Announcements

- The lecture scheduled for **December 7** will be moved to **December 2** and held at the **MSU Museum**.
- Instructions for your **term paper and presentation** will be provided on **September 21**, after your feedback survey.
- We will leave **5–7 minutes at the end of today’s class** to discuss **regrouping and other matters**.

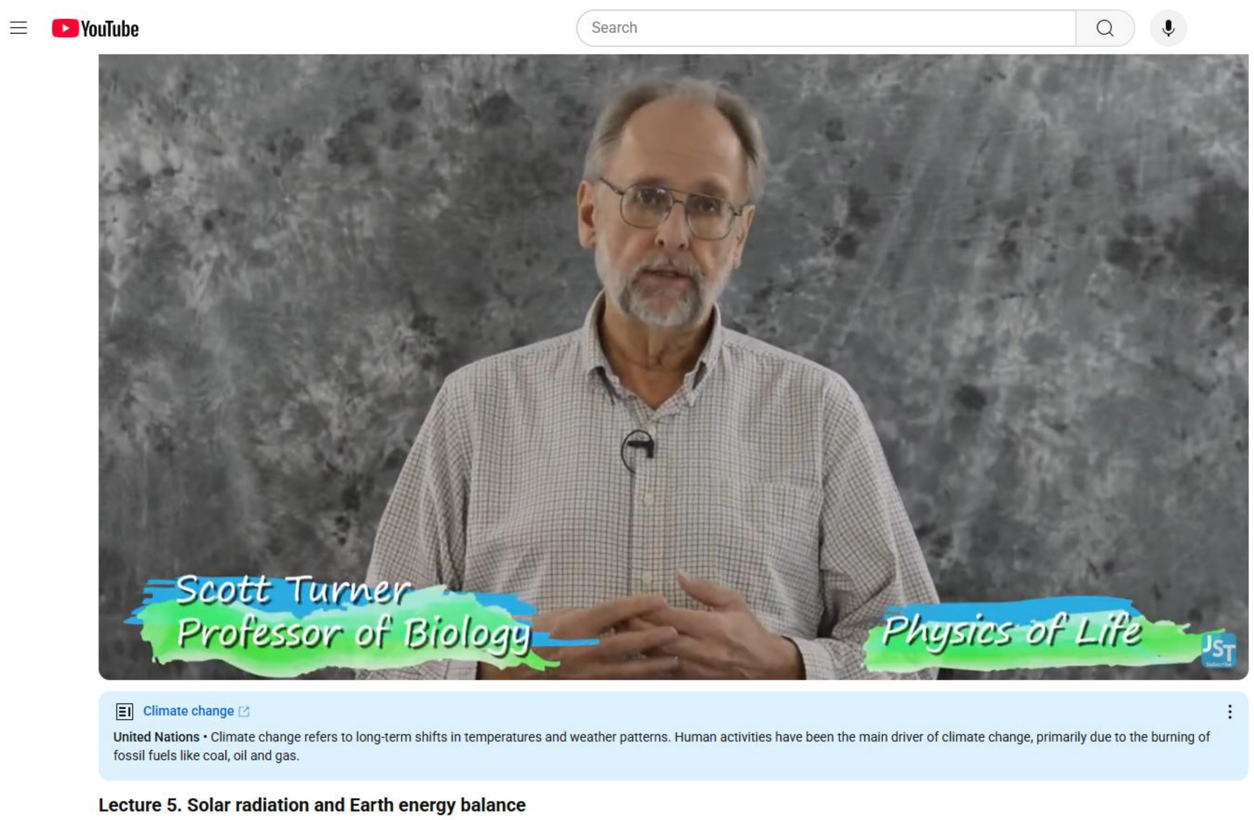
GEO409-FS2026 (3 credits)

Sep 9: Physical Foundations for Global Climatic Changes

- Turner's Lecture on climate change (13 min)
- Physical Laws
- Radiative Processes
- Energy Balance of the Earth

Lecture 5. Solar radiation and Earth energy balance (by Scott Turner)

"Earth climate is fundamentally an energy balance that resolves energy inputs from solar radiation and ultimate loss of energy to the universe. These two streams of energy occur at very different bands of the electromagnetic spectrum, short-wave radiation from the sun, and long-wave radiation to the universe. Climate change boils down to understanding this energy balance."



