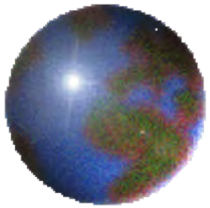
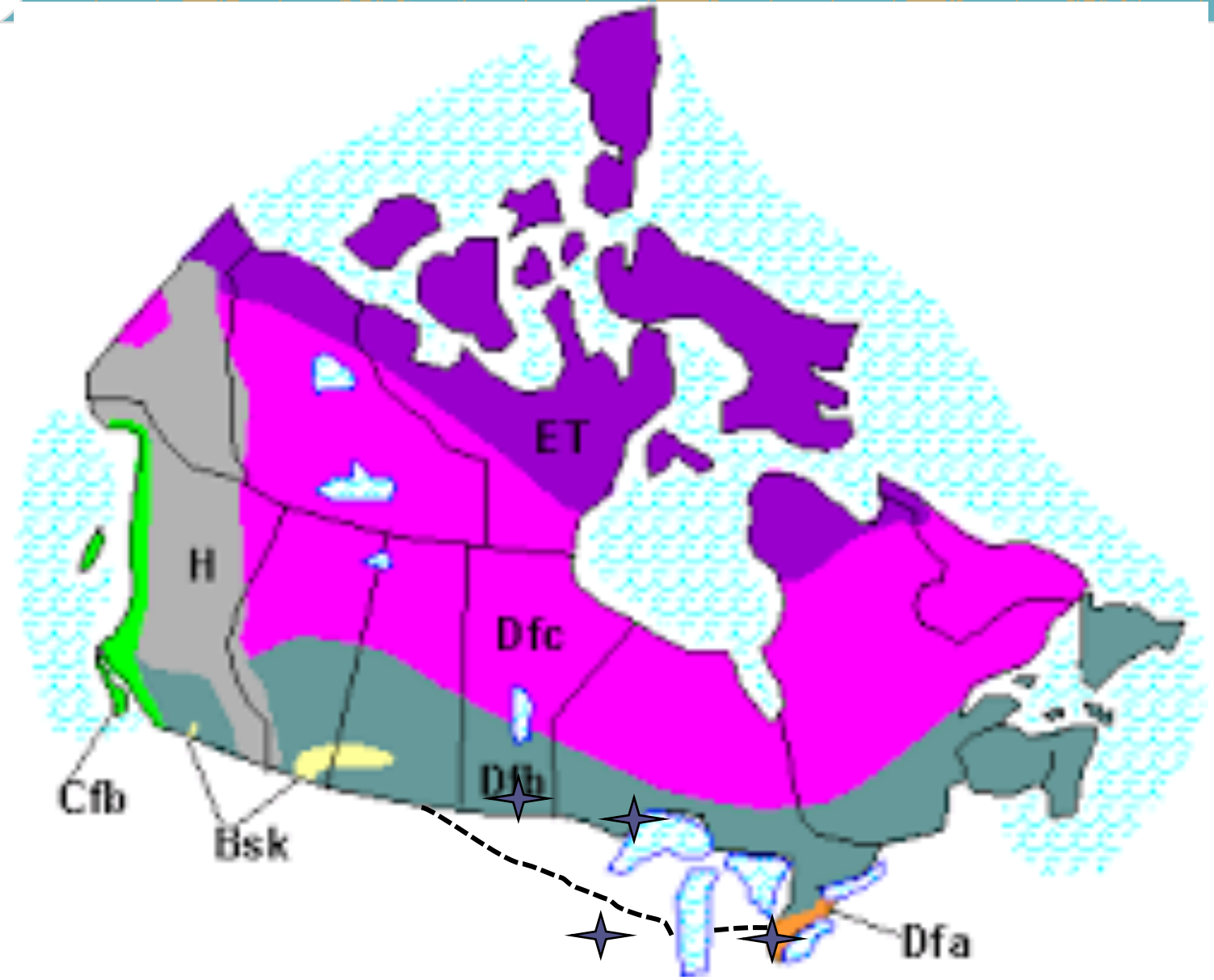
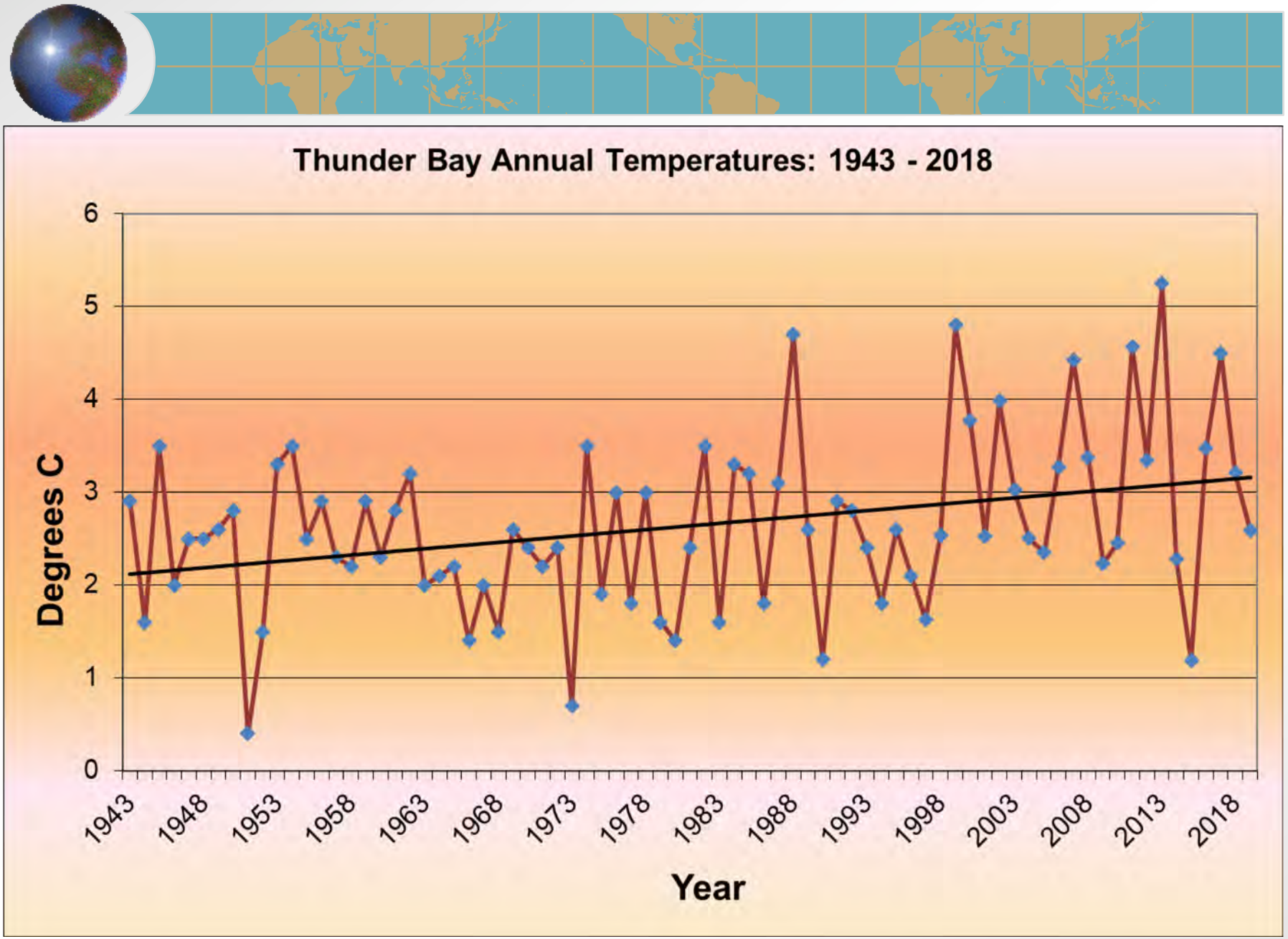


