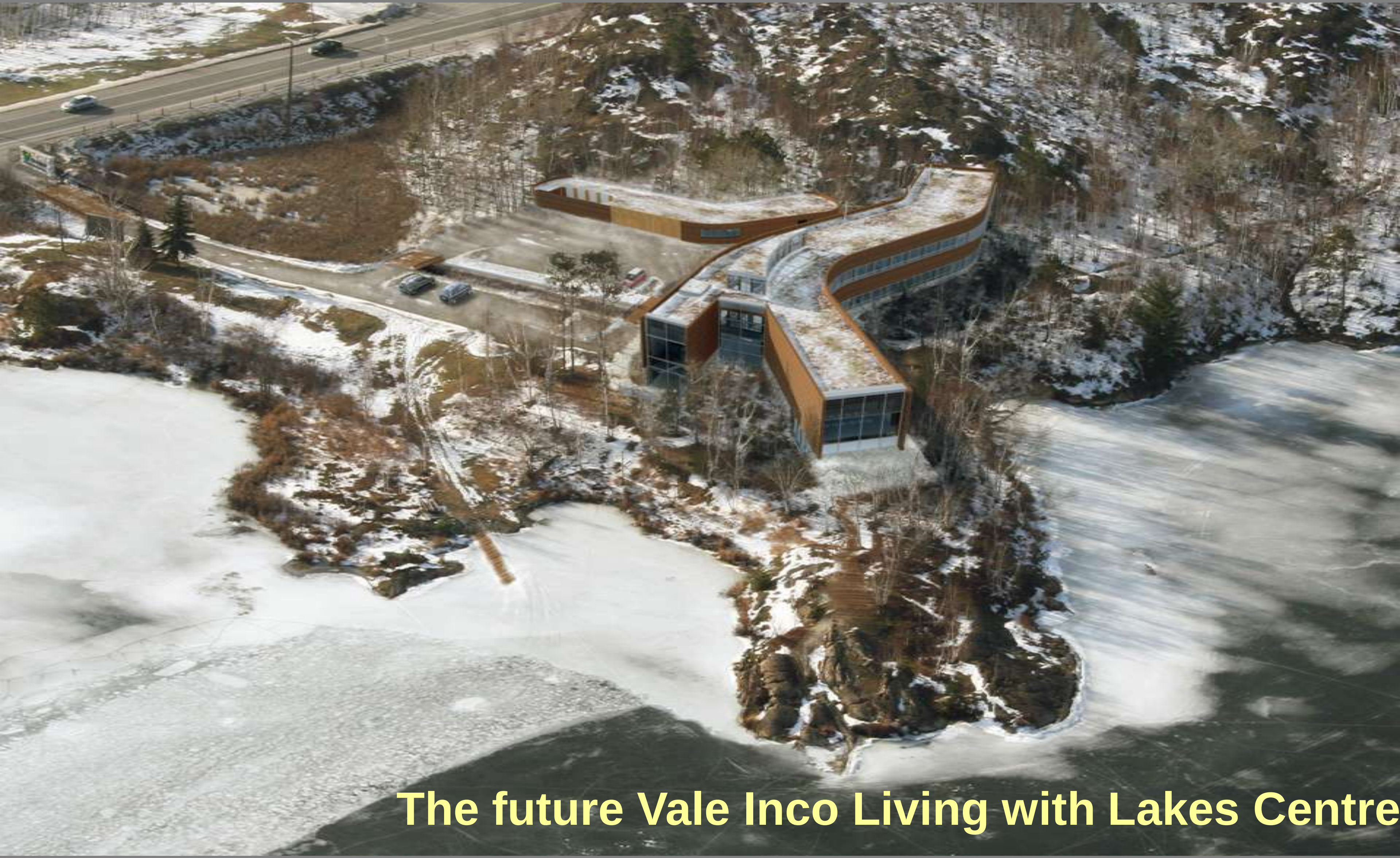
Evaporation from the lake surface totals 1,200 cubic metres a second