NASA Video : https://www.youtube.com/watch?v=bk6mCWfVtbw

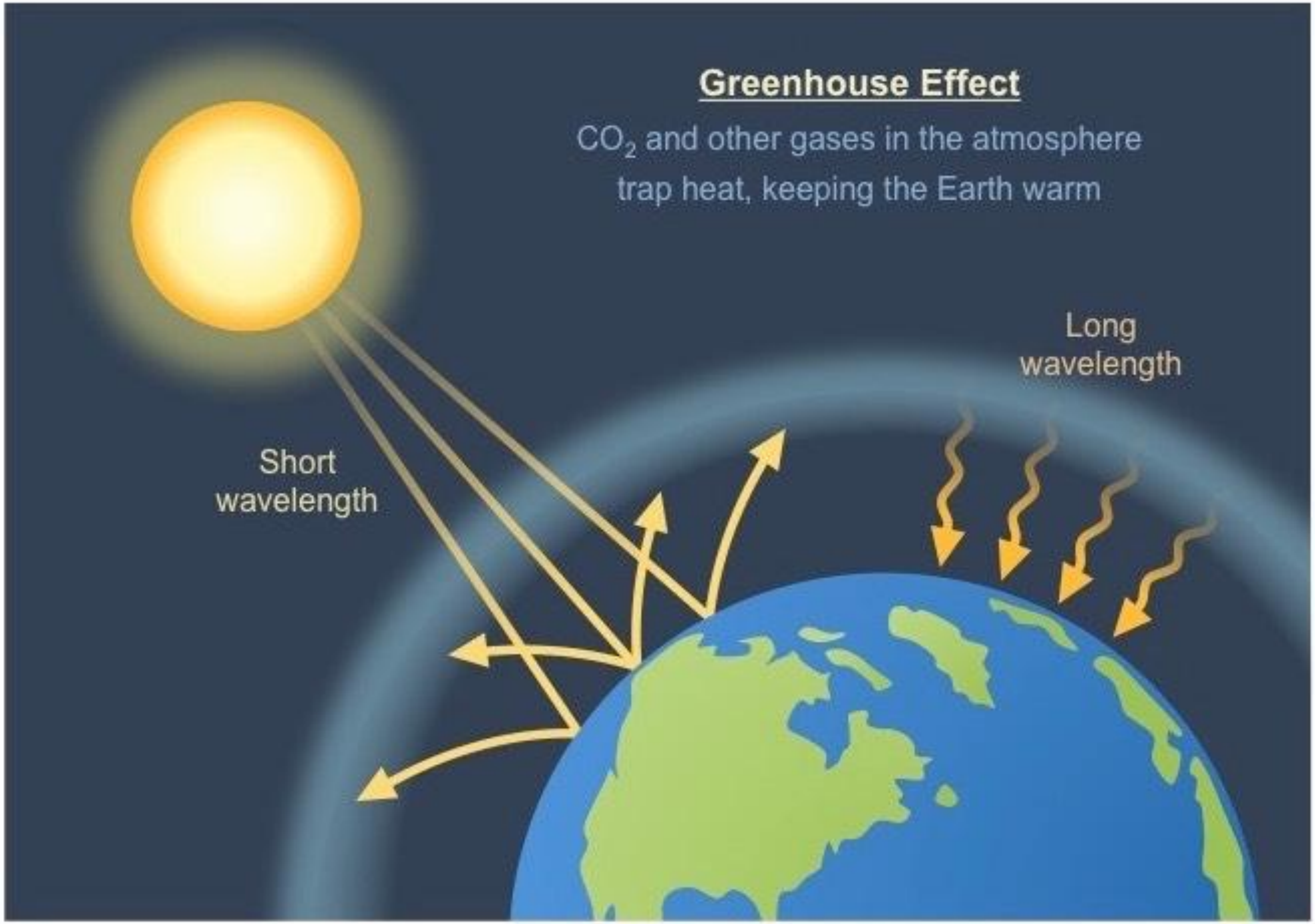
Reading:

IPCC AR6 Working Group I, Chapter 7: *The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity*. Pages: 924-932.

