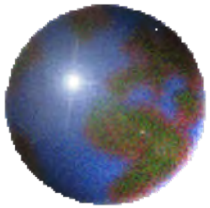


Anthropogenic Climate Change

GEOG/ENST 2331 – Lecture 21

Ahrens: Chapter 16

Midlatitude snow depth in NA

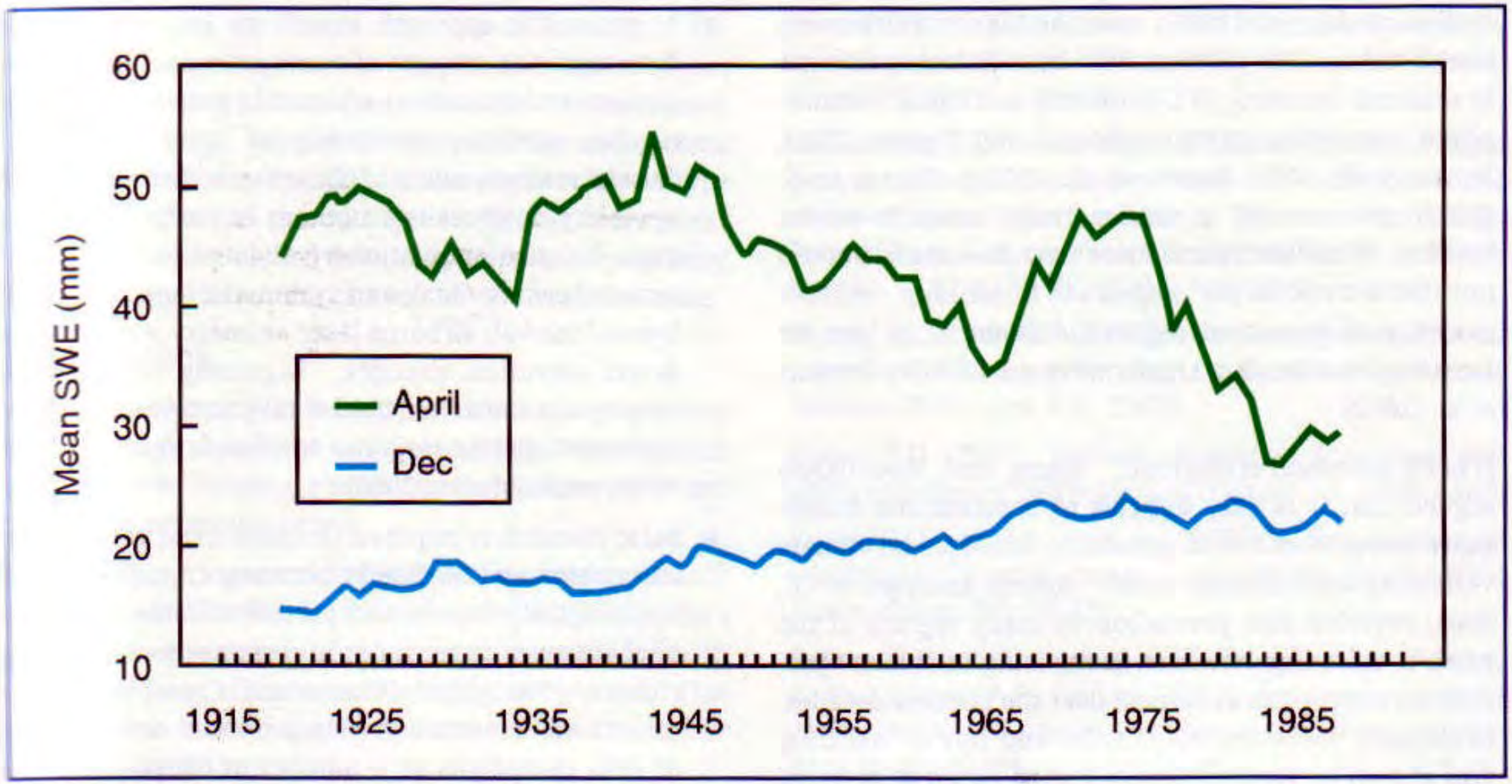


Fig. 1. Historical variation in estimated snow water equivalent (SWE) for December and April over the mid-latitude region of North America. Source: Brown (2000).

