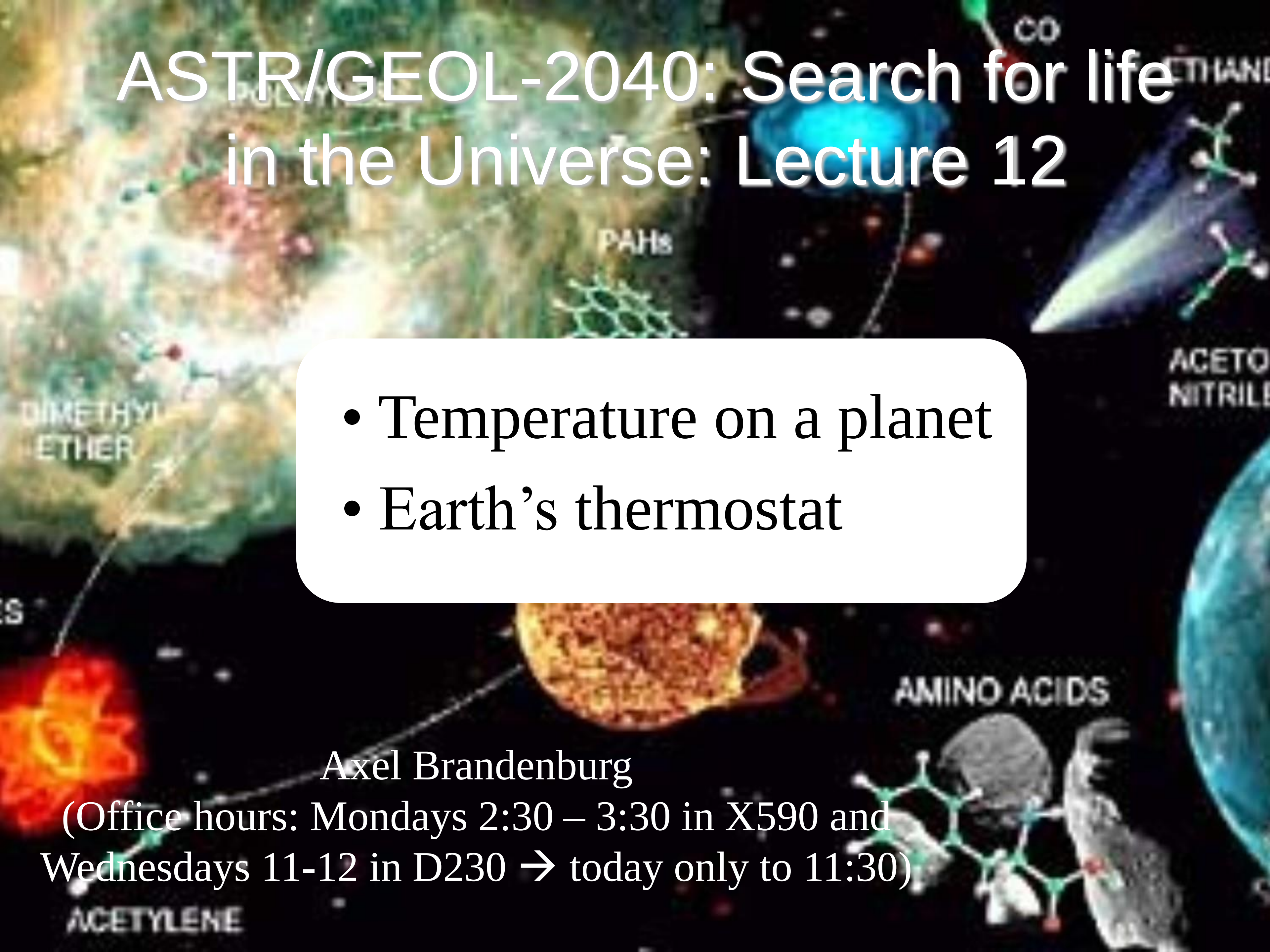
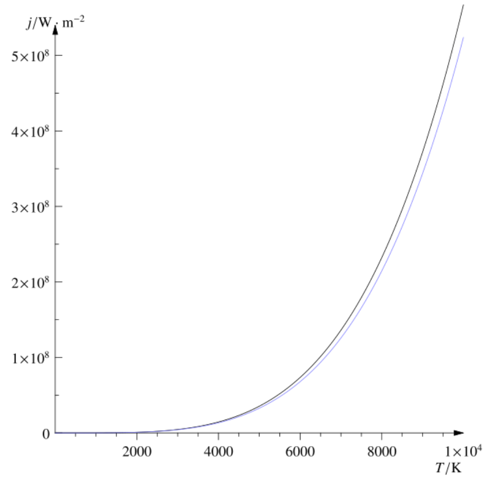
ASTR/GEOL-2040: Search for life in the Universe: Lecture 12



- Temperature on a planet
- Earth’s thermostat

Axel Brandenburg
(Office hours: Mondays 2:30 – 3:30 in X590 and Wednesdays 11-12 in D230 → today only to 11:30)

The hotter, the more it loses



$$F = \sigma_{SB} T^4$$

$$\sigma_{SB} = 5.67 \times 10^{-8} \text{ Wm}^{-2}\text{K}^{-4}$$

- 100 K → 5.67 W m^{-2}
- 1000 K → 5.67×10^4 W m^{-2}
- 10,000 K → 5.67×10^8 W m^{-2}

Lecture 8: solar energy

Table 1.4 Present-day sources of energy averaged over the Earth.

Source	Power/W m^{-2}	J/m^2 yr
total solar radiation	360	$1.1 \cdot 10^{10}$
geothermal heat flow	8.1×10^{-2}	$2.6 \cdot 10^{6}$
electrical discharges (lightning)	5.4×10^{-8}	1.7
cosmic rays	2×10^{-11}	$6.3 \cdot 10^{-4}$
shock waves (atmospheric entry)	1.5×10^{-8}	0.47

- We get 360 W/m^2 (daily average)
- What happens with most of it?

