LECTURE 12:
MAY 27, 2014

# CLIMATE CHANGE

## DEFINITIONS AND SCIENTIFIC EVIDENCE RELATED TO …

Text Reference: Dearden and Mitchell (2012), Ch. 7, pp. 201-209 & 209-217

# Outline



- Upcoming:
  - **June 4 (Field trip):**
    - Urban/Suburban Thunder Bay;
    - MNR Research Forest
    - **Details tba**


*Source: Dearden and Mitchell (2012)*

- Today:
  - (lecture)
    - Part 1: Introduction to CC / Evidence of CC
    - Break:
    - Part 2: Implications of CC
  - (discussion: progress on research paper) – structure; referencing; **choice of presentation instead of paper**
  - (Map Literacy 2)

# Part 1

Introduction:

Definitions and Scientific Evidence Related to Climate Change

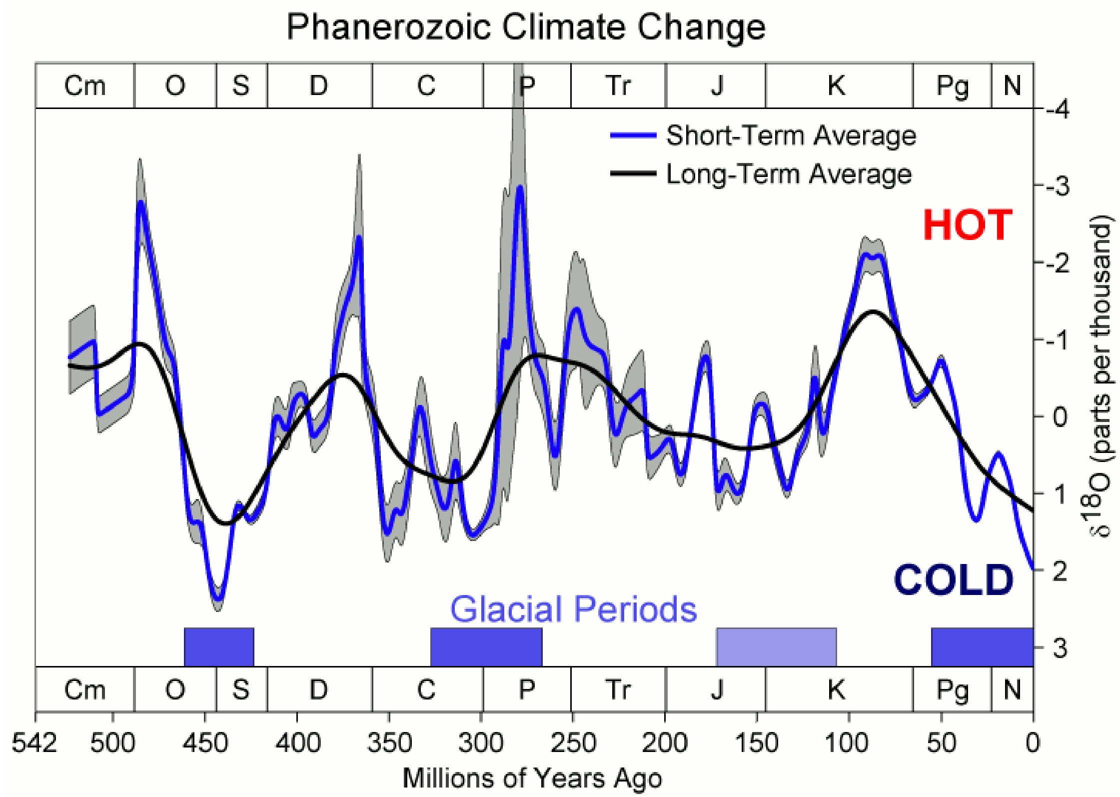
# Outline


*From: Dearden and Mitchell (2012)*

- Definitions:
  - weather, climate, climate change, global warming, greenhouse effect, GCMs,
- Nature of Climatic Change
- Scientific Evidence of Climatic Change

# Overview – *Climate is naturally variable*

- Numerous glacial-interglacial periods during Earth's history
- Notable changes observed in the Earth's climate since period of observations (~last 140 years)
- "Climate Change" is now part of the North American "lexicon" – not so prior to 1990



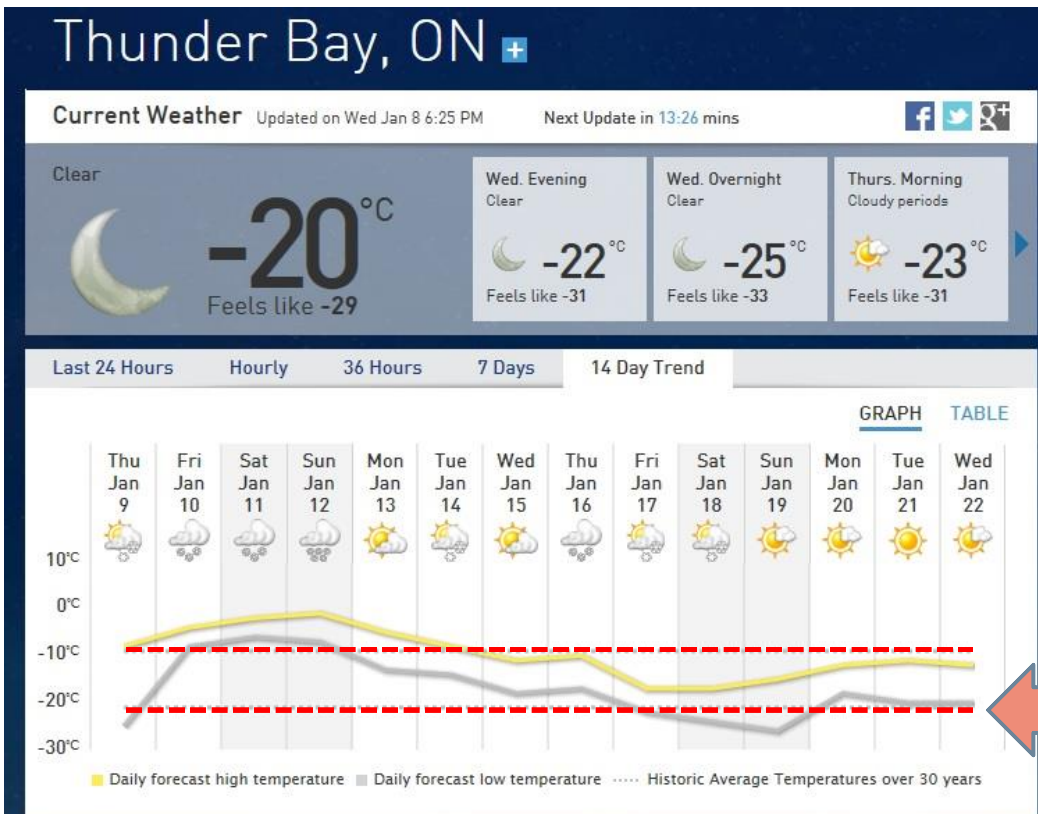
# Weather

- **<u>Weather:</u>** "the condition of the atmosphere at any time and place"
- Includes:
  - Temperature
  - Pressure
  - Humidity
  - Winds
  - Air Pressure


*From: The Weather Network web site (Thunder Bay, Jan. 8, 2014)*

# Climate and “Climate Normals”

- **Climate:** “a composite or generalization of the ***variety*** of day-to-day weather observations”
- Compare “observations” with the ‘typical”




*From: The Weather Network web site (Thunder Bay, Jan. 8, 2014)*

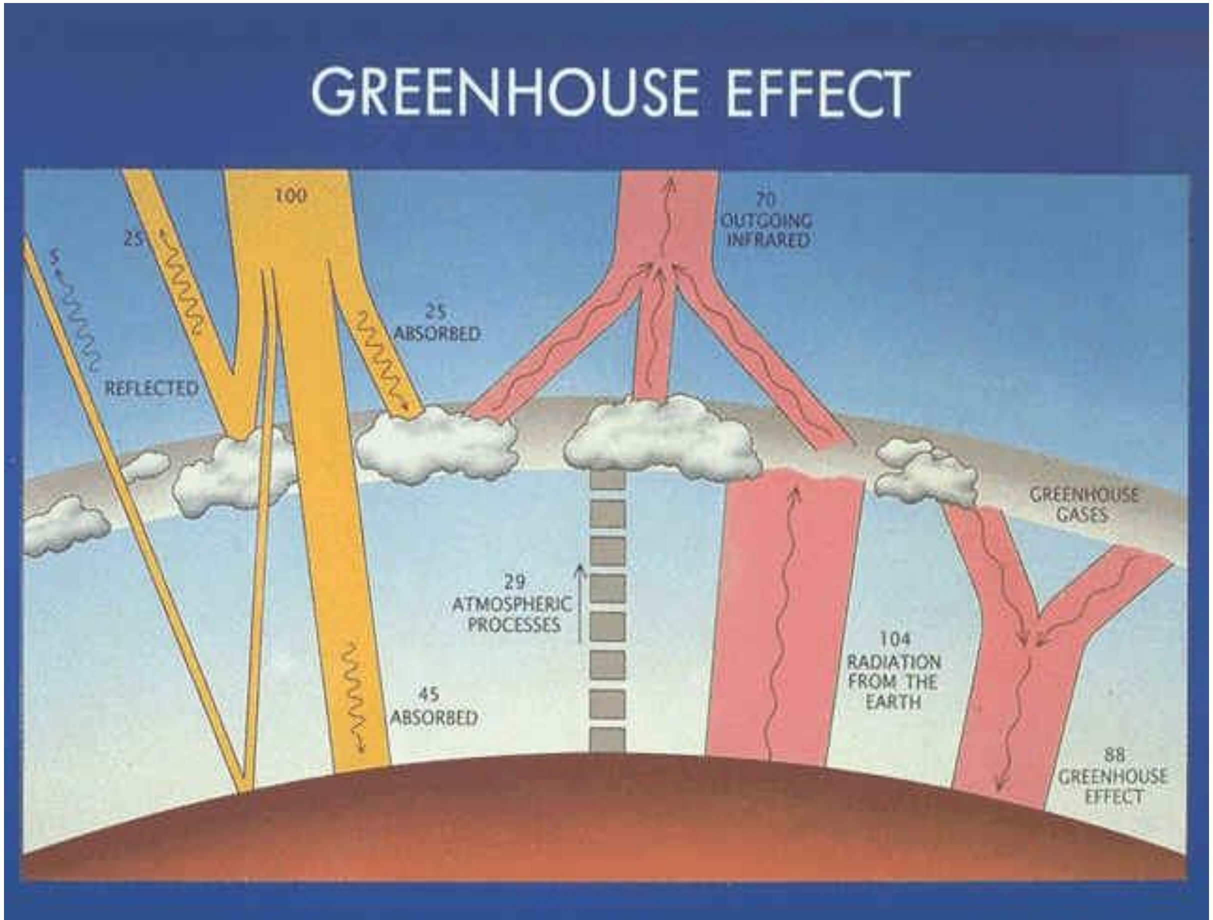
*“Historic Average Temperatures over 30 years”*
*OR*
***CLIMATE NORMALS***
*(1961-1990; 1971-2000; etc)*

# Our activities are universally *weather-dependent* …


*From: Meteo France web site*
*(Predictions for Jan. 9, 2014)*

# Greenhouse Effect

- Balance between incoming Shortwave (SW) radiation and outgoing Longwave (LW) radiation




*http://see-the-sea.org/topics/pollution/air/green-house/greenhouse_effect.htm*

# Natural vs non-natural Greenhouse Effect

- Without the GE, Earth's average temperature would be -18ºC instead of current +15ºC

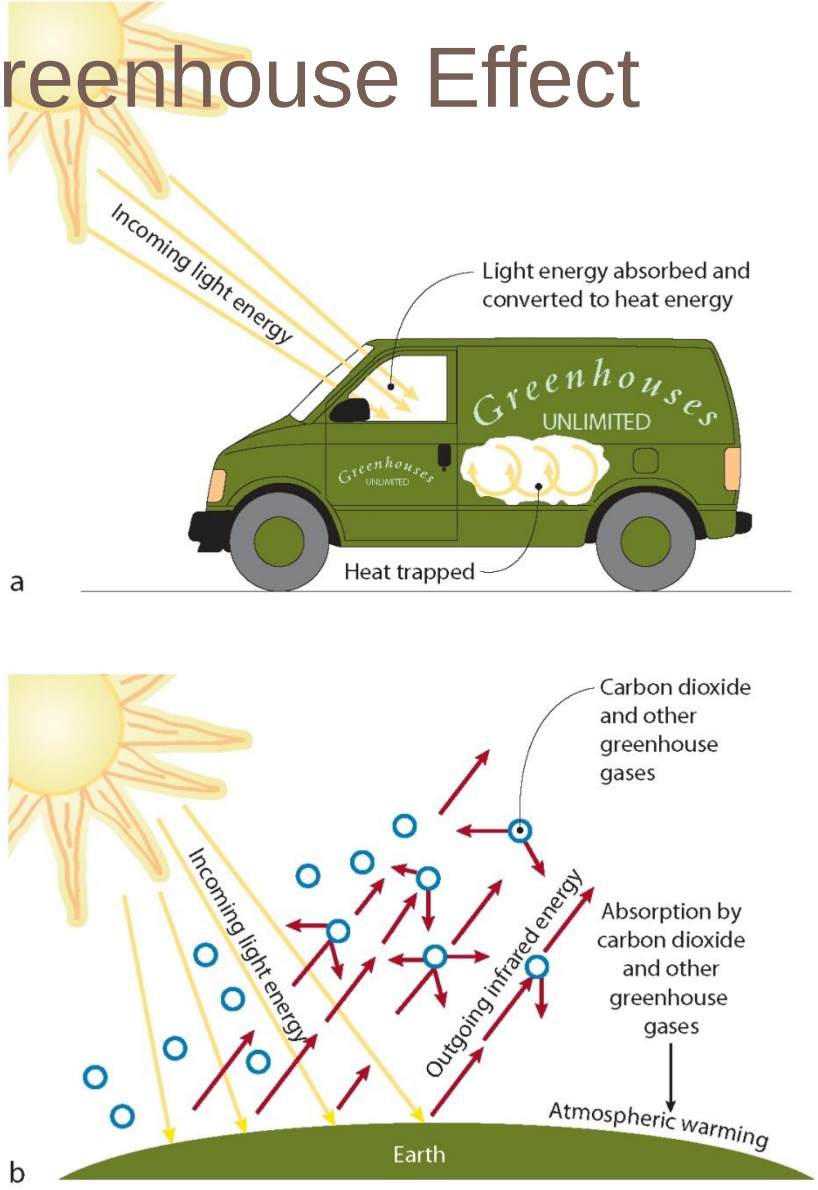
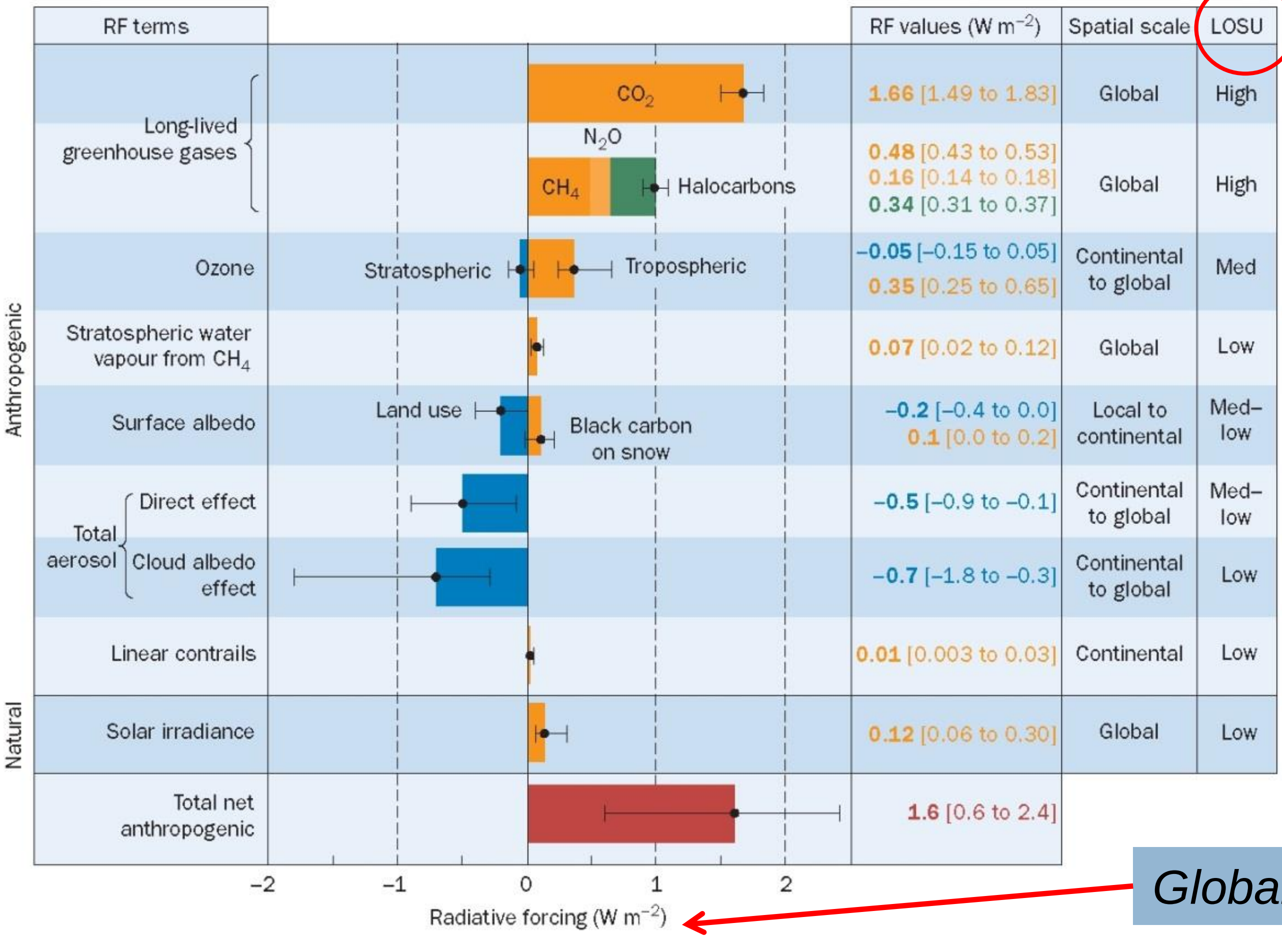



**Figure 7.3** | The greenhouse effect.

*From: Dearden and Mitchell (2012)*

# Impact of various *anthropogenic* GG's and 'reliability' of the science …

Level of Scientific Understanding




*HIGH*

*LOW*

***Note:***
*Large Error Bars!*

*Global Avg Radiative Forcing*

**Figure 7.5** | Global average radiative forcing (RF) estimates and ranges in 2005 for anthropogenic carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). The net anthropogenic radiative forcing and its range are also shown. They require summing asymmetric uncertainty estimates from the component terms and cannot be obtained by simple addition. Additional forcing factors not included here are considered to have a very low LOSU. Volcanic aerosols contribute an additional natural forcing but are not included in this figure because of their episod[…] The range for linear contrails does not include other possible effects of aviation on cloudiness. *Source:* IPCC (2007b[…]