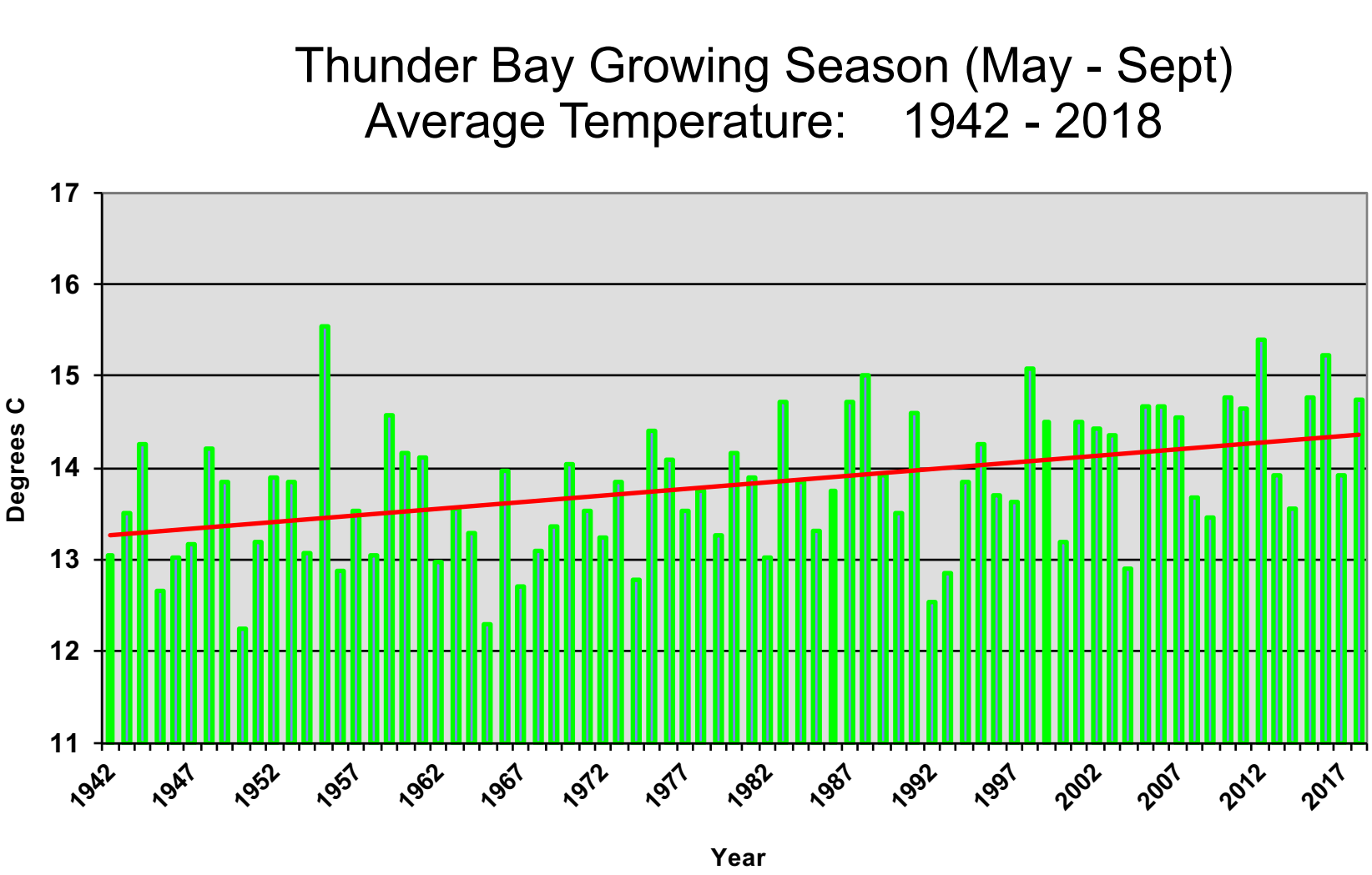
Global Climatic Change

GEOG/ENST 2331 – Lecture 20

Ahrens: Chapter 16


ET
H
Dfc
Dfb
Cfb
Bsk
Dfa


Thunder Bay Annual Temperatures: 1943 - 2018
Degrees C
0
1
2
3
4
5
6
1943
1948
1953
1958
1963
1968
1973
1978
1983
1988
1993
1998
2003
2008
2013
2018
Year


Thunder Bay Growing Season (May - Sept)
Average Temperature: 1942 - 2018
Degrees C
17
16
15
14
13
12
11
1942
1947
1952
1957
1962
1967
1972
1977
1982
1987
1992
1997
2002
2007
2012
2017
Year

Global Climatic Change

- Review: Radiation balance
- Enhanced greenhouse effect
- Climate feedbacks

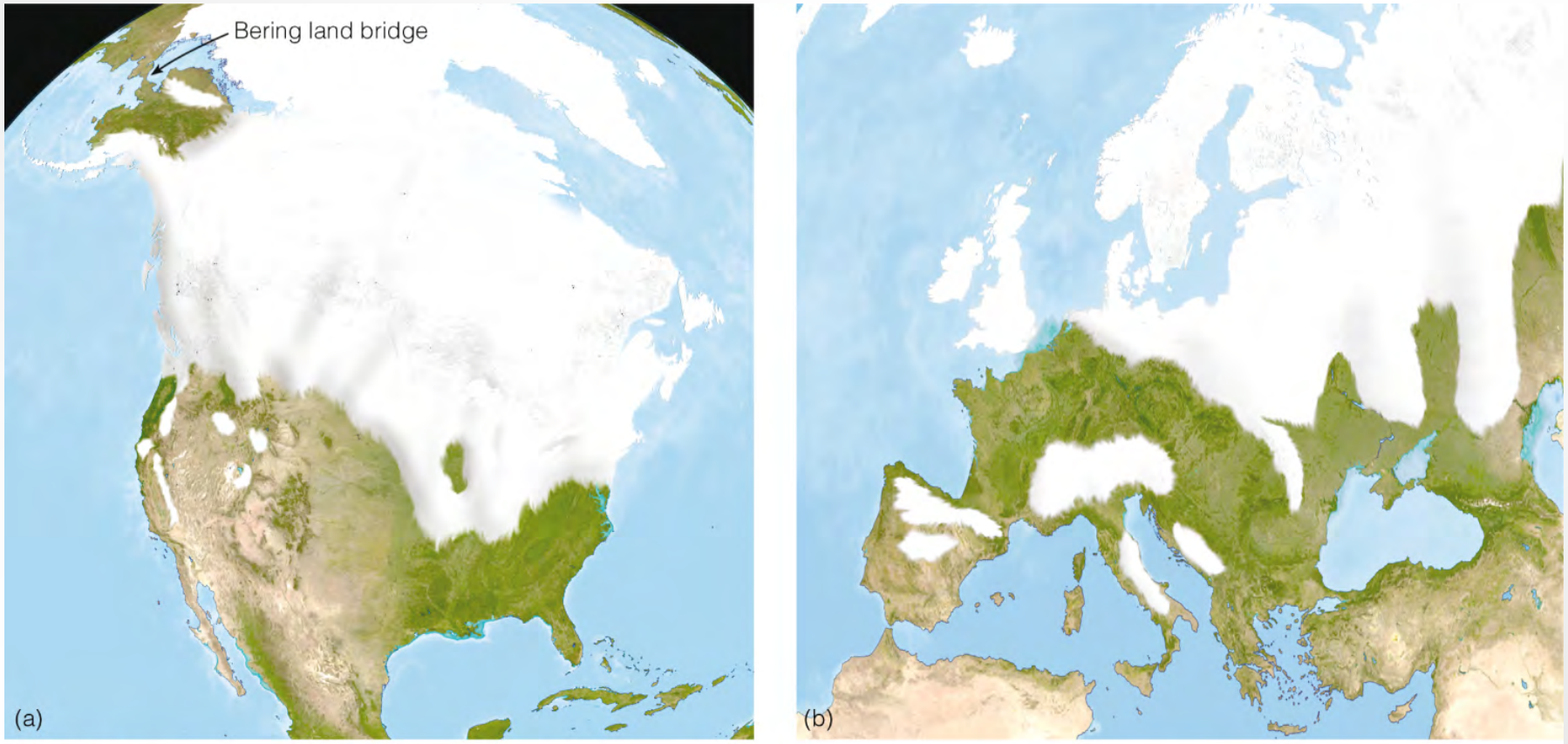
Climatic change

- Climate
  - Long-term description of weather patterns
  - “Expectations”
  - Mean, variability, extremes, frequency
- Climatic change
  - A change in these statistical values

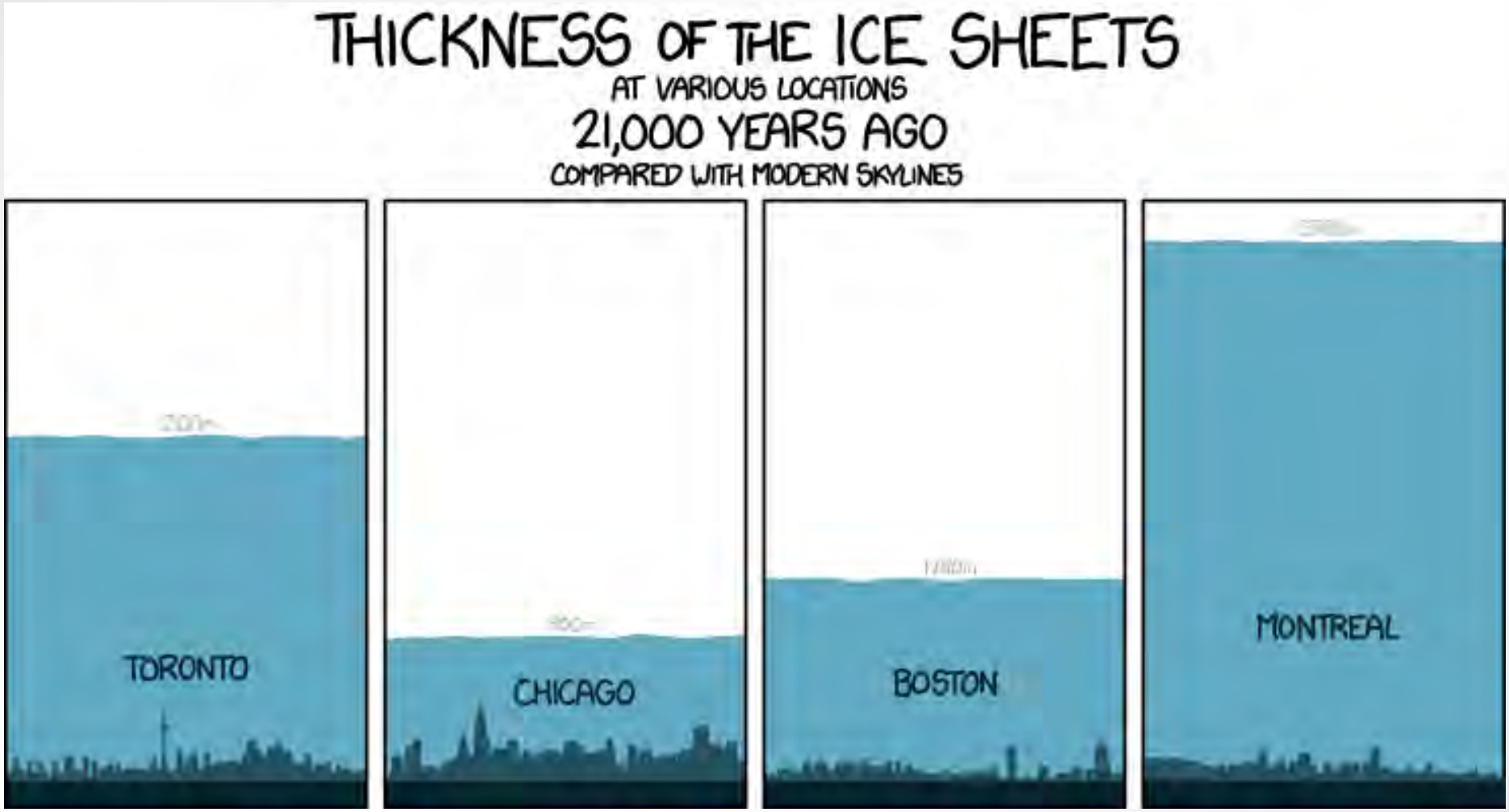
Climate and weather

- Weather changes happen all the time
  - These are regular features of a complex system
- Local climate changes can occur as a result of changes to local conditions
  - Albedo, landforms, water bodies
- Global climate changes require changes in the global energy balance