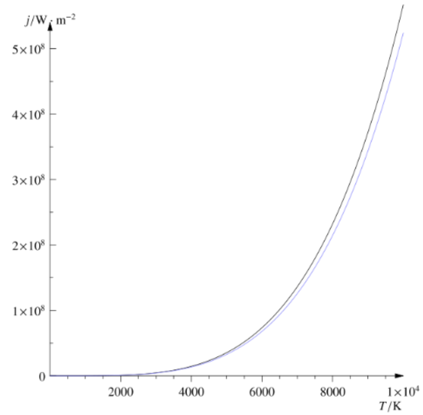
What happens with that energy

- We get 360 W/m^2
- Supply all our solar panels
- Photosynthesis → build trees etc
- Drive hurricanes
- What else?

What else?

- We get 360 W/m^2
- Needed to keep Earth warm
- How warm?

Intermediate values

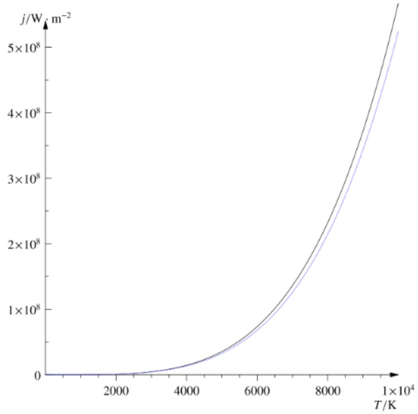


$$F = \sigma_{SB} T^4$$

$$\sigma_{SB} = 5.67 \times 10^{-8}\ \mathrm{Wm^{-2}K^{-4}}$$

- 100 K → $5.67\ \mathrm{W\ m^{-2}}$
- ?? → $5.67\mathrm{x}10^{1}\ \mathrm{W\ m^{-2}}$
- ?? → $5.67\mathrm{x}10^{2}\ \mathrm{W\ m^{-2}}$
- ?? → $5.67\mathrm{x}10^{3}\ \mathrm{W\ m^{-2}}$
- 1000 K → $5.67\mathrm{x}10^{4}\ \mathrm{W\ m^{-2}}$

Intermediate values



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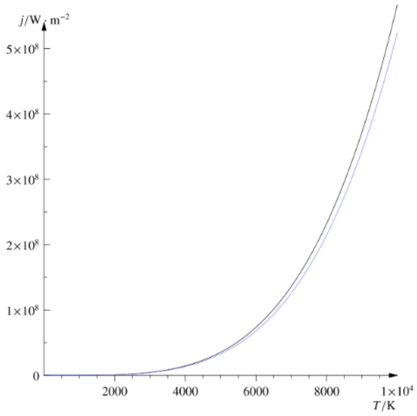
- ?? → $5.67\mathrm{x}10^{2}\ \mathrm{W\ m^{-2}}$
- ?? → $5.67\mathrm{x}10^{3}\ \mathrm{W\ m^{-2}}$
- 1000 K → $5.67\mathrm{x}10^{4}\ \mathrm{W\ m^{-2}}$

Intermediate values

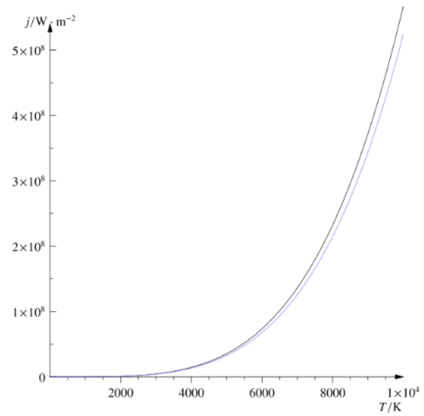


$$F = \sigma_{\mathrm{SB}} T^4$$

$$\sigma_{\mathrm{SB}} = 5.67 \times 10^{-8}\ \mathrm{Wm^{-2}K^{-4}}$$

- 100 K → $5.67\ \mathrm{W\ m^{-2}}$
- ?? → $5.67\mathrm{x}10^{1}\ \mathrm{W\ m^{-2}}$
- 300 K → $5.67\mathrm{x}10^{2}\ \mathrm{W\ m^{-2}}$
- ?? → $5.67\mathrm{x}10^{3}\ \mathrm{W\ m^{-2}}$
- 1000 K → $5.67\mathrm{x}10^{4}\ \mathrm{W\ m^{-2}}$

Intermediate values

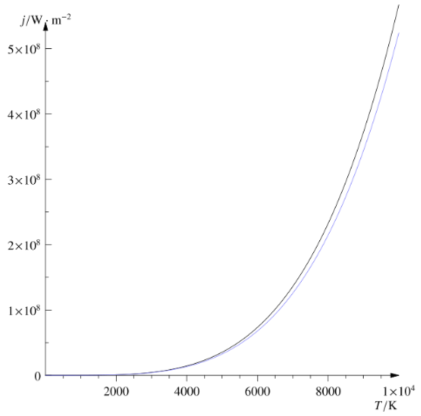


$$F = \sigma_{SB} T^4$$

$$\sigma_{SB} = 5.67 \times 10^{-8}\ \mathrm{Wm^{-2}K^{-4}}$$

- 100 K → $5.67\ \mathrm{W\ m^{-2}}$
- 180 K → $5.67 \times 10^{1}\ \mathrm{W\ m^{-2}}$
- 316 K → $5.67 \times 10^{2}\ \mathrm{W\ m^{-2}}$
- 560 K → $5.67 \times 10^{3}\ \mathrm{W\ m^{-2}}$
- 1000 K → $5.67 \times 10^{4}\ \mathrm{W\ m^{-2}}$