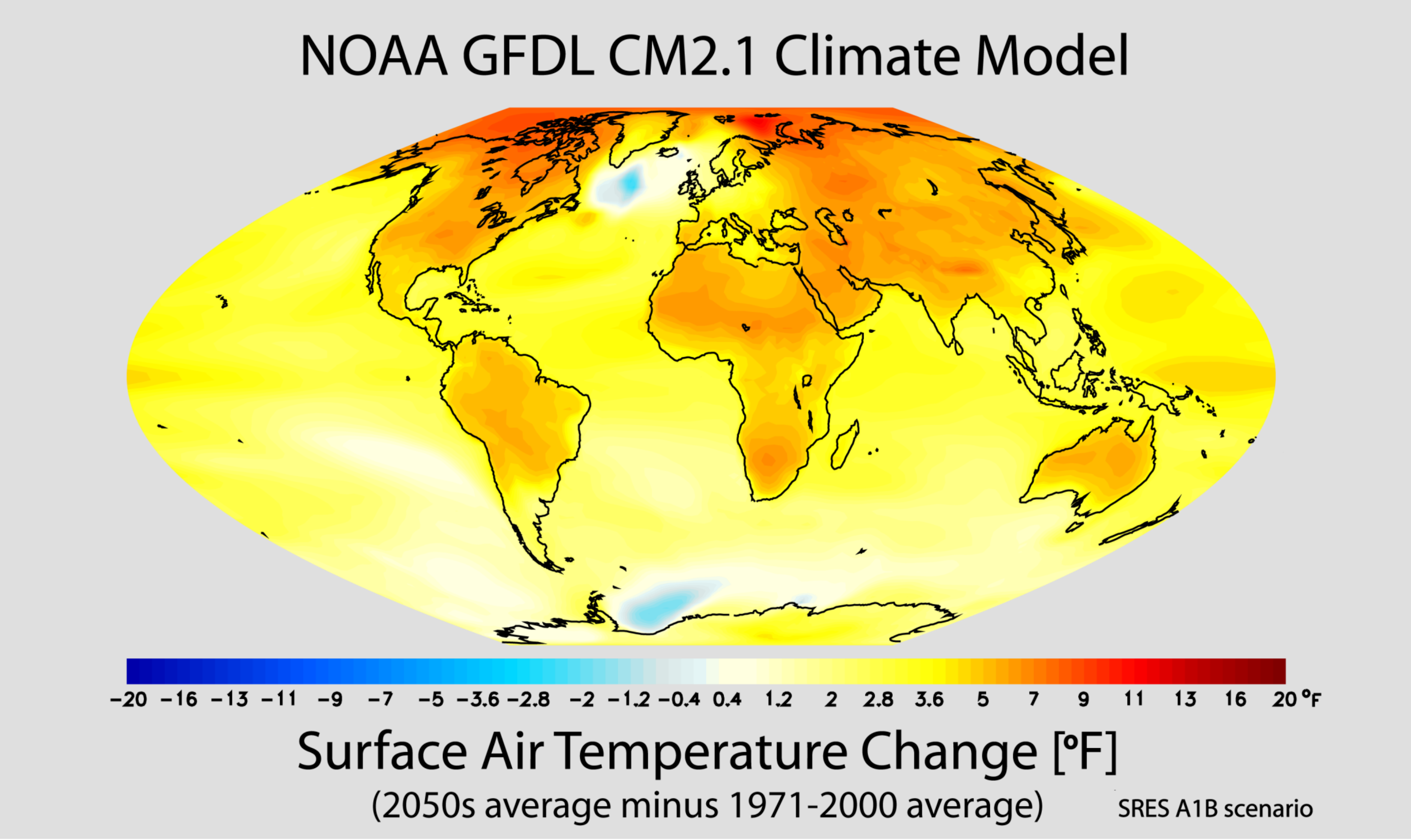
*From: Dearden and Mitchell (2012)*

# Climate Change vs Global Warming

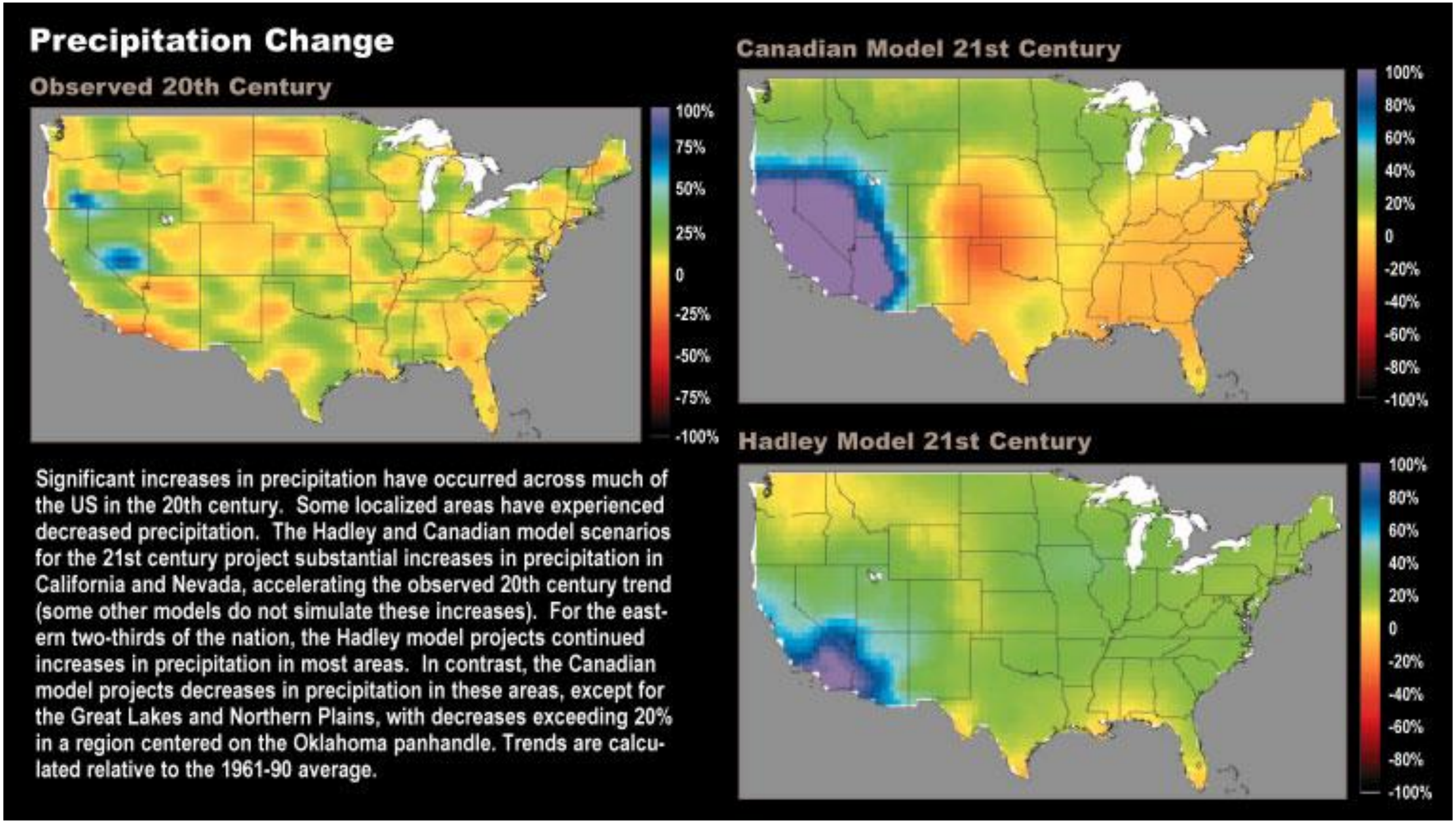
- **Climate Change:**
  - “a long-term shift or alteration of the climate of a specific location, a region, or the entire planet”

- **Global Warming:**
  - “addresses only changes in average surface *temperatures*”

# Climate Change vs Global Warming



# Climate Change vs Global Warming



Percentage Change in Very Heavy Precipitation

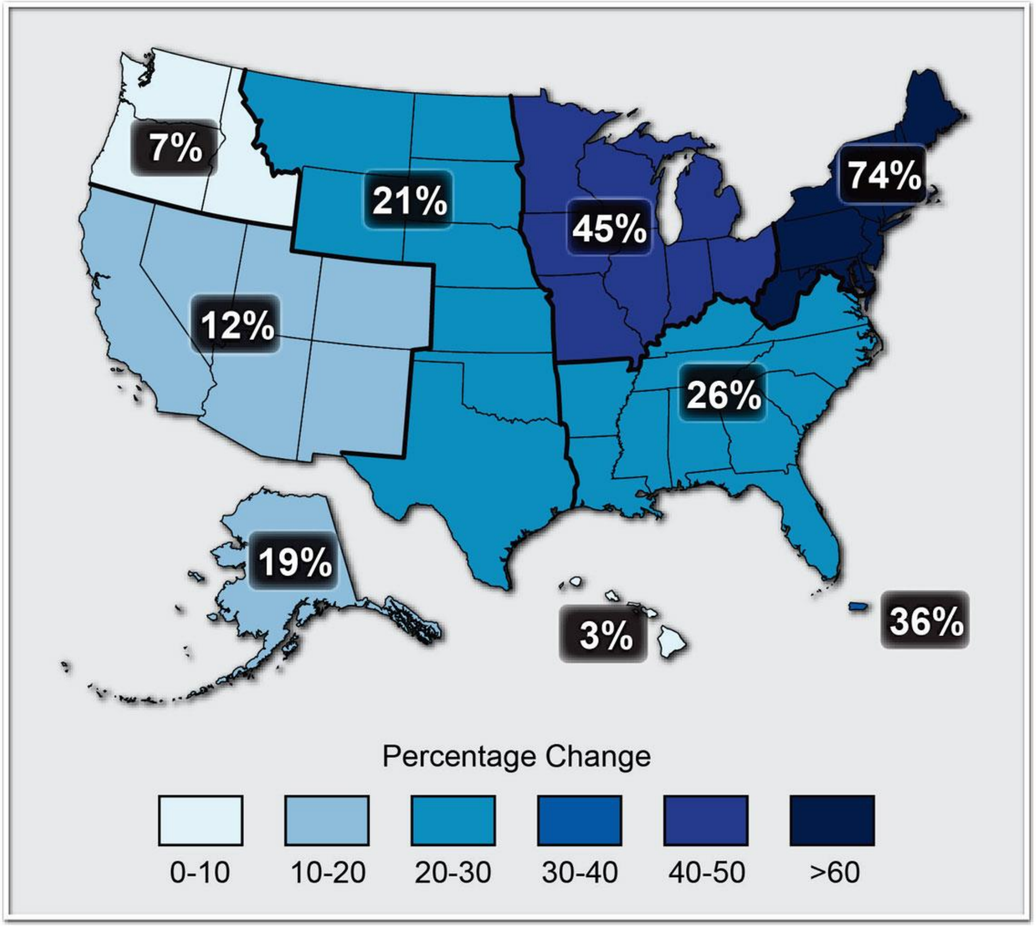
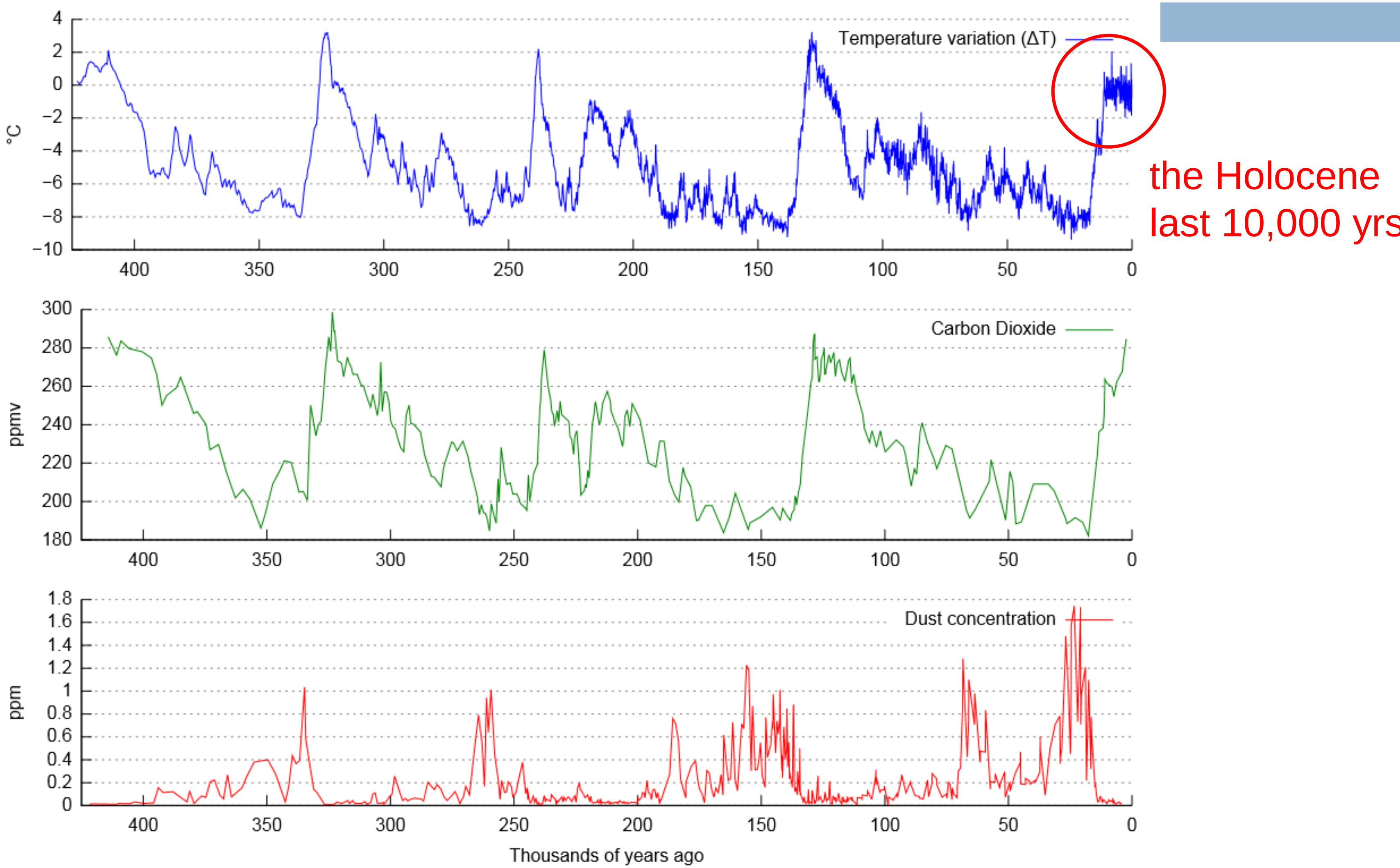



Figure 2.16: Percentage Change in Very Heavy Precipitation
Caption: The map shows percent increases in the amount of precipitation falling in very heavy events (defined as the heaviest 1% of all daily events) from 1958 to 2011 for each region. There are clear trends toward a greater amount of very heavy precipitation for the nation as a whole, and particularly in the Northeast and Midwest.
(Figure source: updated from (Karl et al. 2009) with data from NCDC)

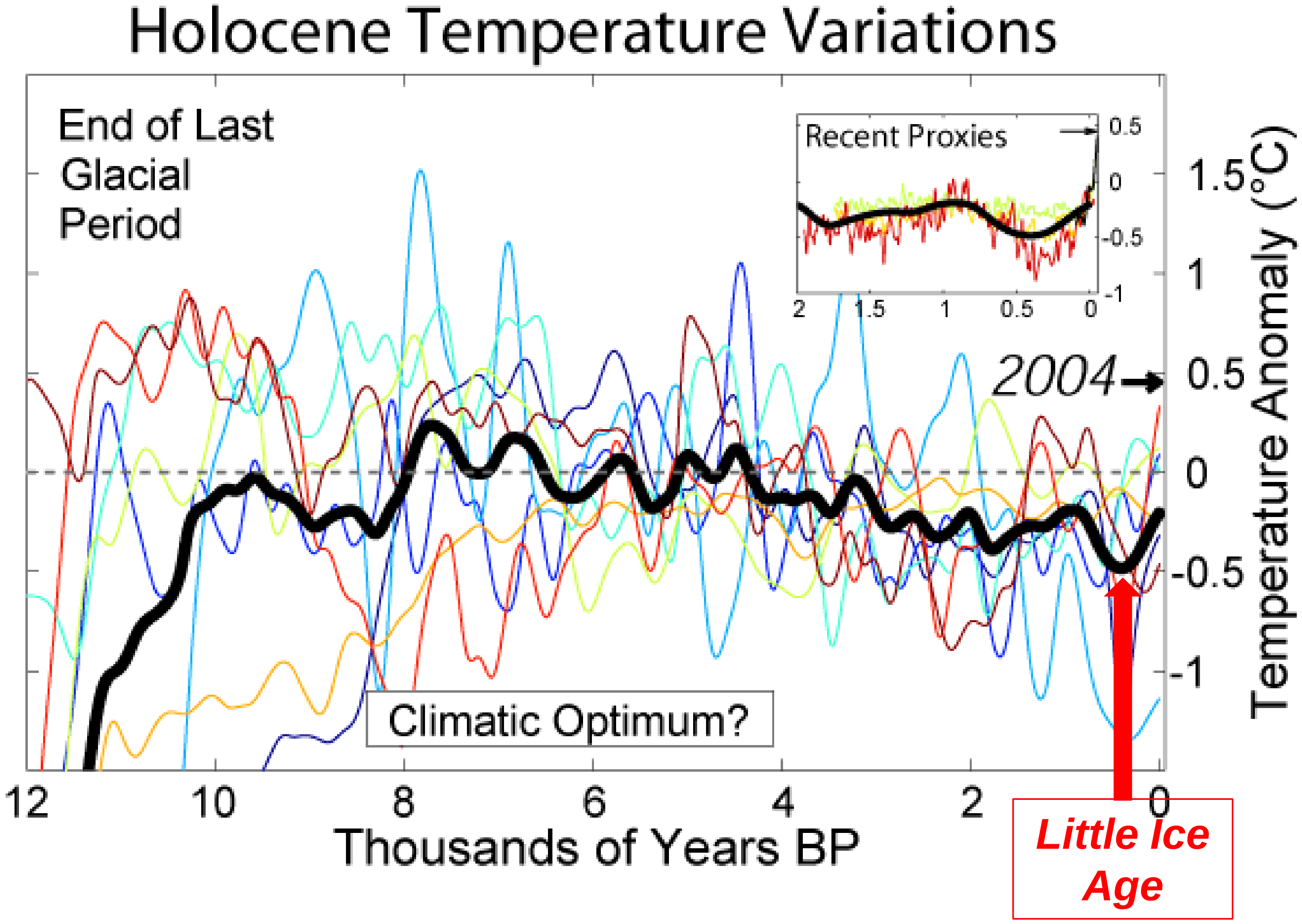
Source: National Climate Assessment Draft January 2013; http://ncadac.globalchange.gov/download/NCAJan11-2013-publicreviewdraft-chap2-climate.pdf

# Time Scales: the Quaternary – primarily glacial (last 2 million years)




Reconstructed from Antarctic ice sheet core data; note: co-variation in $CO_2$ + deltaT.