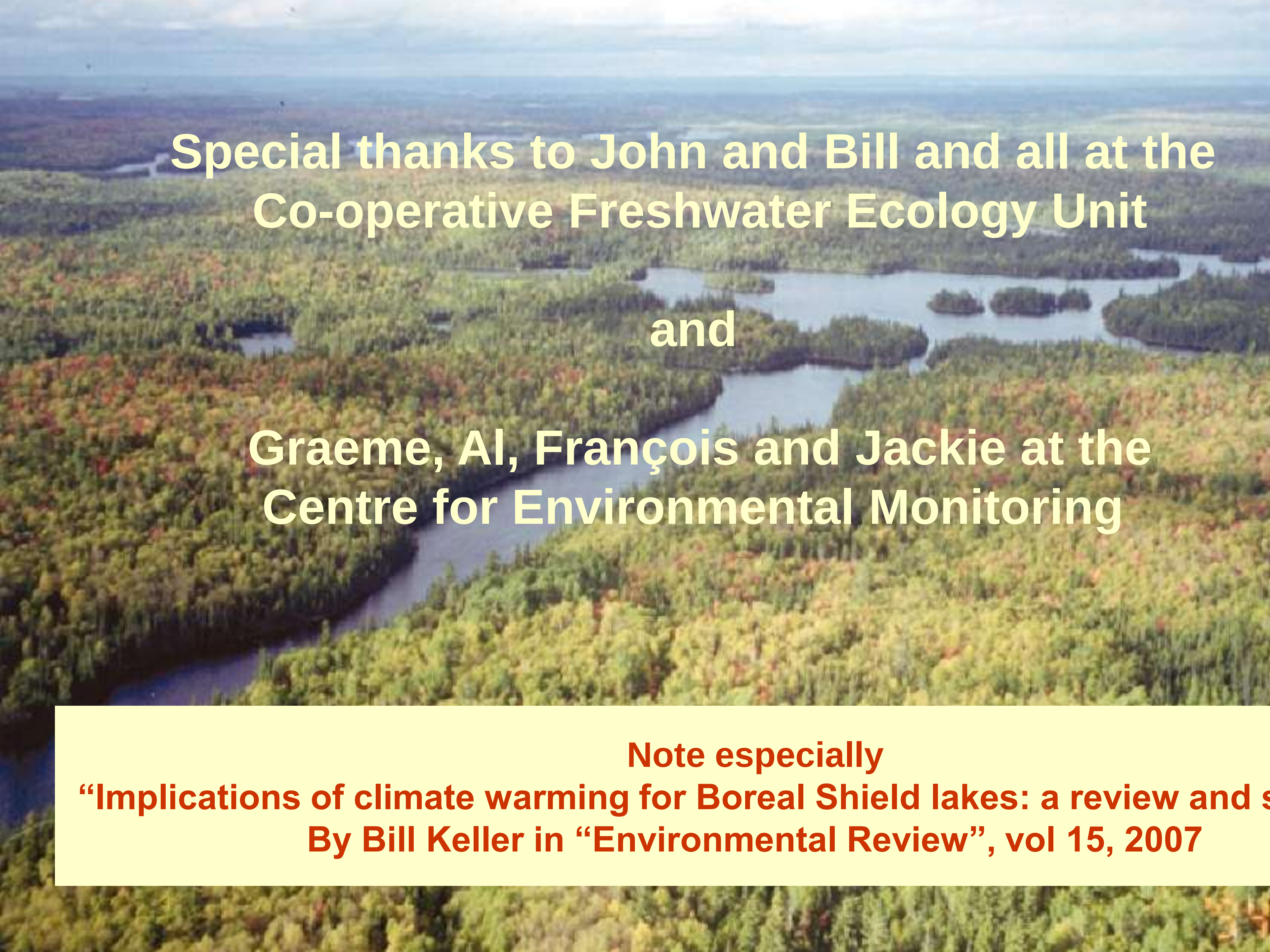
The Great Lakes Basin


Caspian shrimp
NOAA GLERL Nov 2007



Departures in temperature in °C (from the 1990 value)
Observations, Northern Hemisphere, proxy data
Global instrumental observations
Projections
Several models all SRES envelope
We are here
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
Bars show the range in year 2100 produced by several models
Scenarios
A1B
A1T
A1FI
A2
B1
B2
IS92a


The future Vale Inco Living with Lakes Centre

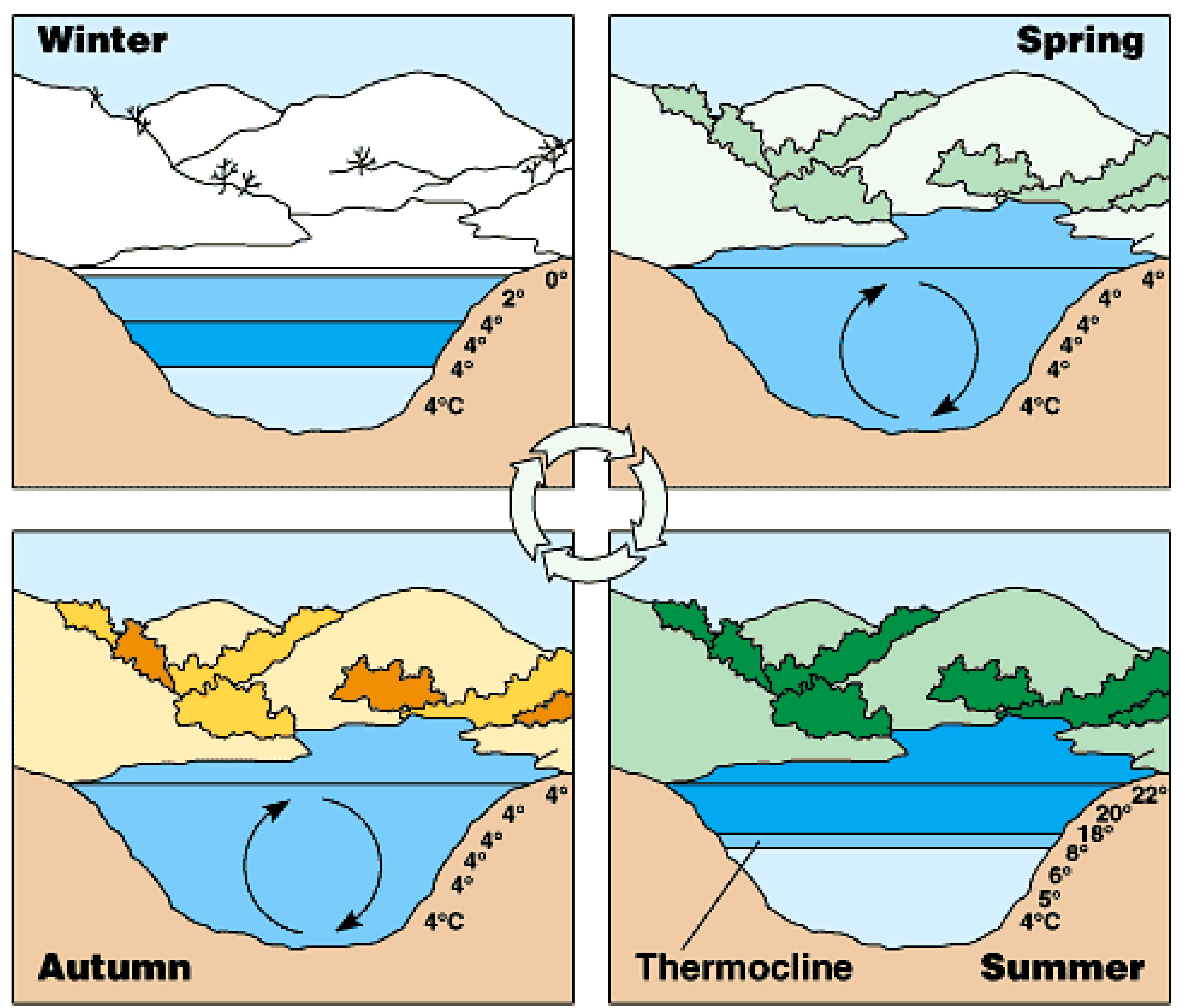


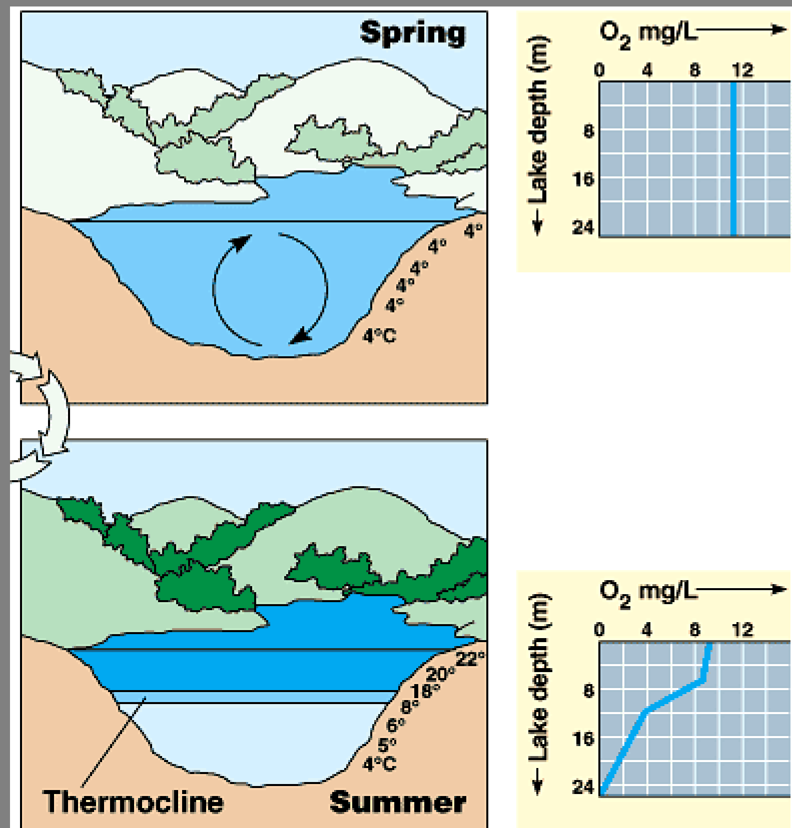
Special thanks to John and Bill and all at the Co-operative Freshwater Ecology Unit

