THE DRIVERS OF CLIMATE CHANGE

GEOG/ENST 3331 – Lecture 20

Ahrens: Chapter 16; A&B: Chapter 16; Turco: Chapter 11

Assignment 8

There are two main methods of pricing carbon,

- Carbon Tax

- Cap-and-Trade

Briefly discuss the merits (2) and problems with each (2).

Your opinion?

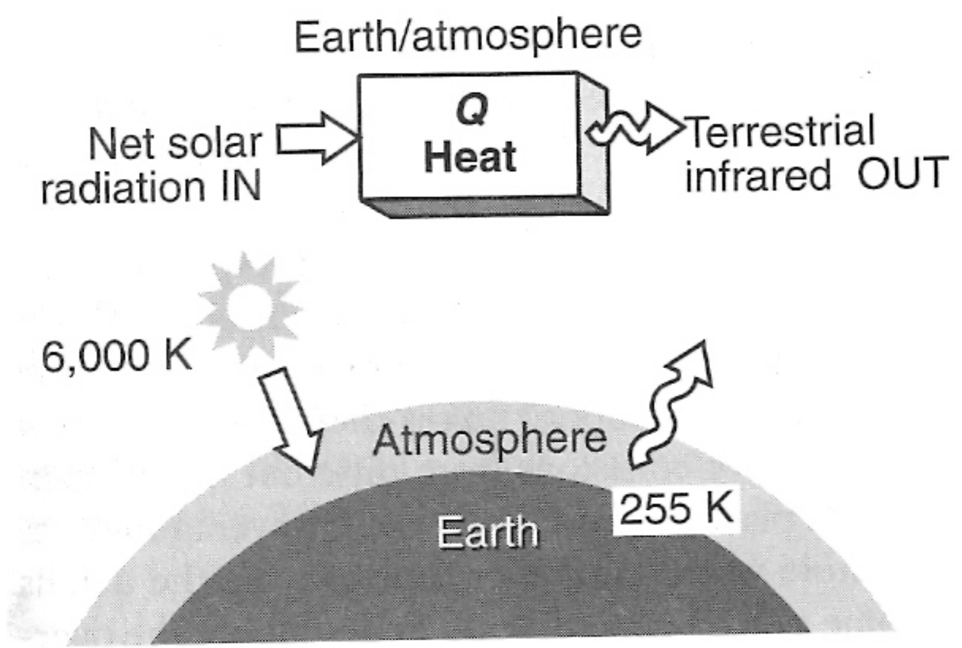
Due on March 30

Driving Factors of Global Climate

- **Radiation budget review**
- Drivers of change
- Feedbacks to change
- "The climate machine"

Box model for energy

- For steady state, energy in must equal energy out
- Amount of heat in the system directly affects sink
  - E_{out} is related to Q
- $E_{in} = E_{out} + \Delta Q$
  - At equilibrium, $\Delta Q = 0$



Turco: Figure 11.8

Stefan-Boltzmann Law

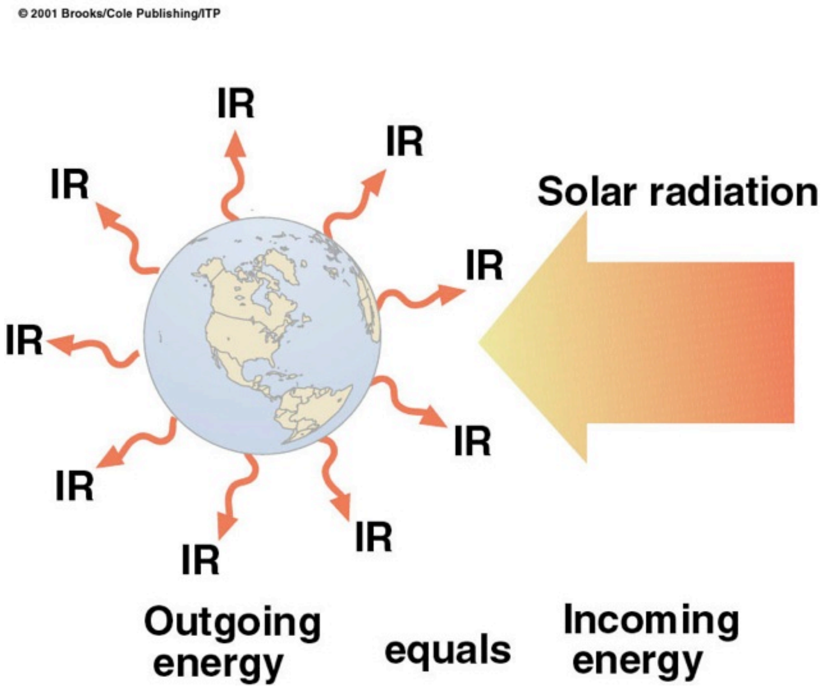
- All matter emits radiation
- Intensity of radiation in W/m^2 is proportional to T^4

$$I = \varepsilon\sigma T^4$$

- $\sigma = 5.67 \times 10^{-8}$ W/m^{2}K^4
- **ε** is the *emissivity* of the object, ranging from 0 to 1.