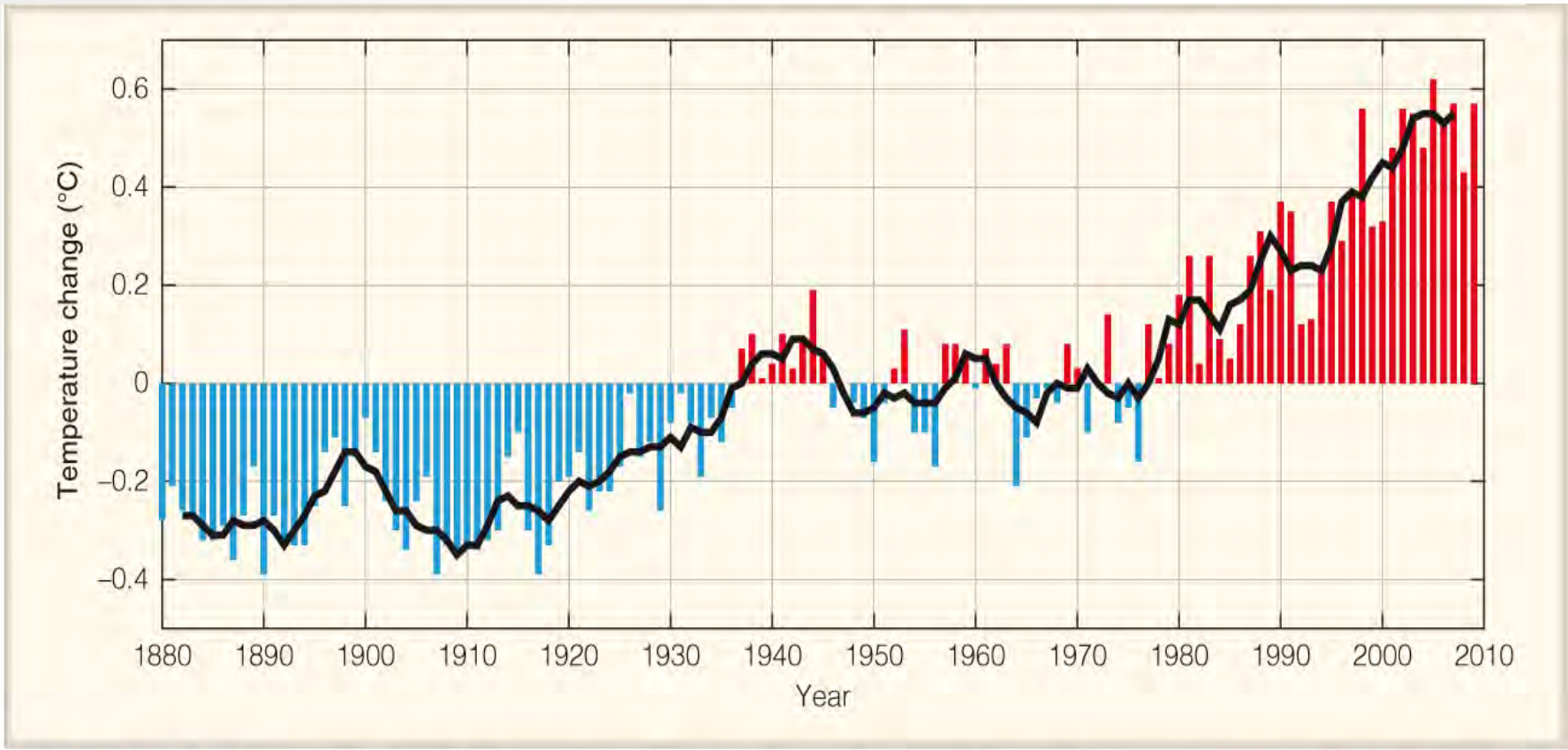
Final lecture

- Enhanced greenhouse effect
  - Anthropogenic increases in greenhouse gases
- Climate feedbacks
  - Water vapour
  - Ice and snow
  - Clouds
- Pricing Carbon

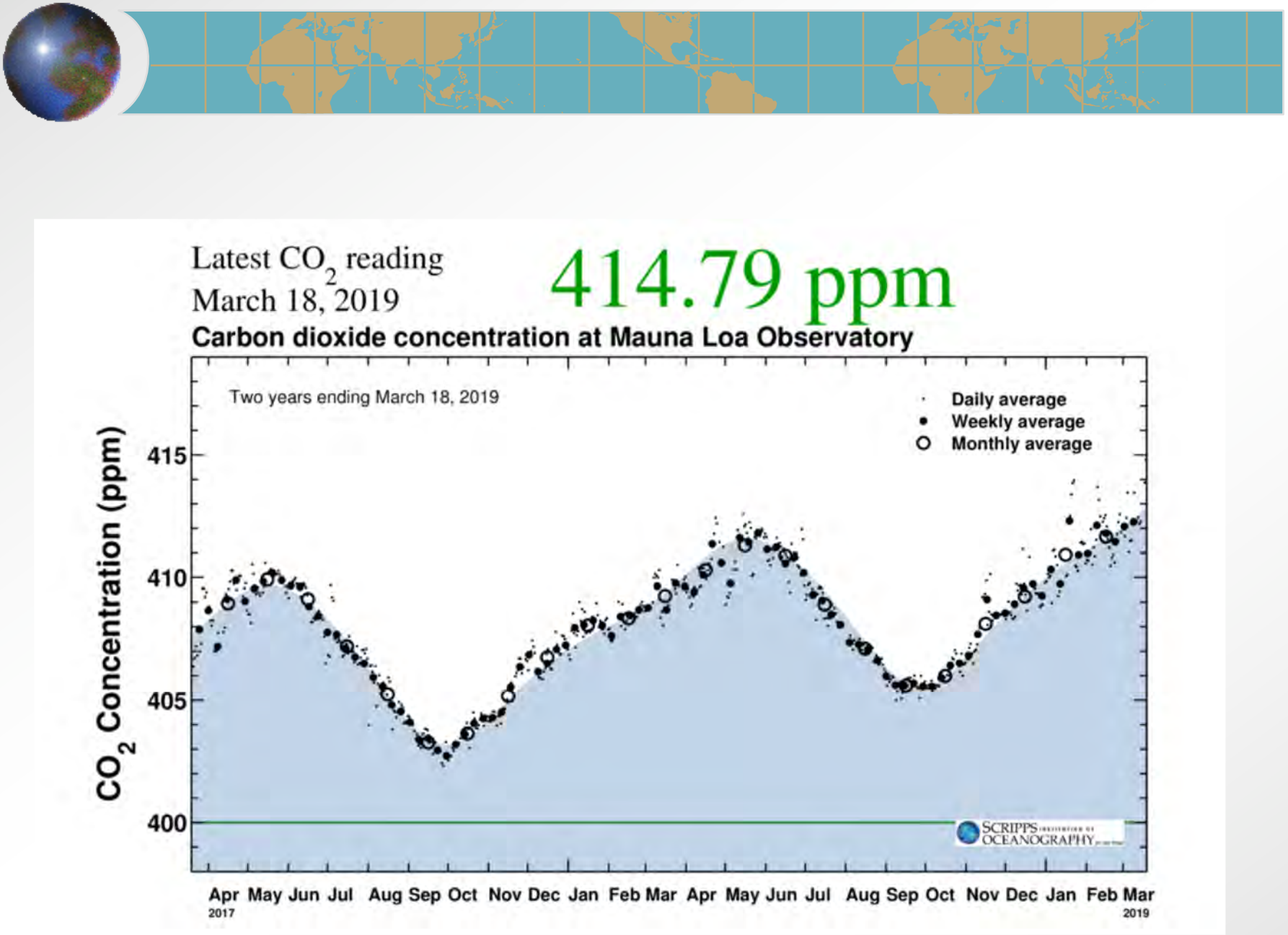
Lecture outline

- **Some climatic responses to 1.5×CO_2**
- Impacts of climate change
- Responses?
- Final exam