# Holocene → Anthropocene



# E’s average surface T increased by 0.6°C since 1850s, but not geographically uniform

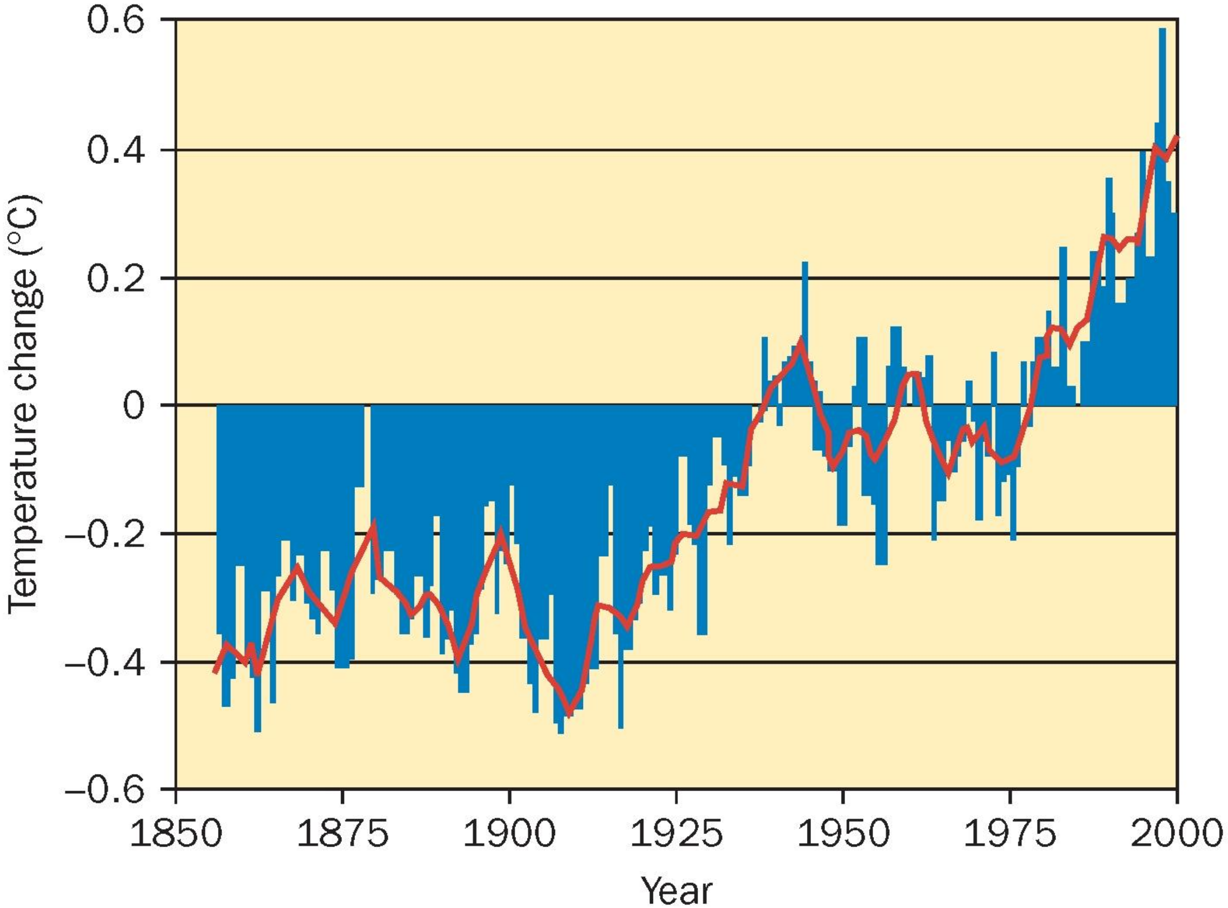



**Figure 7.1** | Variation in global average surface temperature between 1856 and 2000. *Source: Miller (2002: A-2),* 
*Professor Danny Harvey, Department of Geography, University*

From: Dearden and Mitchell (2012)

# Key greenhouse gases at highest concentrations observed in past 420,000 years

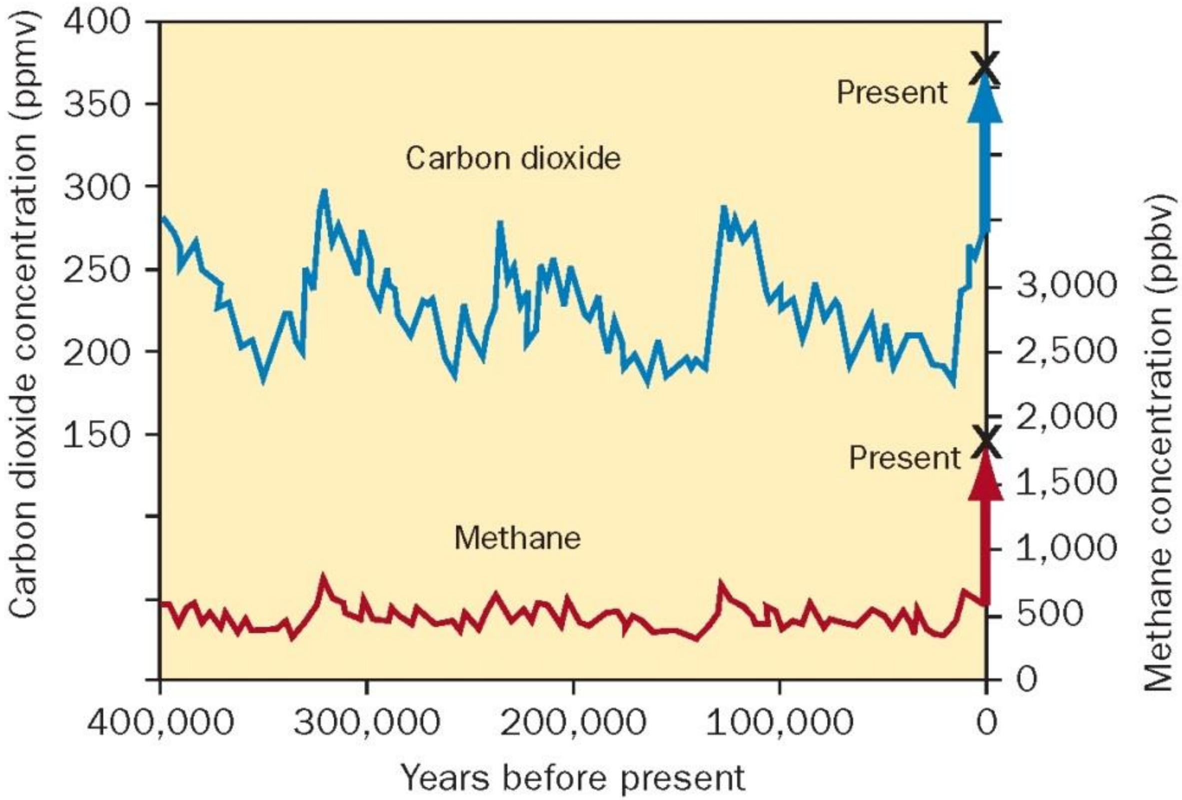
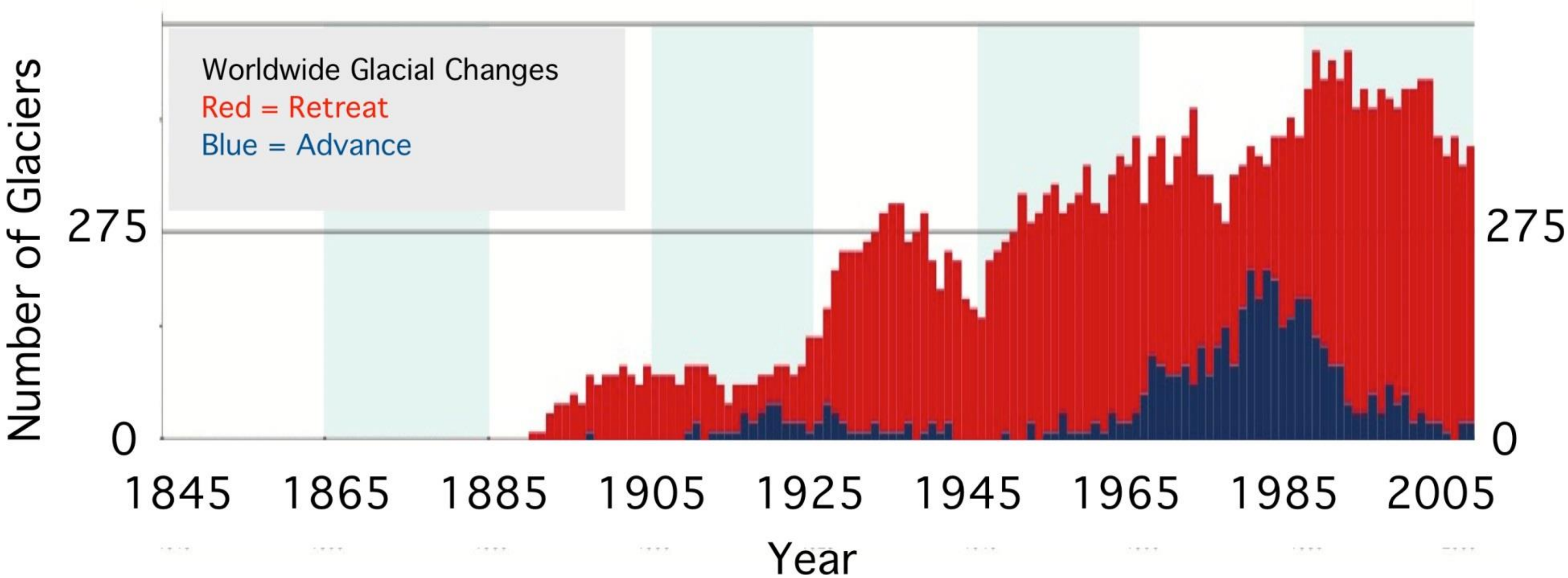



**Figure 7.4** | Variation in atmospheric concentrations of carbon dioxide and methane to 400,000 years before present. Measured in the Vostok ice core in Antarctica (thin lines) and during the past 200 years (heavy line). *Source: Miller (2002: A*

*From: Dearden and Mitchell (2012)*

# Other evidence of observed climate change / global warming

- Negative mass balance in most of the world's glaciers and ice sheets




- Reduced snow cover, earlier spring melts

# Other evidence of observed climate change / global warming

- Negative mass balance in most of the world's glaciers and ice sheets

# Other evidence of observed climate change / global warming

- Permafrost warming and ground ice thawing → potential additional methane release (old methane buried during previous glacial periods)
- Observed sea level rise (~1.8 mm rise per year since 1961) … but one needs to be cautious with respect to interpretation as the landscape in places is still responding to isostatic loading of the last glacial period;

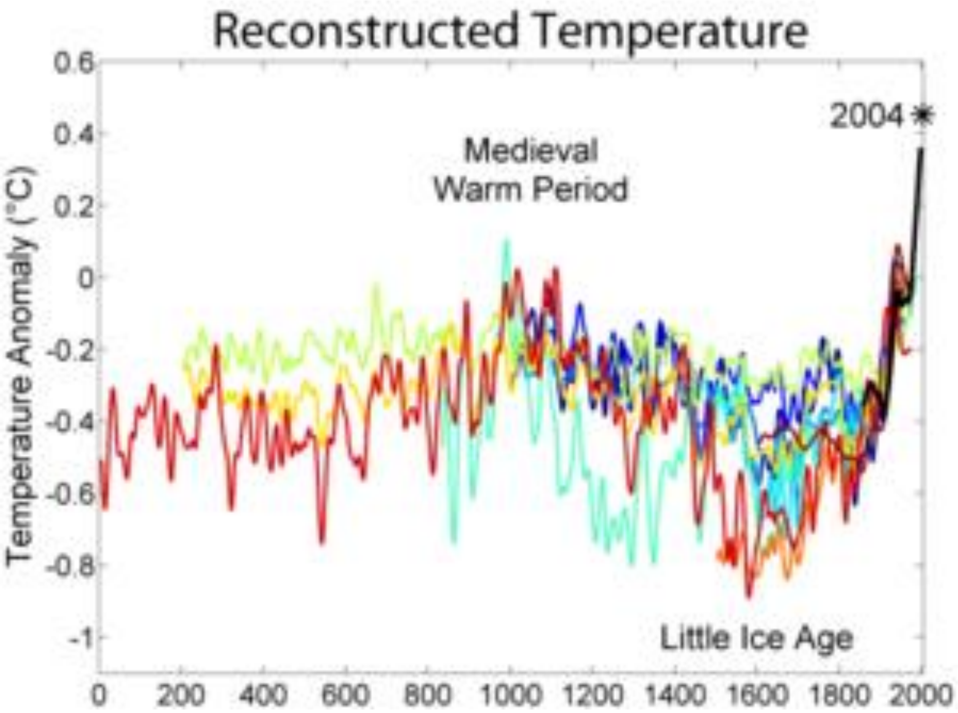
# Modeling Climate Change

- A complex undertaking given complexity of earth-atmosphere-oceanic interactions that create climate
- Thus, all climate models simply certain aspects of the actual systems
- Earliest climate models date from the 1950s
- A key step in modeling *future* climate scenarios is to understand how present variations in climate compare with the *past*.

# Reconstruction of Past Climates

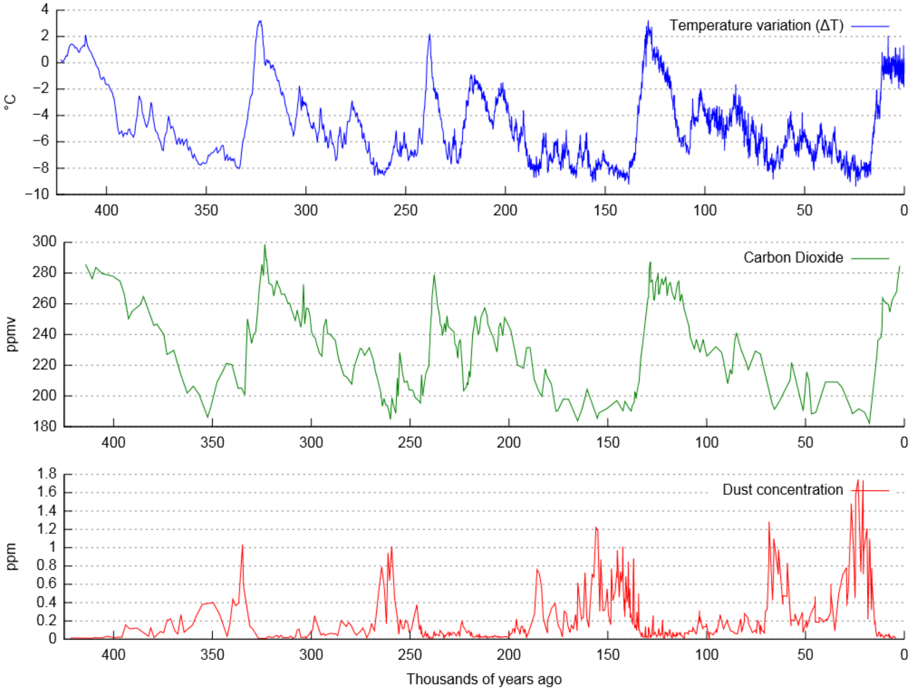
- Last 140 years, temperature (instrumental record)
- Last 35 years, data from upper atmosphere (via satellites)
- Other periods require the use of “proxy data” to build climate histories:

e.g. **<u>Harbour records (ice conditions)</u>** in northern European ports like Reykjavik, Iceland (covers several 100s of years)



# Reconstruction of Past Climates

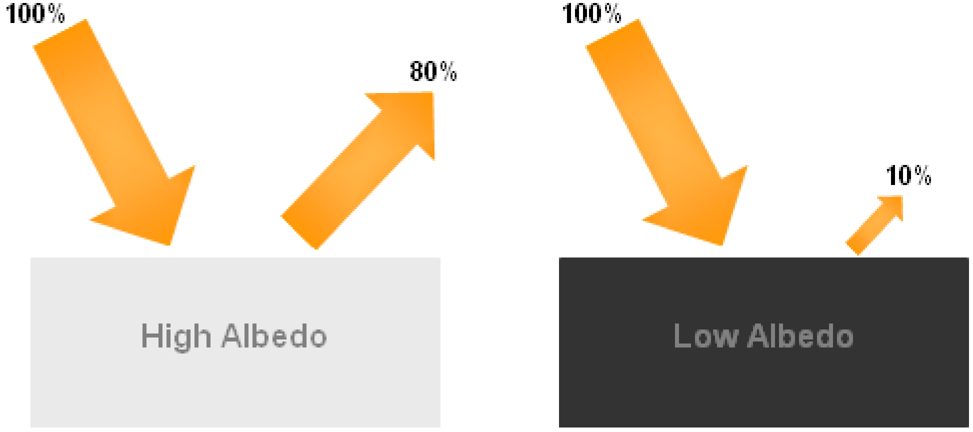
- Also use other climate-sensitive natural indicators such as tree rings and ice cores
  - E.g. ice sheet cores … exceed many 10s of 1000s of years;
  - E.g. tree ring records … some species in coastal BC/Calif. Can go back 1000s



# General Circulation Models (GCMs)

- All GCMs use some (or all) of the five following components to model climate change scenarios …

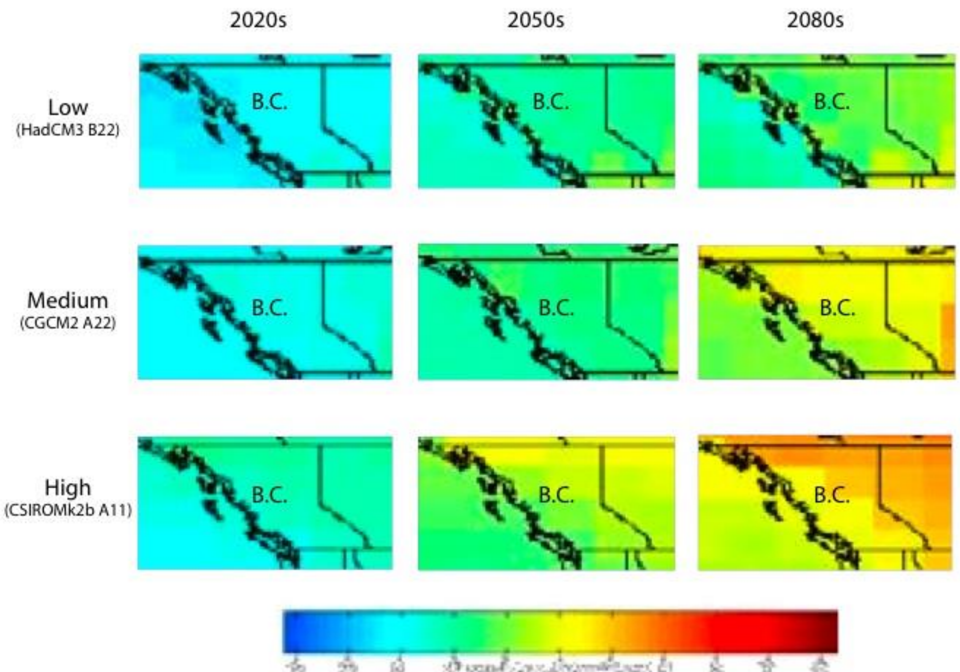
1. radiation – incoming (solar, SW); outgoing (absorbed, reflected, LW)
2. dynamics – horizontal/vertical energy movements
3. surface processes – how E's surface affects climate (e.g., snow cover, vegetation → albedo)




| surface | albedo |
|---|---|
| fresh asphalt | 0.04 |
| deciduous forest | 0.15 – 0.18 |
| fresh snow | 0.80-0.90 |

# General Circulation Models (GCMs)

4. chemistry – chemical composition of the Atmosphere and related interactions with other E processes
5. time step and resolution – time step (minutes or decades); resolution (ie spatial scale … regional vs global)

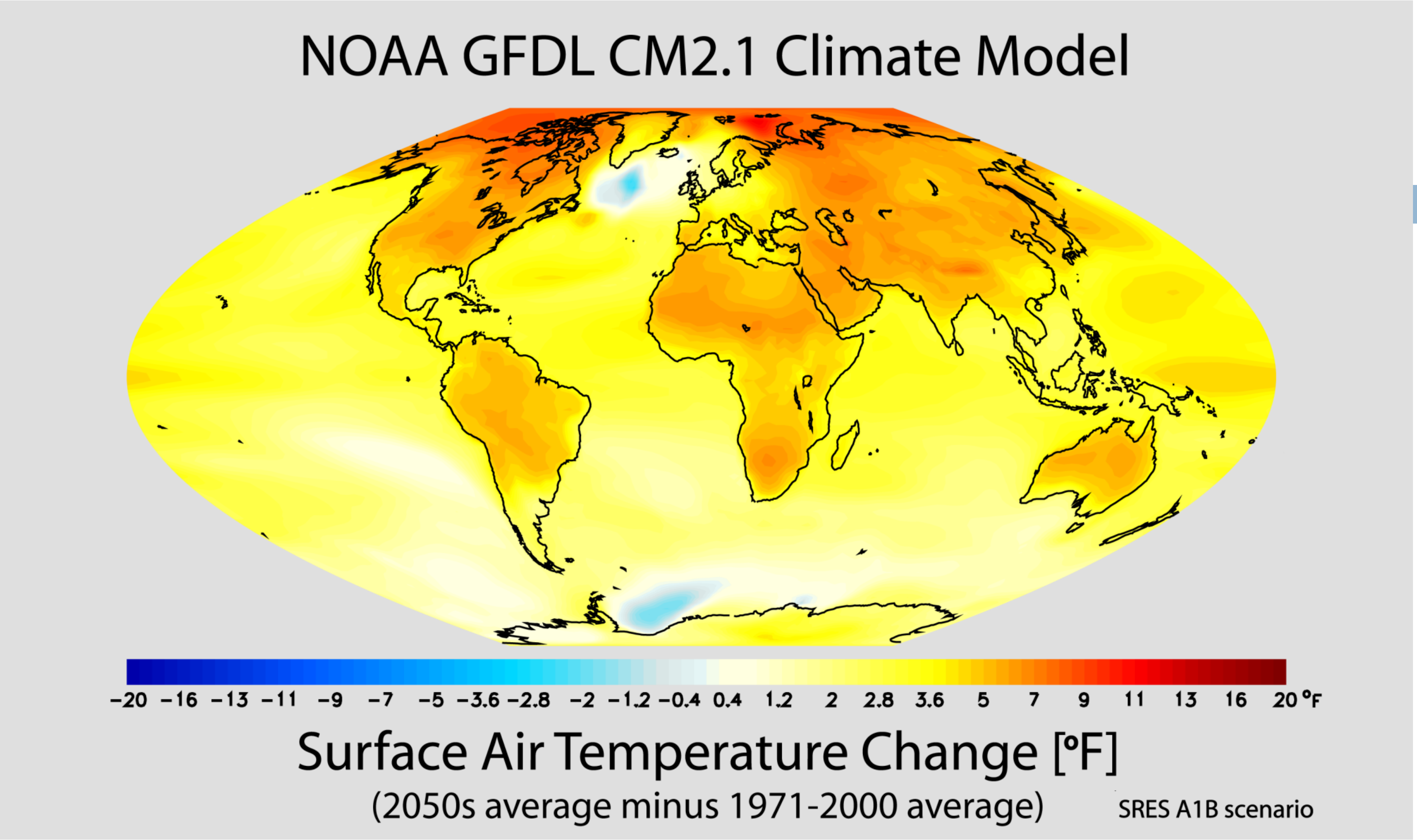



**<u>Figure 37:</u>** Projected mean annual temperature change for the 2020s, 2050s and 2080s for three climate change scenarios: low, medium and high.