Intermediate values

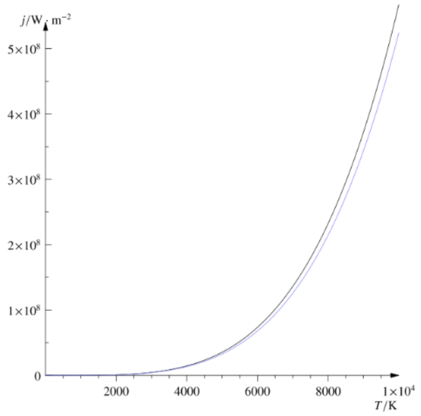


$$F = \sigma_{\mathrm{SB}} T^4$$

$$\sigma_{\mathrm{SB}} = 5.67 \times 10^{-8}\ \mathrm{Wm^{-2}K^{-4}}$$

- 100 K → 5.67 W m^{-2}
- 180 K → 56.7 W m^{-2}
- 316 K → 567 W m^{-2}
- 560 K → 5,670 W m^{-2}
- 1000 K → 56,700 W m^{-2}

Intermediate values



$$F = \sigma_{\mathrm{SB}} T^4$$

$$\sigma_{\mathrm{SB}} = 5.67 \times 10^{-8}\ \mathrm{Wm^{-2}K^{-4}}$$

- 180 K → 56.7 W m^{-2}
- 273 K → 315 W m^{-2}
- 293 K → 418 W m^{-2}
- 316 K → 567 W m^{-2}

Conclusion

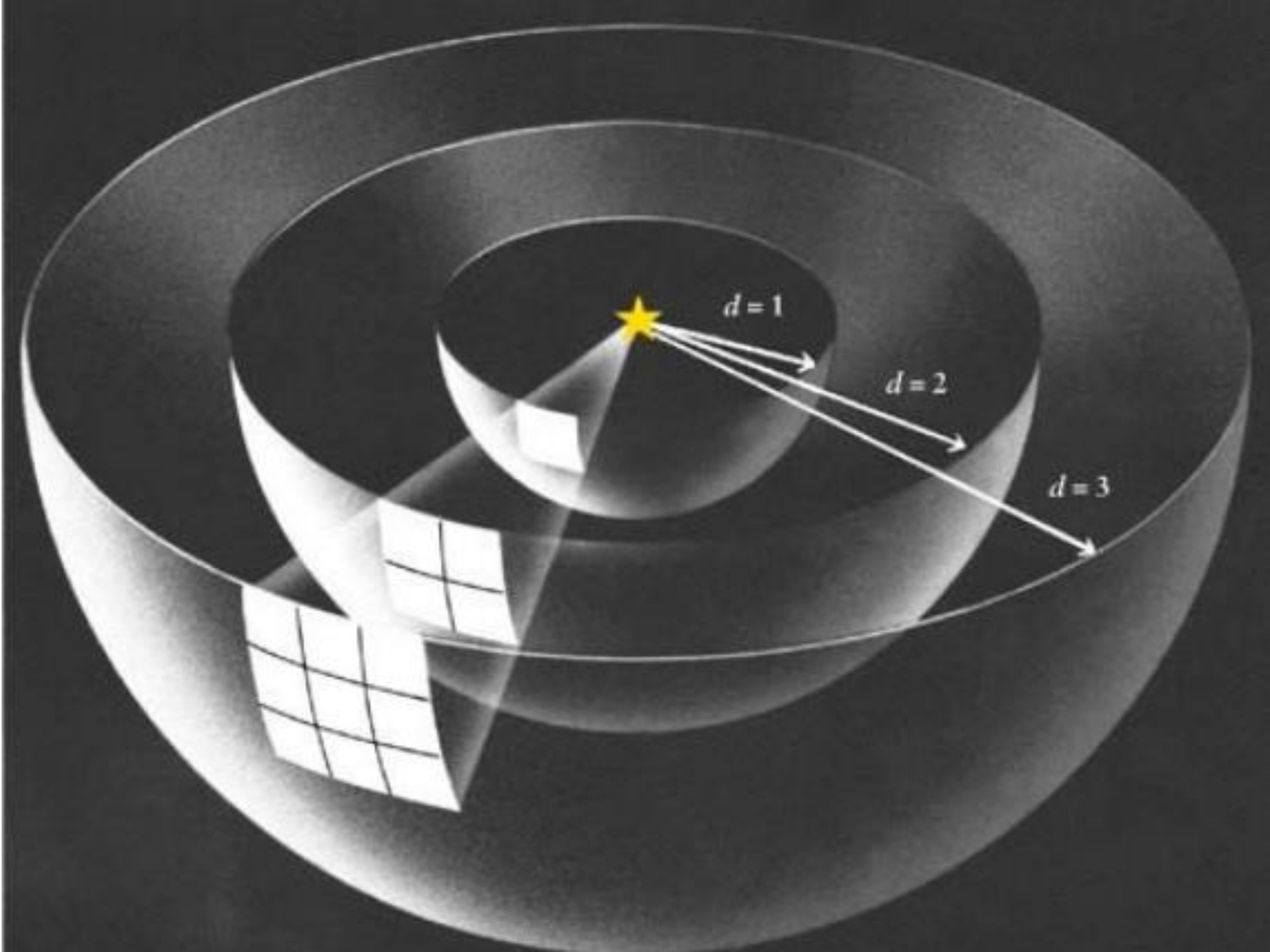
- We get 360 W/m^2
- How warm?
- → slightly above freezing
- Forgot about cloud cover
- → 30% reflected
- → get only 70%
- → only 255 K (p.49 of RGS)
- Why is it usually much warmer?

Why not 255 K on Earth?