Recent global warming



Ahrens: Fig. 16.7


Latest CO_2 reading
March 18, 2019
414.79 ppm
Carbon dioxide concentration at Mauna Loa Observatory
Two years ending March 18, 2019
Daily average
Weekly average
Monthly average
CO_2 Concentration (ppm)
415
410
405
400
SCRIPPS INSTITUTION OF OCEANOGRAPHY
Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar
2017
2019

BUREAU OF METEOROLOGY

JANUARY 2019 FOR AUSTRALIA

WARMEST JANUARY ON RECORD FOR AUSTRALIA

NATIONAL RAINFALL

38 % BELOW AVERAGE

TASMANIA'S DRIEST JANUARY ON RECORD

WARMEST NIGHT ON RECORD ANYWHERE IN AUS

36.6 °C

26 JAN AT WANAARING, NSW

Radiative Forcing

- Some factor that causes a change in the Earth's energy budget
- Generally measured in watts per square metre
- Radiative forcing from doubling CO_2 is 3.7 Wm^{-2}
  - Before feedbacks!

Forcing from Doubling CO_2

- Pre-industrial CO_2: 280 ppmv
- Present CO_2: 415 ppmv
- 2030 CO_2: 451 ppmv (my estimate)

- *Actual* doubling of CO_2: 560 ppmv
  - Likely around 2045
- However, other greenhouse gases are increasing as well
- *Equivalent* $2\times CO_2$ when the combined *radiative forcing* presently 550 ppmv of CO_2

Climate sensitivity

- The globally averaged equilibrium change in temperature in response to a given radiative forcing
  - Decades after a change in forcing, climate will approach a new equilibrium

- The predicted climate sensitivity to $2\times CO_2$ is between 1.5 and 4.5°C

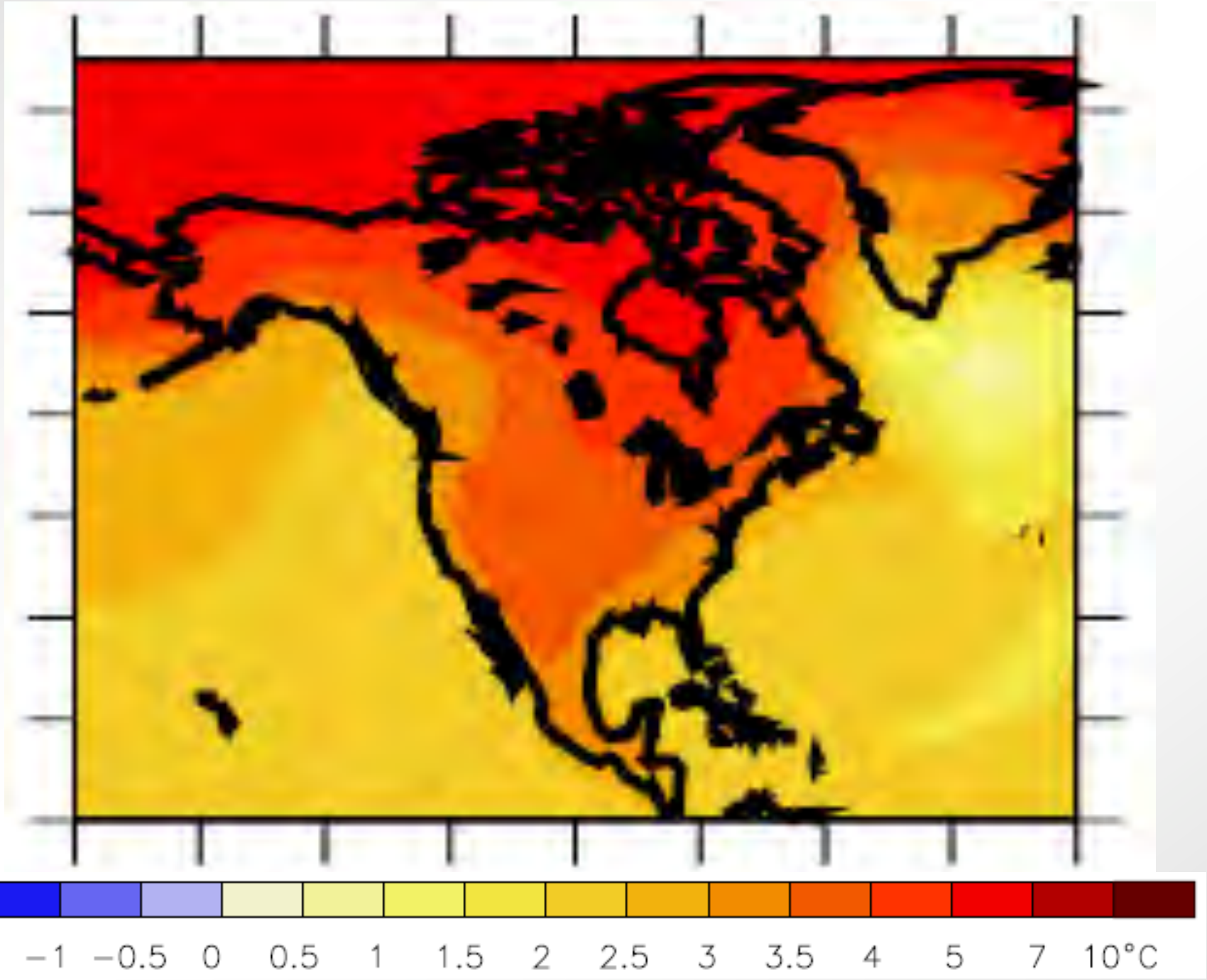
Continentality

- With warmer temperatures, rate of evaporation will increase
  - Evaporation causes latent cooling
  - Increase in evaporation will be larger over open water
- Continents will warm more than the average
  - And oceans will warm less
  - Mid-continents with dry soil will warm the most