Glaciation: 18 000 years ago

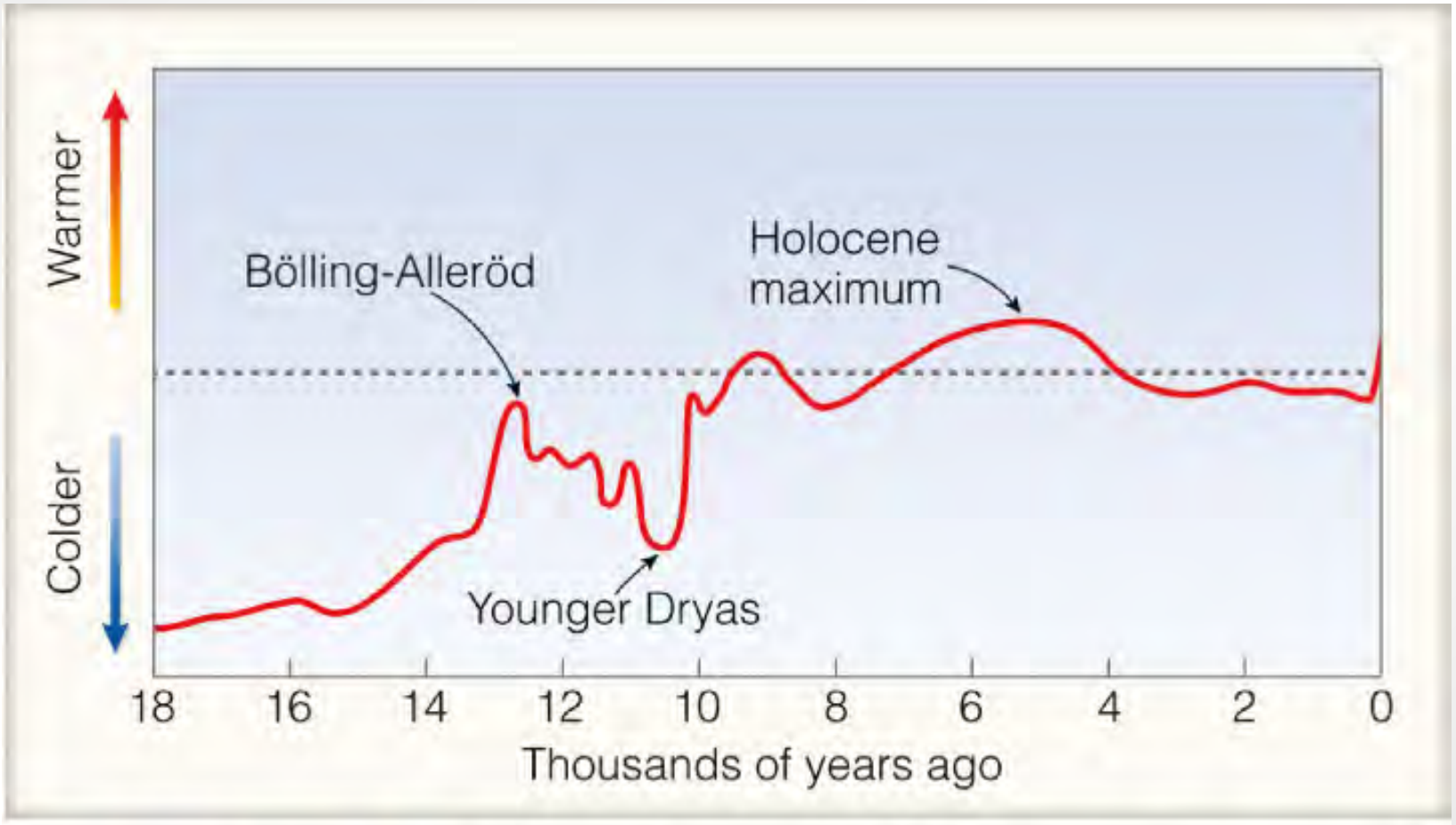


Ahren: Fig. 16.4


THICKNESS OF THE ICE SHEETS
AT VARIOUS LOCATIONS
21,000 YEARS AGO
COMPARED WITH MODERN SKYLINES
TORONTO
CHICAGO
BOSTON
MONTREAL