- …
- … …
- … … …

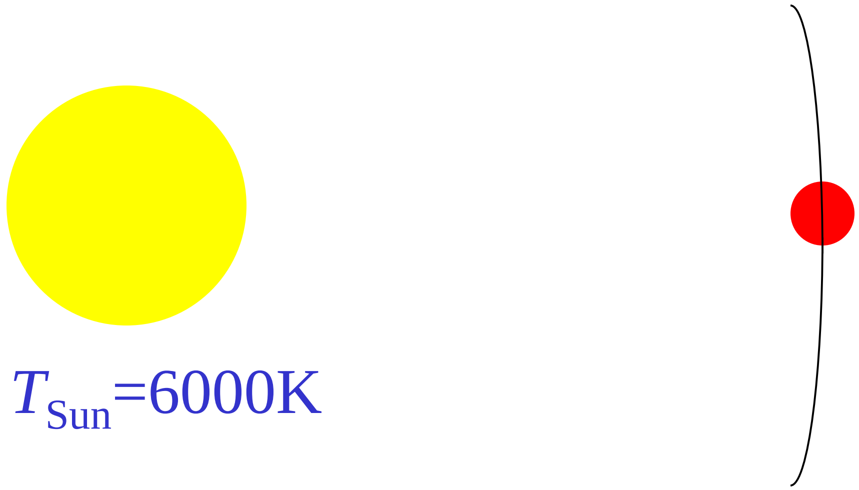
Two "black" bodies

- Hotter → brighter
- Hotter → color changes
  - Yellow → white → blue
  - Cooler → deeper red



$d = 1$
$d = 2$
$d = 3$

Solar flux at the Earth?

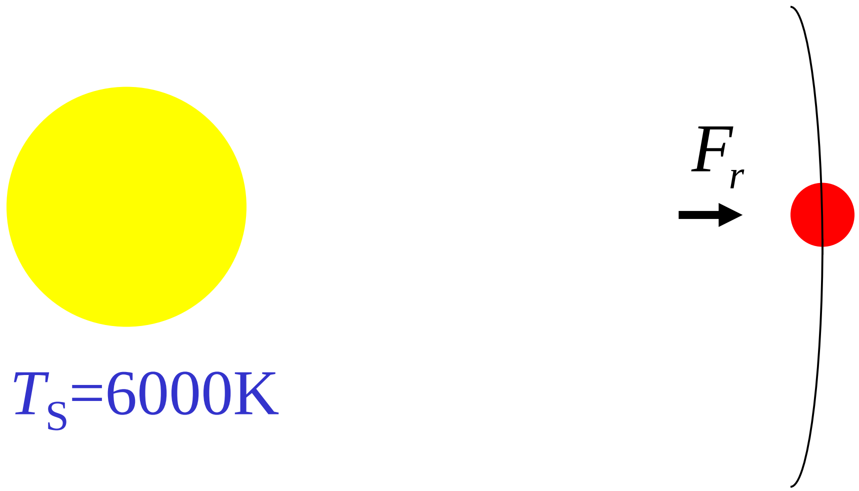


T_{Sun}=6000K

$$4\pi r^2 F_r = \text{const} = L$$

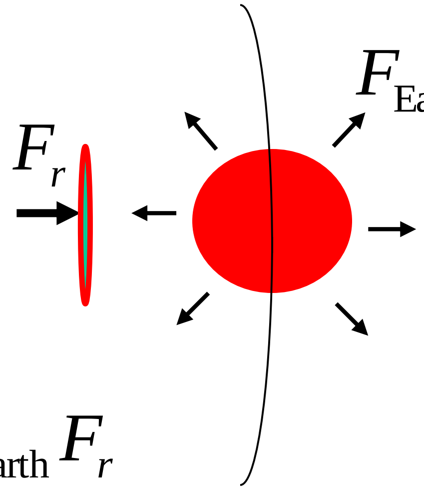
$$L = 4\pi R_{\text{Sun}}^2 \sigma_{\text{SB}} T_{\text{Sun}}^4 = 4\pi r^2 F_r$$

Fraction intercepted by the Earth?



$$\pi r^2 F_r = \text{total energy/sec}$$

In & outgoing energy/sec



$$F_{\text{Earth}} = \sigma_{\text{SB}} T_{\text{Earth}}^4$$

gain over exposed surface $\pi R_{\text{Earth}}^2 F_r$

Total loss (day&night)

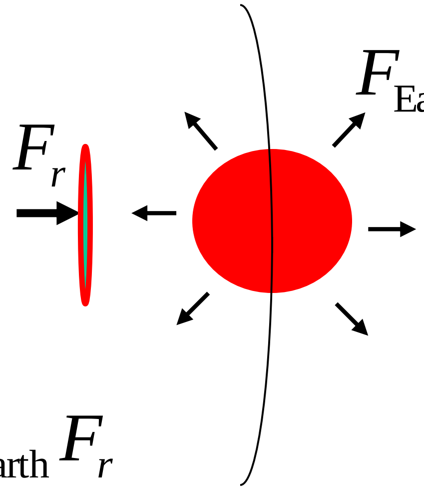
$$4\pi R_{\text{Earth}}^2 \sigma_{\text{SB}} T_{\text{Earth}}^4$$

A. Earth must receive more than it loses

B. Earth must receive as much as it loses

C. Earth must receive less than it loses

In & outgoing energy/sec



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$$4\pi R_{\mathrm{Earth}}^2 \sigma_{\mathrm{SB}} T_{\mathrm{Earth}}^4$$

A. Earth must receive more than it loses

B. Earth must receive as much as it loses

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Eliminate F

$$\pi R_E^2 F_r = 4\pi R_E^2 \sigma_{SB} T_E^4$$

$$4\pi R_S^2 \sigma_{SB} T_S^4 = 4\pi r^2 F_r$$

Google for "Effective Temperature"

$$T_{\text{Earth}} = T_{\text{Sun}}\left(\frac{R_{\text{Sun}}}{2d}\right)^{1/2}(1-A)^{1/4} \leq 279\,\text{K}$$

where

- T_{Earth} → Earth's temperature
- T_{Sun} → Sun's surface temperature
- R_{Sun} → Radius of the Sun
- d → distance between Sun and Earth
- A → Albedo (=how much is reflected)

temperature:

$$T = \sqrt[4]{\frac{L(1-a)}{16\pi\sigma D^2}}$$

Note that the planet's radius has cancelled out of the final expression.