and

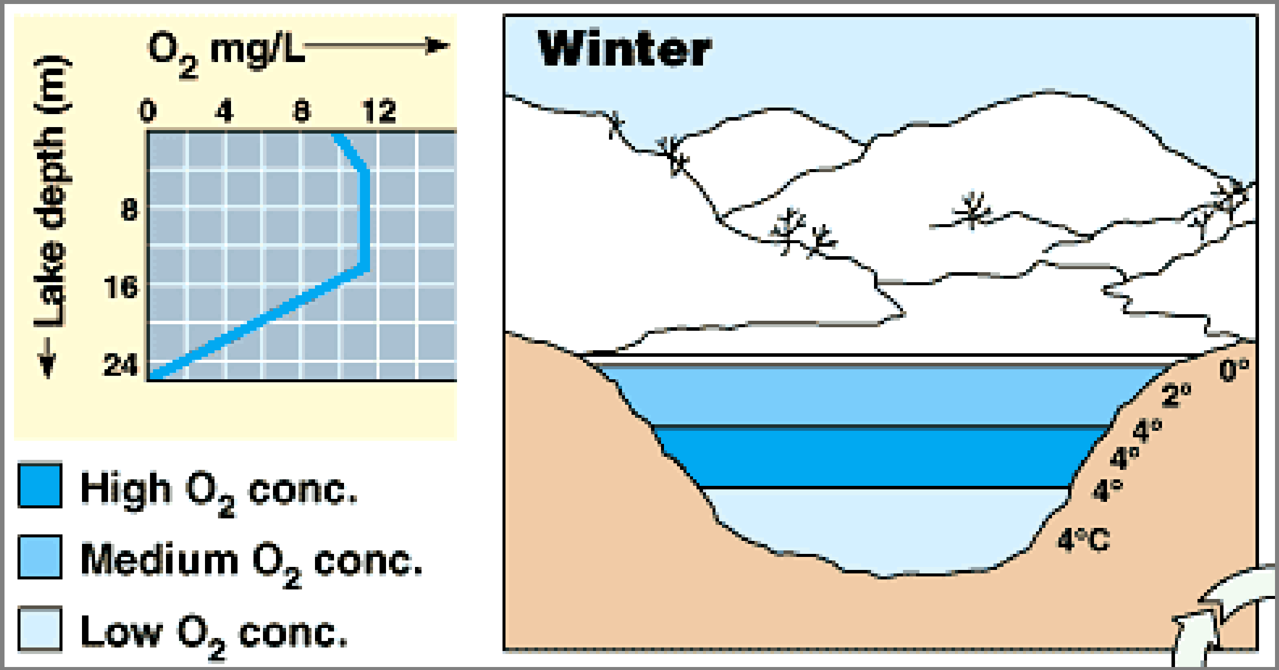
Graeme, Al, François and Jackie at the Centre for Environmental Monitoring

Note especially
“Implications of climate warming for Boreal Shield lakes: a review and s
By Bill Keller in “Environmental Review”, vol 15, 2007