Why is temperature increasing?

Because "the top-of-atmosphere (**TOA**) energy budget" that determines the net amount of energy entering or leaving the climate system has been altered, due to changes in

1) The atmospheric properties
2) Land surface properties!



Two examples

Minneapolis is obscured by wildfire smoke on Wednesday. Photograph: Steven Garcia/NurPhoto/Shutterstock

As of Thursday, air quality alerts have been issued for parts of North Carolina, Minnesota, Vermont, Connecticut, New York, Massachusetts, Rhode Island, New Jersey, New Hampshire, Pennsylvania, Illinois, Indiana, Ohio, Delaware, West Virginia, Colorado, Virginia, Maryland, Washington DC, Michigan and Wisconsin.

https://www.theguardian.com/us-news/2026/jul/16/smoke-canadian-wildfires-air-quality

Albedo-inducted Global Warming Potentials due to land cover & land use changes (LCLUC)

Physical Foundation: Radiation & Heat Unit

Energy

- Amount: Joule (J)
- Rate of energy use: Watt

- 1 W=1 J/s
- 1 Wh=3600 J
- A 60 W bulb on for 1 minutes:

$$E = 60\ W \times 60\ s = 3600\ J$$

Flux is the rate of energy transfer per unit area: $W \cdot m^{-2}$

Solar Constant: ≈ $1361\ W \cdot m^{-2}$

Latent heat of vaporization (L_v): To evaporate 1 gram of water at 100 °C and 1 atm: ~2260 $J \cdot g^{-1}$

$$L_v \approx 2260\ J/g = 2.26 \times 10^6\ J \cdot kg^{-1}$$

Question: how much energy is needed for 1 mm rain to completely evaporate?

$2.26\ MJ/m^2$

Blackbody Theory

Any object with a temperature higher than absolute zero (-273.15 ^{o}C) emits energy.

Stefan–Boltzmann Law

The total energy (E) radiated from an object is proportional to the 4th power of its temperature (T), with σ as the emissivity (i.e., Stefan–Boltzmann constant):

$$E = \sigma \cdot T^4$$

$\sigma = 5.67 \times 10^{-8}\, W \cdot m^{-2} \cdot K^{-4}$

Grey Body: actual emissivity (ε)

$$E = \underline{\varepsilon \cdot \sigma} \cdot T^4$$

- A perfect blackbody: $\varepsilon = 1$
- Real materials: $0 < \varepsilon < 1$

Planck's Radiation Law describes the electromagnetic radiation emitted by a black body in thermal equilibrium at a given temperature. This is described by :

$$E = \frac{h \cdot c}{\lambda}$$

h = Planck's constant; 6.62607015×10^{-34} joule/s (J/s)

λ = frequency of radiation (nm)

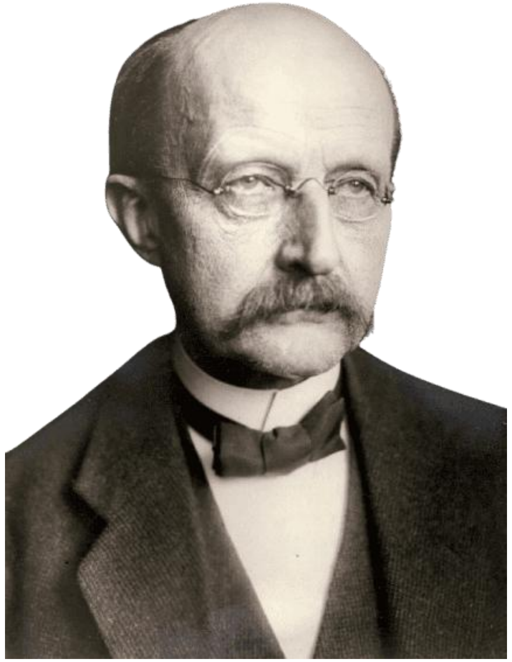
c = speed of light (m/s)