The effective temperature for Jupiter from this calculation is 112 K and 51 Pegasi b (Bellerophon) is 1,258 K.[citation needed] A better estimate of effective temperature for some planets, such as Jupiter, would need to include the internal heating as a power input. The actual temperature depends on albedo and atmosphere effects. The actual temperature from spectroscopic analysis for HD 209458 b (Osiris) is 1,130 K, but the effective temperature is 1,359 K.[citation needed] The internal heating within Jupiter raises the effective temperature to about 152 K.[citation needed]

Surface temperature of a planet [edit]

The surface temperature of a planet can be estimated by modifying the effective-temperature calculation to account for emissivity and temperature variation.

The area of the planet that absorbs the power from the star is A_{abs} which is some fraction of the total surface area $A_{\text{total}} = 4\pi r^2$, where r is the radius of the planet. This area intercepts

Google for "Effective Temperature"

$$T_E = T_S \left(\frac{R_{Sun}}{2d} \right)^{1/2} (1 - A)^{1/4} \leq 279\,\mathrm{K}$$

What would happen if the Earth were bigger

A. The Earth gains more heat

B. The Earth gains less heat

C. The Earth temp remains unchanged

temperature:

$$T = \sqrt[4]{\frac{L(1-a)}{16\pi\sigma D^2}}$$

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$$T_{\text{Earth}} = T_{\text{Sun}} \left(\frac{R_{\text{Sun}}}{2d} \right)^{1/2} (1-A)^{1/4} \leq 280\ \text{K}$$

What would happen if the Earth were bigger

A. The Earth gains more heat

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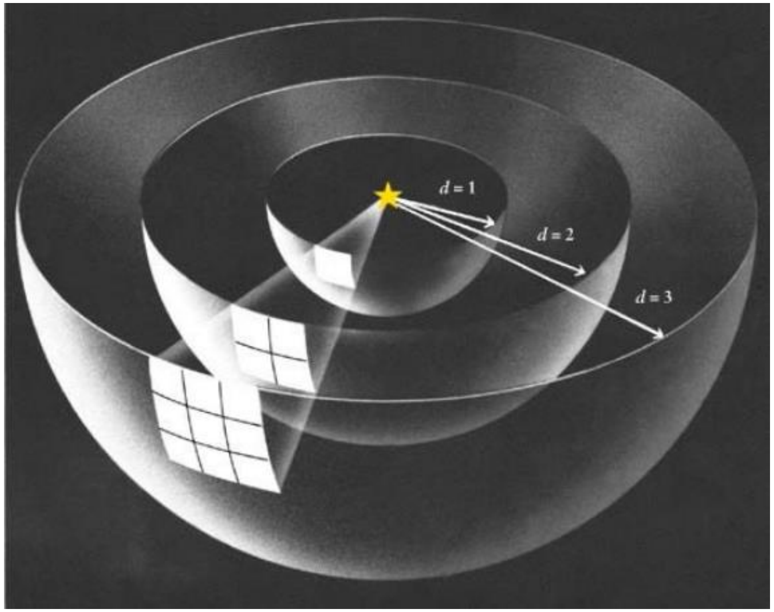
C. The Earth temp remains unchanged

What does it mean?

$$T_{\text{Earth}} = T_{\text{Sun}}\left(\frac{R_{\text{Sun}}}{2d}\right)^{1/2}$$

$$F \propto 1/d^2$$

$$F = \sigma_{\text{SB}} T^4$$



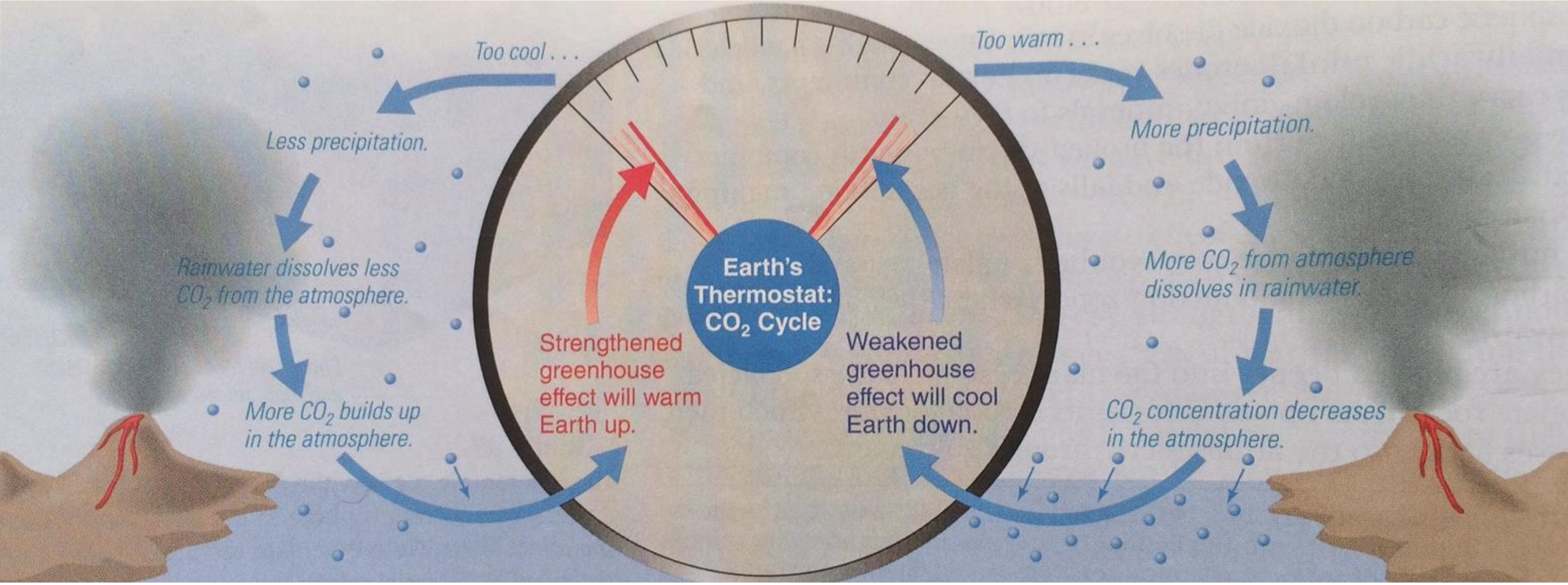
What if distance *d* were 4 times larger