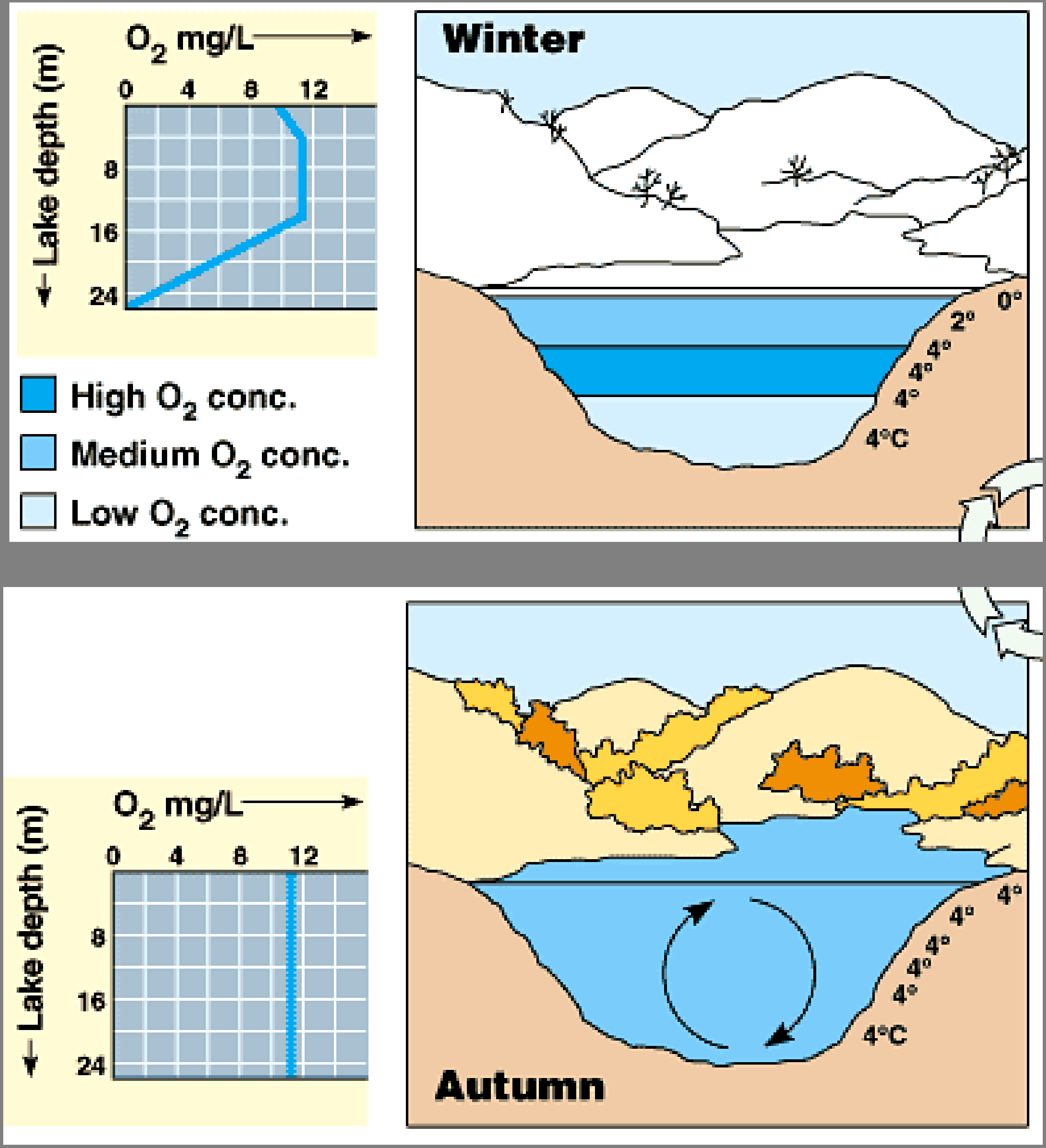

Winter
0°
2°
4°
4°
4°
4°C
Spring
4°
4°
4°
4°
4°
4°C
Autumn
4°
4°
4°
4°
4°
4°C
Summer
22°
20°
18°
8°
6°
5°
4°C
Thermocline



Spring
4°
4°
4°
4°
4°
4°C
O2 mg/L
0
4
8
12
Lake depth (m)
8
16
24
Thermocline
Summer
22°
20°
18°
8°
6°
5°
4°C
O2 mg/L
0
4
8
12
Lake depth (m)
8
16
24



O_2 mg/L
0
4
8
12
Lake depth (m)
8
16
24
High O_2 conc.
Medium O_2 conc.
Low O_2 conc.
Winter
0°
2°
4°
4°
4°
4°C



O_2 mg/L
0
4
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Lake depth (m)
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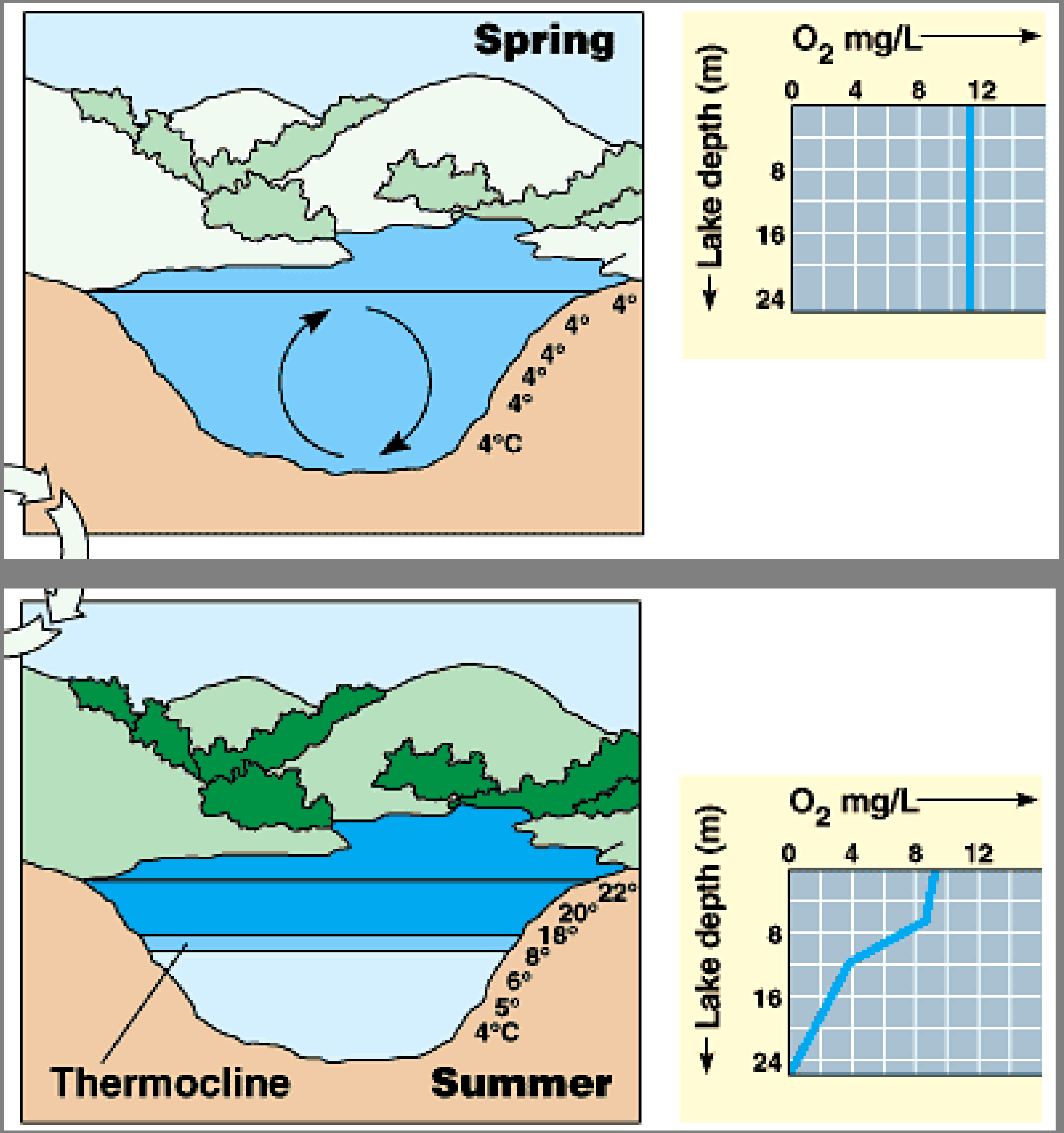
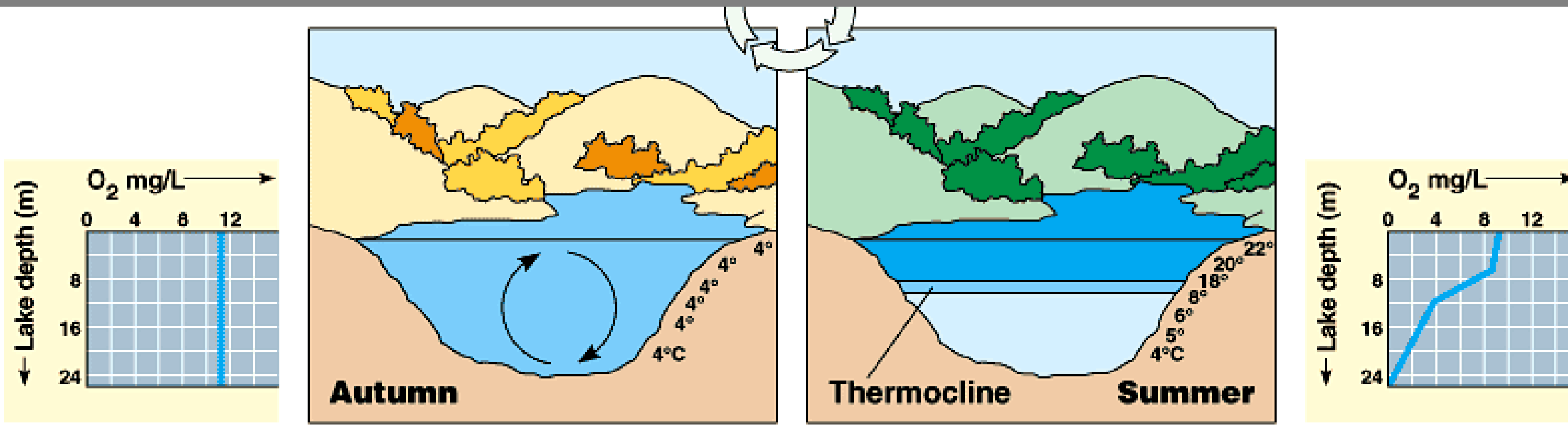
16
24
High O_2 conc.
Medium O_2 conc.
Low O_2 conc.
Winter
0°
2°
4°
4°
4°
4°C
O_2 mg/L
0
4
8
12
Lake depth (m)
8
16
24
4°
4°
4°
4°
4°
4°C
Autumn