Planck's law is a formula for the *spectral radiance* of an object at a given temperature as a function of frequency (L_f) or wavelength (L_λ). It has dimensions of power per solid angle per area per frequency *or* power per solid angle per area per wavelength.

$$L_f = \frac{2hf^3}{c^2} \frac{1}{e^{hf/kT} - 1} \qquad \left[\frac{\mathrm{W}}{\mathrm{sr\ m^2\ Hz}}\right]$$

$$L_\lambda = \frac{2hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1} \qquad \left[\frac{\mathrm{W}}{\mathrm{sr\ m^2\ m}}\right]$$

Planck's Law is a mathematical relationship formulated in 1900 by German physicist Max Planck to explain the spectral-energy distribution of radiation emitted by a blackbody (a hypothetical body that completely absorbs all radiant energy falling upon it, reaches some equilibrium temperature, and then reemits that energy as quickly as it absorbs it).

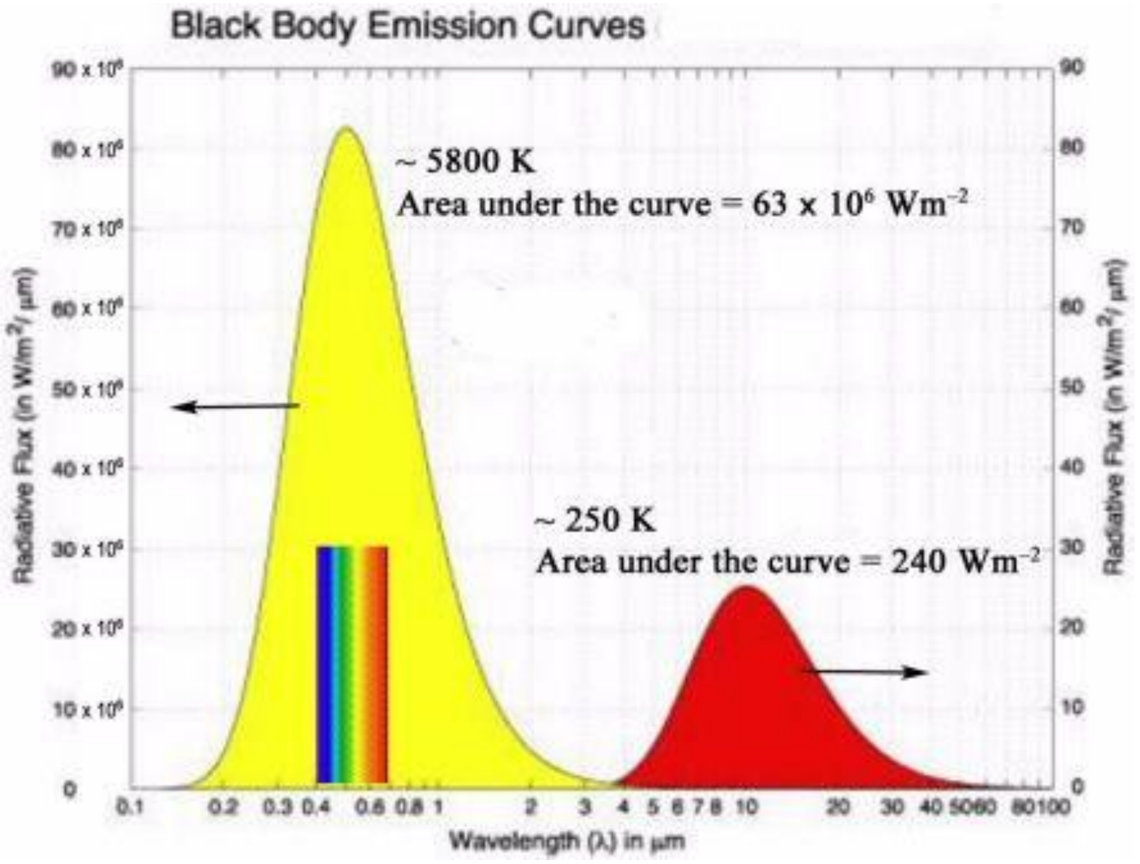


1) Radiant emittance from the sun (T = 6000 K) varies from 0.2 nm to 3.0 nm and peaks at spectra of ~0.55 nm, with most energy coming from a wavelength of 0.3-0.7 nm (>50%). These wavelengths are loosely called “shortwave radiation” or “visible light”).