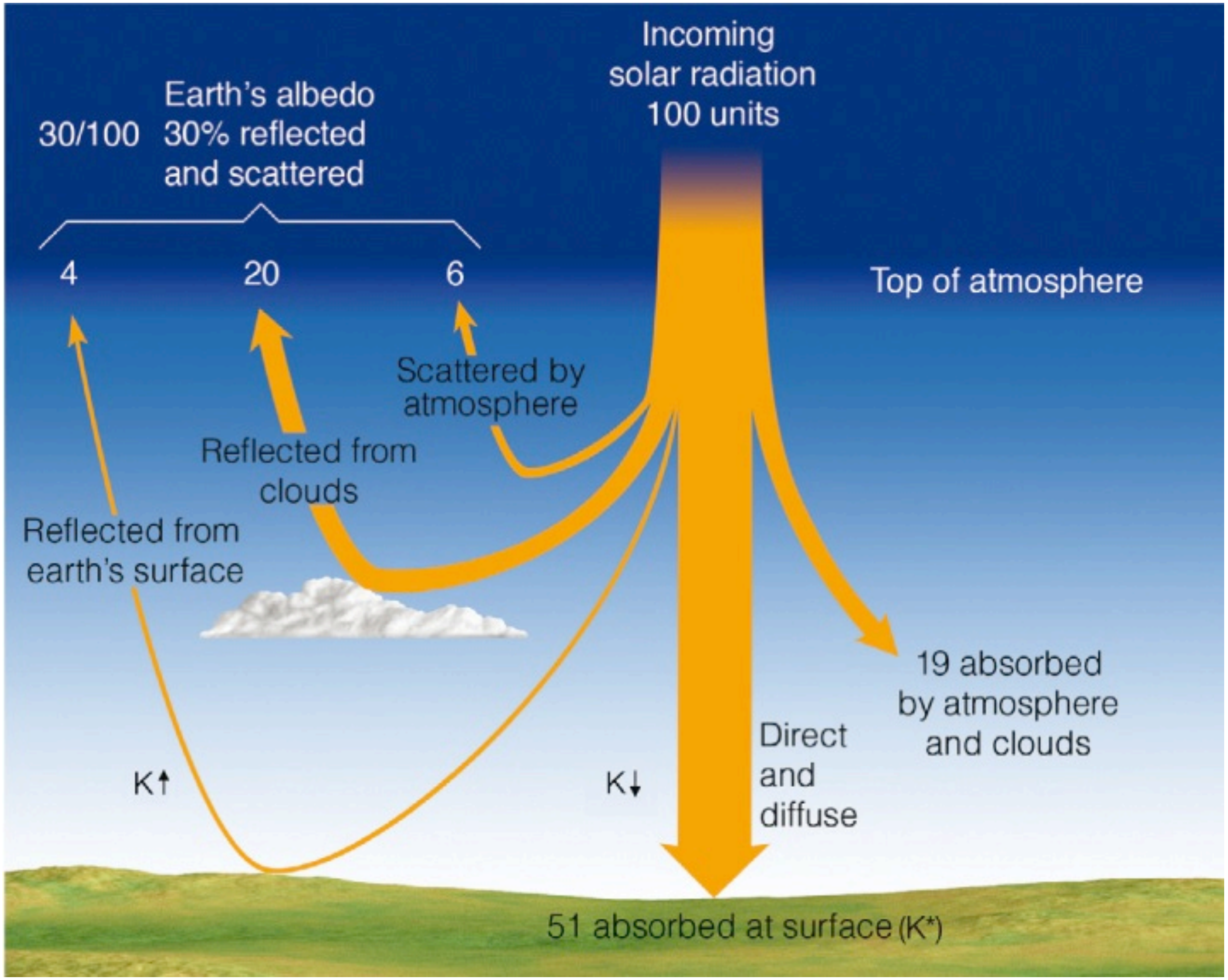
Solar constant

- Energy received by the Earth from the sun: 1367 Wm^{-2}
  - 30% reflected, rest is absorbed
- Roughly 1000 Wm^{-2} is absorbed
  - Over the sunlit area
- To balance this, roughly 250 Wm^{-2} must be emitted
  - Over the entire area
- Leads to T = 255 K