Spring
4°
4°
4°
4°
4°
4°C
O2 mg/L
0
4
8
12
← Lake depth (m)
8
16
24
22°
20°
18°
8°
6°
5°
4°C
Thermocline
Summer
O2 mg/L
0
4
8
12
← Lake depth (m)
8
16
24



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Lake depth (m)
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16
24
Autumn
4°
4°
4°
4°
4°
4°C
Thermocline
Summer
22°
20°
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8°
6°
5°
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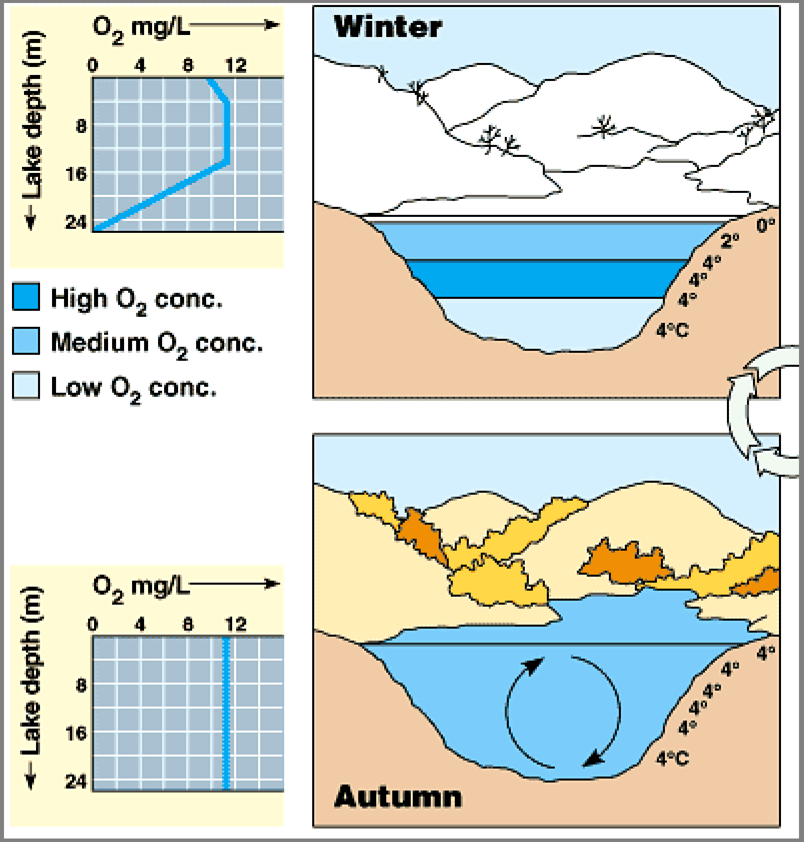

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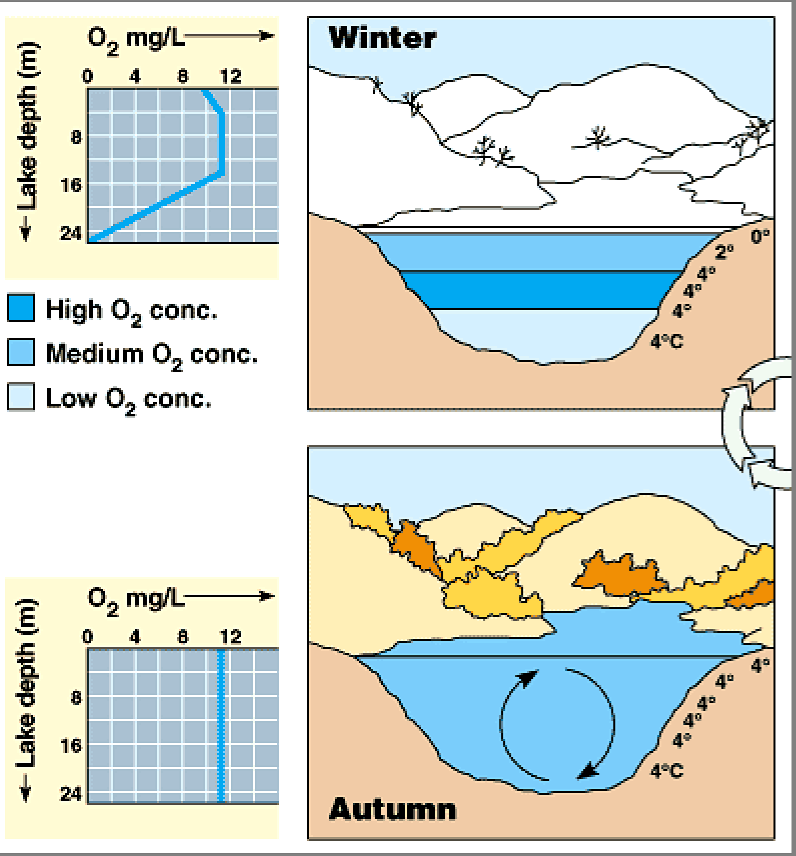
24
4°
4°
4°
4°
4°
4°C
Autumn