Latitude

1. Greater warming is occurring at higher latitudes due to the ice albedo feedback

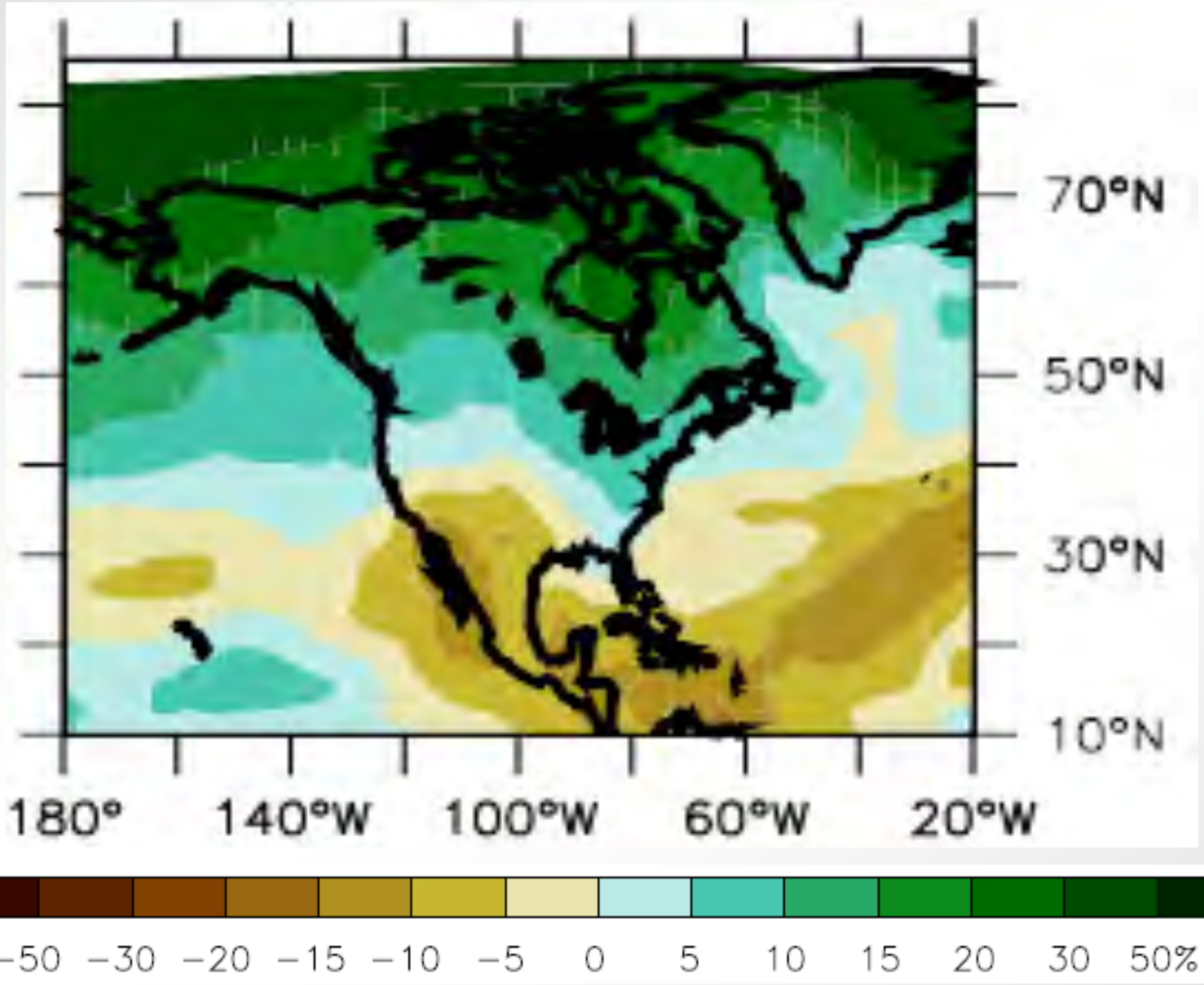
2. In the winter, sea ice insulates cold air from warmer water
   - Thinner ice means less insulation
   - Even greater polar amplification in winter


−1 −0.5 0 0.5 1 1.5 2 2.5 3 3.5 4 5 7 10°C

Hydrological cycle

- More intense overall
  - Increased evapotranspiration, precipitation
  - More E means = P – not necessarily at same locations
  - Will be less P at some locations

- Likely (but less certain):
  - Drier soils at mid-continents in summer
  - Midlatitude precipitation belts will shift poleward
  - Increased variability of precipitation
    - More droughts and floods
  - Stronger monsoons in Asia and West Africa


70°N
50°N
30°N
10°N
180°
140°W
100°W
60°W
20°W
−50 −30 −20 −15 −10 −5 0 5 10 15 20 30 50%

Storms

- Summer thunderstorms
  - High confidence in becoming more intense and frequent
- Midlatitude cyclones
  - May get weaker
- Tropical cyclones (hurricanes)
  - Opposing factors at work
  - Could become less frequent but more intense

Rise in sea level

- Melting ice sheets
  - Greenland
  - Antarctica: too cold for inland melting; but shelves could collapse into a warmer sea
  - Mountains
- Thermal expansion