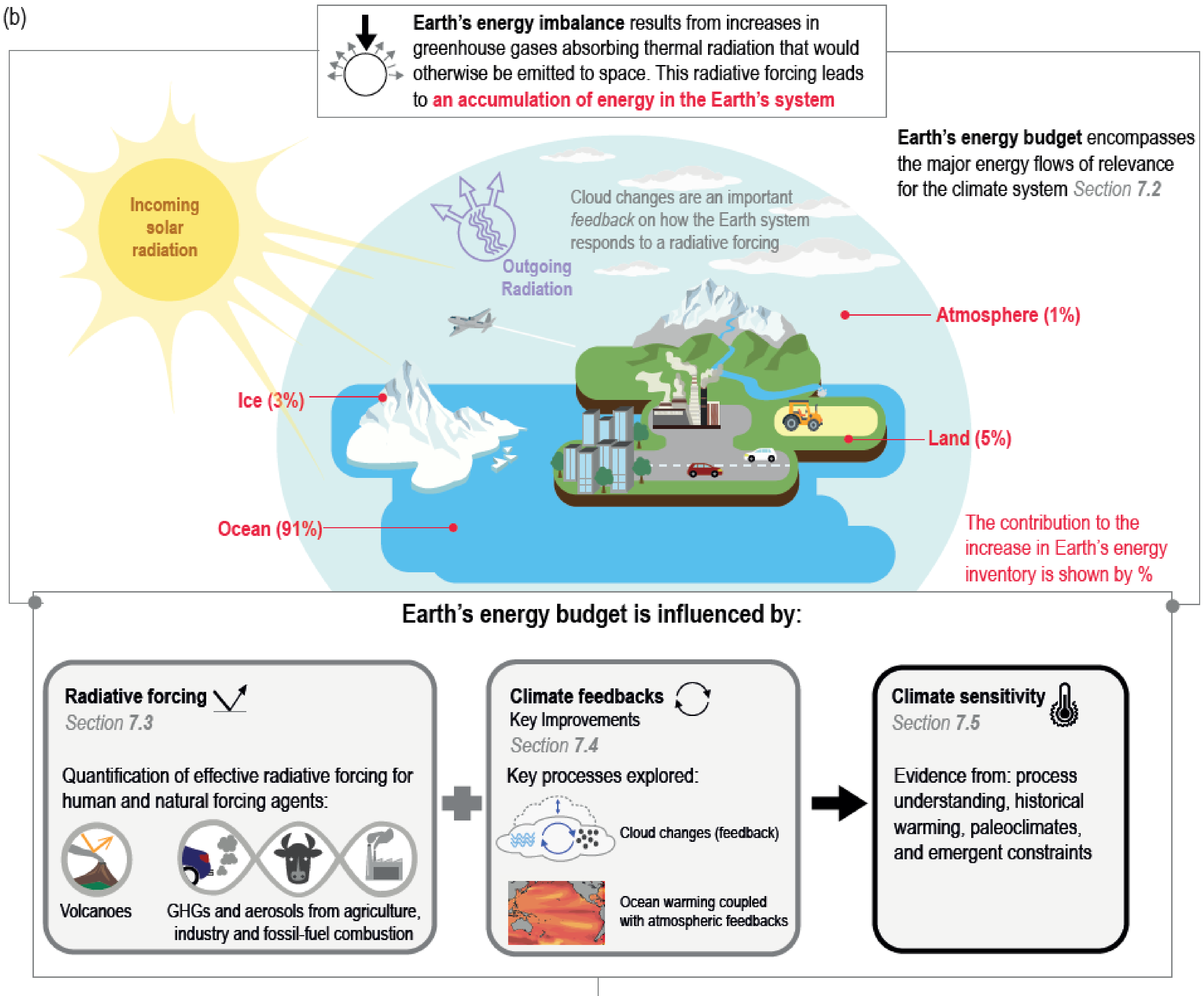
2) The Earth’s (T = 288 K) peak emittance is 9.5-10.0 nm. In sum, Earth’s temperature is mostly maintained by the balance of incoming shortwave radiation from the sun and outgoing longwave radiation from the Earth.