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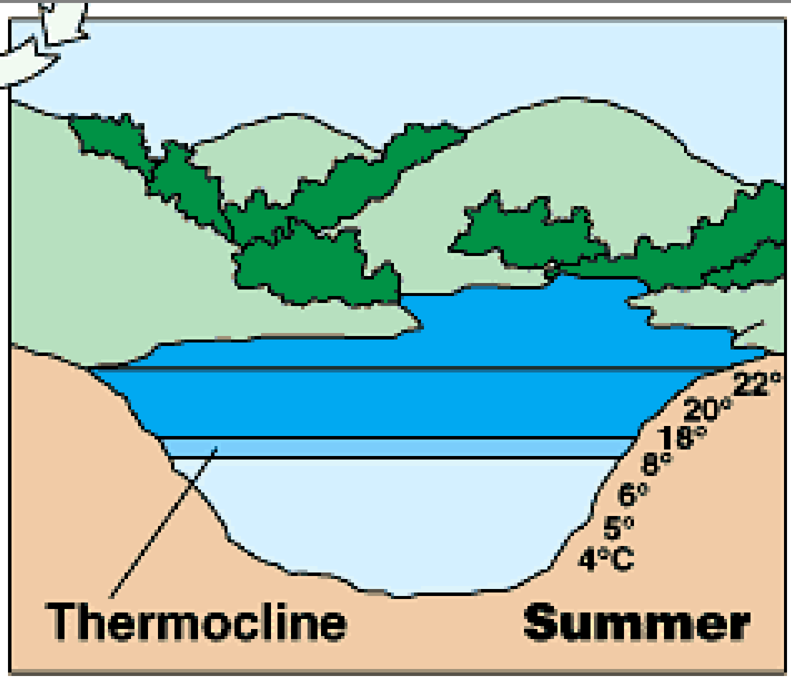
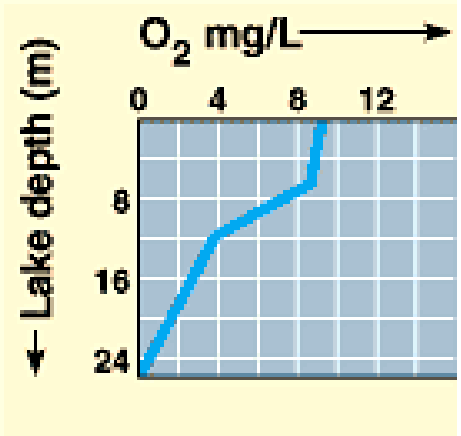
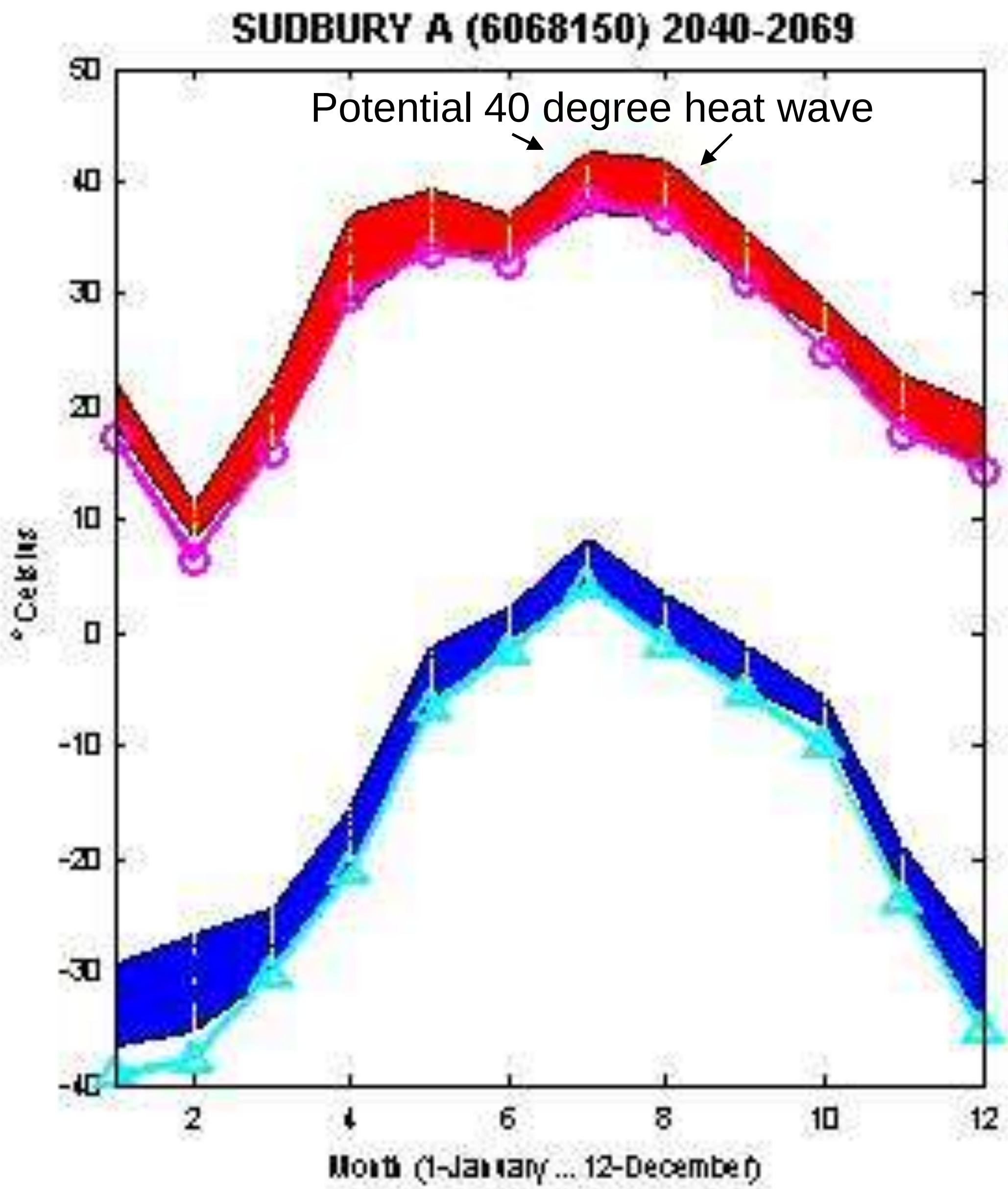
4°
4°
4°
4°
4°
4°C
Autumn


22°
20°
18°
8°
6°
5°
4°C
Thermocline
Summer


O_2 mg/L
0
4
8
12
Lake depth (m)
8
16
24

Location and community context …

Extreme Temperature Range



(Univ of Victoria – Climate Change Scenarios - on line)

1961-1990 Max Temp Extreme
1961-1990 Min Temp Extreme
Scenarios Max Temp Extreme
Scenarios Min Temp Extreme