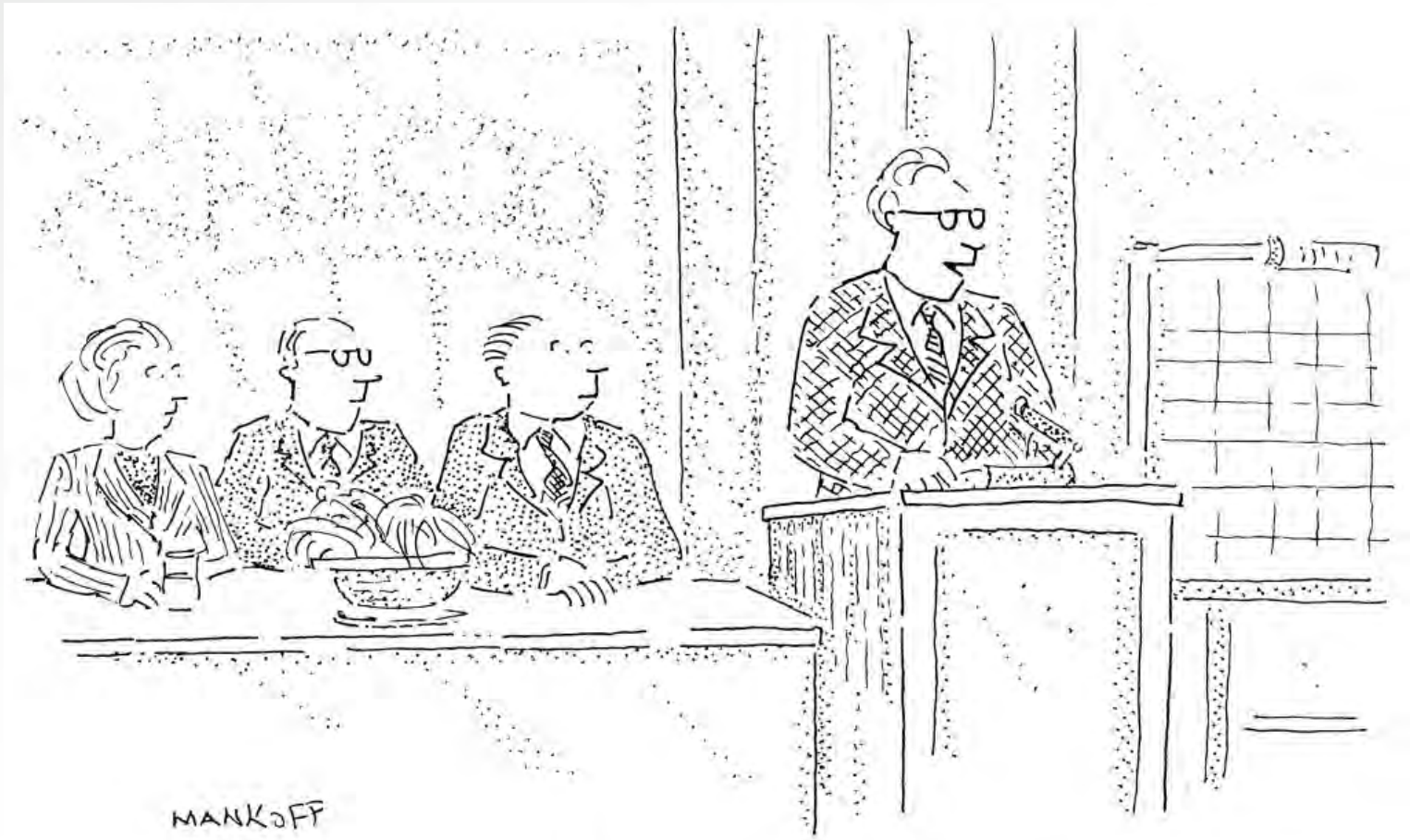
Rise in sea level

- IPCC expects 30-100 cm by 2100
  - **Probably a low estimate**
  - Much more on the way; sea level rise is slow

- Inundation
- Infiltration
- Storm damage

ENSO

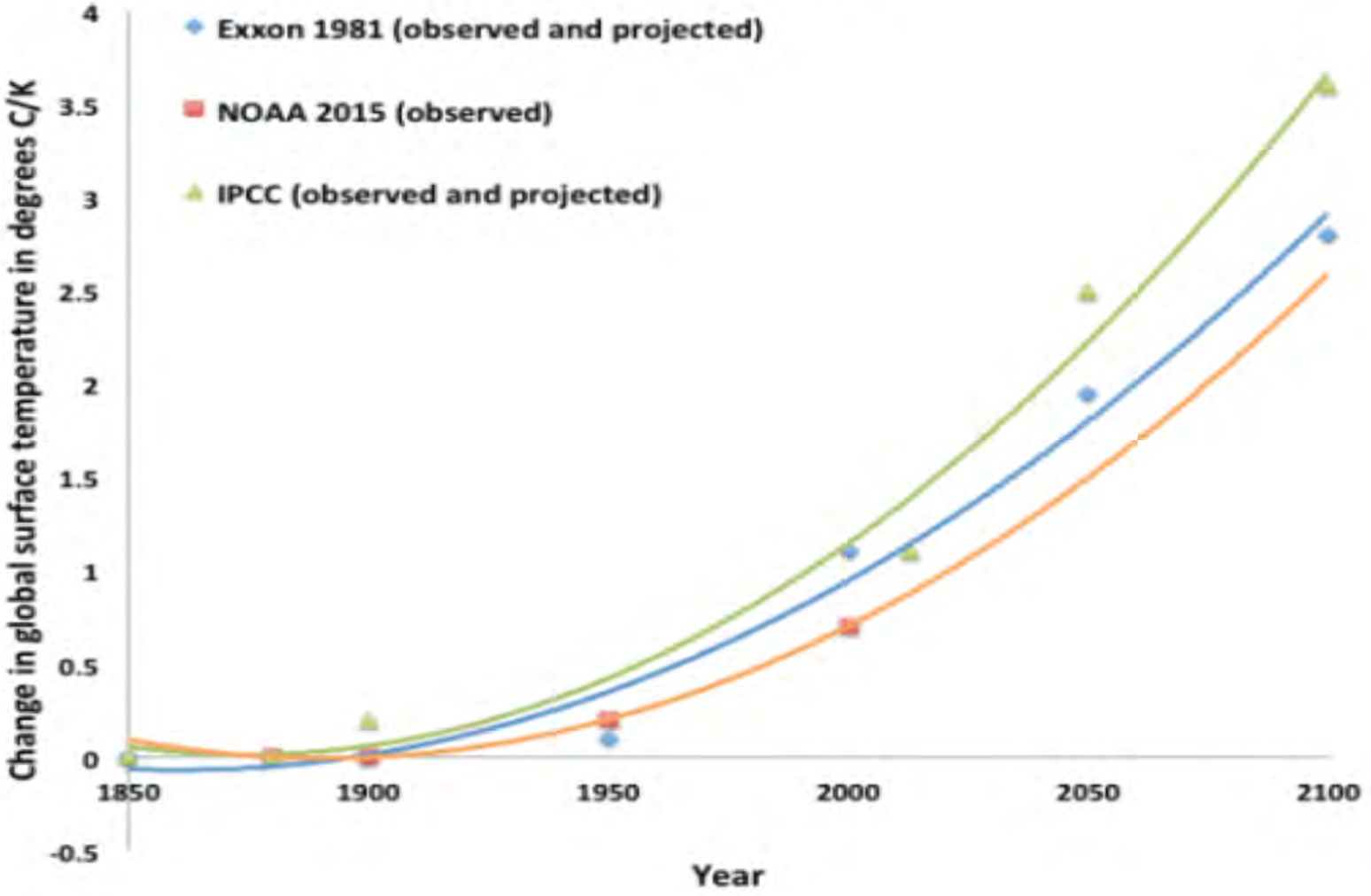
- Average climatic conditions could become more El Niño-like
- El Niño events could become stronger and/or more frequent, increasing climatic variability.