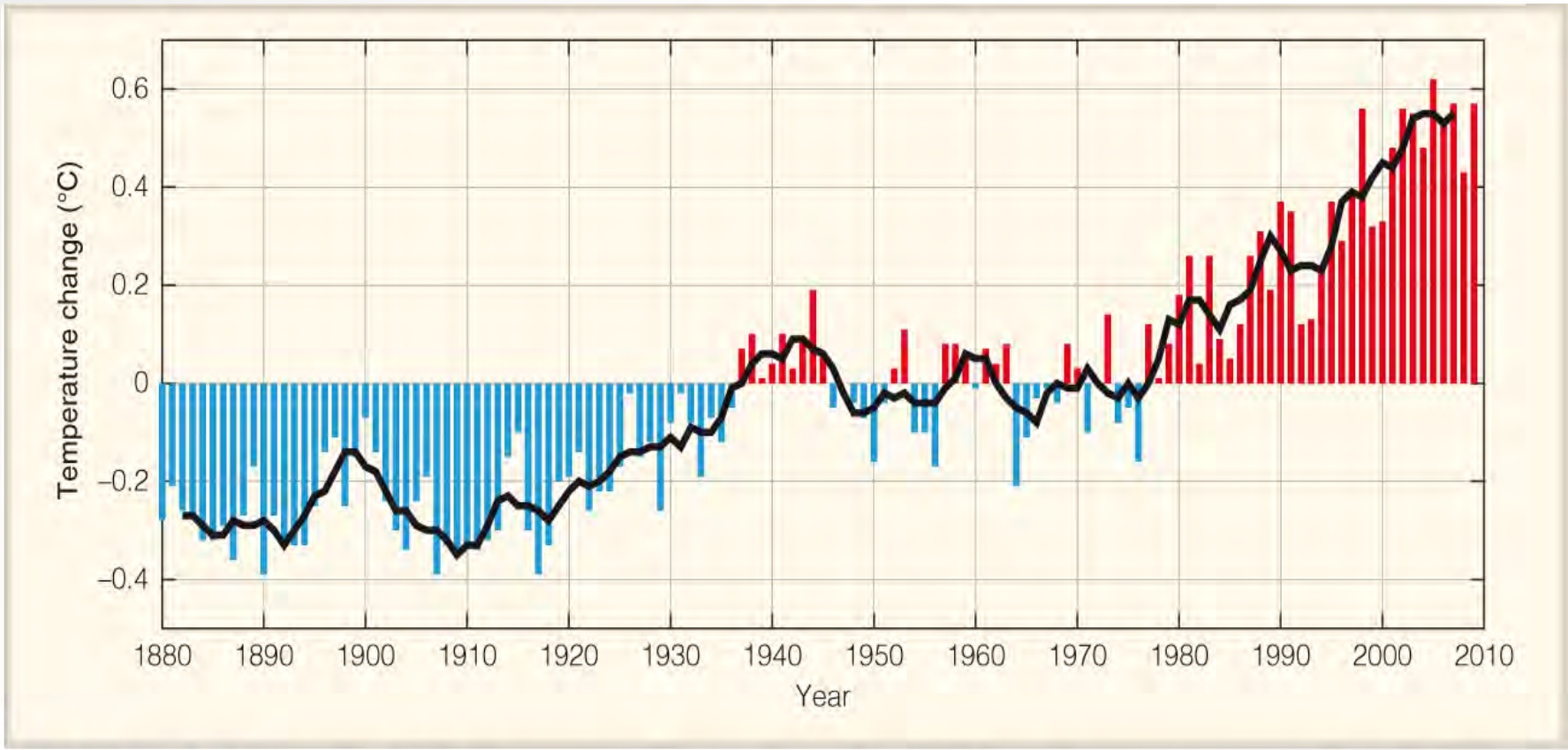
Comic: xkcd

Climate change history



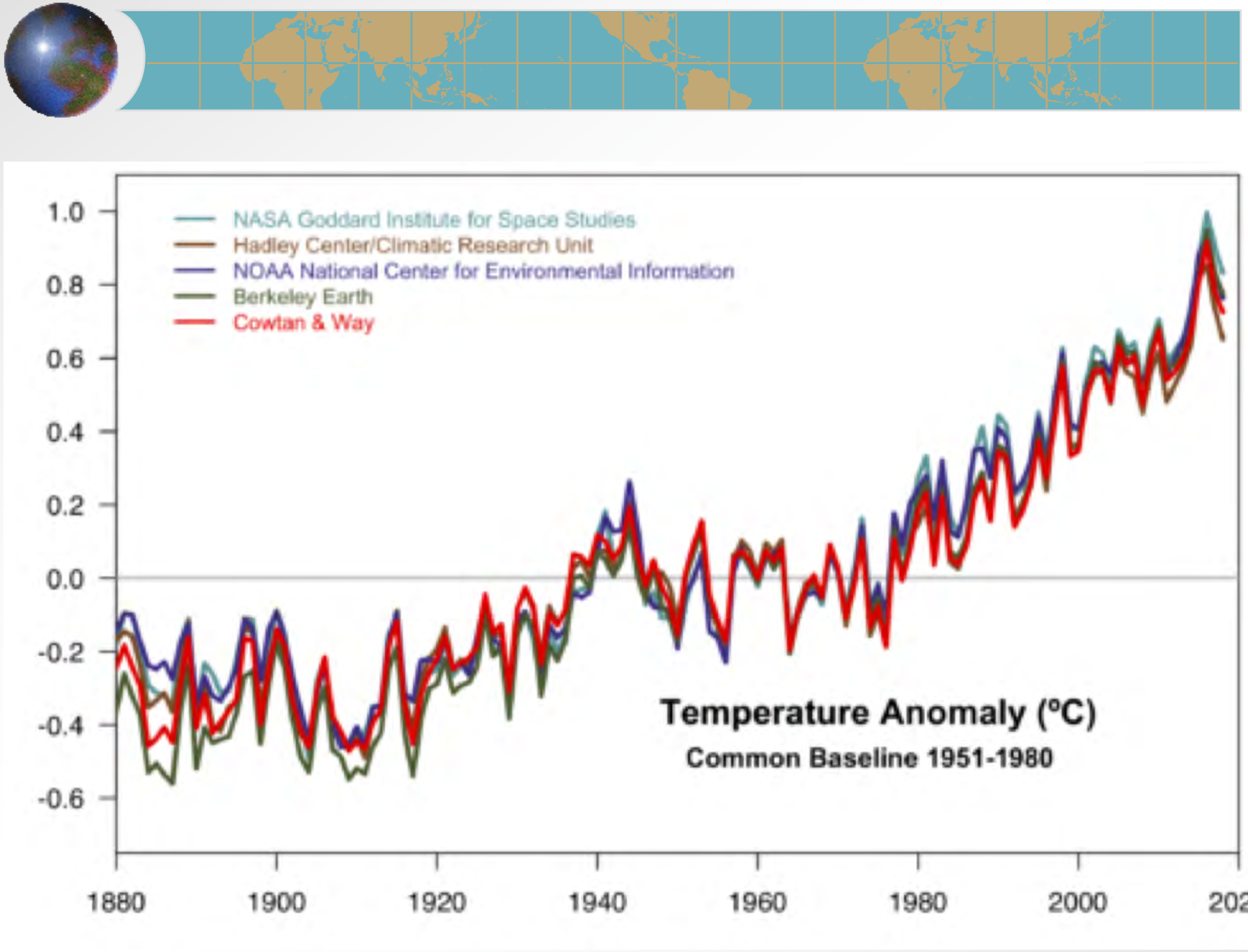
Ahrens: Fig. 16.5

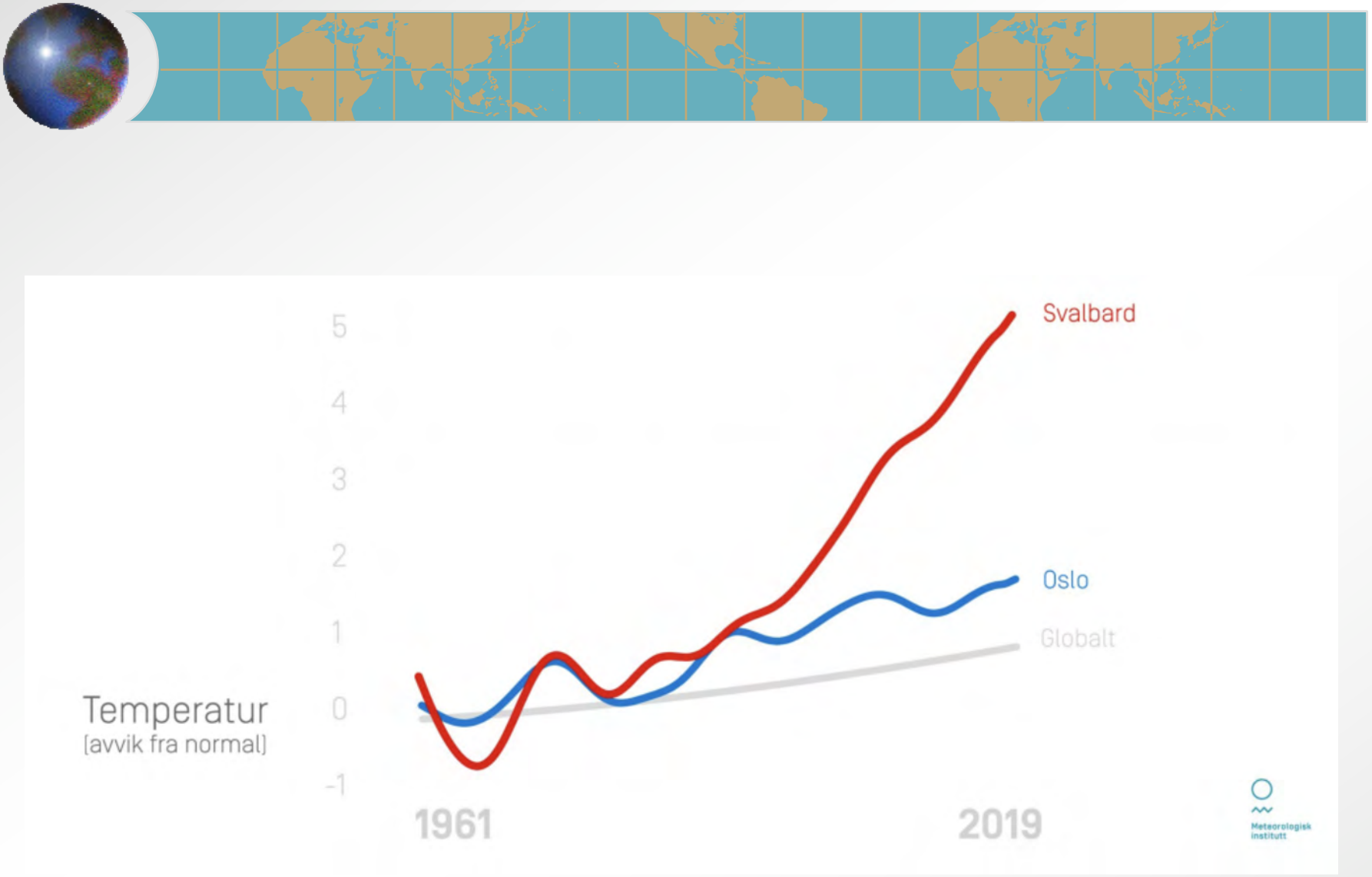
Recent global warming



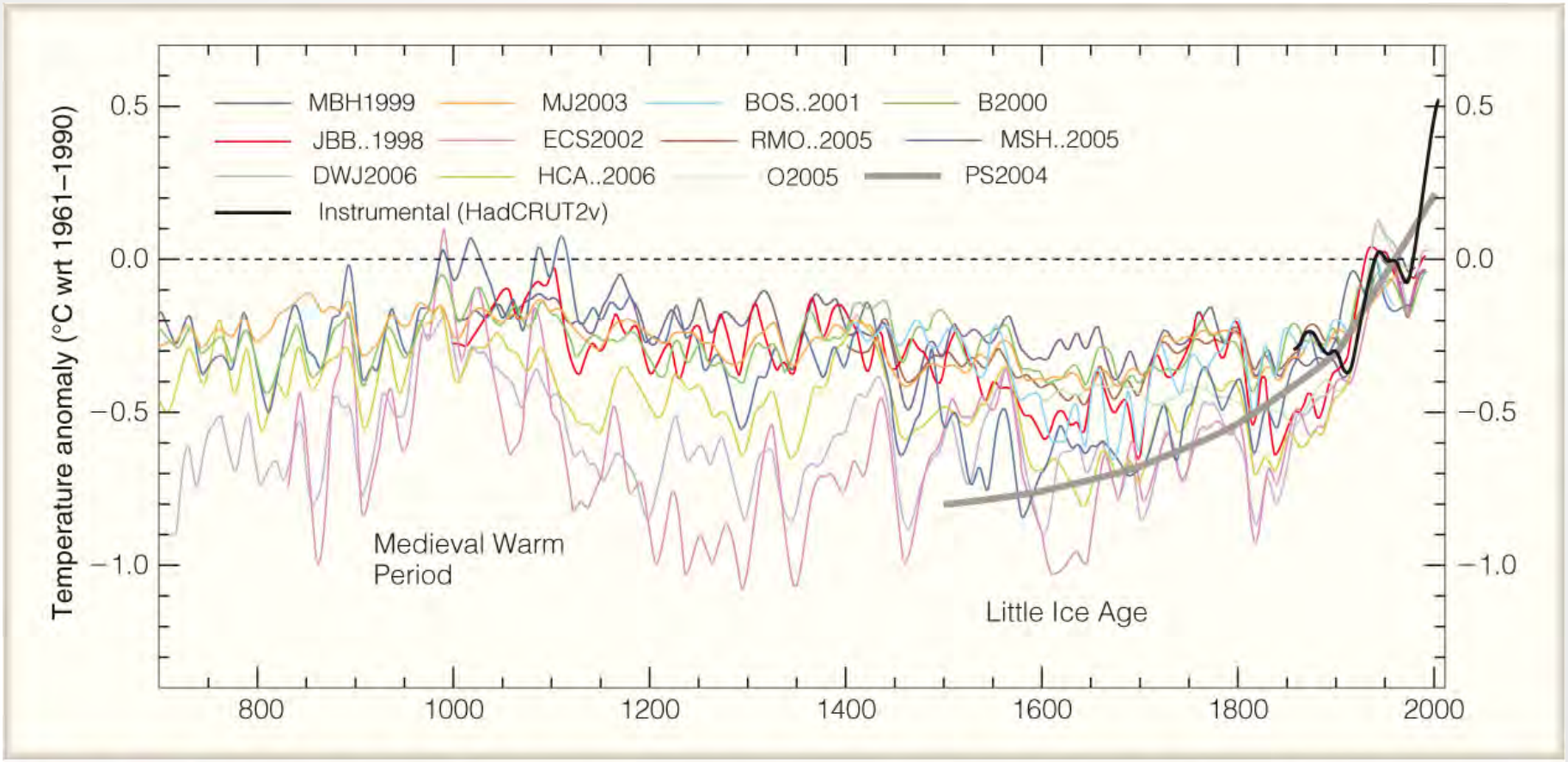
Zero line is 1951-1980

Ahrens: Fig. 17.6


NASA Goddard Institute for Space Studies
Hadley Center/Climatic Research Unit
NOAA National Center for Environmental Information
Berkeley Earth
Cowtan & Way
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
1880
1900
1920
1940
1960
1980
2000
2020
Temperature Anomaly (°C)
Common Baseline 1951-1980


Svalbard
Oslo
Globalt
5
4
3
2
1
0
-1
Temperatur
(avvik fra normal)
1961
2019
Meteorologisk institutt

Last 1300 years



Zero line is 1961-1990 average global temperature

Ahrens: Figure 17.5

Thermodynamics

- First Law of Thermodynamics
  - Energy cannot be created or destroyed