***Source:*** Threats to Biodiversity in British Columbia *(http://www.biodiversitybc.org/EN/main/downloads/tnp-3.html)*

# Limitations of GCMs

- While GCMs provide overall indications of future climates, their limitations for policy and planning need to be appreciated
- Many scientists have recognized that the coarse spatial resolution, poor predictive capacity for precipitation, fairly weak simulation of oceans, lack of baseline data, and many other limitations cause GCM outputs to be highly variable
- Because of necessary simplifications in modelling climate system, GCMs are most suitable at global scales not for regional representations of climatic change




- little doubt that it will be warmer; the uncertainty is the magnitude of the changes for locations around the world;

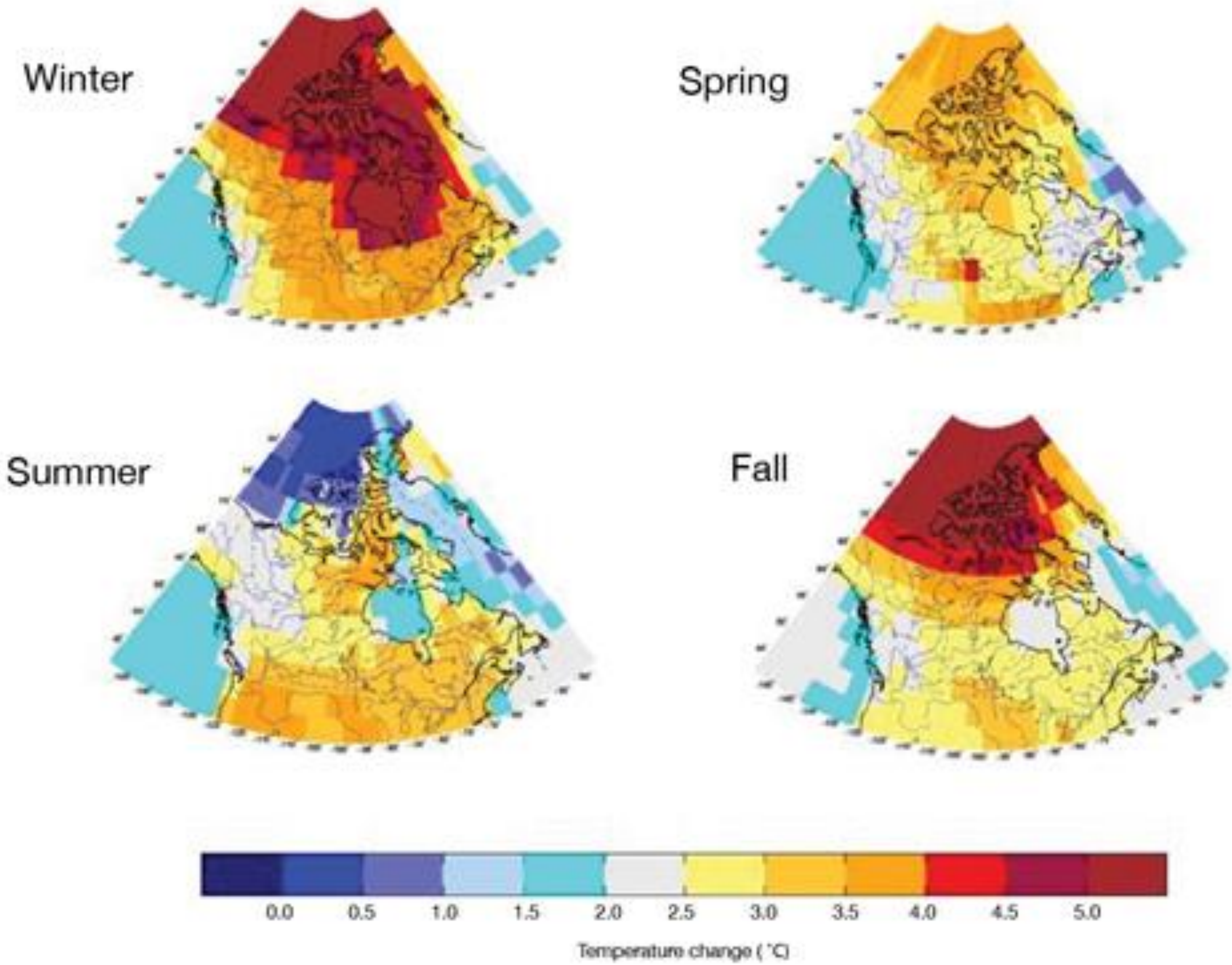



**Figure 2.1:** Seasonal Change in Temperature across Canada by 2050

Source: NRC 2007

# Part 2

Impacts (Implications) of Climate Change

Map Literacy (ML.2)

# Outline

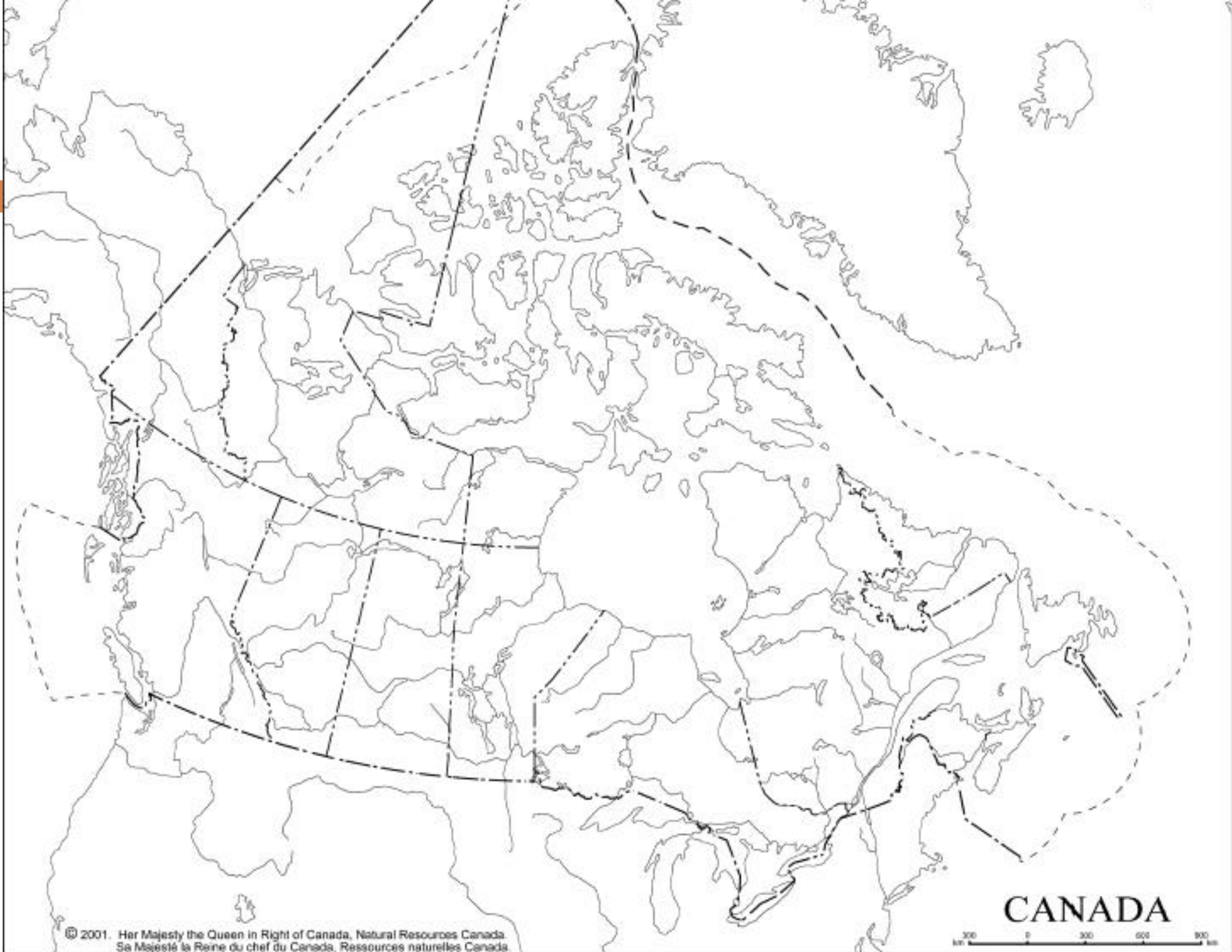
*Low-lying island nation in the Indian Ocean (Maldives) is planning to re-locate should predicted sea level rise occur. From: Dearden and Mitchell (2012)*

- ***Activity:*** Map Literacy List #2
- Figure 7-6:
  - Summary of expected impacts in Canada over the 21$^{st}$ Century
- ***Specific Impacts*** {Terrestrial Systems; Agriculture; Freshwater Systems; Fisheries; Cryosphere; Oceans and Coastal Systems; Infectious Diseases}
- Other important global impacts {Ozone depletion; Global Sea Level Rise}

# Map Literacy 2 (Spring 2014)

Lectures 7 to 12

May 27, 2014


CANADA
300 km
0
300
600
900 km

# Map Literacy (list 2, May 27, 2014)

## Communities, Parks Jurisdictions

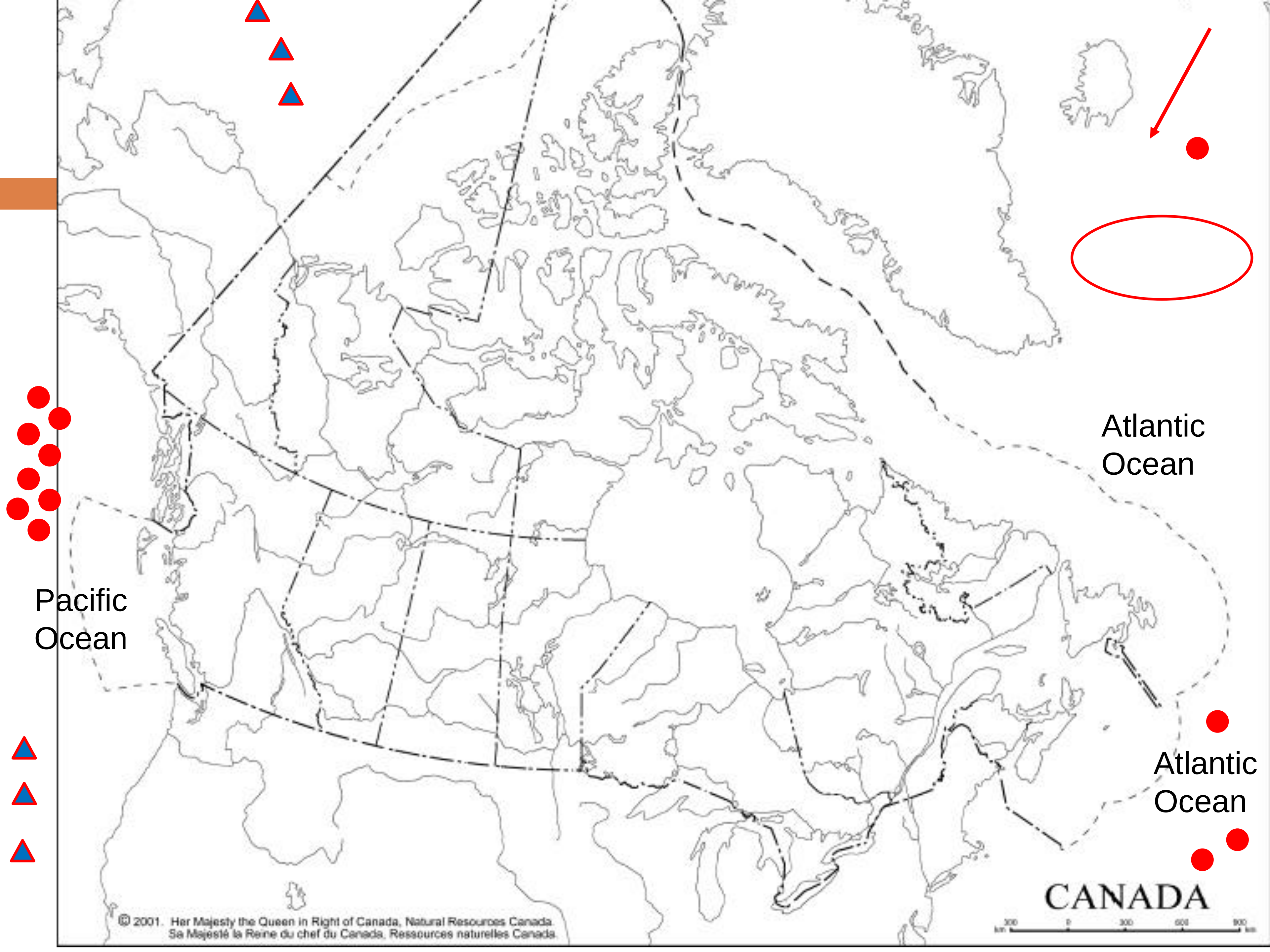
1. Detroit
2. Cleveland
3. Sudbury
4. Trail, BC
5. Wapusk Nat. Park
6. Inuvik
7. Churchill

## Physical Features

1. Mt. St Helens
2. Georgian Bay
3. Peel River, YK
4. Richardson Mountains
5. Mackenzie River
6. Ellesmere Island
7. Mackenzie Delta

## Basics (1):

1. Greenland


Atlantic Ocean
Pacific Ocean
Atlantic Ocean
CANADA
© 2001. Her Majesty the Queen in Right of Canada, Natural Resources Canada.
Sa Majesté la Reine du chef du Canada, Ressources naturelles Canada.

# Summary of Impacts

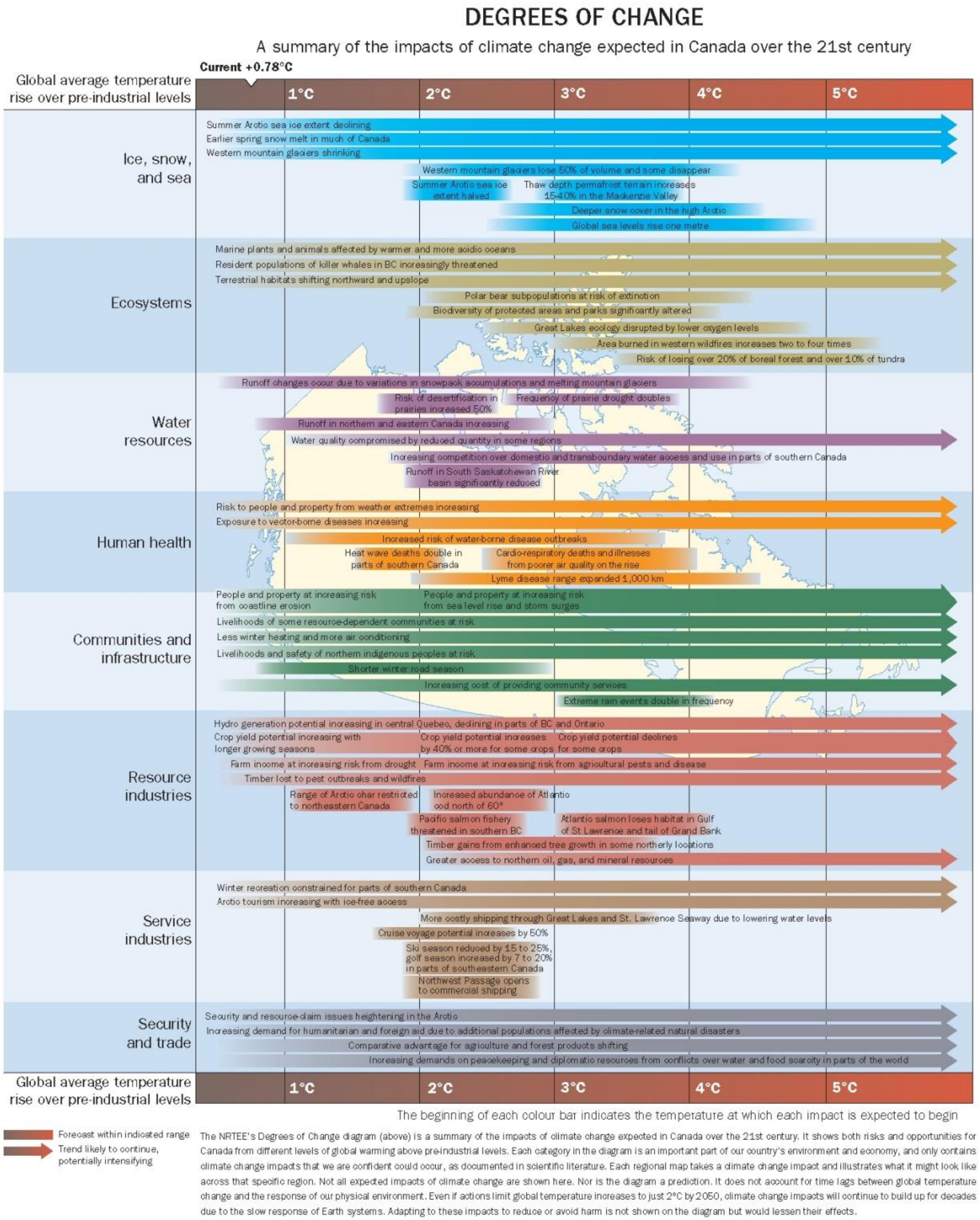


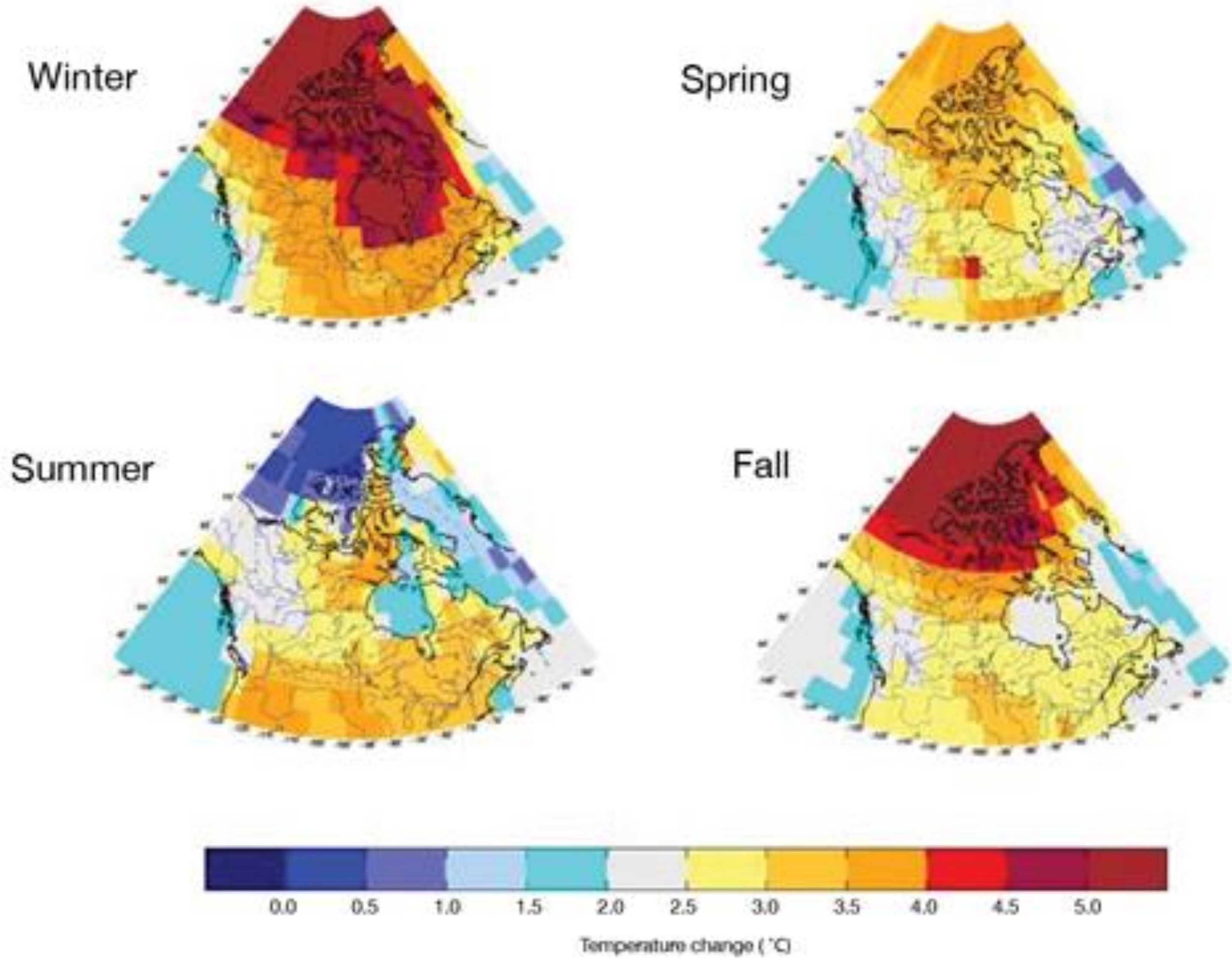

**Figure 7.6** | Summary of the impacts of climate change expected in Canada over the twenty-first century. *Source:* NRTEE (2010: O15).