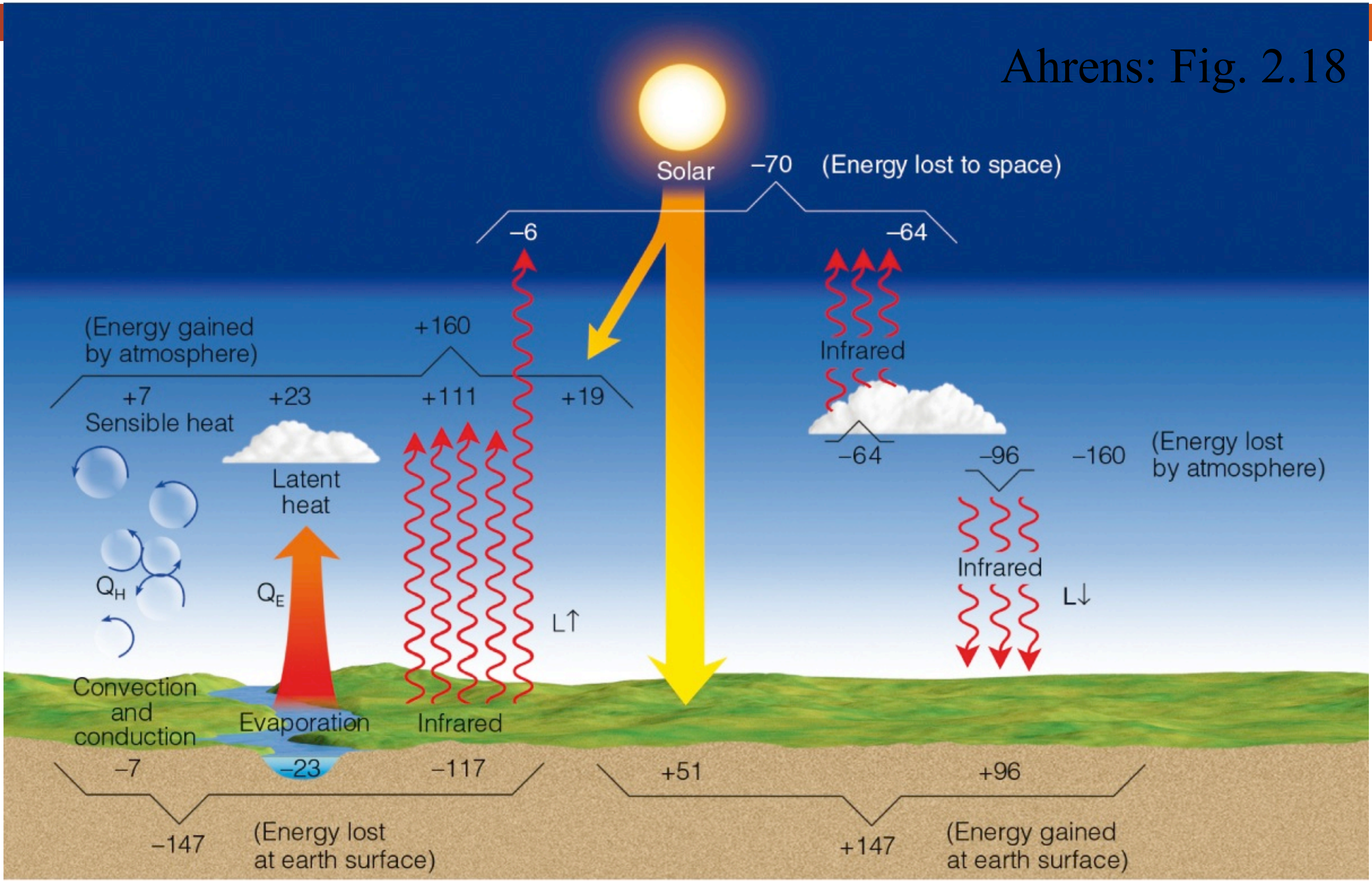


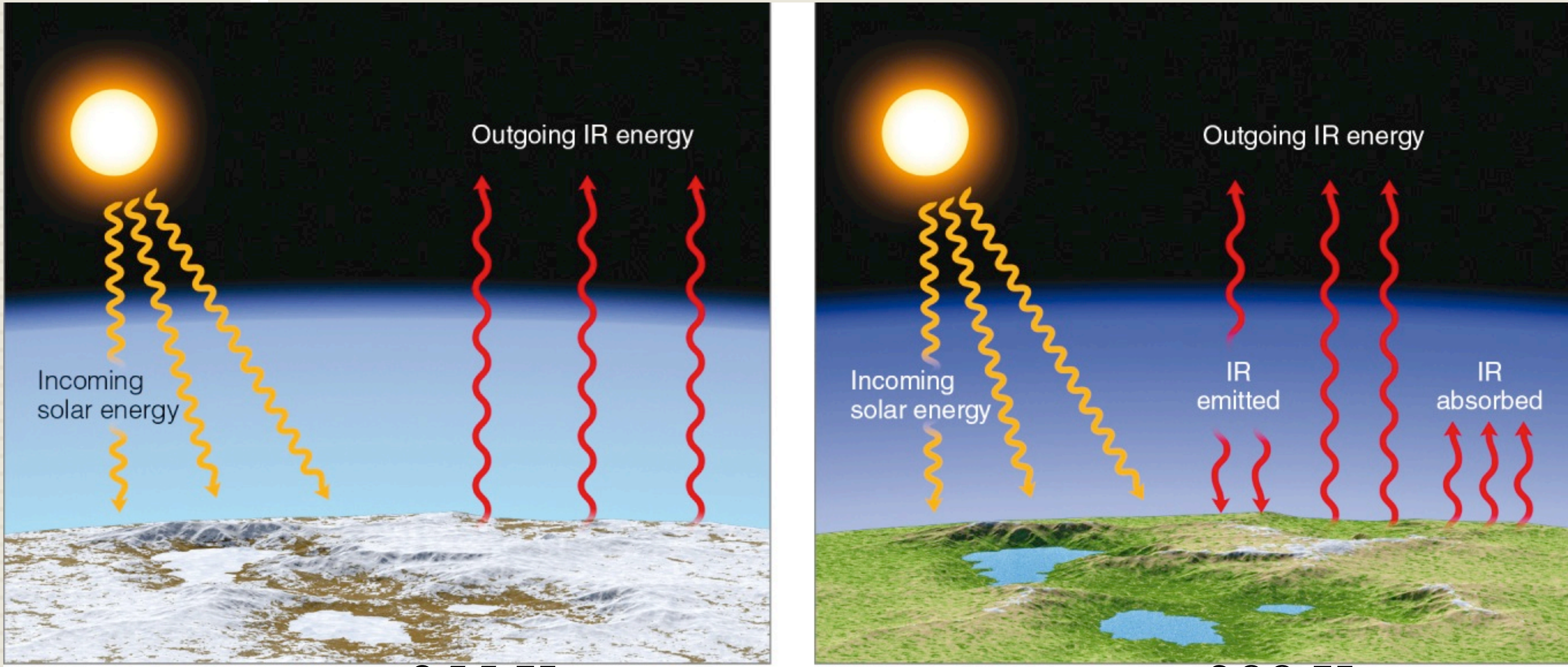
Incoming radiative balance

Ahrens: Fig. 2.17



Outgoing radiative balance





(a) Without greenhouse gases 255 K

(b) With greenhouse gases 288 K

The Greenhouse Effect

Ahrens, Fig. 2.12

Lecture outline

- Radiation budget review
- **Driving factors**
  - **Solar forcing**
  - **Albedo**
  - **Greenhouse gases**
- Feedbacks
- "The climate machine"

Solar constant

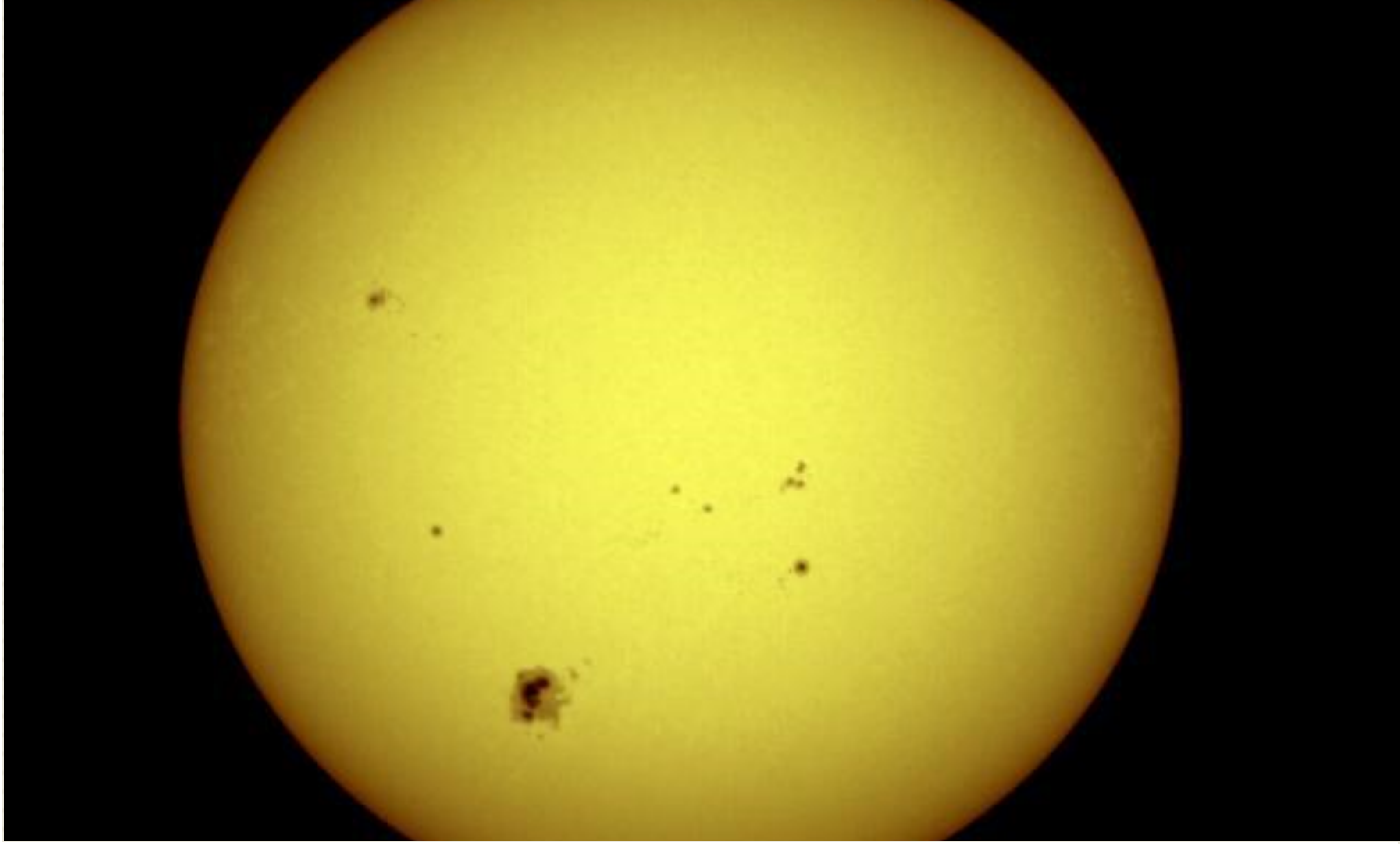
- Energy received by the Earth from the Sun
  - Determines E_{in}
- 1367 Wm-2
  - 30% is reflected (albedo)
  - Rest is absorbed either by the atmosphere or the surface
  - Must be matched by outgoing energy