  - $E_{in} = E_{out} + \Delta E_{stored}$
  - At equilibrium, $\Delta E_{stored} = 0$ and $E_{in} = E_{out}$
- Note that T is a function of E_{stored}

Thermodynamics

- Stefan-Boltzmann Law
  - All matter emits radiation proportional to the fourth power of its temperature
  - E_{out} is proportional to T^4

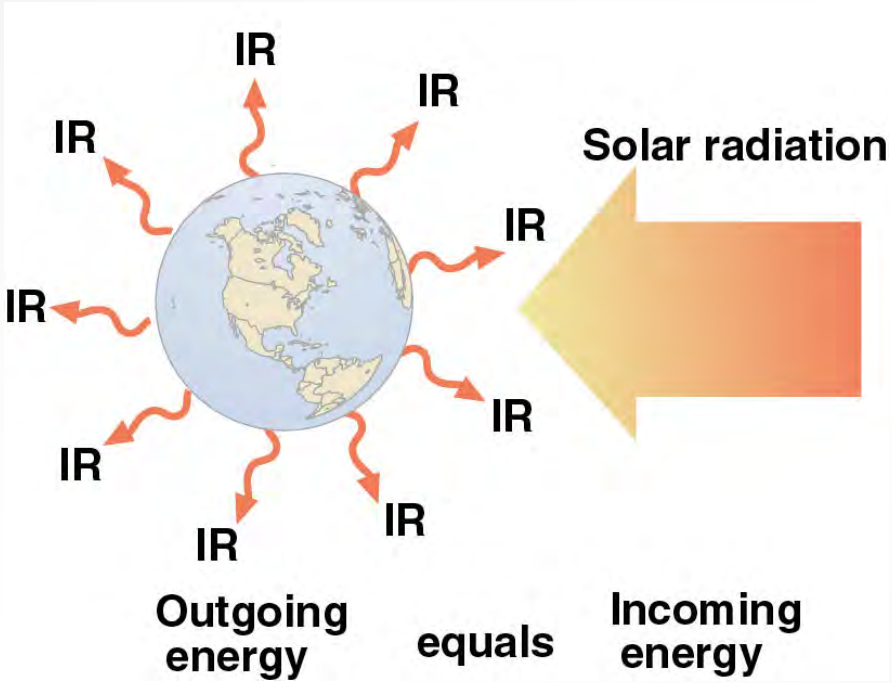
Thermodynamics

- For the Earth:
  - E_{in} is radiation coming from the sun
  - E_{out} is radiation emitted by Earth

Thermodynamics

- So:
  - At *equilibrium*, Earth's temperature must be such that $E_{out} = E_{in}$
  - If E_{out} is less than E_{in} there will be an increase in E_{stored}
  - This will cause T to increase until the fluxes are equal again

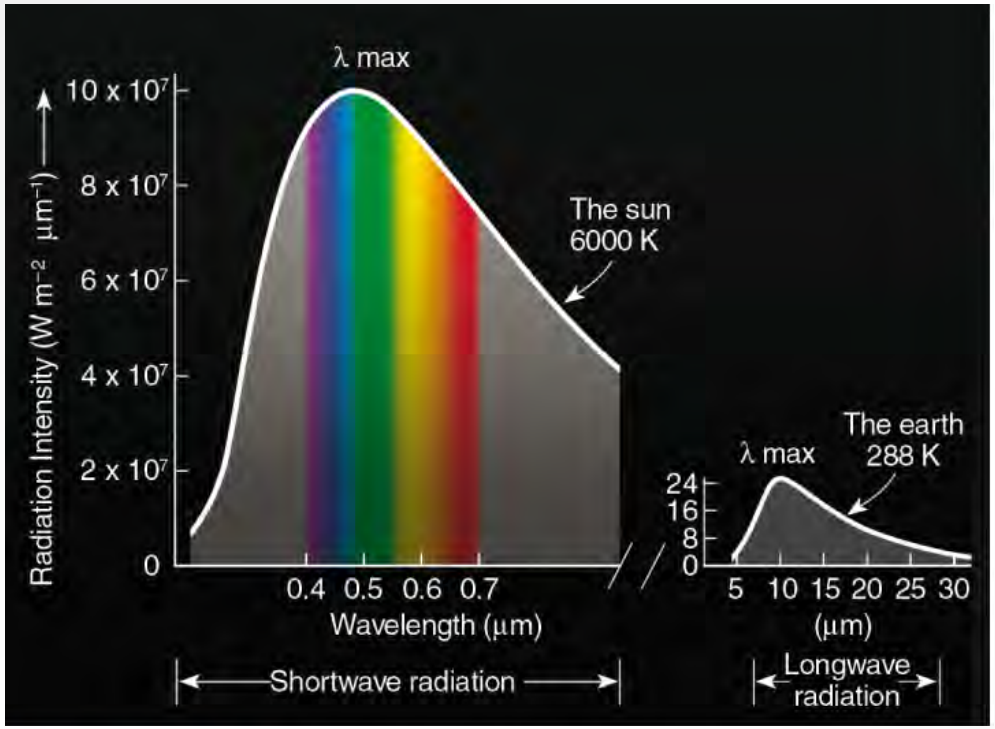
Earth's Energy Balance



- We calculated the effective radiative temperature of Earth:

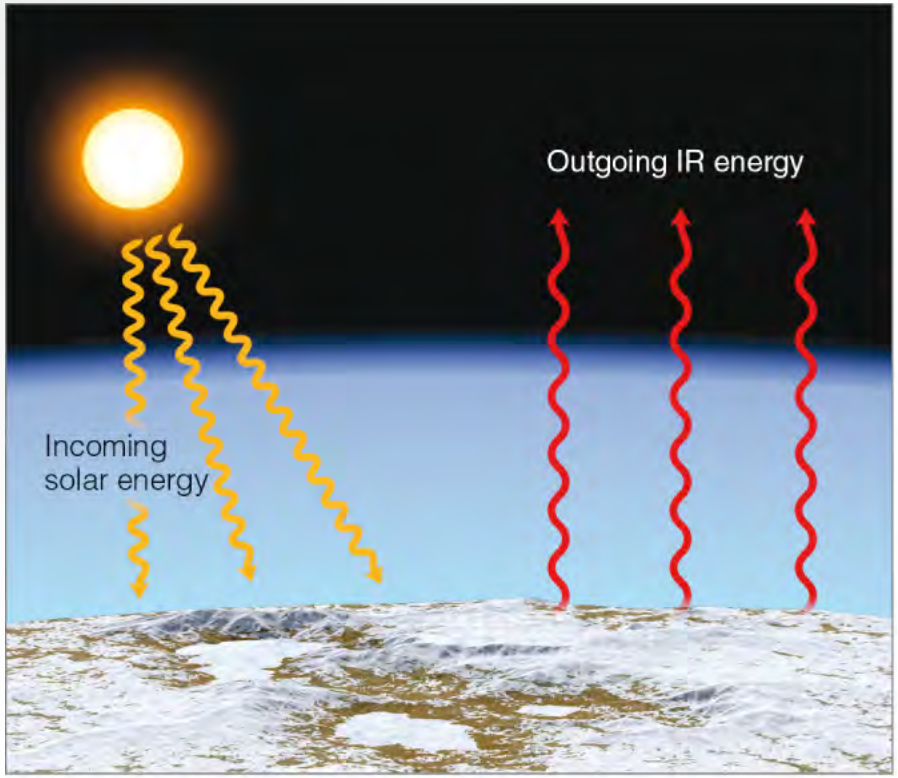
  255 K (-18°C)