***Figure 7.6:***
*Summary of the impacts of climate change expected in Canada over the twenty-first century. Source: NRTEE (2010).*

*From: Dearden and Mitchell (2012)*

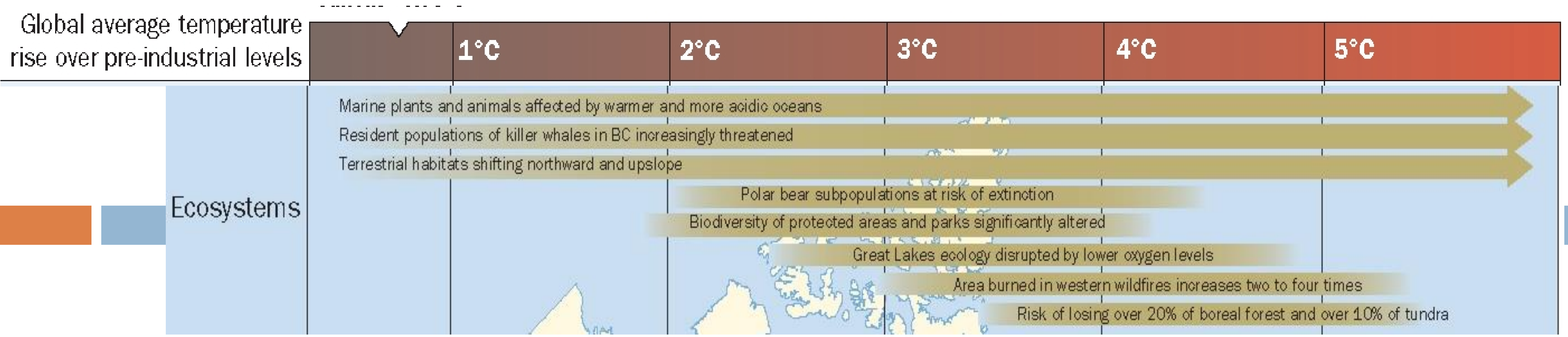
# Expected Implications of Climatic Change

- Explore the range of physical, environmental, social and economic implications of expected climatic change;
- Current warming +0.78 deg C over pre-industrial levels;
- Projected temperature changes are anticipated to have greater seasonal and latitudinal variations in Canada (*see next slide*)




**Modeled Seasonal Change in Temperature across Canada by 2050**

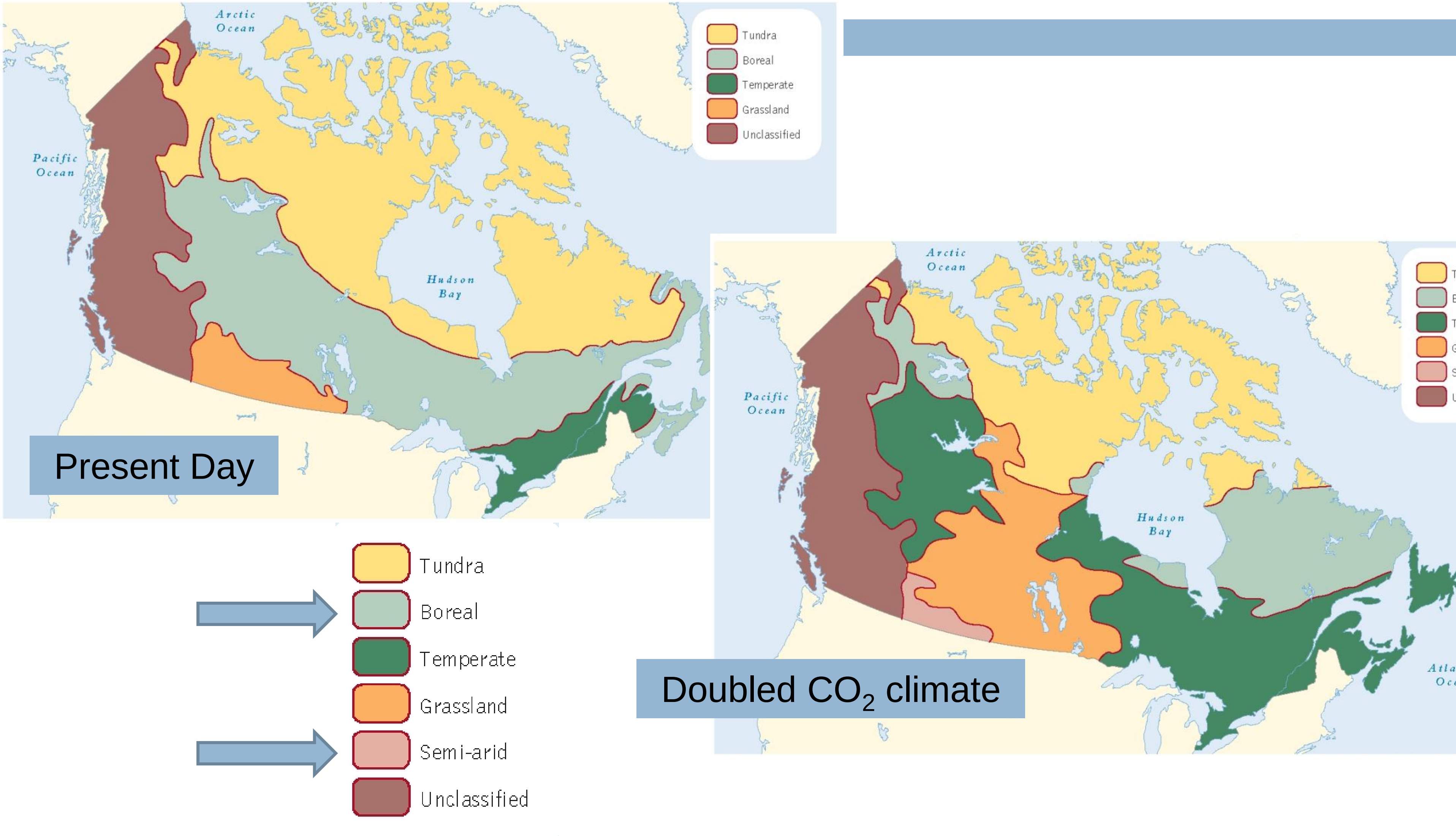
Source: Natural Resources Canada (2007b)



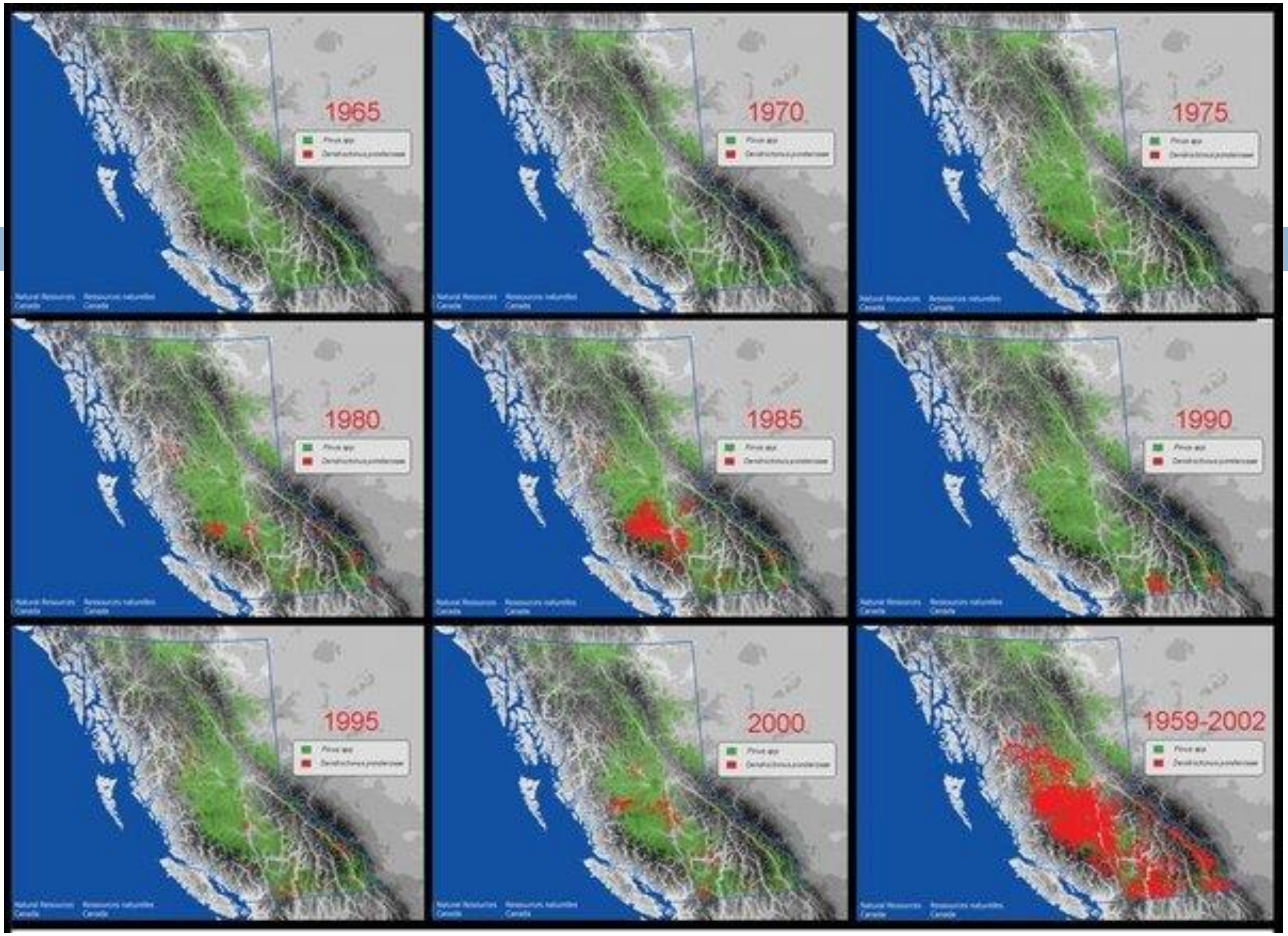

# Impacts on the Ecosystems

- Significant changes for both terrestrial and aquatic systems (including those to flora and fauna)
- Dramatic shifts of boreal forest (e.g.), and these forests more susceptible to insect infestation, disease and fires
- Future of polar bear habitat along Hudson Bay (future of Wapusk National Park) – similarly other NPs may evolve away from the representative ecosystems they were created to protect

# Figure 7.7 Changes in forest and grassland boundaries (modelled for a doubled $CO_2$ climate)

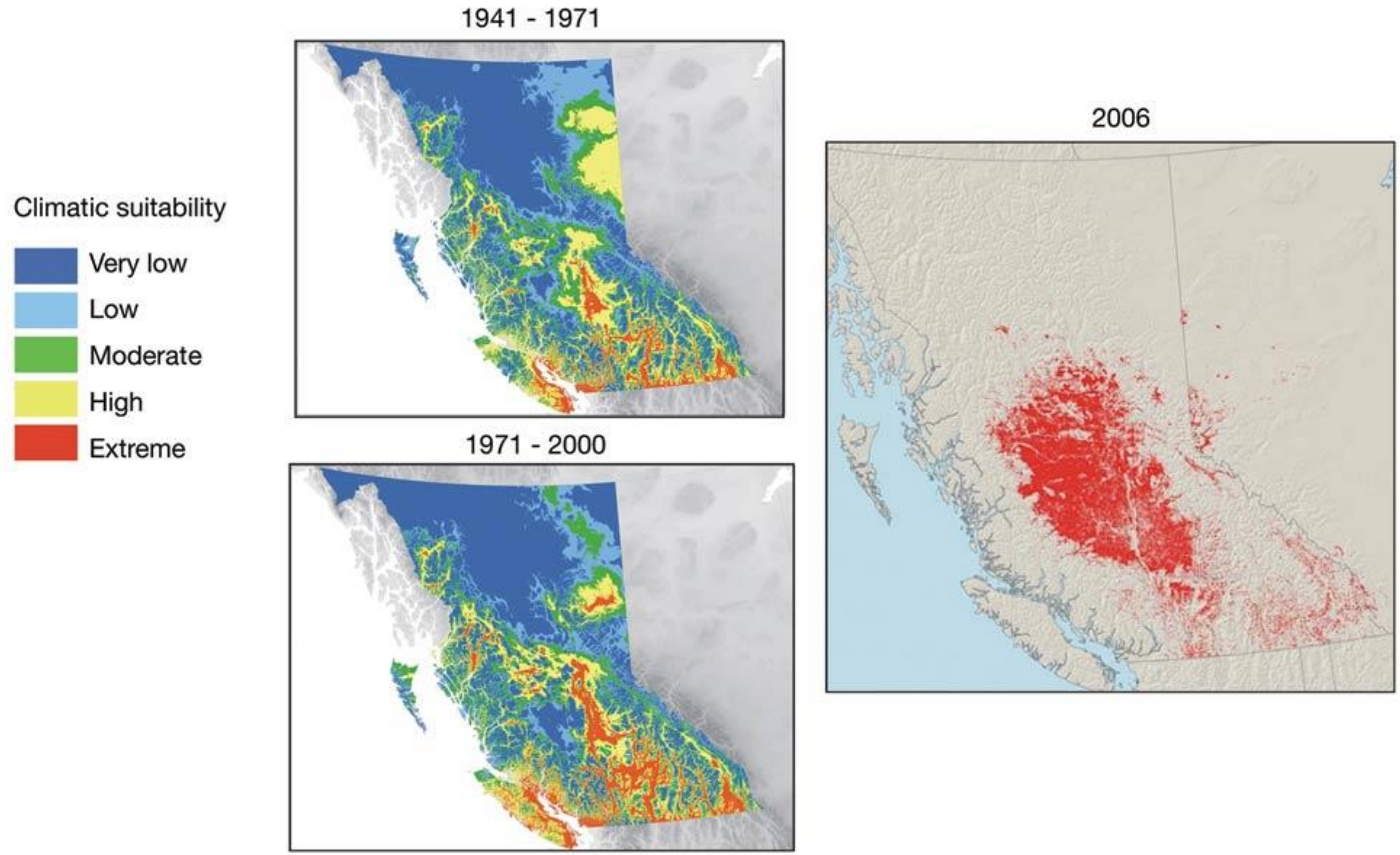



*Adapted from Hengeveld 1991 and Curran 1991 by Dearden and Mitchell (2012)*

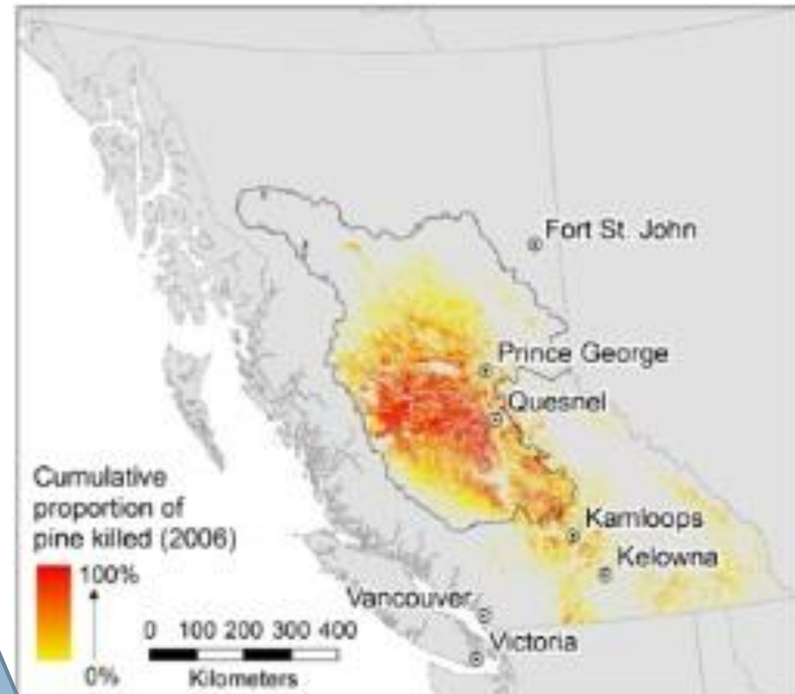



British Columbia is ground zero for mountain pine beetles with rapid increases in infestations starting in the late 1990s and early 2000s.The final image shows all the areas where infestations have been recorded between 1959 and 2002. Image: Natural Resources Canada

(Read more at: http://phys.org/news190275053.html#jCp)

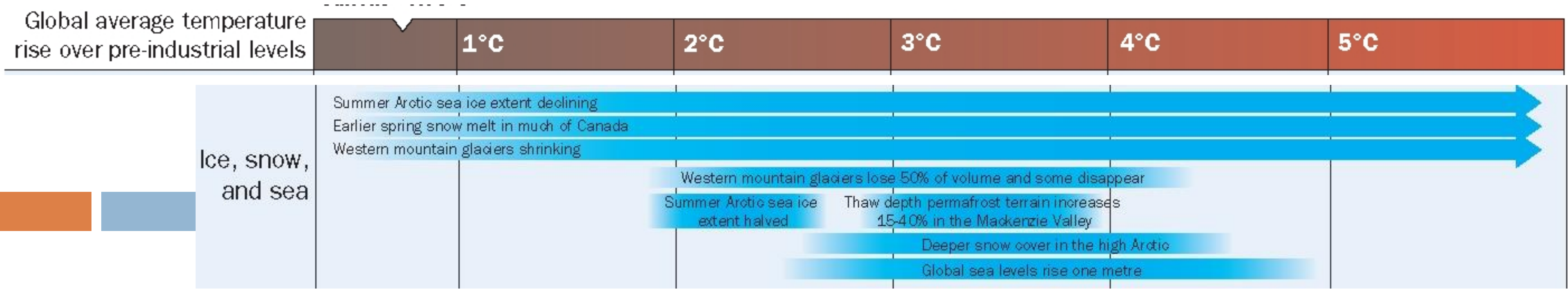



(Left) Historical distributions of climatically suitable habitats for the mountain pine beetle (MPB) in British Columbia (adapted from Carroll et al., 2004). Areas with 'very low' suitability are unsuitable for MPB, where as 'extreme' areas are those considered climatically optimal. (Right) Total area affected by mountain pine beetle in British Columbia in 2006 (Natural Resources Canada, 2007a)




http://science.natureconservancy.ca/central
interior/central.php

Socio-economic impacts




# Impacts on the Cryosphere

- Higher prospective temperatures at higher latitudes;
  - → ice sheets (Greenland Ice Sheet, Fig. 7.8; Antarctic Ice Sheet, )
  - → reduced valley glacier extents
  - → sea ice cover (albedo feedbacks)
  - → sea level forecasts
  - → shifting of permafrost zones and thawing of ground ice