Small yellow dots in range are actual values within range from all experiments

Summer in 2050

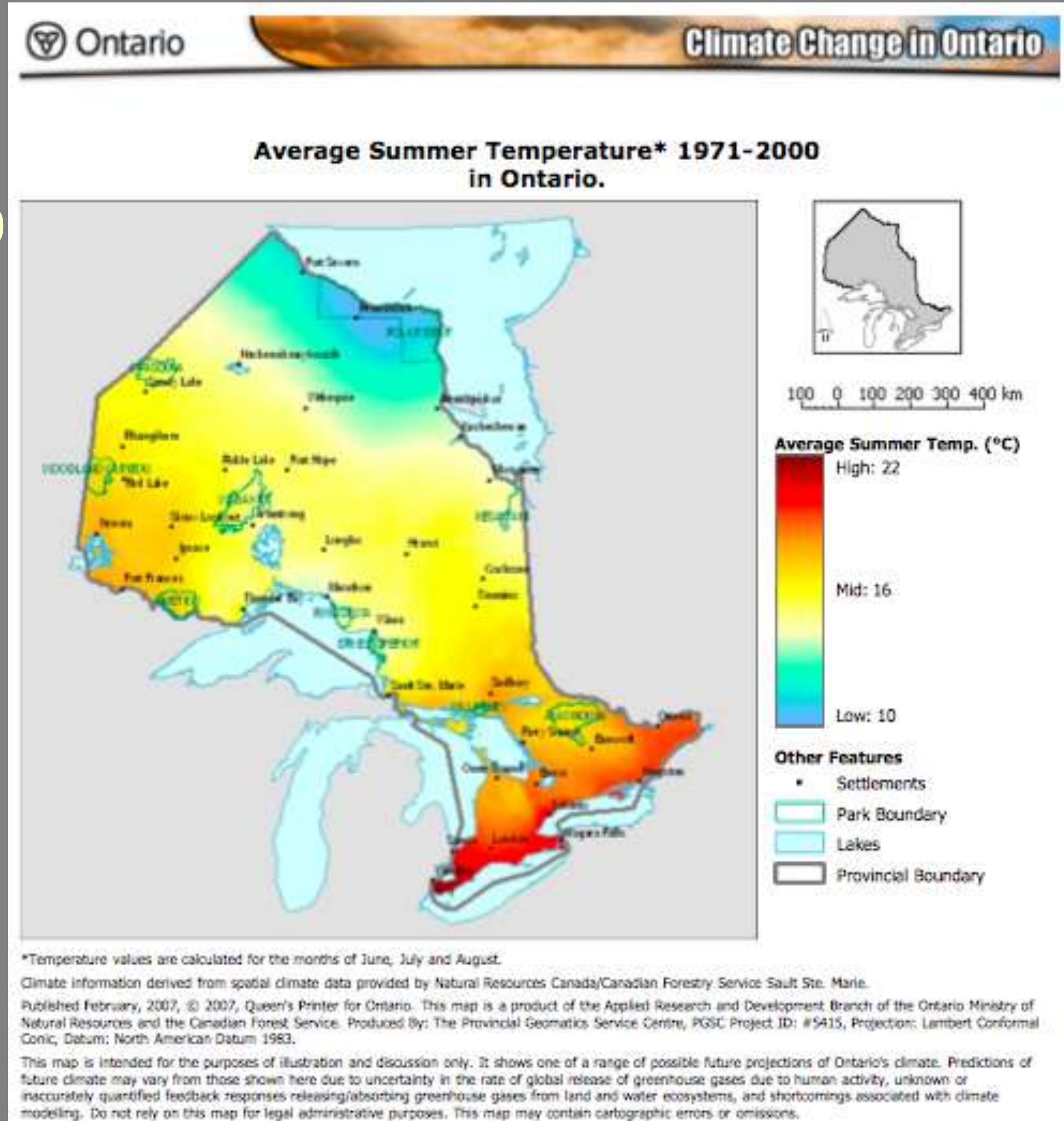
Hot July / August days 3 weeks potential over 40 C