Wien's Law

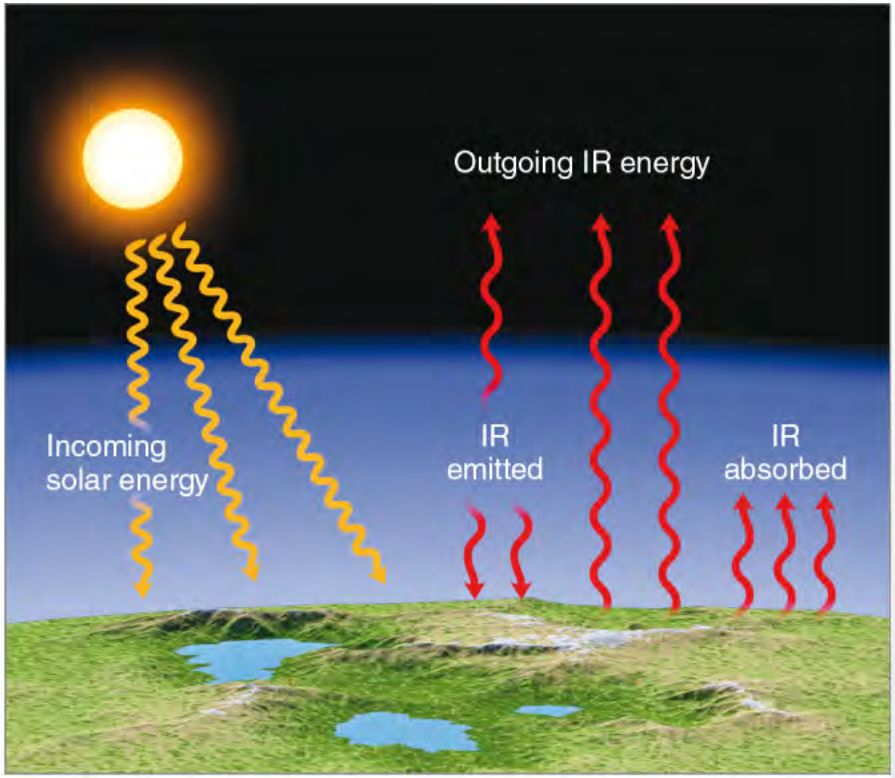


- Peak wavelength is inversely proportional to temperature
- The Sun radiates most of its radiation near the visible range
- The Earth radiates most of its radiation in the infrared range

The Greenhouse Effect



255 K



288 K

Ahrens, Fig. 2.12

What can change the global energy balance?

- Incoming energy
  - Solar strength
  - Aerosols (e.g. volcanoes)
- Outgoing energy
  - Greenhouse gases

Greenhouse effect

Natural

- H_2O
- CO_2
- CH_4
- N_2O
- O_3

Enhanced

- CO_2
- CH_4
- N_2O
- O_3
- Halocarbons (CFCs)
- SF_6
- Perfluorocarbons (PFCs)

Carbon Dioxide

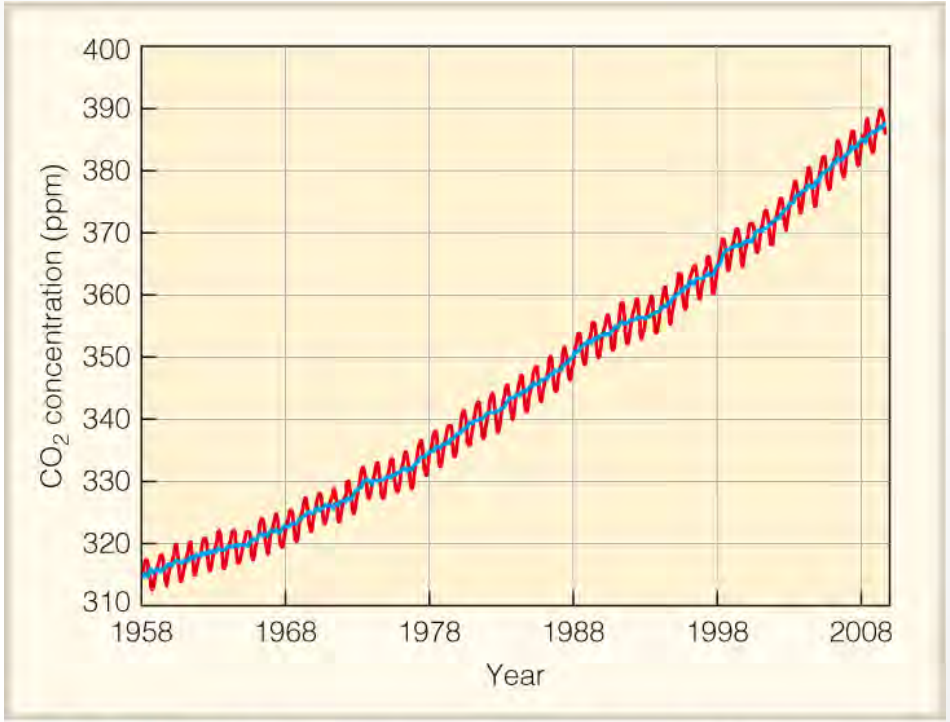
Preindustrial concentration was 280 ppmv

Current concentration is about 415 ppmv

Emissions:

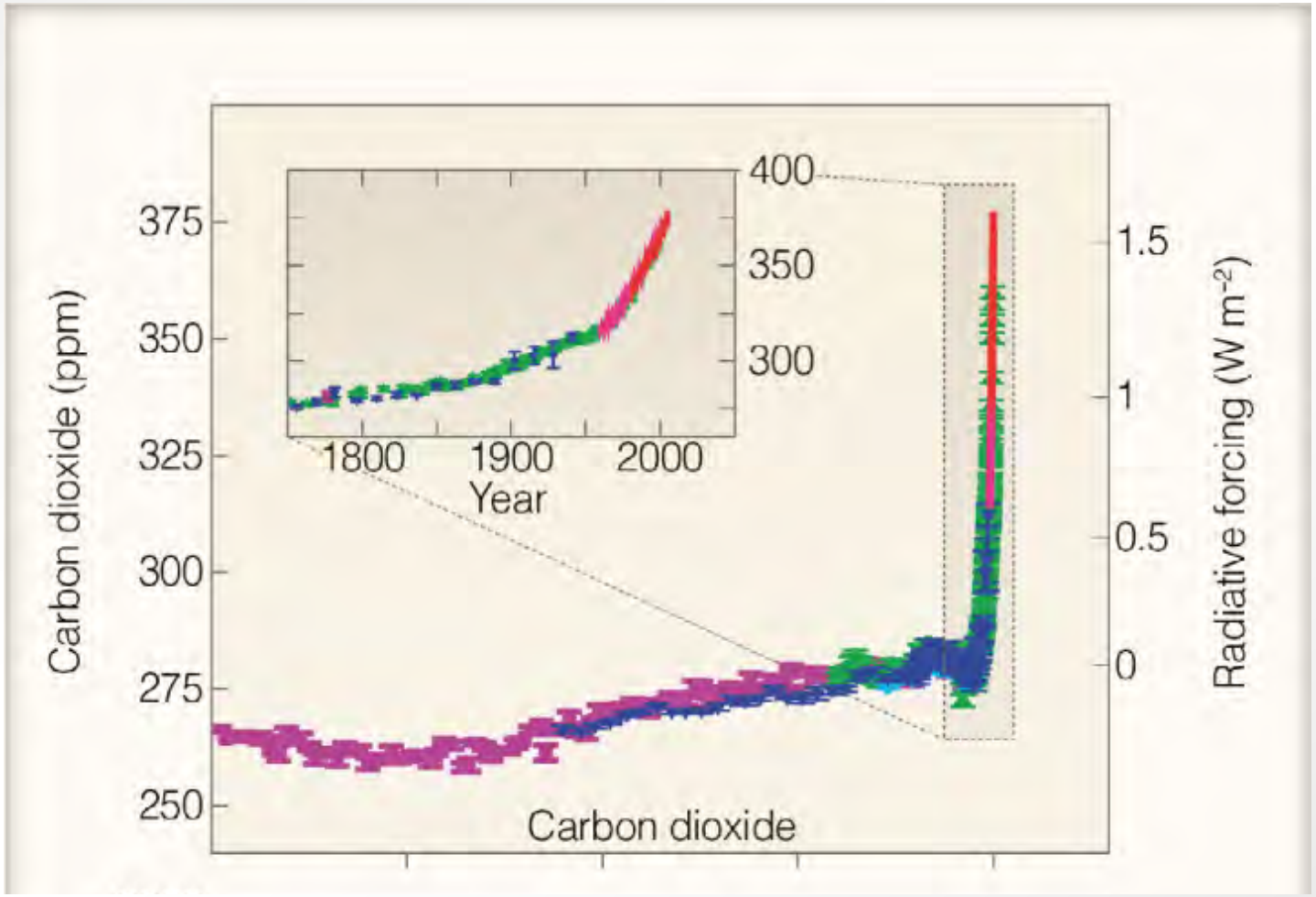
- Fossil fuels, 9 GtC/year
- Deforestation, 2 GtC/year

CO_2 doubling will occur around 2050 (560 ppmv)