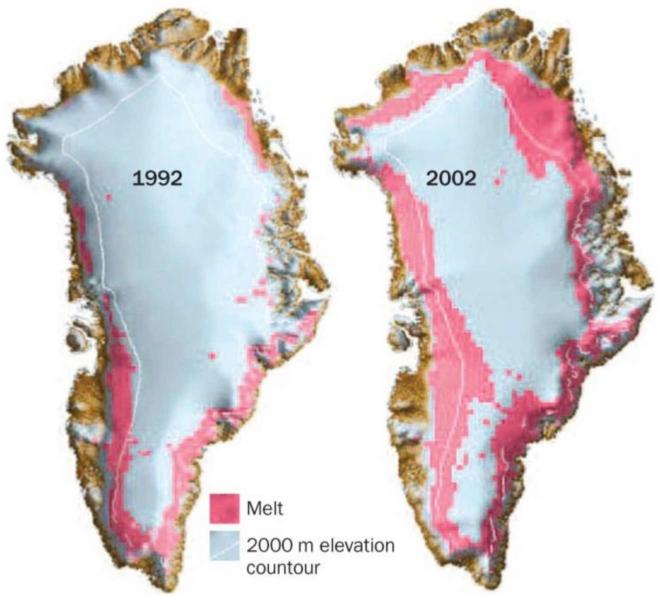
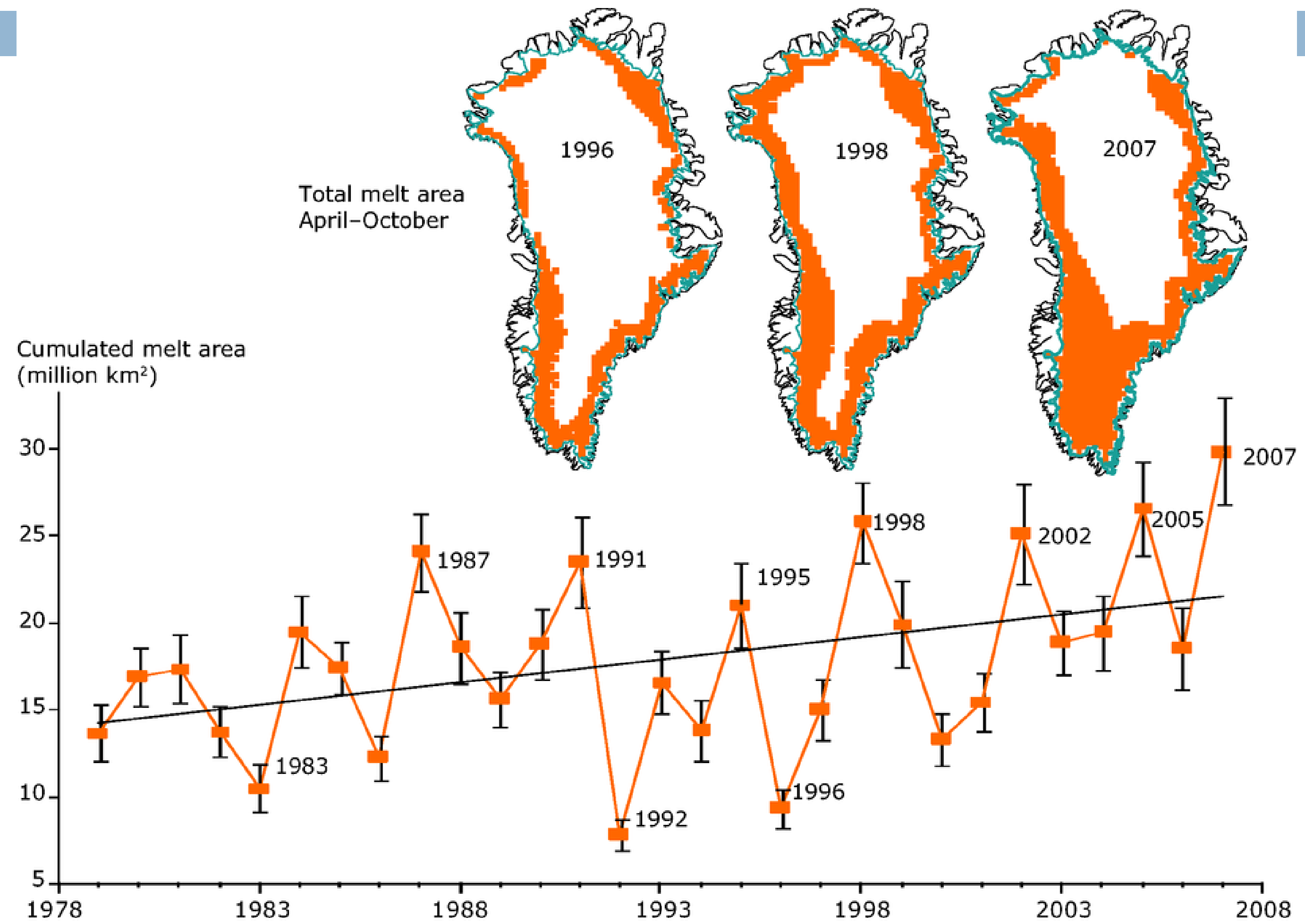



**Figure 7.8** | Greenland ice sheet melt, 1992 and 2002. *Source: Walsh et al. (2004: 205).*

*From: Dearden and Mitchell (2012)*

# Melt, Greenland Ice Sheet (1979 to 2007)

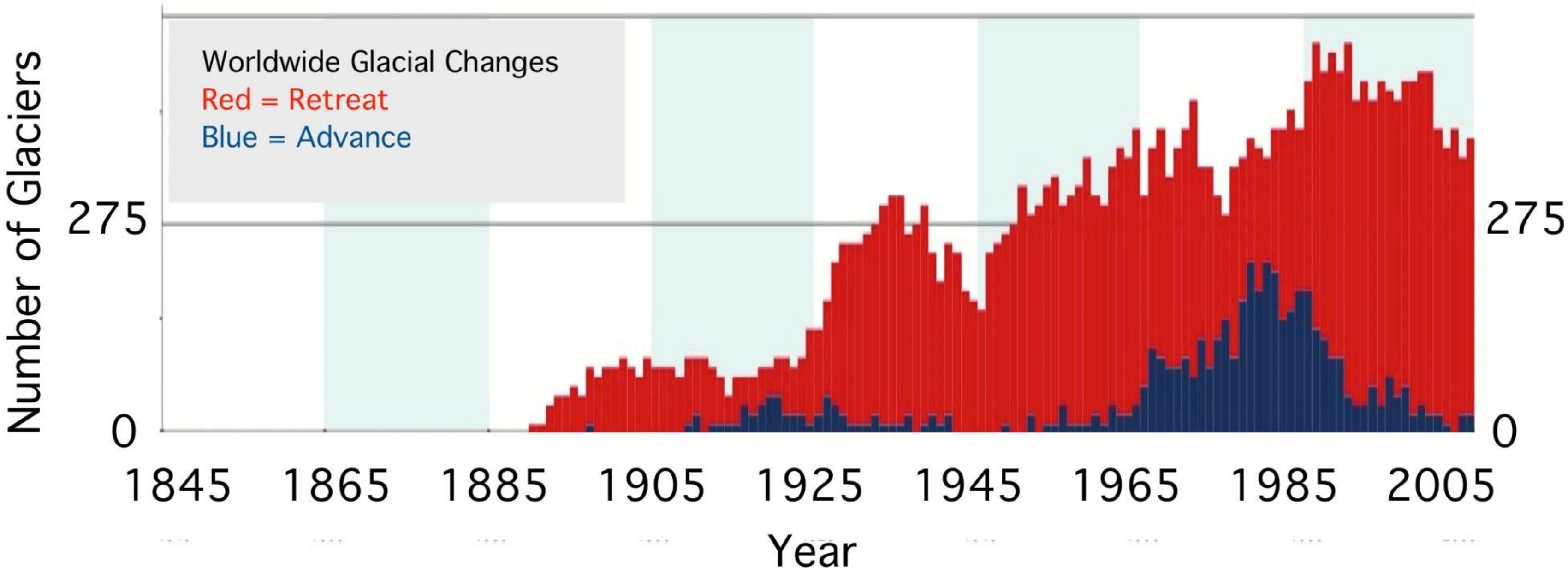



Source: European Environment Agency (2007)

http://wwws3.eea.europa.eu/data-and-maps/figures/area-of-greenland-ice-sheet-melting-1979-2007/image_xlarge

# Other evidence of observed climate change / global warming

- Negative mass balance in most of the world's glaciers and ice sheets



# Sea Ice Extent (Polar Ice Cap)

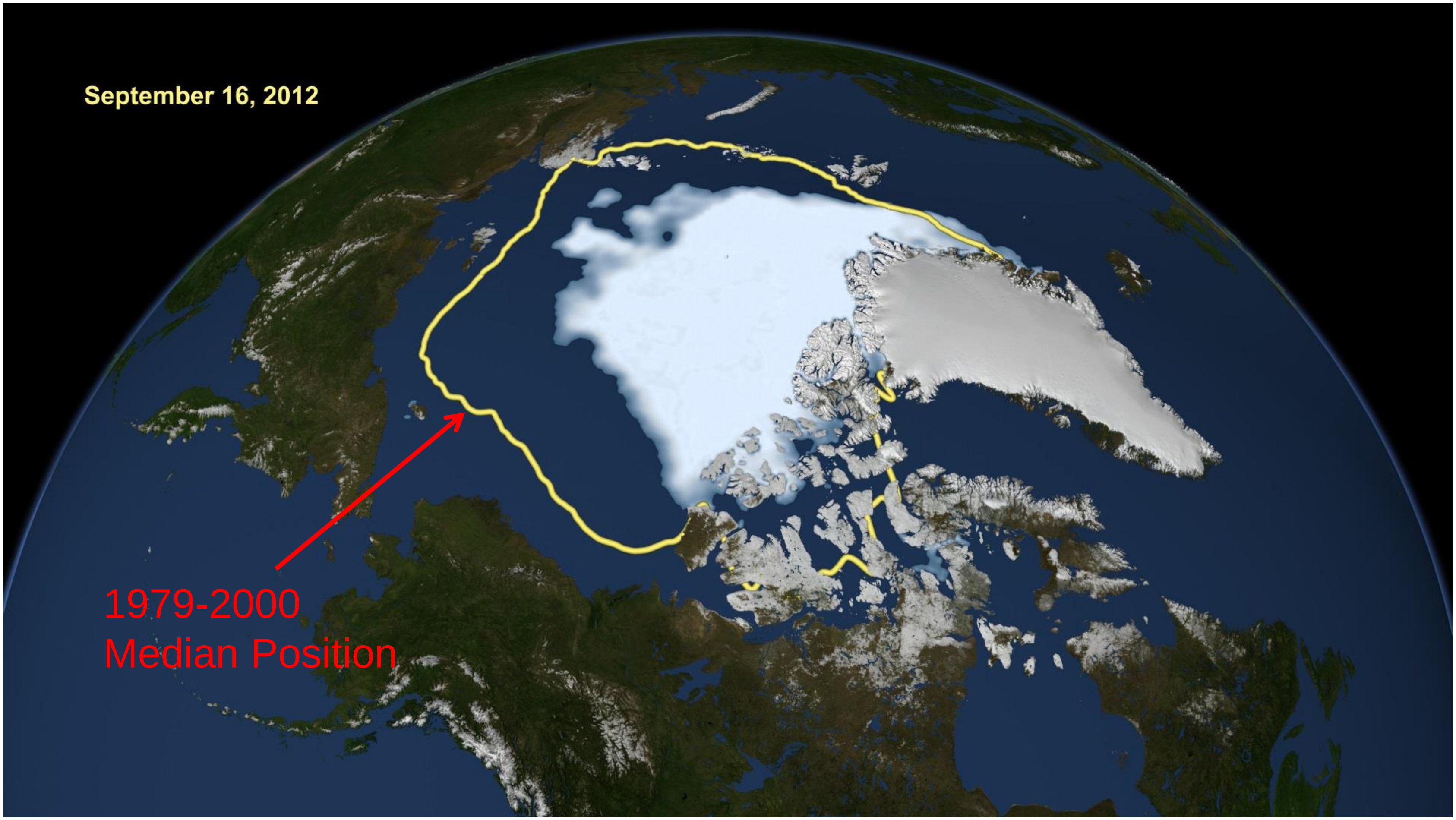
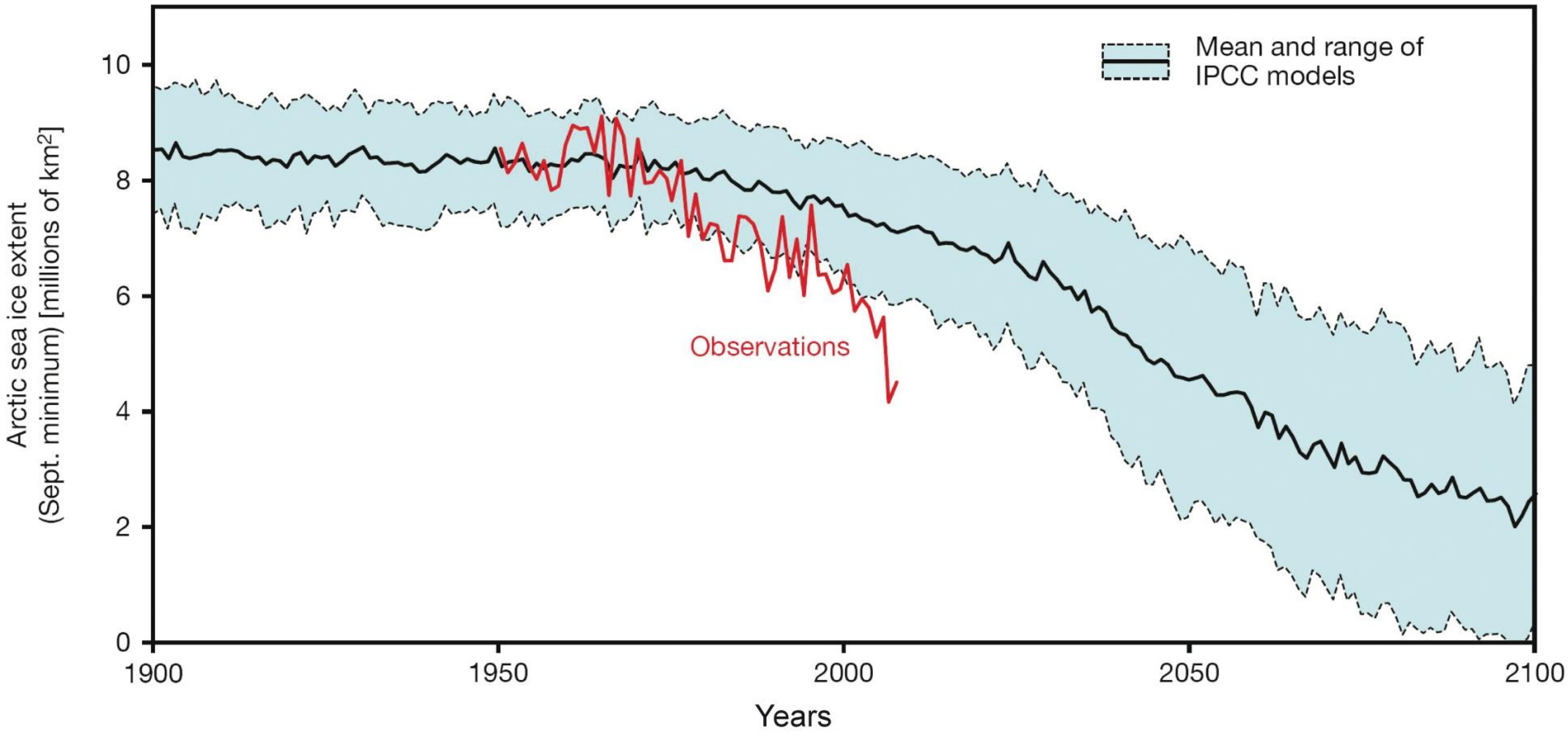


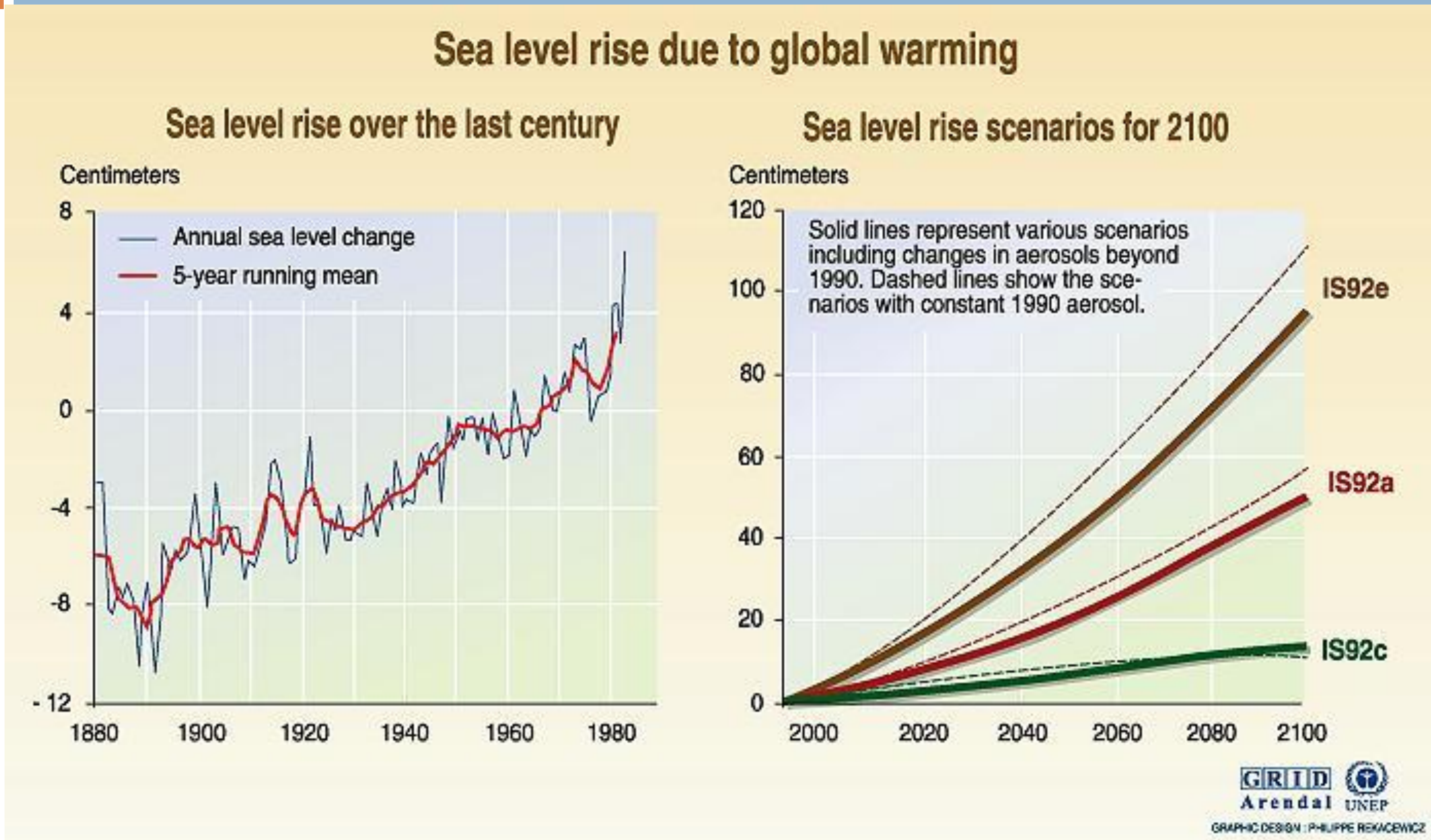

Image Source: NASA
Interpretation: http://inhabitat.com/

# Arctic Sea Ice Extent (Observed & Forecast)




http://www.pik-potsdam.de/news/press-releases/files/sea-ice.jpg

# Sea Level Changes (Observed & Forecast)




Source: Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge university press, 1996; Sea level rise over the last century, adapted from Gornitz and Lebedeff, 1987.