- Solar strength has increased on geologic time scales

Solar flares

- Explosions in the sun's atmosphere
- Large amounts of radiation over all wavelengths
  - Radio waves may disrupt communications
  - X-rays and UV rays enhance auroras
  - Directly hazardous to astronauts

- More frequent during sunspot cycle peaks



Sunspots

Image: NASA

Magnetic structures inhibiting local convection in the solar atmosphere

Not really 'constant'

- Sunspots: ±0.1% to E_{in}
- Long term cycles and changes

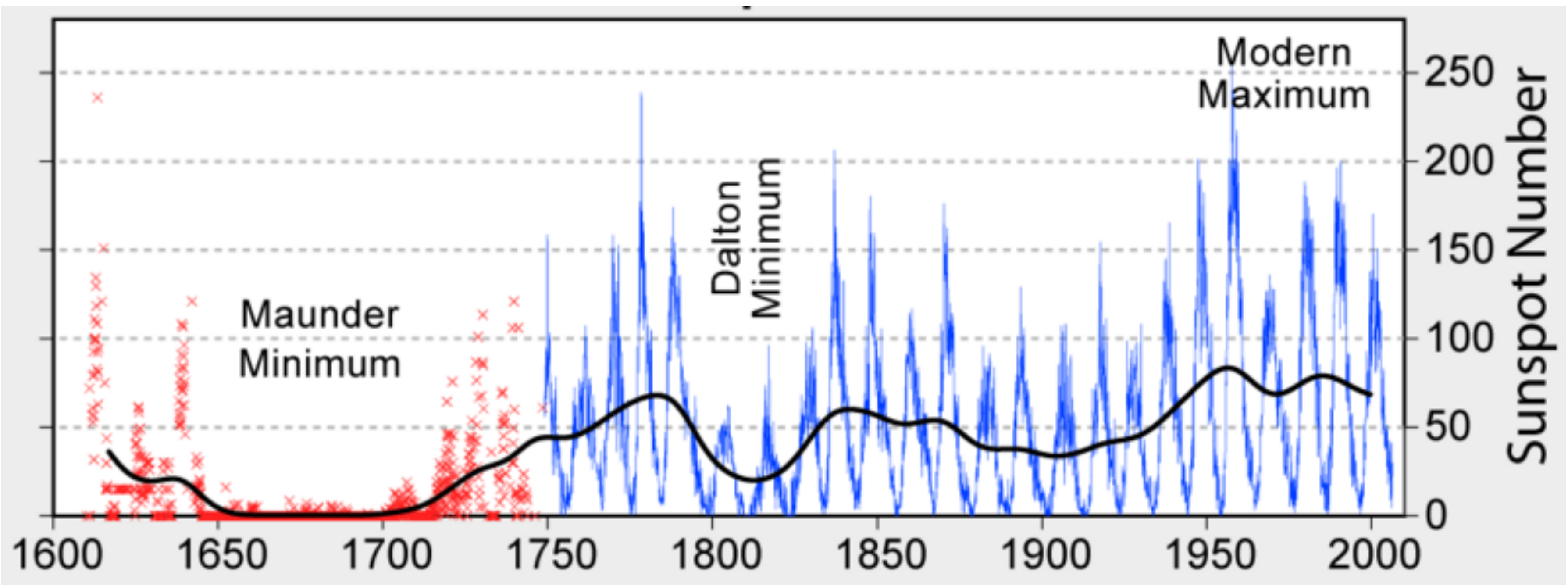


Image: 400 Years of Sunspot Observations, Global Warming Art Project

Solar cycles

- Maunder minimum roughly coincides with the "Little Ice Age"
  - Colder temperatures in Europe; possibly global
- Only 40 years of direct observations of solar strength
  - Magnitude of long-term cycles is unknown
  - Very long-term cycles may also exist
  - Constrained; not large on time scale of decades

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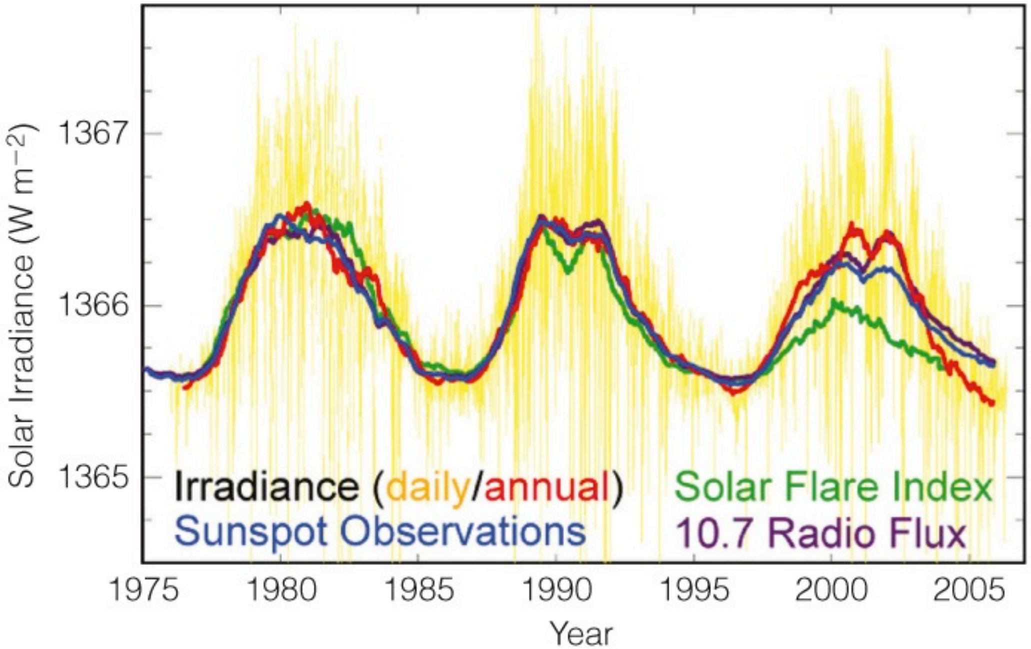


Ahrens: Fig. 16.16

Albedo

- Reduces E_{in}
- Reflection of radiation back into space
  - Earth's albedo is 30%
  - Majority by clouds and backscatter from the atmosphere