"And so, while the end-of-the-world scenario will be rife with unimaginable horrors, we believe that the pre-end period will be filled with unprecedented opportunities for profit."

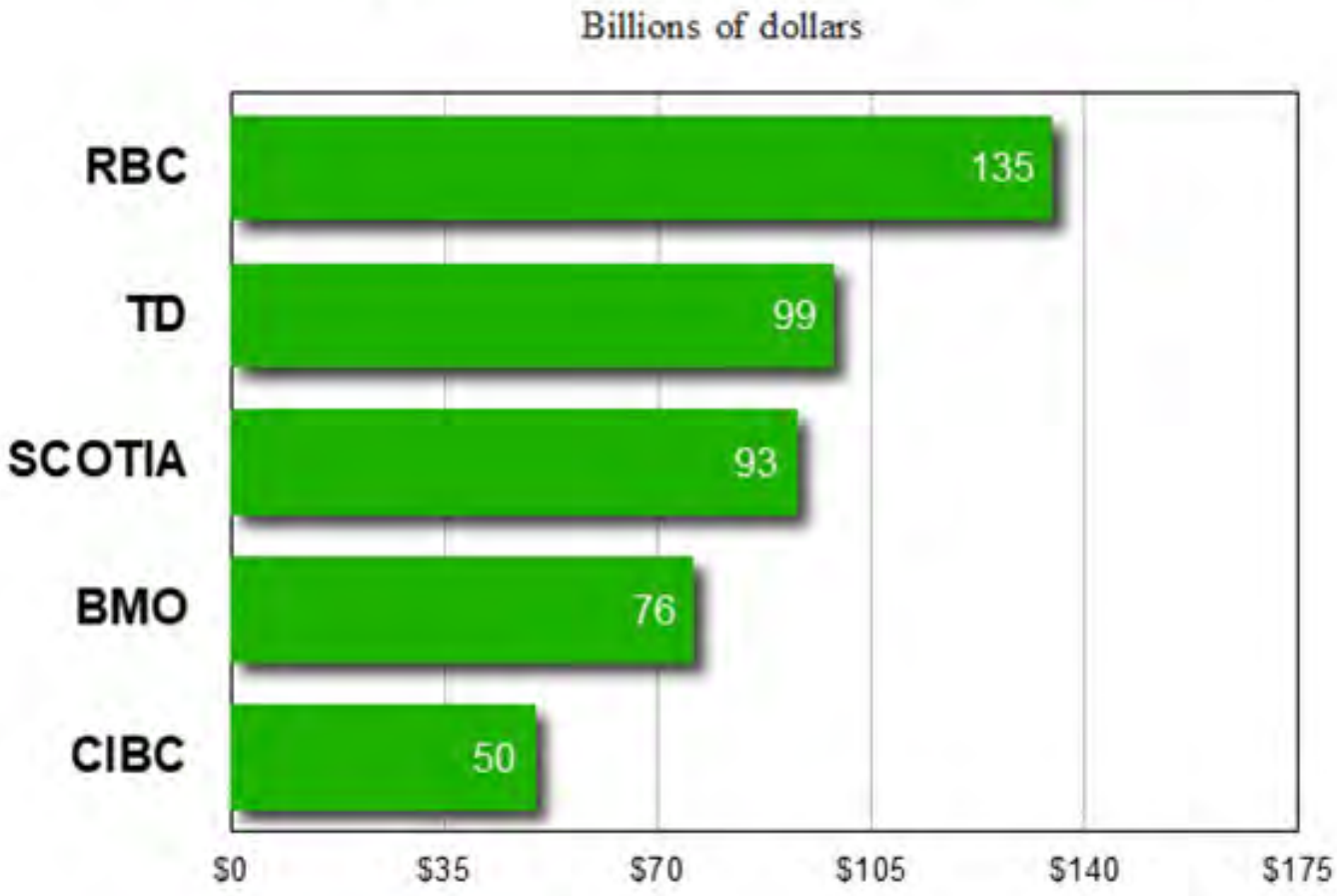
Global Warming: What Did We Know And When Did We Know It?