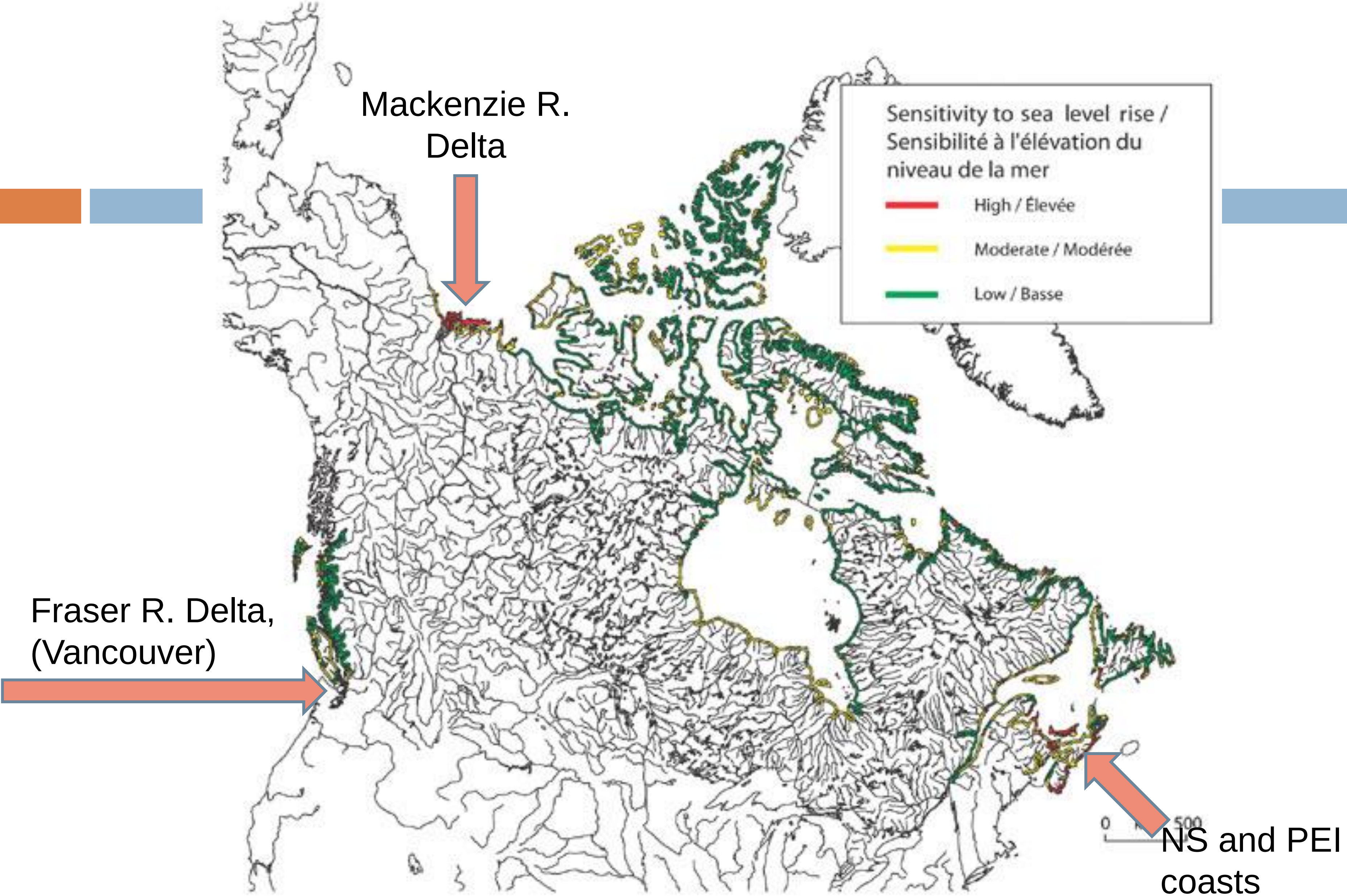
# Sea Level Changes

## Predictions of sea level rise in responses to a modeled rise in global temperature by 2100 (compiled by Mallory Carpenter 2009)


| Author(s) | Area of Study | Modeled Temp. Change (C) | Minimum Prediction | Maximum Prediction |
|---|---|---|---|---|
| **Alley, R. B. *et al.* (2005)** | Greenland | 5° | 40 cm | 50 cm |
| **Aunap, R. *et al.* (2001)** | Estonia | 2.3-4.5° | n/a | 100 cm |
| **Begin, Y. and Robichaud, A. (1997)** | New Brunswick | n/a | 20 cm | 40 cm |
| **Bray, M. J. and Hooke, J. M. (1997)** | England | n/a | n/a | 50 cm |
| **Daniels, R. C. (1992)** | South Carolina | 1-5° | 25 cm | 200 cm |
| **Ely. C. and Jorgenson, T. (2000)** | Alaska | n/a | 10 cm | 90 cm |
| **Fitzgerald, D. M. *et al.* (2008)** | Conceptual | n/a | 20 cm | 60 cm |
| **Harvey. N. and Woodroffe, C. (2008)** | South Australia | n/a | 33 cm | 110 cm |
| **IPCC (2001)** | Conceptual | 1.8 ° | 9 cm | 88 cm |
| **NRC (2007)** | Canada | 1.4° | 9 cm | 88 cm |
| **Nicholls, R. J. (2002)** | Global | n/a | 23 cm | 96 cm |
| **Senior C. A. *et al.* (2002)** | England | n/a | 9 cm | 88 cm |
| **Shaw, J. *et al.* (1998)** | Canada | 2° | n/a | 49 cm |
| **Thumerer, T. *et al.* (2000)** | England | 1.5° | 49 cm | 94 cm |
| **USGS (2000)** | Eastern USA | n/a | 15 cm | 95 cm |

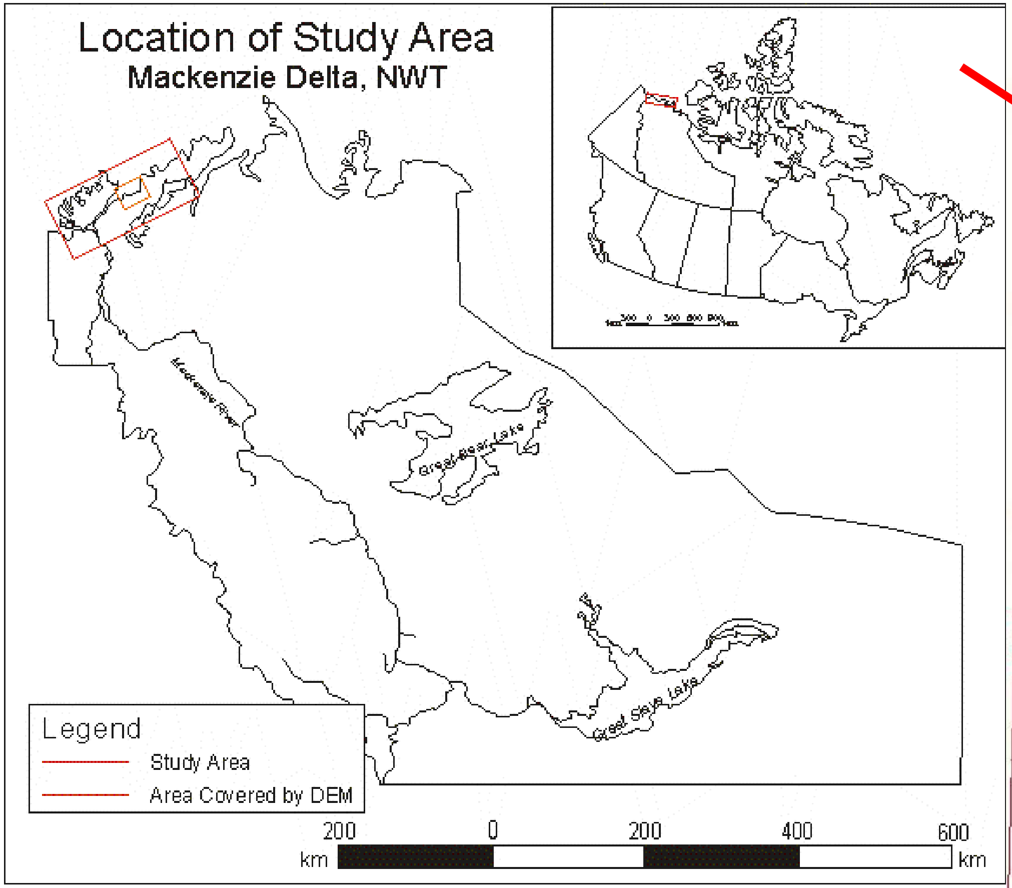
IPCC predicts 9 to 88 cm by 2100

+
Storm Surge

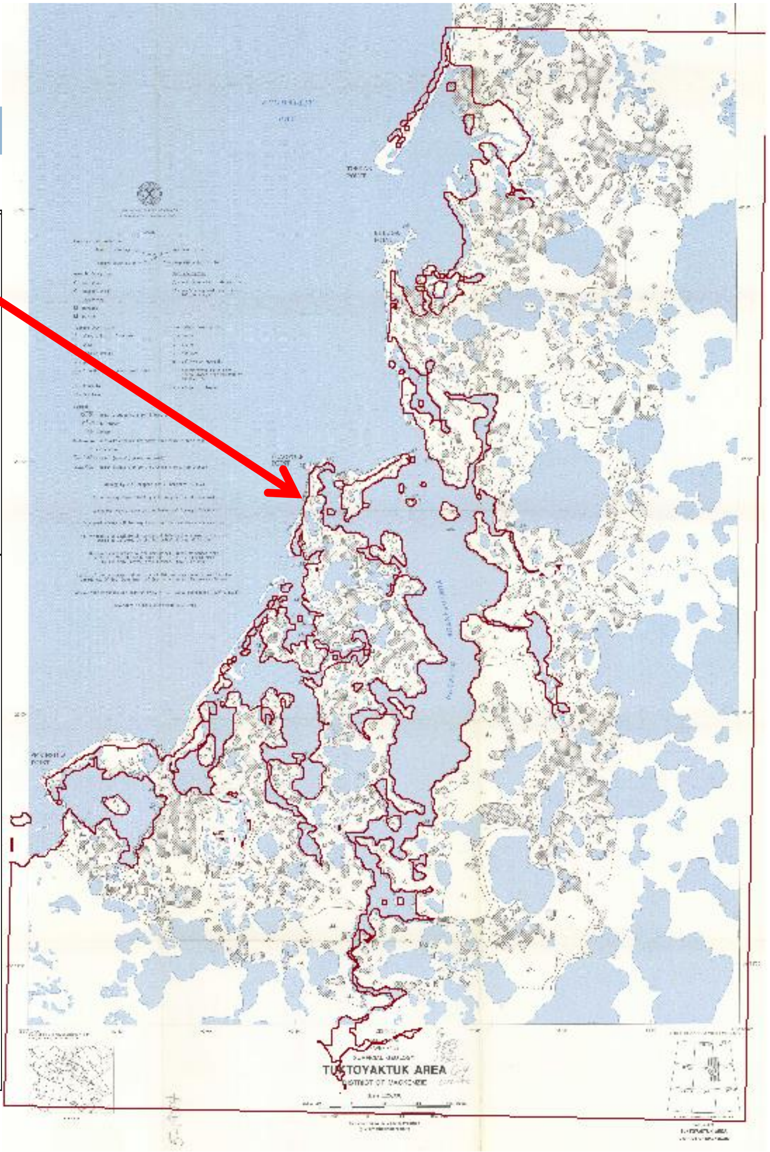



Sensitivity of Canadian coasts to sea level rise as determined by NRC's 2004 adaptation report. Source: NRC (2004)

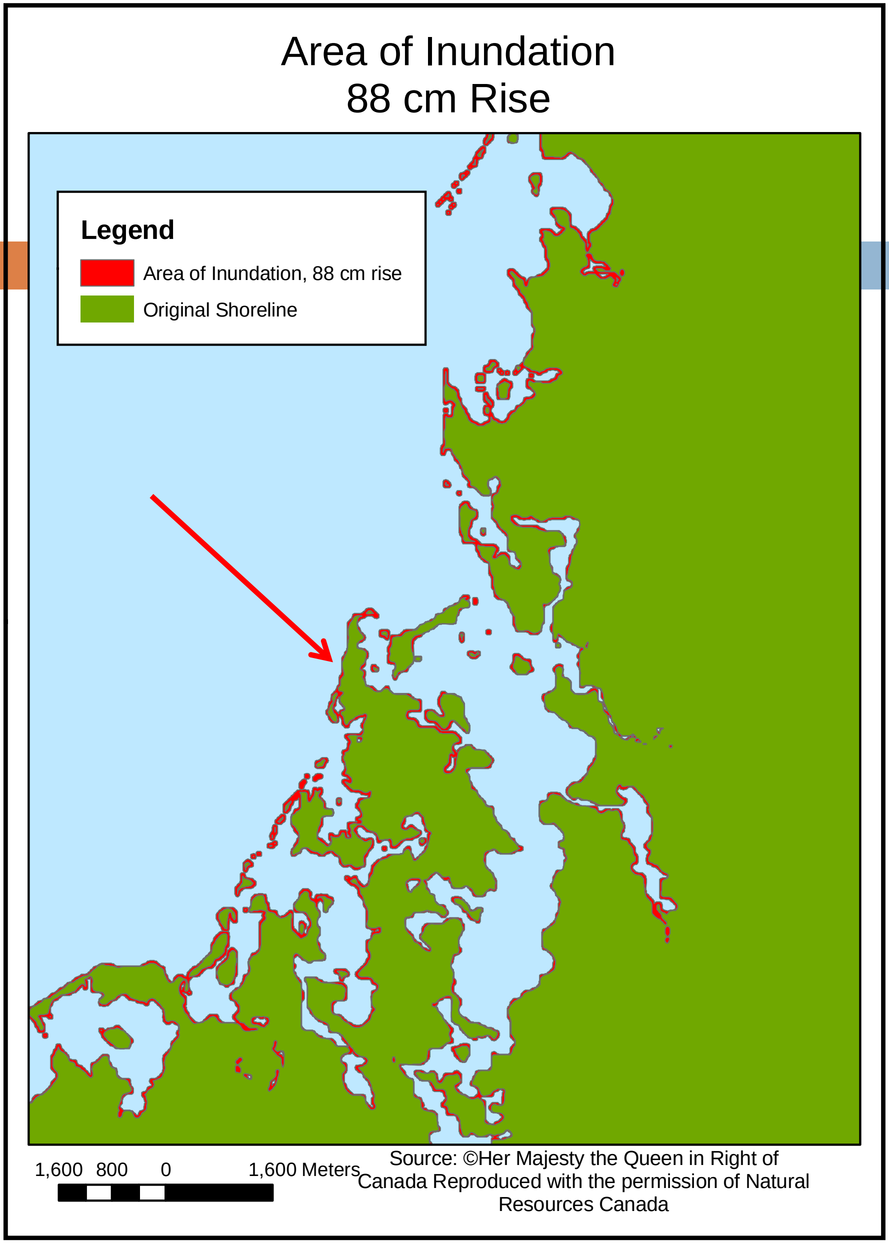
# Case Study: Sea Level Impacts (Tuktoyaktuk, NWT)

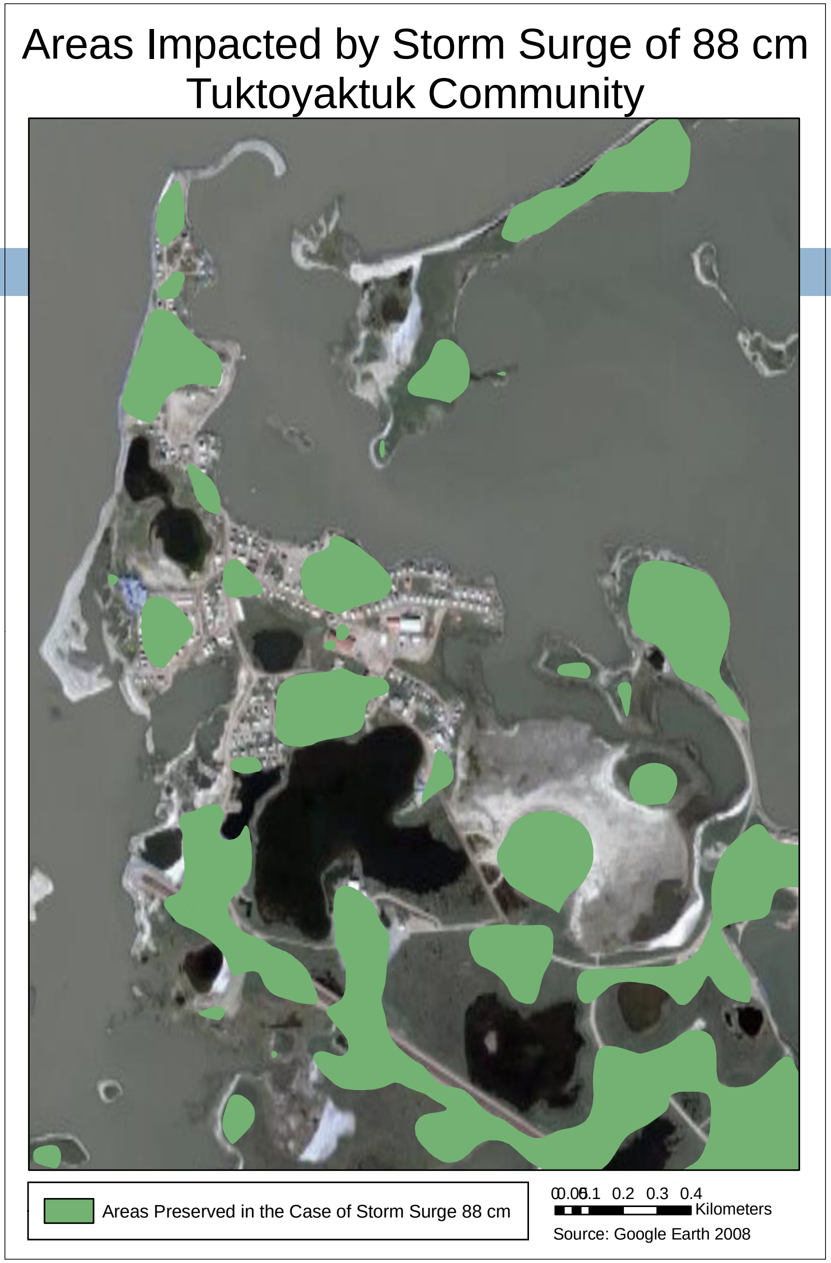



Source: Carpenter (2009).

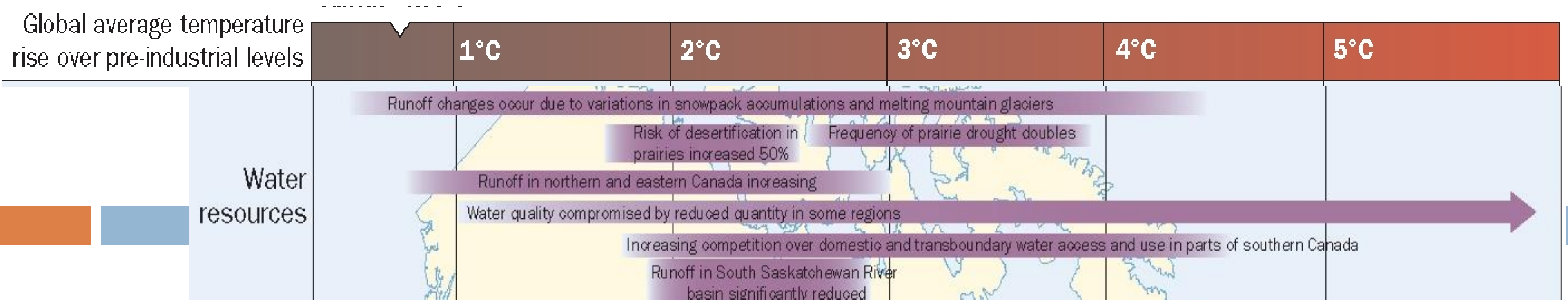



Surfcial Geology for coastline near Tuk



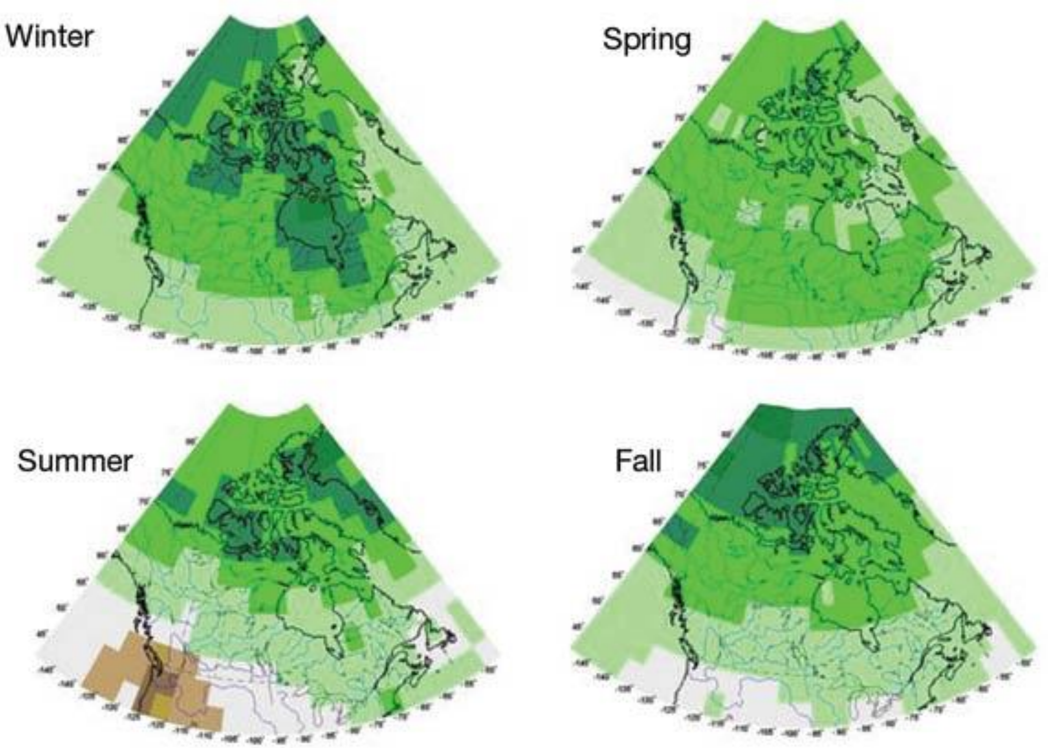

(L) Area of inundation in event of projected 88 cm sea level for Tuktoyaktuk and environs; (R) Areas affected by 88cm + 2.5m storm surge. Source: Carpenter (2009).