Aerosols

- Tiny particles suspended in the atmosphere
- Many are reflective (increase albedo)
  - SO_x and NO_x
- Also act as cloud condensation nuclei
  - Encourage cloud formation
  - Enhance cloud reflectivity
- Some aerosols absorb sunlight (reduce albedo)
  - Black carbon (soot)

Volcanoes

Volcanic eruptions may inject sulfate aerosols into the stratosphere

Remain for a year or more

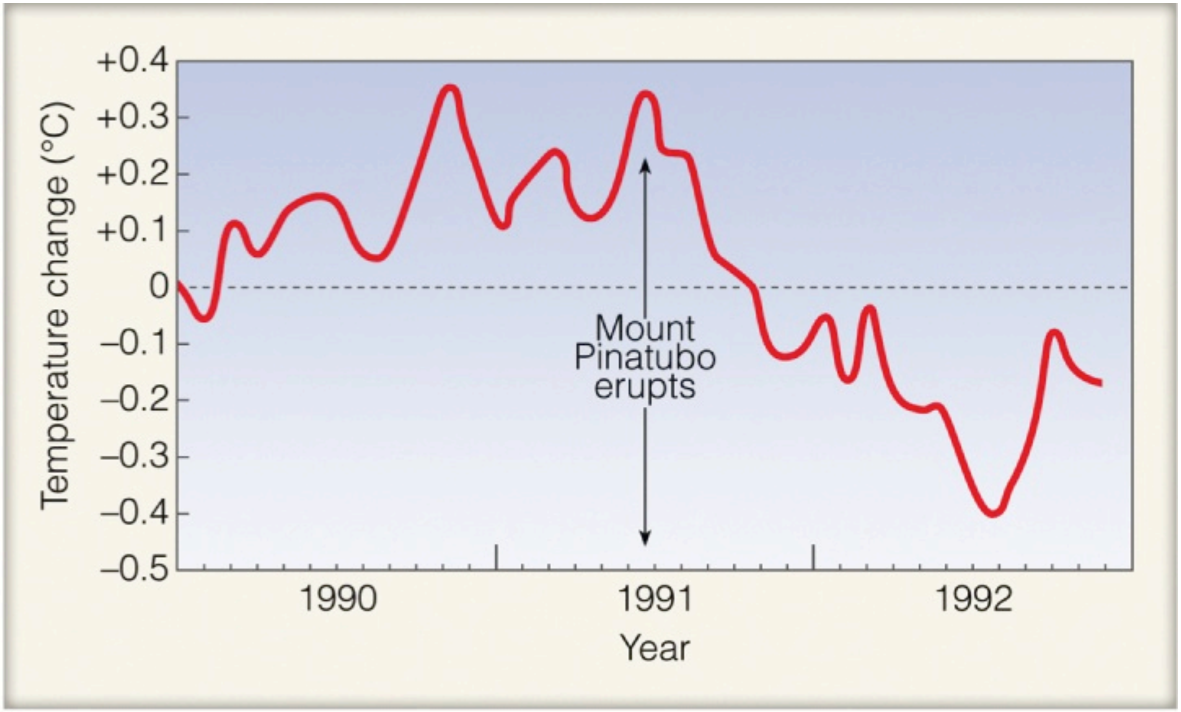
Mt Pinatubo, June 15, 1991: 18 MtSO_2

Ahrens: Fig. 16.13

USGS

Volcanoes

- But this is short term
  - Aerosols reach troposphere eventually
  - Temperature recovers



Ahrens: Fig. 16.15

Air pollution

- NO_x emissions
  - Lightning: 5 MtN/year
  - Fossil fuels: 22 MtN/year
  - Agriculture: 28 MtN/year
- SO_x emissions
  - Volcanoes: 20 MtS/year
  - Oceans: 30 MtS/year
  - Anthropogenic: 90 MtS/year

Air pollution

- Aerosol residence times are very short
- Concentration closely tied to source
  - Constant emission → constant loading
  - Trend?

Land surface cover

- Urban heat islands
- Deforestation
  - Agriculture
- Desertification

- Net effect is real but small cooling

Table 2.3 Typical Albedo of Various Surfaces

SURFACE	ALBEDO (PERCENT)
Fresh snow	75 to 95
Ice	30 to 40
Sand	15 to 45
Grassy field	10 to 30
Dry, ploughed field	5 to 20
Water	10*
Forest	3 to 10
Clouds (thick)	60 to 90
Clouds (thin)	30 to 50
Earth and atmosphere	30
Moon	7
Venus	78
Mars	17

*Daily average.

Ahrens: Table 2.3

The greenhouse effect

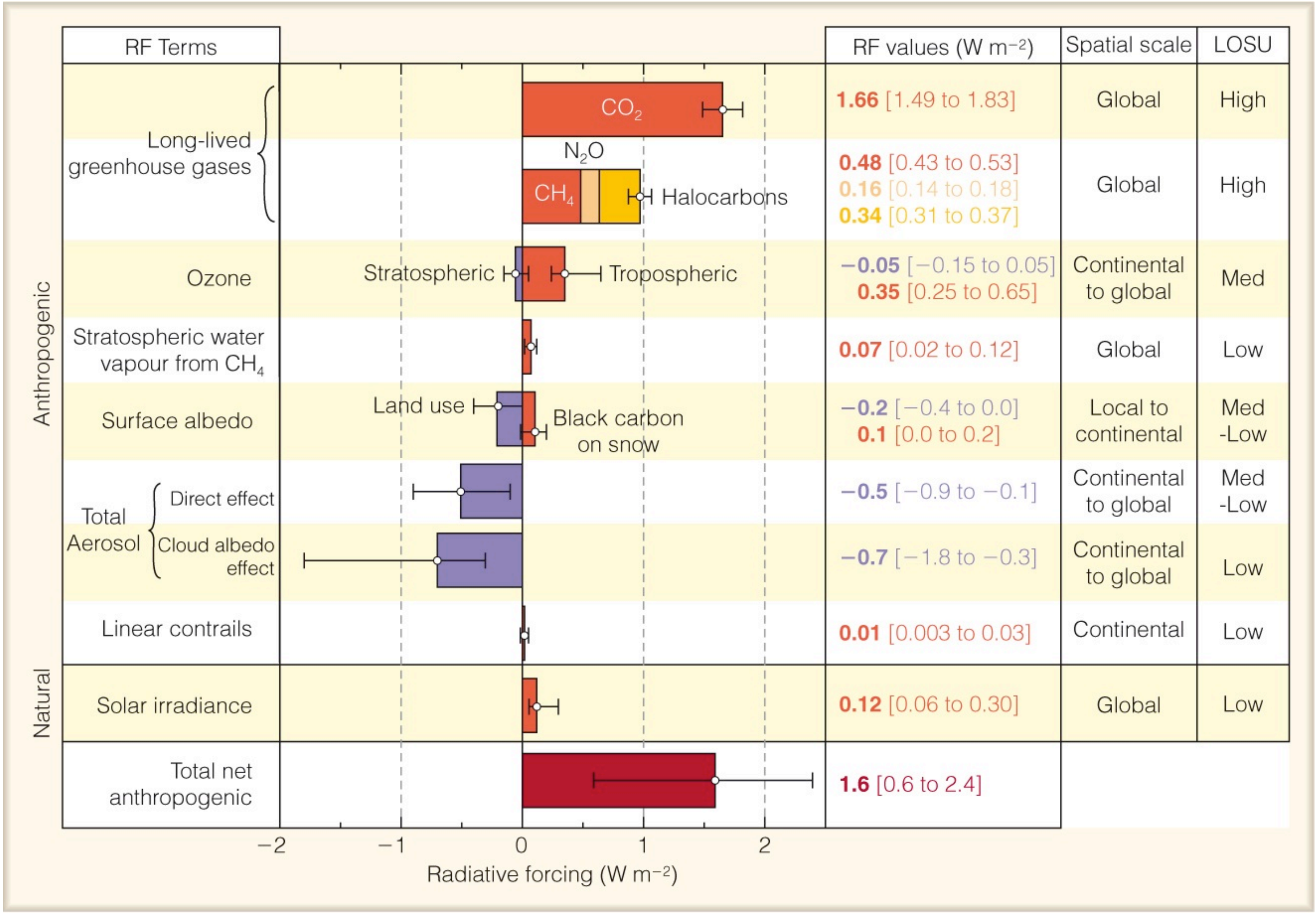
- Reduces E_{out}
- Selective absorbers
  - Most substances absorb only certain wavelengths of radiation
  - E.g. Glass absorbs ultraviolet and infrared radiation, but not visible radiation
- *Greenhouse gases* are transparent to visible radiation, but absorb infrared radiation
  - Therefore they have no effect on E_{in} but reduce E_{out}