Winter in 2050

Coldest Jan days -30 C

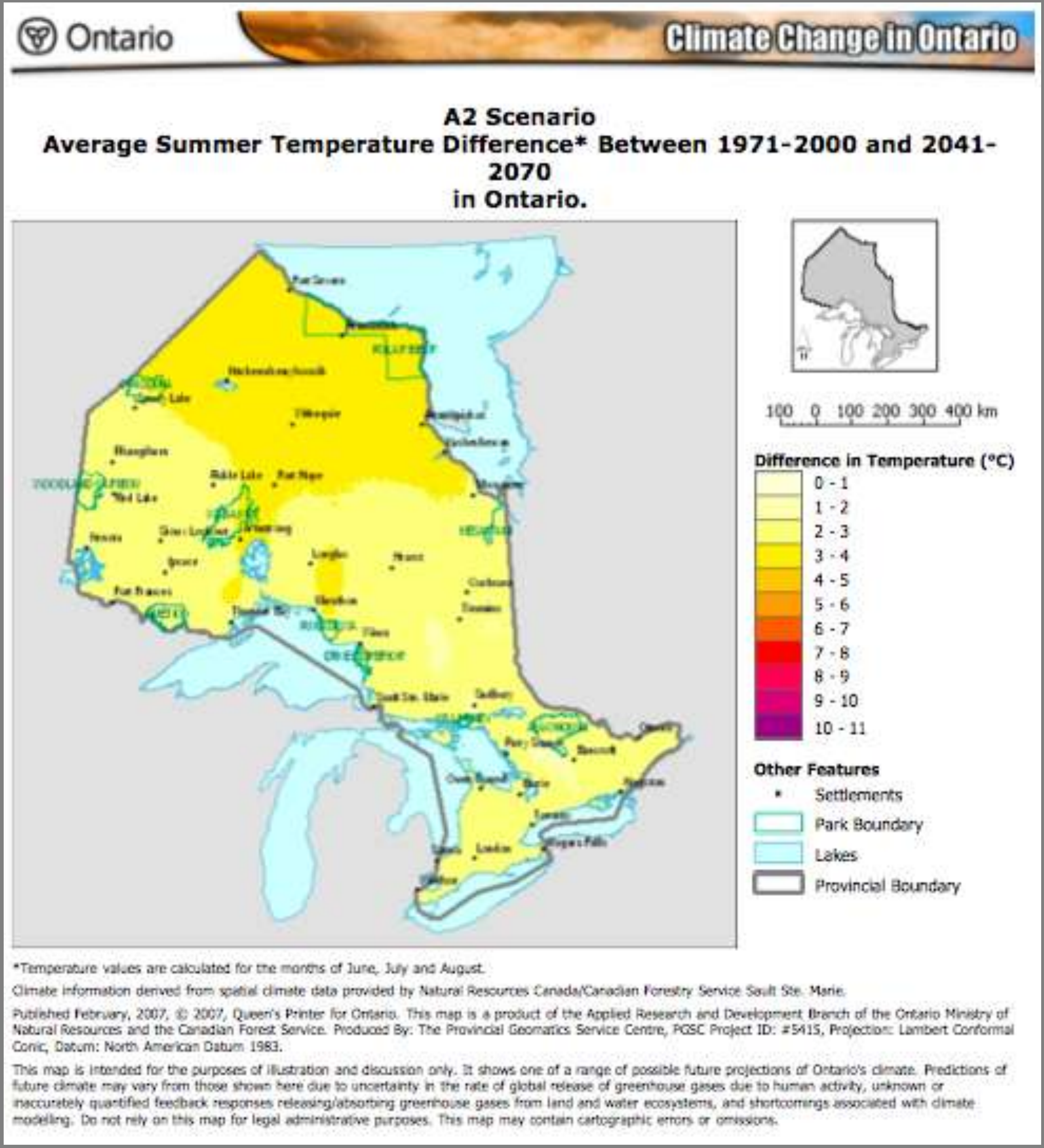
Average Summer Temp 1971 – 2000

Baseline for "Future Climate" scenarios



Average Summer Temp difference between 1971 - 2000 baseline and 2041 – 2070

A2 emission scenario:
15 billion popln
1320 ppm CO2 by 2100



Present day drainage

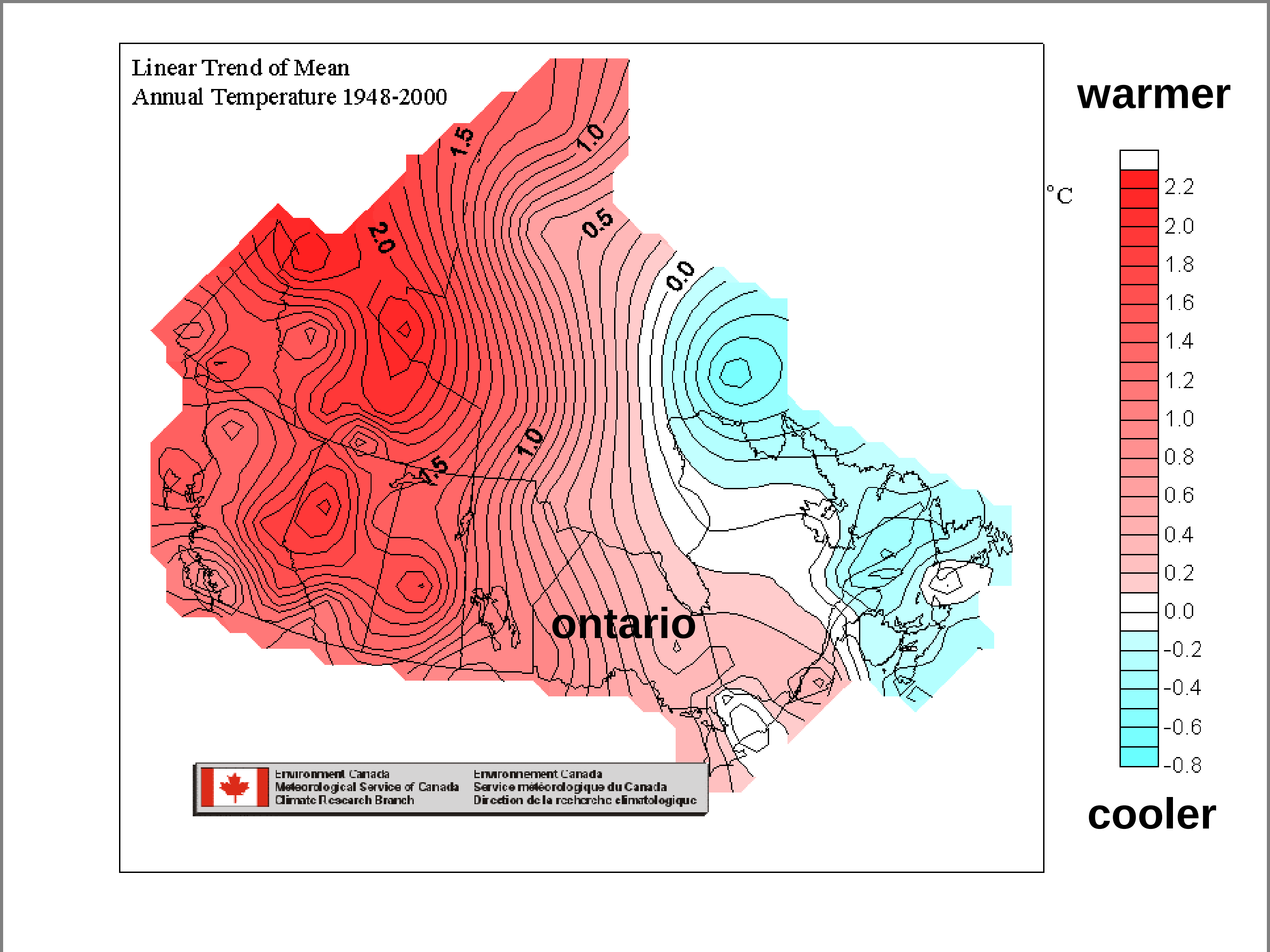
Pre Ice Age drainage

From Marshack
2001


LAKE
AGASSIZ

Communicating the science ….

Ontario is already warmer than in the 1960s



Expert Panel on Climate Change Adaptation

Members

- **Chief John Beaucage**, Anishinabek First Nation
- **Alain Bourque**, Consortium on Regional Climatology and Adaptation to Climate Change (OURANOS)
- **Dr. Quentin Chiotti**, Pollution Probe, Director, Climate Change Program
- **Dr. Judith Guernsey**, Community Health and Epidemiology, Dalhousie University
- **David Lapp**, Engineers Canada
- **Eva Ligetti**, Exec Director, Clean Air Partnership

Expert Panel on Climate Change Adaptation

- **Dr. Gord McBean**, FRS, Policy Chair, Institute for Catastrophic Loss Reduction, Univ W.Ontario
- **Jo-Ellen Parry**, International Institute for Sustainable Development, Winnipeg
- **Dr. Barry Smit**, Prof., Canada Research Chair in Global Environmental Change

Co-Chairs:

- **Dr. Ian Burton**, Prof. Emeritus, Env. Studies, Univ. of Toronto
- **Dr. David Pearson**, Prof. Earth Sciences, and Science Communication, Laurentian Univ.

Mandate

To provide advice to government

- concerning issues related to climate change impacts and adaptation such as

- actions, plans and best practices
- adaptation policies
- research needs

and to

- respond to requests for advice on impact and adaptation topics or issues as requested - utilizing external expertise when required

Ontario Centre for Climate Impacts and Adaptation Resources

(at Laurentian University)

To promote and deliver resources and outreach activities related to climate change impacts and adaptation in Ontario through:

- workshops for communities and stakeholders
- an adaptation "toolkit" for municipalities to mainstream adaptation to climate change into everyday decision making processes
- communicating the science of climate change, and potential impacts and adaptation issues

Ontario Centre for Climate Impacts and Adaptation Resources

- developing adaptation resource materials related to impacts on communities and stakeholders
- maintaining a climate change “knowledge” and stakeholder network
- maintaining a bibliographic database
- maintaining a website of impacts and adaptation information, links etc
- promoting regional climate modeling