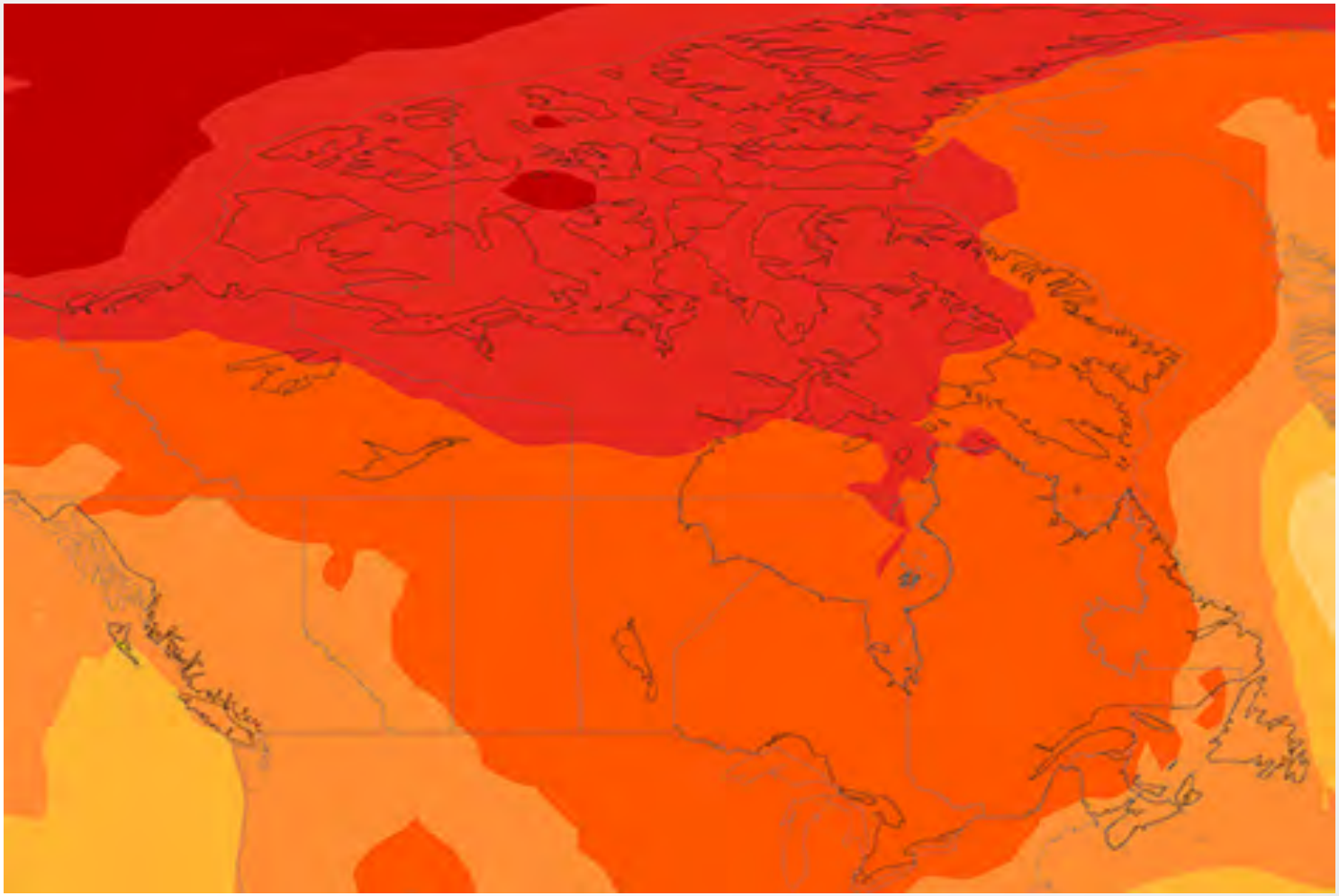
Comparing three representations of global warming through the end of the 21st century.



Big Banks, Big Investments in Fossil Fuels

Financing for fossil fuel projects from 2016 to 2018





Pricing carbon: April 1, 2019

- Climate remedy?
  - Calculating your Basic Climate Incentive
  - $154 + 15.4 = $169.4
  - $154 + 77 + 38 = 269 + 27 = $296
- Politically vulnerable? Ruse?

Brief history of carbon pricing

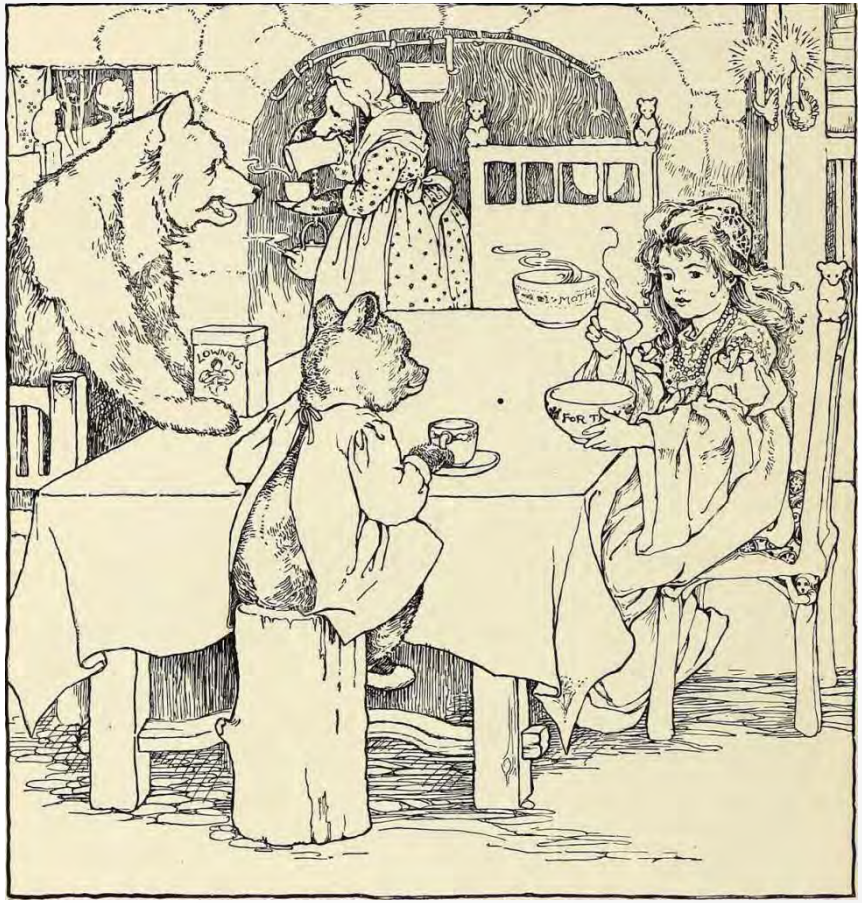
Carbon pricing addresses that CO_2 (and other greenhouse gases) is a **negative externality** — various damage that is not accounted for in the price. [**Discuss**]