Greenhouse gases

- The action of greenhouse gases is to trap heat
  - Prevent radiation into space
- *Natural* greenhouse effect
  - Global average temperature 33°C warmer than it would be otherwise (15°C instead of -18°C)
  - Most important gas is H_2O
  - Also significant are CO_2, CH_4, N_2O, O_3
- ***Enhanced* greenhouse effect**
  - **CO_2, CH_4, Halocarbons, O_3, N_2O, others**

Forcings

- Insolation
- Albedo changes
  - Volcanoes
  - Aerosols
  - Land cover
- Greenhouse gases



Ahrens: Fig. 16.18

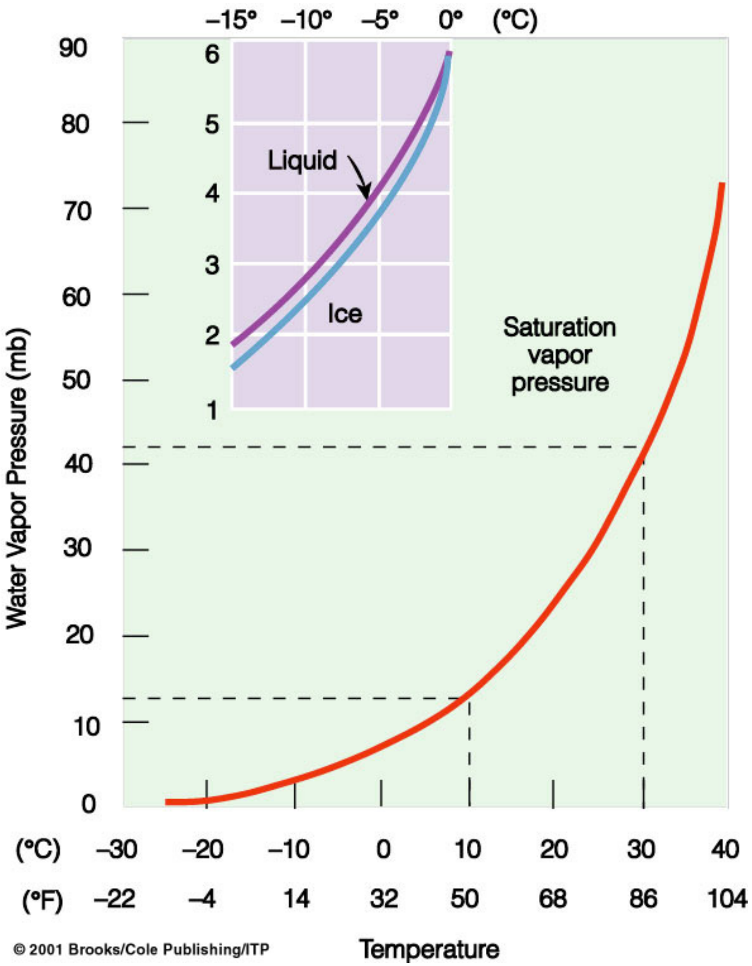
Feedbacks

- A feedback is a response to an initial change that influences that same change
  - A cause-and-effect chain with a loop
  - A positive feedback reinforces the initial change
  - A negative feedback counteracts the initial change
- E.g. thermostat

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
- Albedos:
  - Open water: 0.1
  - Ice: 0.3 – 0.4
- Sensitive to changes in temperature
- Also a positive feedback

Ahrens: Fig. 2.13

The Many Roles of Clouds

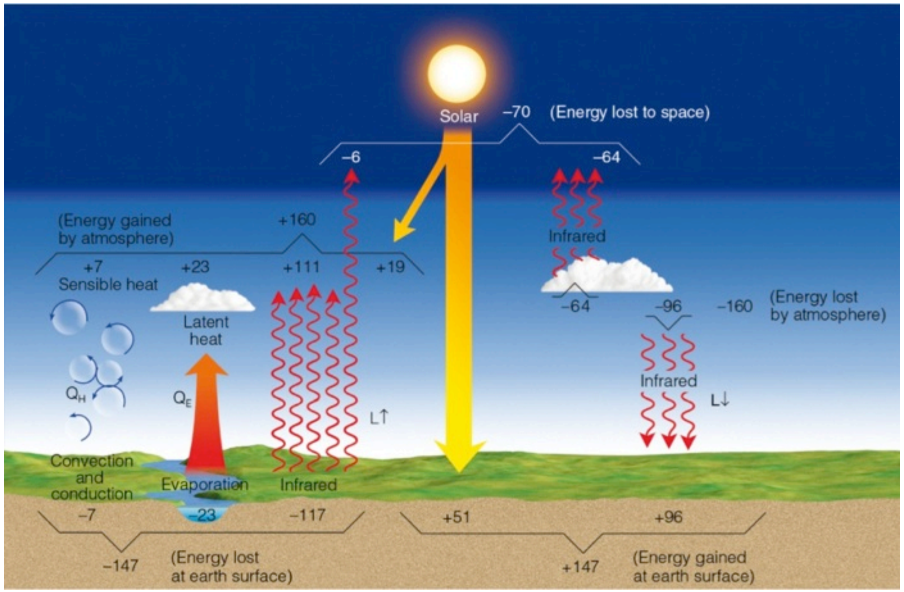
- Reflect shortwave (solar) radiation
  - Cover 50% of surface, albedo of 50%
- Absorb longwave (terrestrial) radiation
- Emit radiation to space and back down to the surface