- $1/d^2$ becomes 16 times smaller
- F decreases by 1/16
- T_{Earth} decreases by 1/2

The CO_2 thermostat

CO_2 low, cool, less rain

CO_2 high, warm, more rain



atmospheric CO_2 builds up

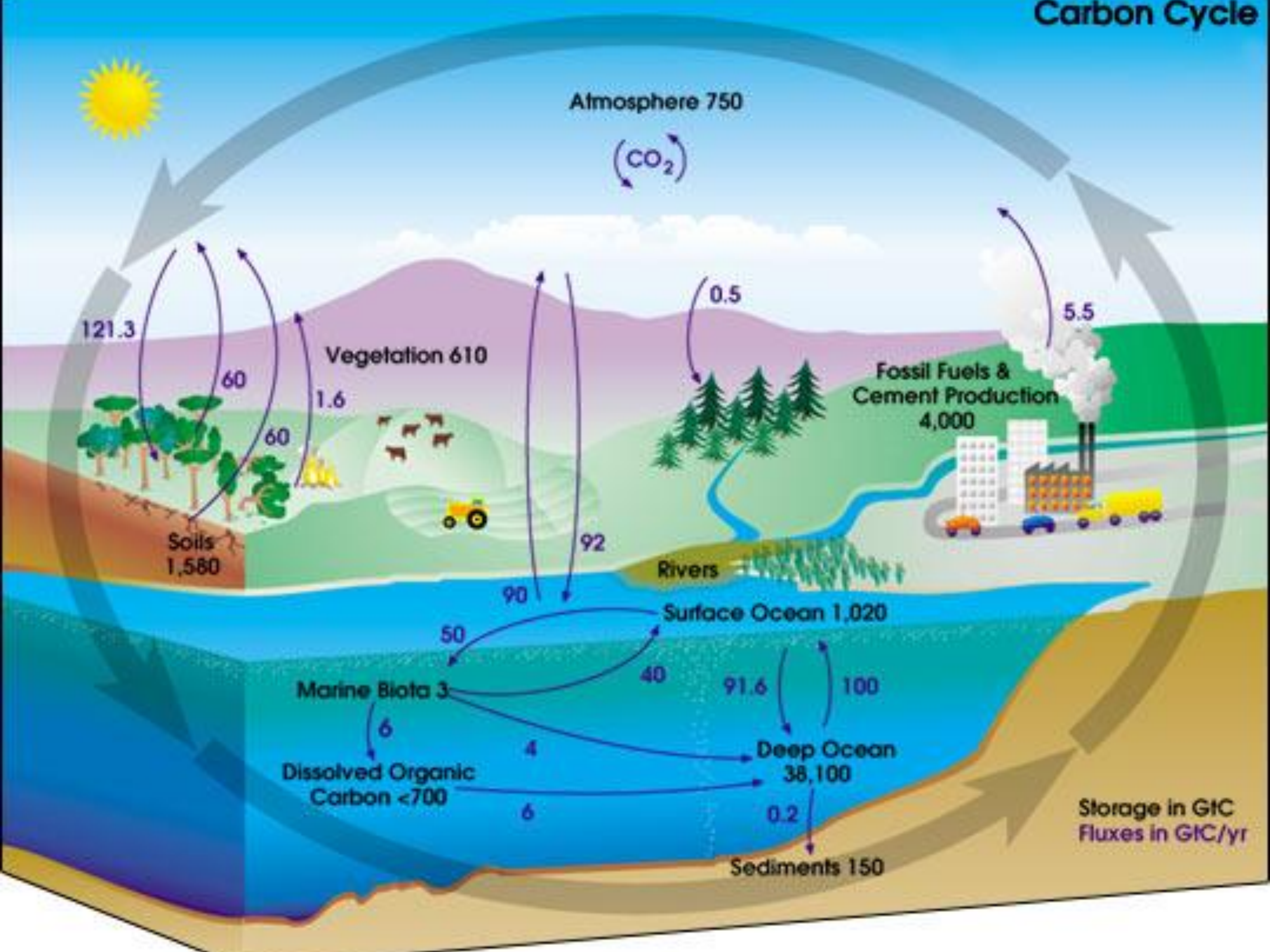
atmospheric CO_2 reduced

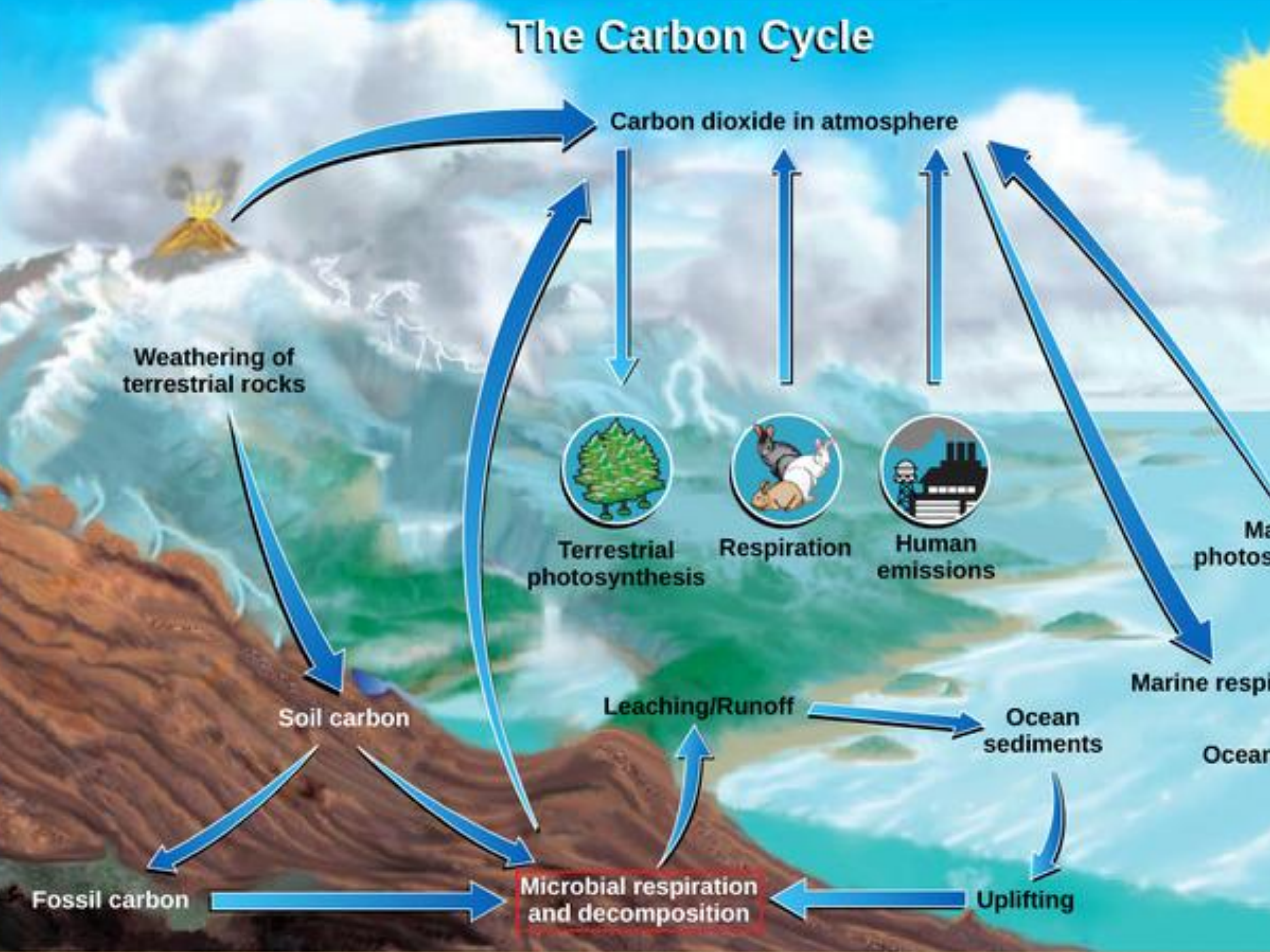
On Earth, CO_2 is recycled

- Sources of CO_2
  - ….
  - ….
- Sinks of CO_2
  - …
  - …

On Earth, CO_2 is recycled

- Sources of CO_2
  - Animal life on Earth
  - Oxidation of exhumed CH_2O
  - Other C oxidation (e.g. fire)
  - Outgassing (volcanoes)
  - $CaCO_3 \rightarrow CaO + CO_2$ or rather
    - Silicate minerals + $CaCO_3 \rightarrow$ new silicate minerals+CO_2


Carbon Cycle
Atmosphere 750
CO_2
121.3
60
60
1.6
Vegetation 610
90
92
0.5
5.5
Fossil Fuels &
Cement Production
4,000
Soils
1,580
Rivers
Surface Ocean 1,020
50
40
Marine Biota 3
91.6
100
6
4
Deep Ocean
38,100
Dissolved Organic
Carbon <700
6
0.2
Sediments 150
Storage in GtC
Fluxes in GtC/yr



The Carbon Cycle
Carbon dioxide in atmosphere
Weathering of terrestrial rocks
Terrestrial photosynthesis
Respiration
Human emissions
Soil carbon
Leaching/Runoff
Ocean sediments
Fossil carbon
Microbial respiration and decomposition
Uplifting

Sinks of CO_2

- Photosynthetic life (of course)
- Acid rain: $H_2O+CO_2 = H_2CO_3$
  - Contact with rock: weathering
- $CaSiO_3 + H_2CO_3 \rightarrow CaCO_3 + SiO_2$
  - Calcium carbonate
  - solid deposit (sea bed)
  - carbonate rock (limestone)
  - Details in RGS p.51

Sinks of CO_2

- Acid rain: $H_2O+CO_2 = H_2CO_3$
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  - Calcium carbonate (solid deposit)
  - Details in RGS p.51
- On Earth: 170,000 times more CO_2 in carbonate rocks than in atmosphere

See BS p.139 for details!

The CO_2 thermostat

- Recycling rate sensitive to temperature
- CO_2 → warmer (greenhouse)
  - More evaporation, more rainfall
- Pulling more CO_2 out of atmosphere
  - Weaker greenhouse effect
- Negative feedback