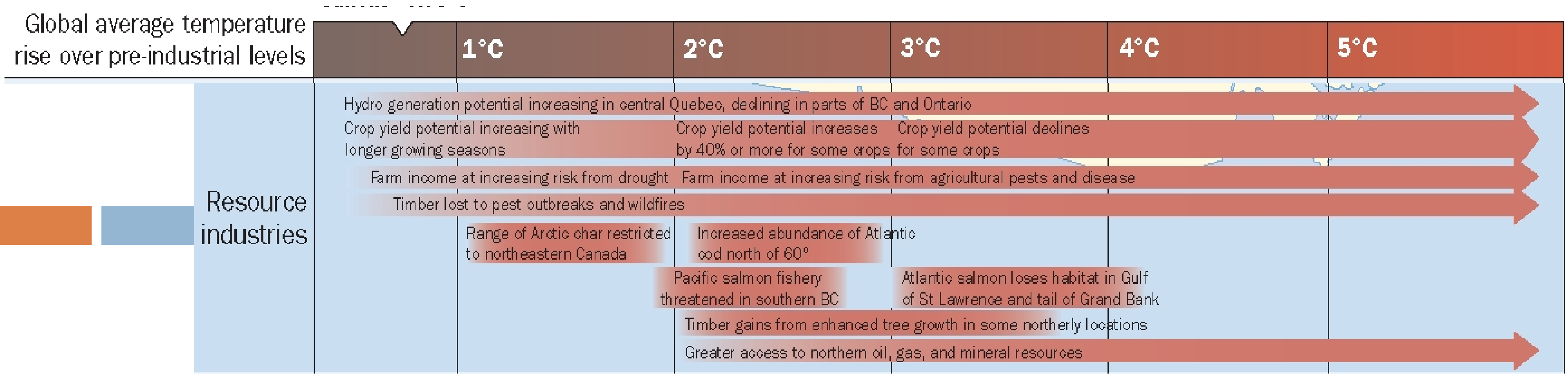



# Impacts on Water Resources

- every part of Canada except the southern Prairies has become wetter

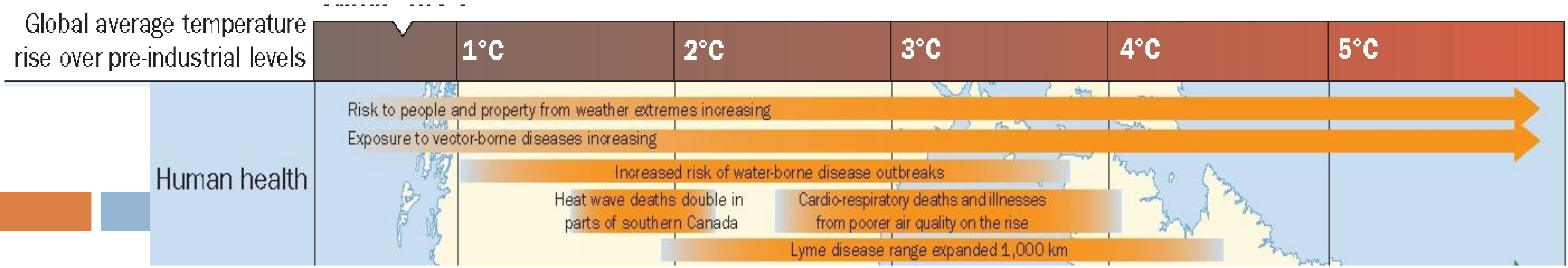
**Modeled Seasonal Change in Precipitation (relative to 1960-1990) based on the median of seven global climate models across Canada by 2050 (green = wetter; brown = drier)**
Source: Natural Resources Canada (2007b)





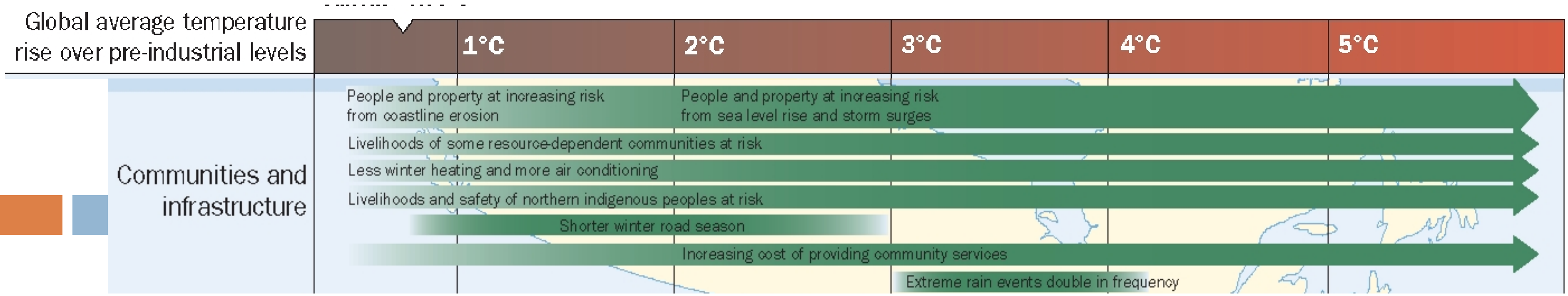

# Impacts on Resource Industries

- (AGRICULTURE) Positive impact for all regions but the Prairies (one of the few countries in the world to benefit) – *extended growing season; reduced frost damage*
- (FORESTRY) Increasing losses of timber to pest outbreaks and wildfires
- (FISHERIES) Fish are vulnerable to changes in temperature, precipitation, wind patterns, and chemical conditions. If water levels drop or there are more periods of lower water levels, the mortality of spawning salmon in BC rivers is likely to increase.




# Impacts on Human Health

- Given the prediction of the IPCC about climate change in North America, Health Canada has indicated that Canadians can expect to experience a greater incidence of disease
- This includes infectious diseases such as Lyme disease, dengue fever, West Nile virus, and malaria



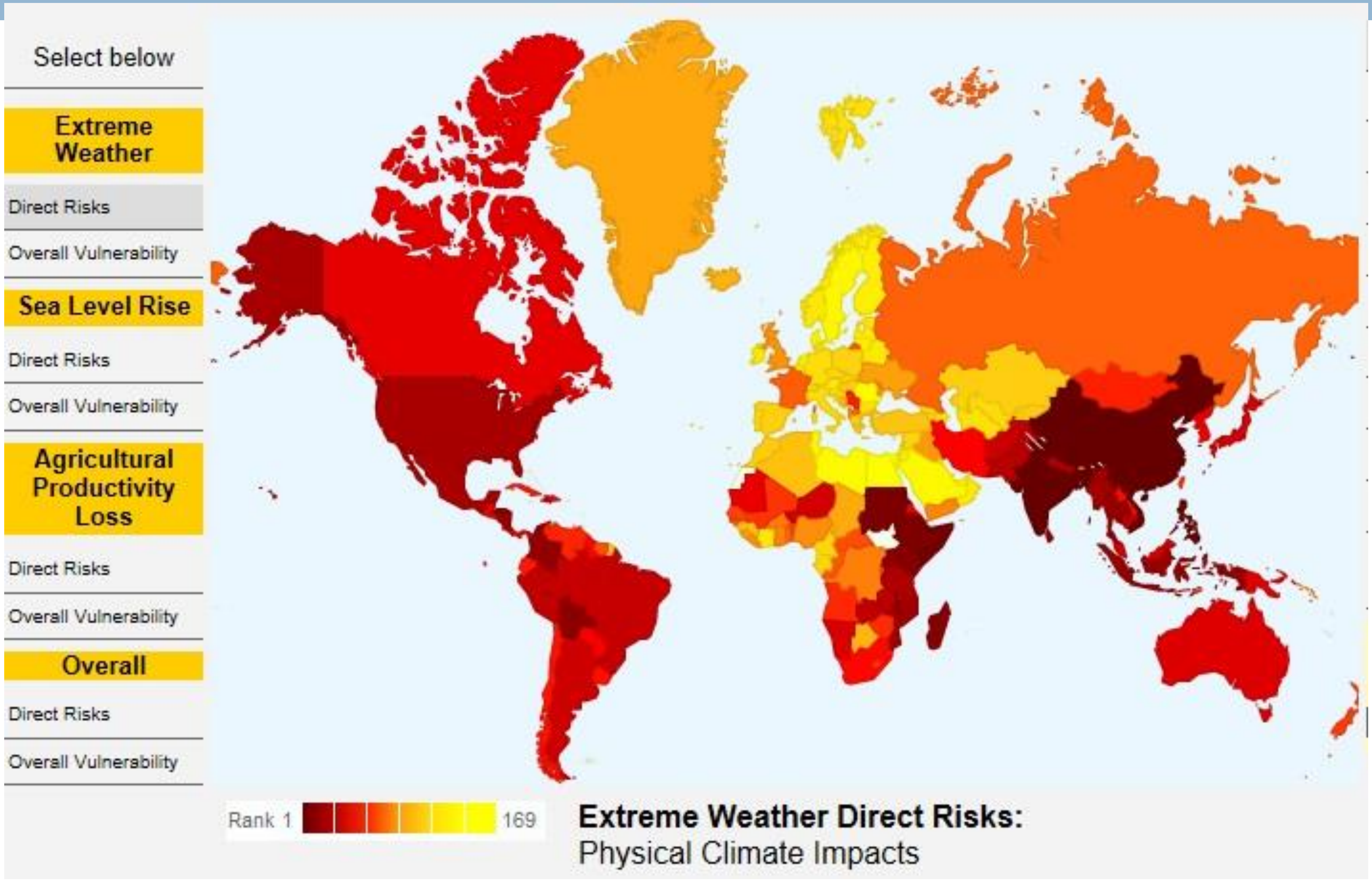

# Impacts on Communities and Infrastructure

- Livelihoods affected in *some* resource-dependent communities, especially northern indigenous communities
- Shorter winter road season
- Property risks (coastal areas, including inland) from rising sea levels and increased storminess …

# Online interactive map – Impact of Climate Change (Wheeler, 2011)

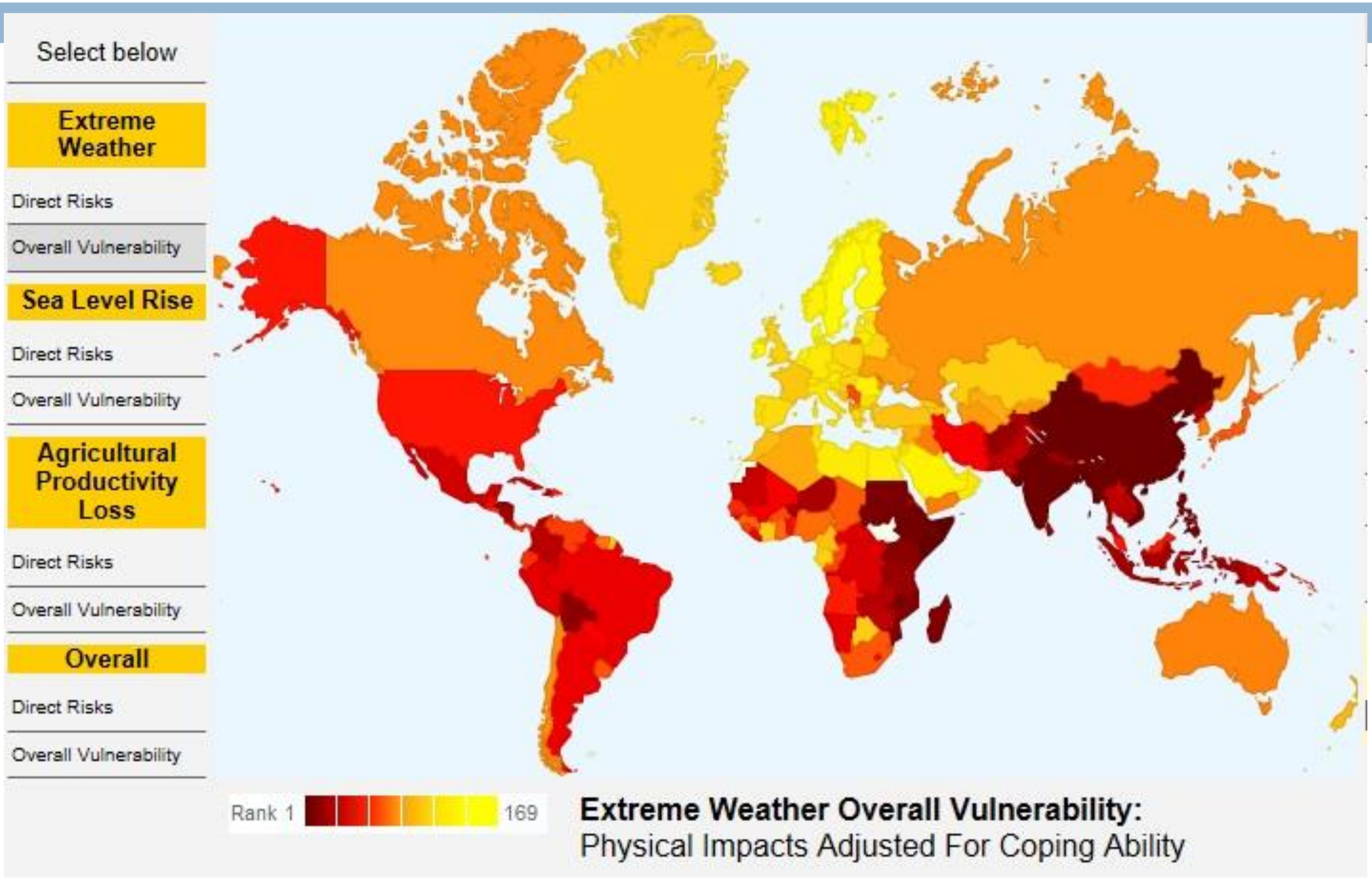
- Centre for Global Development (based in Washington DC) – accessed January 2014
  - http://www.cgdev.org/page/mapping-impacts-climate-change?utm_=
- Two dimensions of mapping impacts
  - "Direct Risk" (risk from physical climate impacts alone)
  - "Overall Vulnerability" (direct risks adjusted for countries' ability to cope with climate impacts).

# Example 1: Risks: Extreme Weather



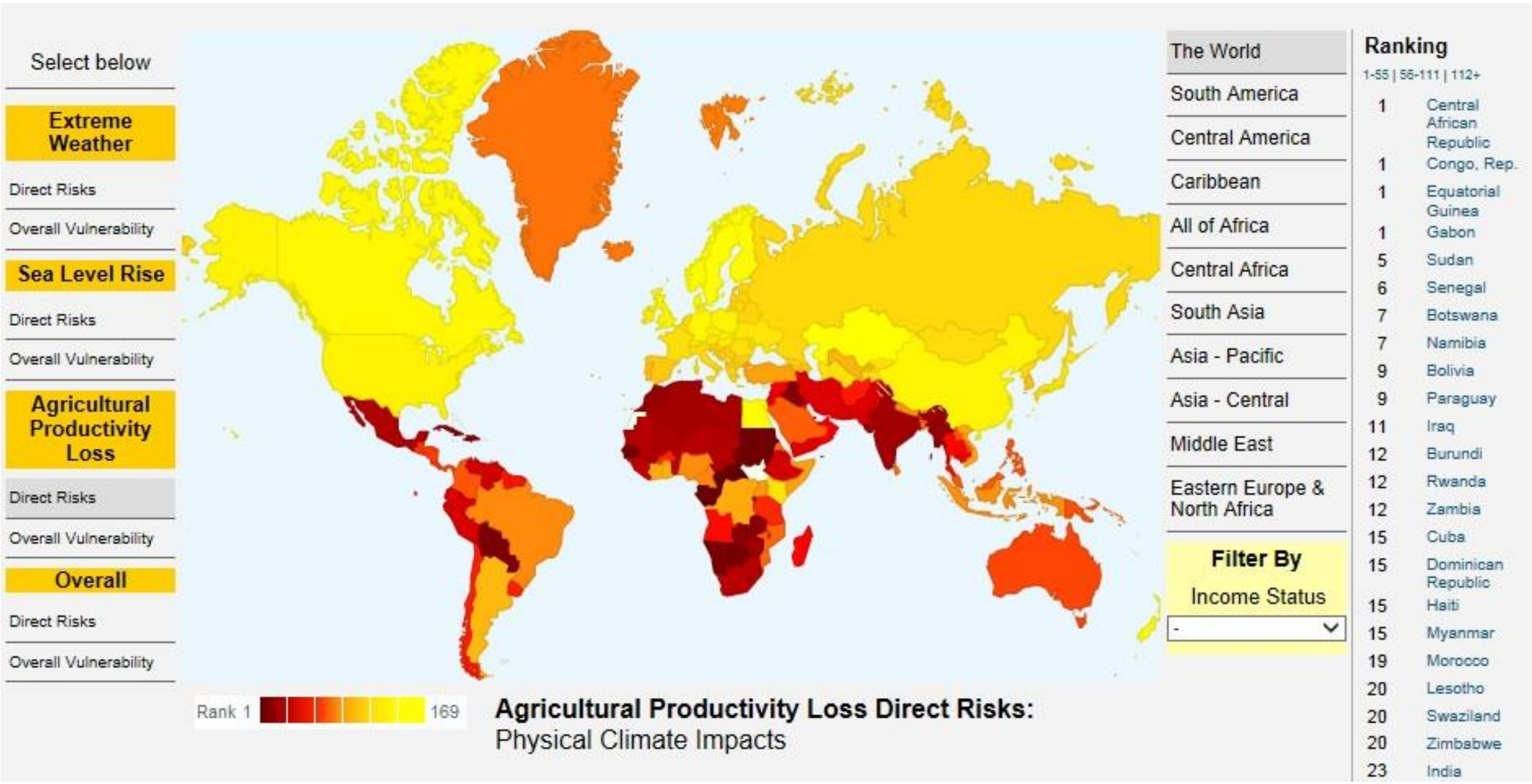

http://www.cgdev.org/page/mapping-impacts-climate-change?utm_=

# Example 1: Overall Vulnerability: Extreme Weather




http://www.cgdev.org/page/mapping-impacts-climate-change?utm_=

# Example 1: Risks: Agricultural Productivity Loss




http://www.cgdev.org/page/mapping-impacts-climate-change?utm_=

# Looking Ahead to the next lectures

**May 27 & 28:** Climate Change: definitions and scientific evidence of

Read ahead (Chpt. 7, pp. 201 →)

**May 29 & June 2:** Forests

Read ahead (Chpt. 9, pp. 282 →)

# References


- Carpenter, M. 2009. *Modeled Impacts of Future Sea Level Changes for the Tuktoyaktuk Peninsula, NWT using a Geographic Information System*, Unpublished HBA thesis, Department of Geography, Lakehead University
- Dearden, P and Mitchell, B. 2012. *Environmental Change and Challenge*, Fourth Edition, Don Mills, Ontario: Oxford University Press {Chapter 7: 'Climate Change'}
- Wheeler, David 2011. Quantifying Vulnerability to Climate Change: Implications for Adaptation Assistance, *Working Paper by Center for Global Development*. Washington, DC, 53 pp. {pdf available at http://www.cgdev.org/sites/default/files/1424759_file_Wheeler_Quantifying_Vulnerability_FINAL.pdf}
- Natural Resources Canada (NRC). (2004) Climate Change Impacts and Adaptation: A Canadian Perspective. Ottawa: Natural Resources Canada.
- Natural Resources Canada 2007a. "Towards Adaptation: Case Studies in British Columbia" (date accessed January 14, 2014) http://www.nrcan.gc.ca/environment/resources/publications/impacts-adaptation/reports/assessments/2008/ch8/10393
- Natural Resources Canada. 2007b. *From Impacts to Adaptation: Canada in a Changing Climate 2007*. Ottawa: Natural Resources Canada.