- Changes in the extent of clouds increases all three

Cloud height

- Altitude affects temperature
  - High clouds are colder
  - Colder clouds emit less radiation

- An increase in high clouds has a heating effect
- An increase in low clouds has a cooling effect



Cloud particles

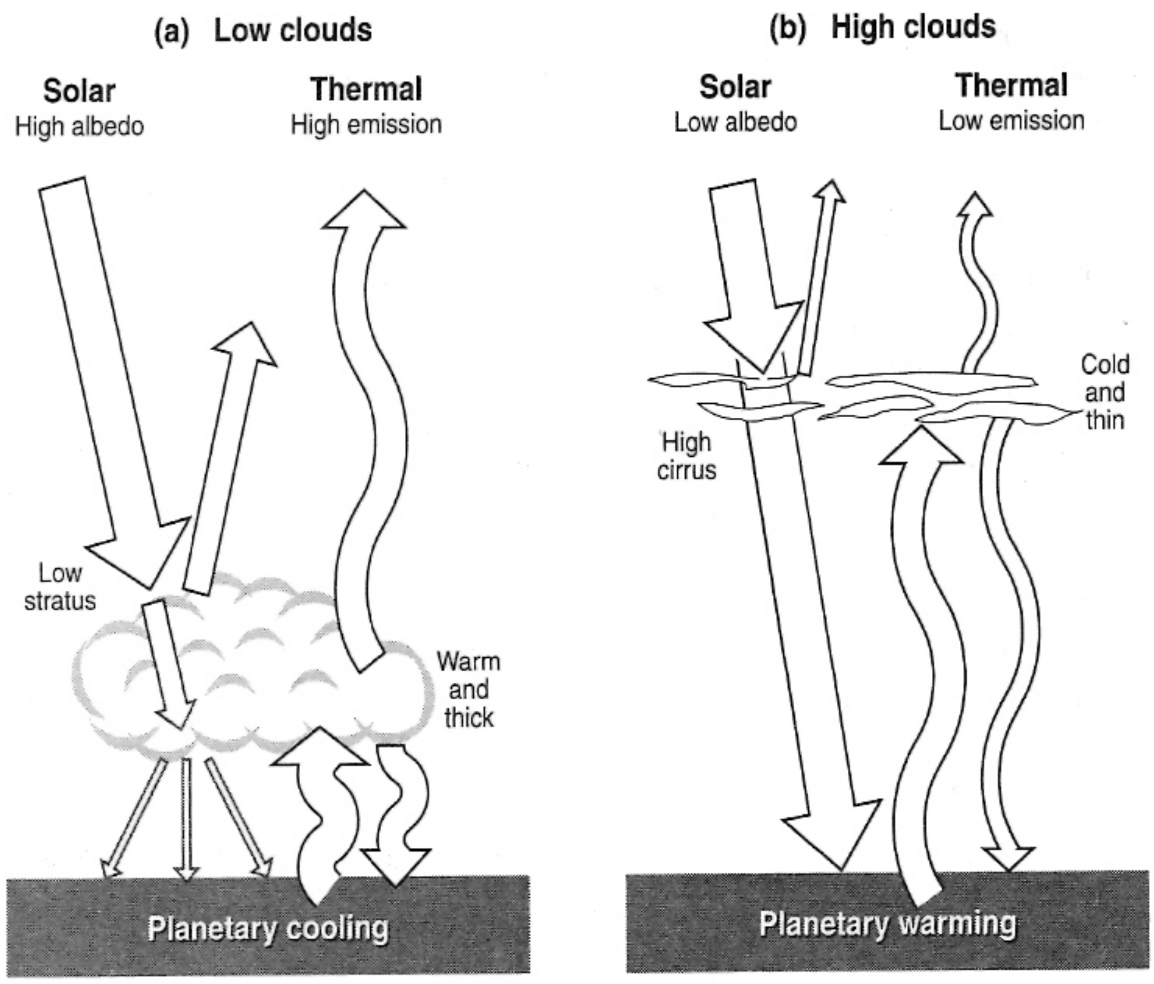
- Water droplets are more reflective than ice crystals
- Clouds with many smaller droplets are more reflective than those with fewer, larger ones
- Thicker clouds are more reflective than thin ones

Summary: Cloud feedbacks

Net effect of the cloud feedback is uncertain.

Magnitude could be significant for future climatic change.

Turco: Figure 11.13



Driving climate change

- Driving factors:
  - Solar change
  - Albedo
  - Greenhouse gases
- Climate Feedbacks
  - Water vapour (positive)
  - Snow cover (positive)
  - Clouds (uncertain)

The climate flywheel?

- A flywheel is a device for storing mechanical energy
  - Rotating device resists changes to rotational speed
  - E.g. Bicycle wheel
- By “climate flywheel” Turco refers to elements of the climate system that are resistant to change
  - Residence time of heat in the land surface is less than a year
  - Residence time of heat in the surface ocean is in decades
  - Residence time of heat in the deep ocean is in centuries

Oceans

- Surface (100 m or less)
  - Well-mixed (winds)
  - Photosynthesis only in top few metres
  - Takes part in surface energy balance
- Deep ocean (average nearly 4 km deep)
  - Thermohaline: very slow circulation
  - Heat that enters the deep ocean delays surface equilibrium
  - Response to changes in forcing occur over decades

Ice cover (cryosphere)

- Also stores a considerable amount of energy
- More important is the energy required to freeze or thaw the ice
  - Delays temperature change