Ahrens: Fig. 1.5

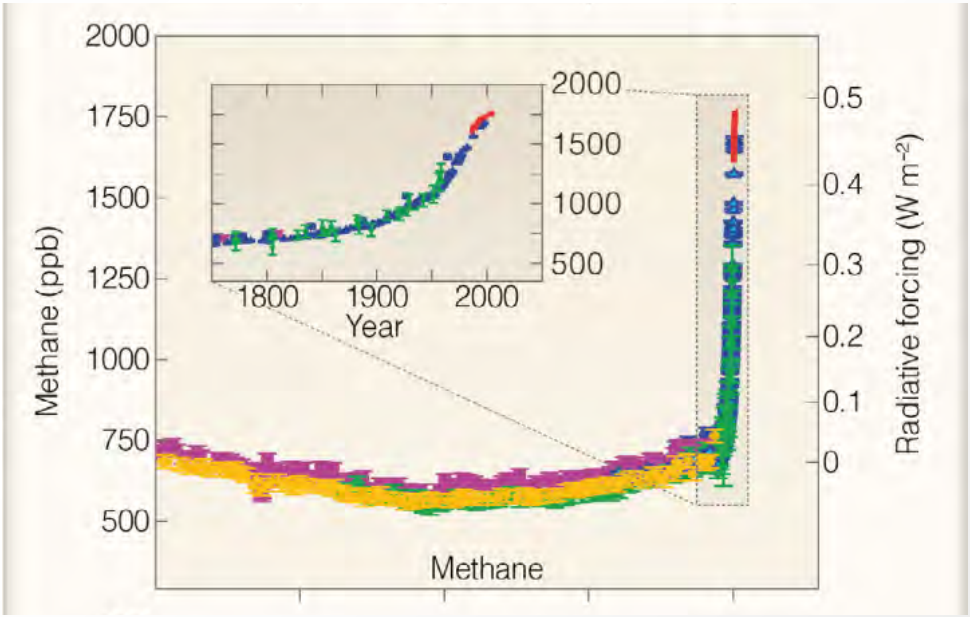
Historical Carbon Dioxide



10000 years from the present

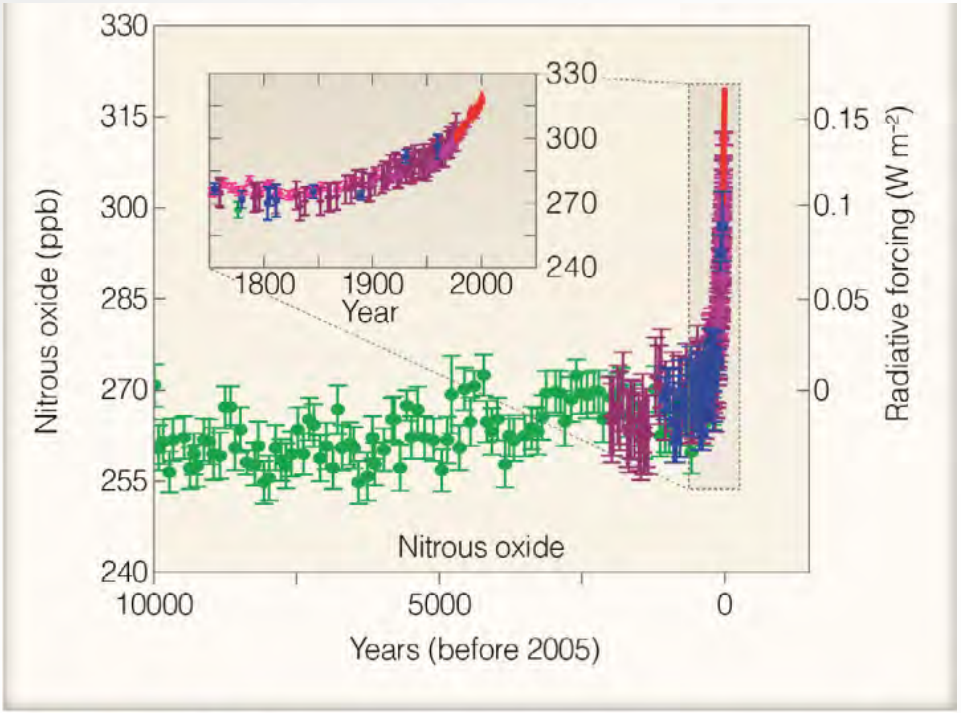
Methane: CH_4

Preindustrial	0.7 ppmv
Current	1.78 ppmv
Atmospheric Lifetime	8-12 years
Anthropogenic Emissions	Livestock (cattle) Natural Gas Leaks Oil and Coal Extraction Landfills Biomass Burning Sewage Treatment Rice Paddies
Strength vs. CO_2	26 times



10000 years before present

Nitrous Oxide: N_2O



Preindustrial	0.275 ppmv
Current	0.32 ppmv
Atmospheric Lifetime	120 years
Anthropogenic Emissions	Fertilizers Fossil Fuels Deforestation
Strength vs. CO_2	206 times

Ahrens: Fig. 16.27

Halocarbons: CFCs, HCFCs, HFCs

- Used in refrigeration and air conditioning
- Per molecule, often several thousand times as strong as CO_2

- Rapid increase in concentration since 1960s
- CFCs deplete stratospheric ozone; replaced by HCFCs and HFCs

Other anthropogenic gases

- Sulphur Hexafluoride (SF_6)
  - Electrical insulator for power distribution
  - Lifetime: 3 200 years
  - Strength: 36 000 times as strong as CO_2

- Perfluorocarbons (PFCs)
  - Solvents, refrigerants
  - Lifetime: thousands of years
  - Strength: thousands of times as strong as CO_2

Tropospheric ozone: O_3

- Doubled in the NH; in many cities it is up by 5-10 times preindustrial levels.
- Very short lifespan (hours)
- Ozone precursors:
  - NO and NO_2
  - Hydrocarbons
  - CO
- Main sources:
  - Burning biomass and fossil fuels

Stratospheric ozone: also O_3

- Decreasing trend due to CFCs, HCFCs, and others

- **Loss contributes to global *cooling* in the stratosphere**

Other contributors to global climatic change

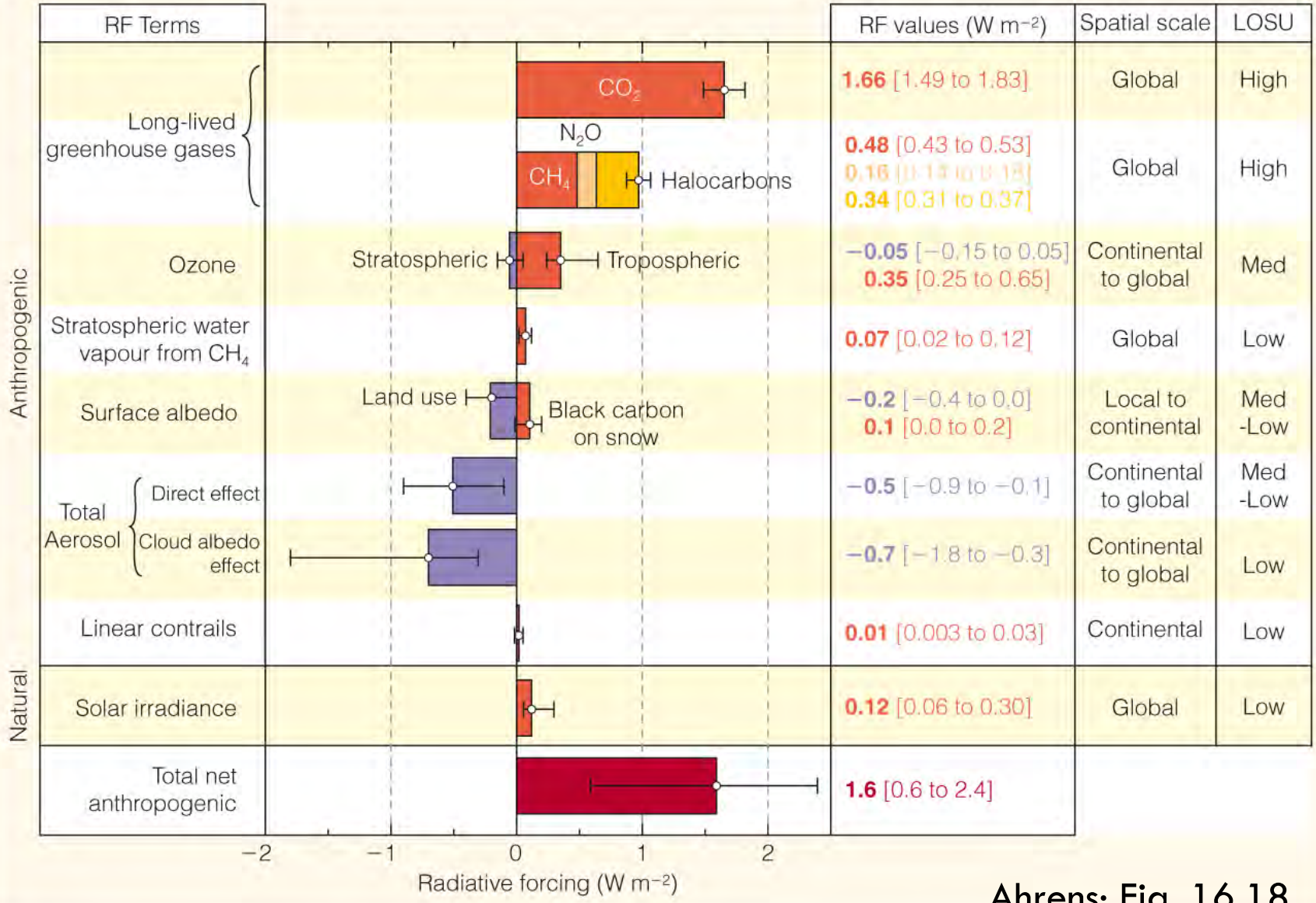
- Aerosols
  - Tiny particles suspended in the air
  - Reflect sunlight and increase cloud reflectivity

  - Tropospheric air pollution (SO_x, NO_x)
  - Volcanoes

Other contributors to global climatic change

- Land cover change
  - Urban heat islands
  - Deforestation increases surface albedo
- Solar variation
  - Observed changes have been small
  - Long-term cycles not well-understood

Radiative Forcing



Ahrens: Fig. 16.18

Feedback

- A response to an change that acts to amplify or diminish the initial change
- E.g. sound system amplifier, thermostat

- A climate feedback responds to a change in climate by causing *less or further change*
  - Positive feedback: more change
  - Negative feedback: less change

Who knew what when?