A price per tonne is added to the purchase price.

(Ideally equal to the monetary value of the damage caused the emissions – but this is rarely done.)

- Carbon pricing began in Finland in 1990.
- Sweden and Norway followed in 1991.
- Carbon pricing of fossil fuels usually in the forms of a carbon tax or purchase of permits ("allowances“) to emit, generally known as cap-and-trade.
- Carbon tax processes are in Finland, Sweden, Norway, India, Japan, South Korea, Denmark, France, the Republic of Ireland, the Netherlands, the United Kingdom, Switzerland, Costa Rica, in BC, Quebec and Alberta and parts of the US.

- Cap-and-trade came in being in 2005 in Europe


LOWNEY'S

Federal-Provincial Carbon Coordination

- An analogy about national carbon pricing policy involves the three porridge bowls in the Goldilocks and the Three Bears fairy tale.
- From childhood: the first bowl was too cold, the second too hot and third just right. There are three broad options:

(1) a bottom-up approach with no interference;

(2) an aggressive top-down approach; or

(3) a middle ground approach.

Bottom-up: too cold

- The federal government would play little or no role in coordinating carbon pricing policies. This is what has happened since 2006.
- This maintains jurisdictional power of provinces over environmental matters.
- But relying on voluntary provincial initiatives is not meet current national targets.
- This approach is likely to be increasingly costly and not acceptable at the international level.

Top-down: too hot

Federal action - supersede existing provincial policies and force the implementation of carbon pricing policy on provinces and territories.

- A single, unified carbon price is likely the most cost-effective way to achieve the national target.
- But would create political conflict by not respecting the progress of some provinces and be potentially unfair for the unprepared provinces and territories.
- If federal action also meant that the federal government keeps the carbon-pricing revenue, then even more political issues are raised.

Carbon coordination done just right

The federal government could set some kind of minimum threshold, for carbon pricing policy.

- If provincial policy exceeds the threshold, they are exempt from federal policy.
- If not, the federal government would step in. It would gradually bring the lagging provinces into play while respecting the existing initiatives implemented by provinces.
- This would increase cost-effectiveness but the threshold is key.
- Will this approach will be sufficient for Canada to meet its national target. If carefully, this could be the policy bowl that Goldilocks finds just right.

- **But is this Goldilocks solution possible?**

Impacts on natural systems

- Loss of habitat
- Species extinctions
- Ecosystem reorganization
- Forest diebacks
  - Increased fire frequency

Impacts on built systems

- Agricultural losses, especially in tropics
  - Heat-sensitive crops
  - Valuable coastal land lost to sea level
  - Droughts and floods
- Population centres affected by sea level rise
- Melting permafrost at high latitudes
  - Buildings, road, railways, pipelines

Impacts on humans

- Water supply
  - Moisture deficits more common
  - Timing of rainfall can cause stress
  - Saline intrusion along coastlines
- Infectious diseases
  - Disease vectors will shift poleward
  - E.g. Malaria mosquito
- Heat stress

Final exam

- Sunday, December 15
  - 1 – 3 pm
  - RB 2024
- Cumulative for all lecture material

- Same format as the midterm
  - 90 multiple choice 90
  - 9 short answer 45
  - Total 135/3

Atmospheric circulations

- Thermal winds
  - Land/lake breeze
  - Mountain/valley breeze
  - Monsoon
- Global circulation
  - Three cell model
  - Jet Streams
  - Planetary Waves
- ENSO

Moving air

- Air masses
  - Source regions and classification
  - Modifying air masses
- Fronts
  - Warm, cold, stationary, occluded, dryline
  - Changes in temperature, humidity, wind direction, pressure and cloud cover

Midlatitude cyclones

- Polar front theory
  - Life cycle and dissipation
- Upper air divergence
  - Baroclinic instability
  - Jet streaks
  - Vorticity

Thunderstorms

- Ordinary storms
- Multicell storms
- Supercell storms

- Lightning and thunder
- Hail
- Tornadoes

Hurricanes (Tropical Cyclones)

- Climatology
- Dynamics
- Lifespan

- Hazards
  - High winds
  - Storm surge
  - Heavy rains
- Forecasting

- Polar lows

Climate Classification

- The Köppen system
- Based on vegetation
- 5 types, plus ‘Highland’

Global climatic change

- Causes
  - Review of the radiation balance
  - Anthropogenic greenhouse gases
  - Radiative forcing
  - Feedbacks
- Results
  - Climate sensitivity
  - Distribution of changes in temperature and precipitation
  - Sea level rise

Questions via email up to December 14

Potential review: December 5?

DO WELL!