Other influences: General circulation

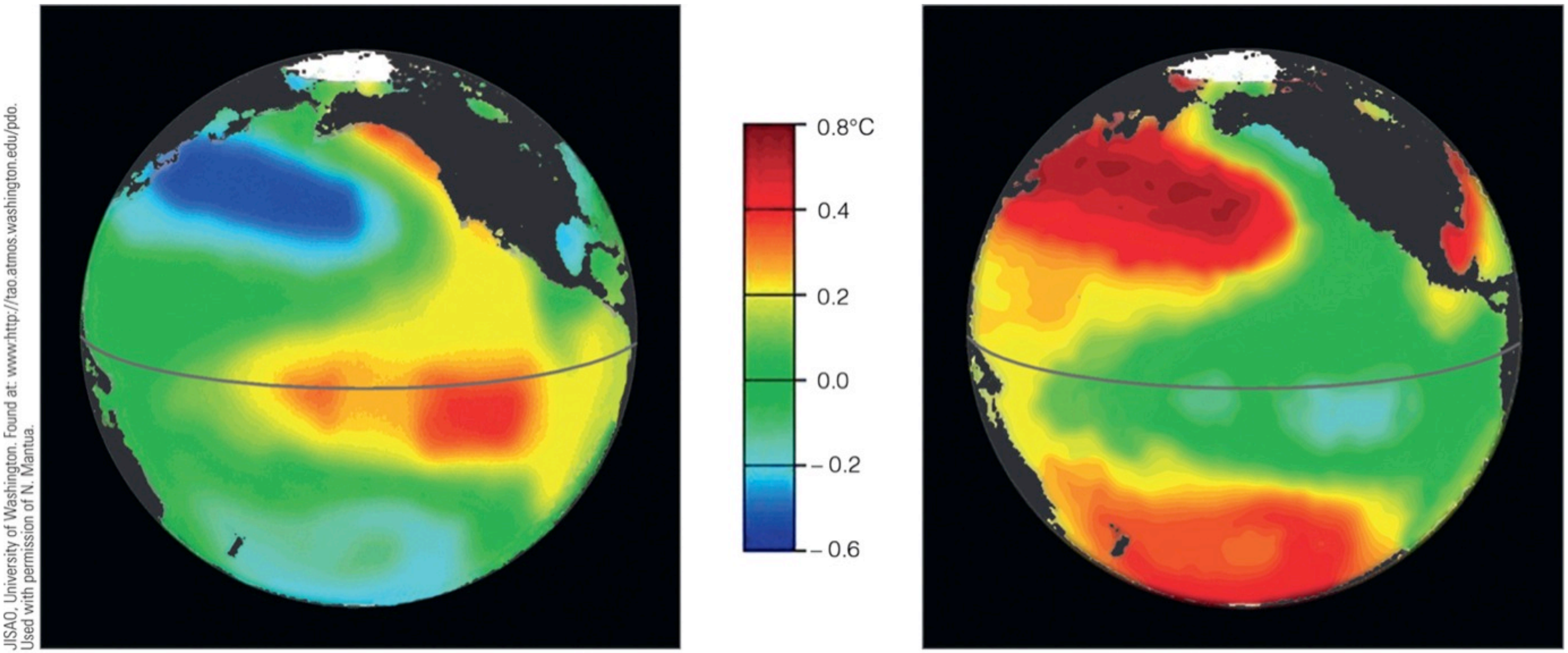
- Atmospheric and oceanic circulations transfer heat from tropics to poles
  - Oceanic transfer is half that of the atmosphere

- Changes in circulations affect the internal transfers of the energy budget
  - Very significant on timescales of decades-centuries

Other influences: Internal variability

- El Niño / Southern Oscillation (ENSO)
- Pacific Decadal Oscillation (PDO)
- Other long and short cycles

Pacific Decadal Oscillation

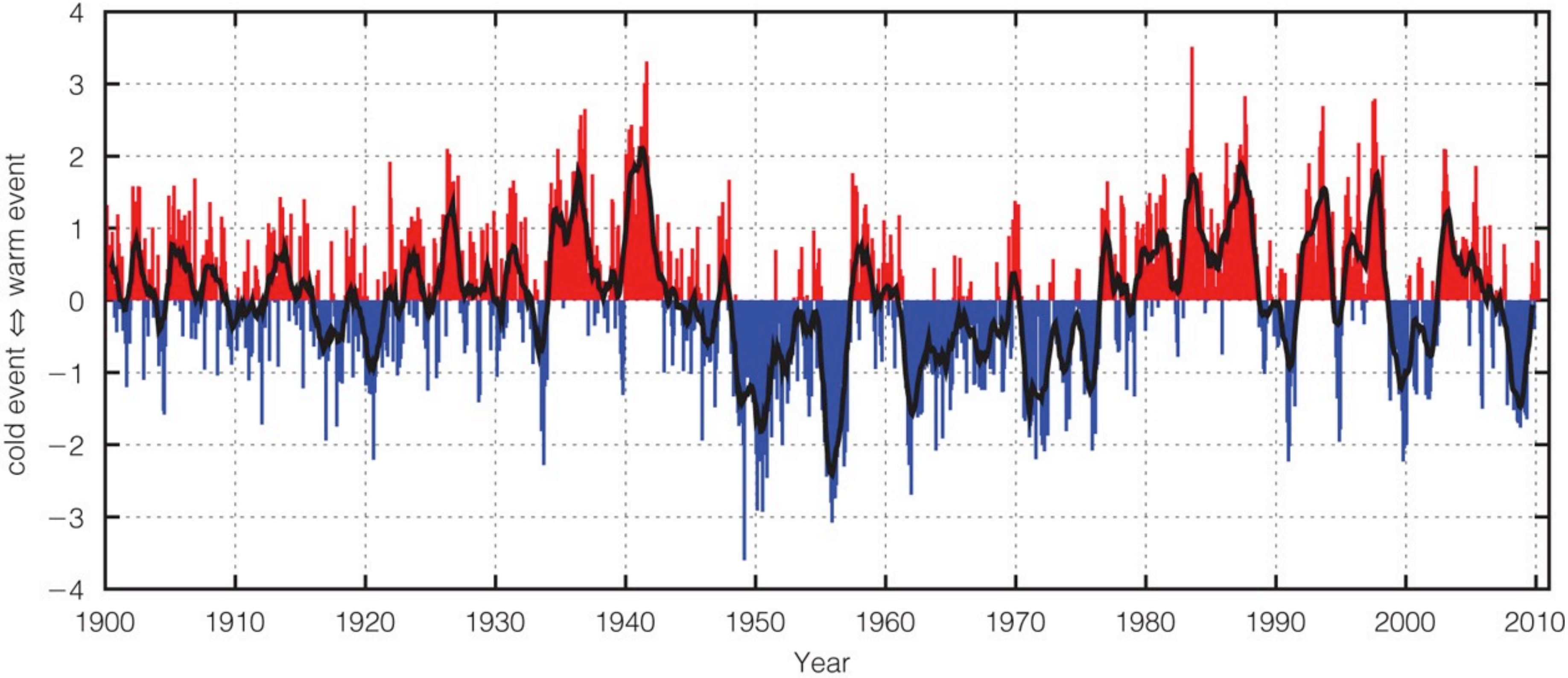


(a) Warm (positive) phase Warm

(b) Cool (negative) phase Cool

Ahrens: Fig. 10.25

Pacific Decadal Oscillation



Ahrens: Fig. 10.26

Other potential feedbacks

- Carbon dioxide dissolves in the ocean
  - Solubility decreases as temperature increases
- Carbon dioxide, methane, nitrous oxide are all influenced by the biosphere
  - Drier soils
  - Dying forests
  - Melting permafrost

Next lecture

- Global Warming