EXXON RESEARCH AND ENGINEERING COMPANY

P.O. BOX 101, FLORHAM PARK, NEW JERSEY 07932

M. B. GLASER
Manager
Environmental Affairs Programs

Cable: ENGREXXON, N.Y.

November 12, 1982

CO_2 "Greenhouse" Effect

82EAP 266

TO: See Distribution List Attached

Attached for your information and guidance is briefing material on the CO_2 "Greenhouse" Effect which is receiving increased attention in both the scientific and popular press as an emerging environmental issue. A brief summary is provided along with a more detailed technical review prepared by CPPD.

The material has been given wide circulation to Exxon management and is intended to familiarize Exxon personnel with the subject. It may be used as a basis for discussing the issue with outsiders as may be appropriate. However, it should be restricted to Exxon personnel and not distributed externally.

Very truly yours,

M. B. Glaser

Exxon

In 1982, CO2 concentration was approx. 340 ppm. Exxon predicted “2020 CO2 to approach 420ppm”.
419 ppm likely next spring ✓
Temperature increase from 1982 to 2020 predicted 0.85 C. Likely 0.8 C over 1982 level next year ✓

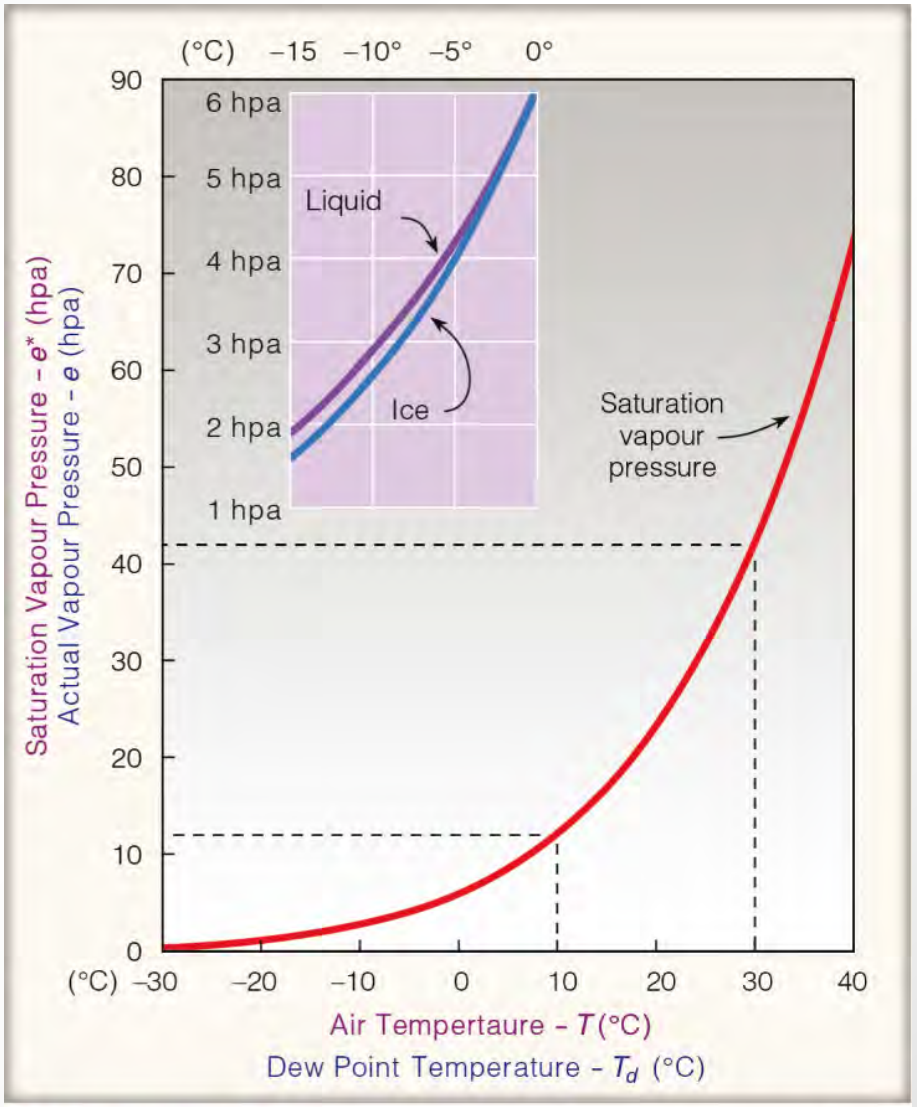
Exxon had a good climate model running then.

Document 39 pages – predictions with text, tables, figures.
References include many scientists including
Arrhenlus, S. 1896. On the influence of carbonlc acld in the alr upon the temperature of the ground. PbiLos. Hag. 41'.237-76.

Water vapour

- Saturation vapour pressure depends on temperature
- Higher temperatures lead directly to increased water vapour

- Water vapour is a greenhouse gas
- Positive feedback



Ice and snow

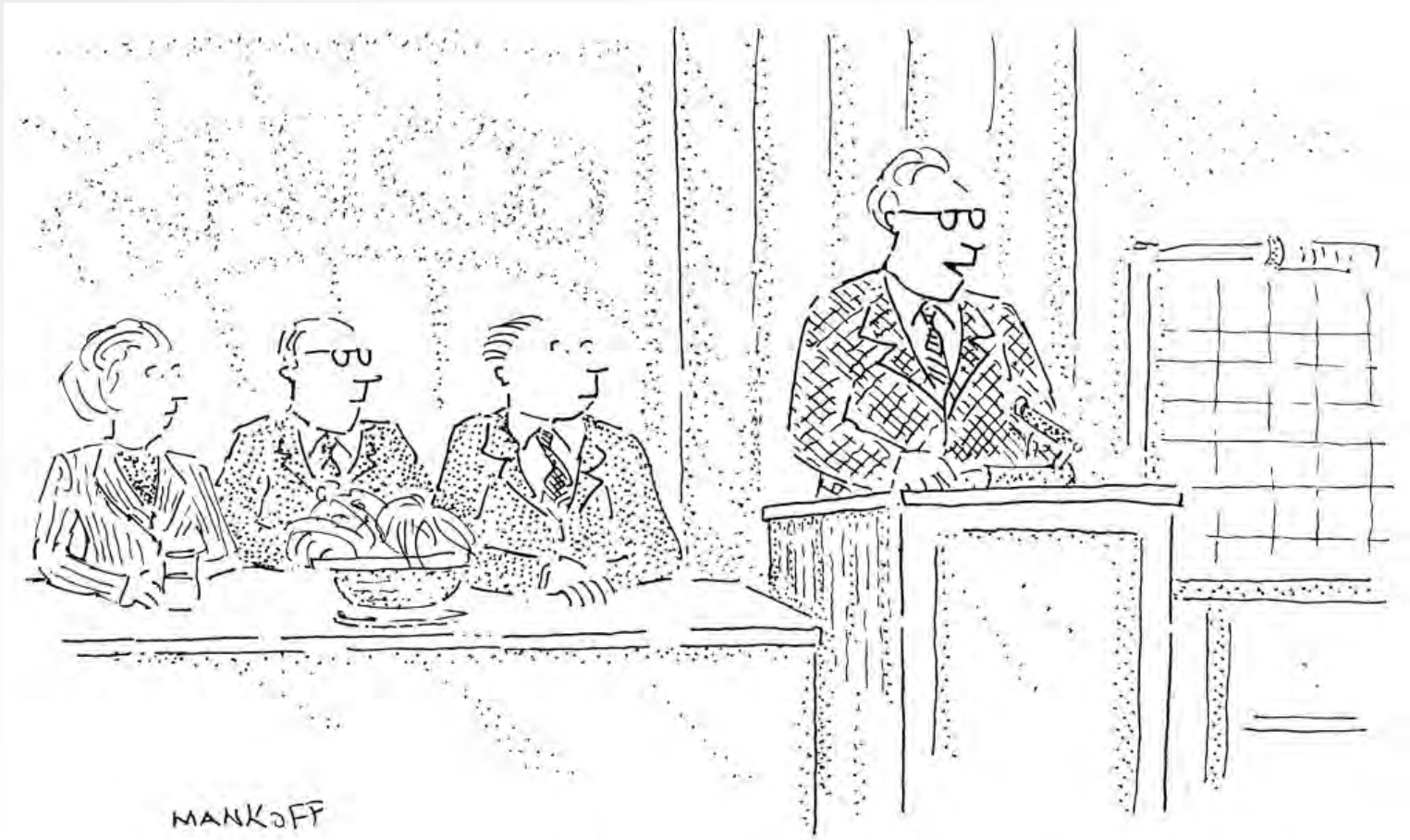
- Ice and snow are very reflective
- Sensitive to changes in temperature
- Also a positive feedback

Ahrens: Fig. 2.13

Clouds

- Reflect shortwave (solar) radiation
  - Cover 50% of surface, albedo of 50%
- Absorb longwave (terrestrial) radiation
- Emit radiation to space and back down to the surface

- Changes in the extent of clouds affects all three



"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."

Next lecture

- What changes in climate have happened in recent decades
- What are coming by 2030, 2050, 2100?
- Adaptation?

- Notes on final exam