Feedbacks

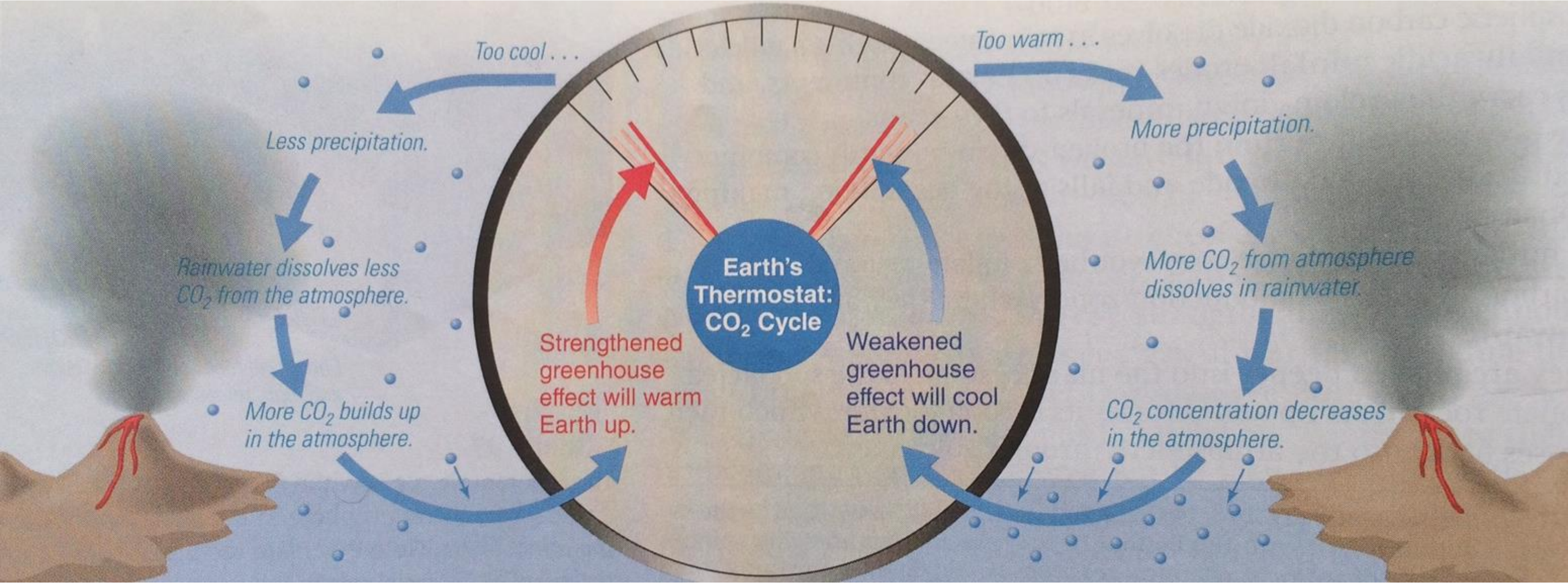
- Negative feedback
  - Stable
- Positive feedback
  - Unstable, runaway
- Examples?
  - loudspeaker

CO_2 thermostat: other way around

- Less CO_2 → cooler
  - less evaporation, less rainfall
- Less removal of CO_2 out of atmosphere
  - greenhouse effect becomes stronger
  - and it gets warmer again
- Again: negative feedback

The CO_2 thermostat

CO_2 high, warm, more rain

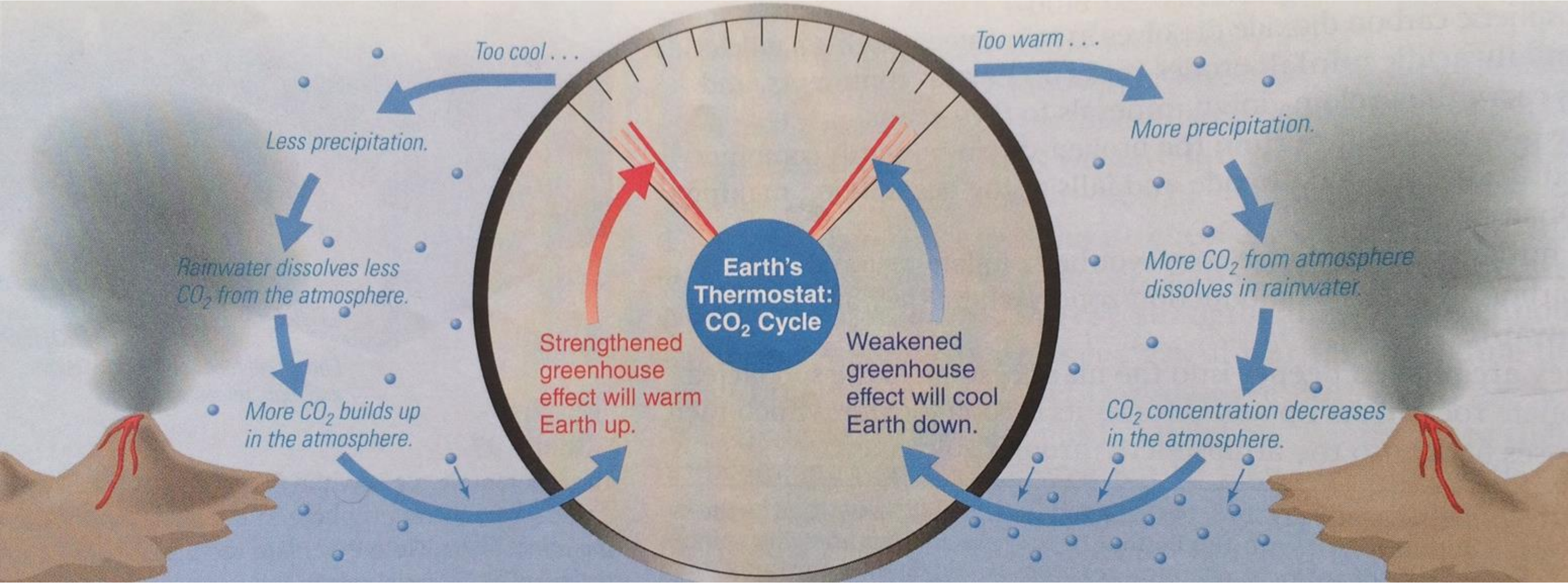


atmospheric CO_2 reduced

The CO_2 thermostat

CO_2 low, cool, less rain

CO_2 high, warm, more rain



atmospheric CO_2 builds up

atmospheric CO_2 reduced

Next time

- Carbon cycle
- Plate tectonics
- Great Oxidation Event (GOE)
- pp. 50 - 53