Quiz:
Why does it get warm inside a car?

[Greenhouse Effects]

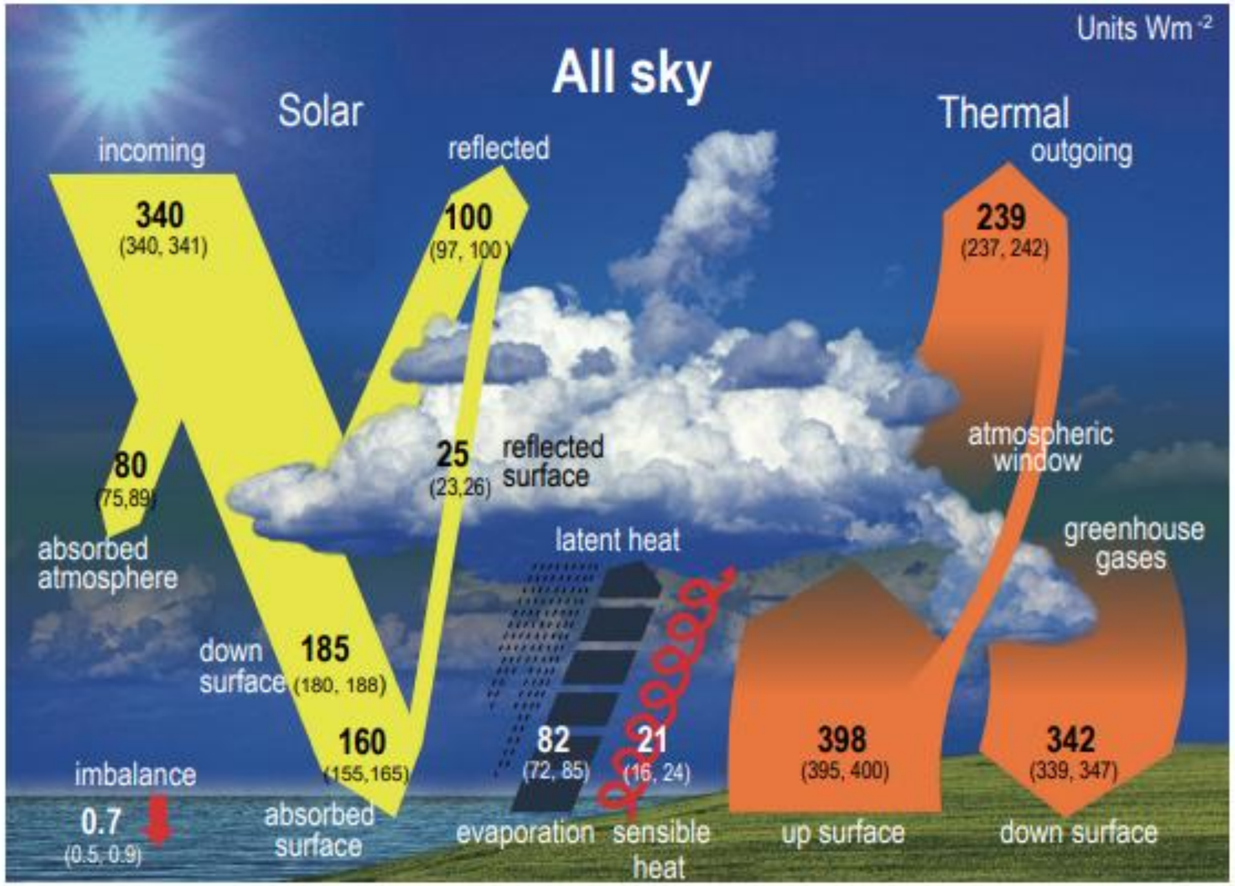


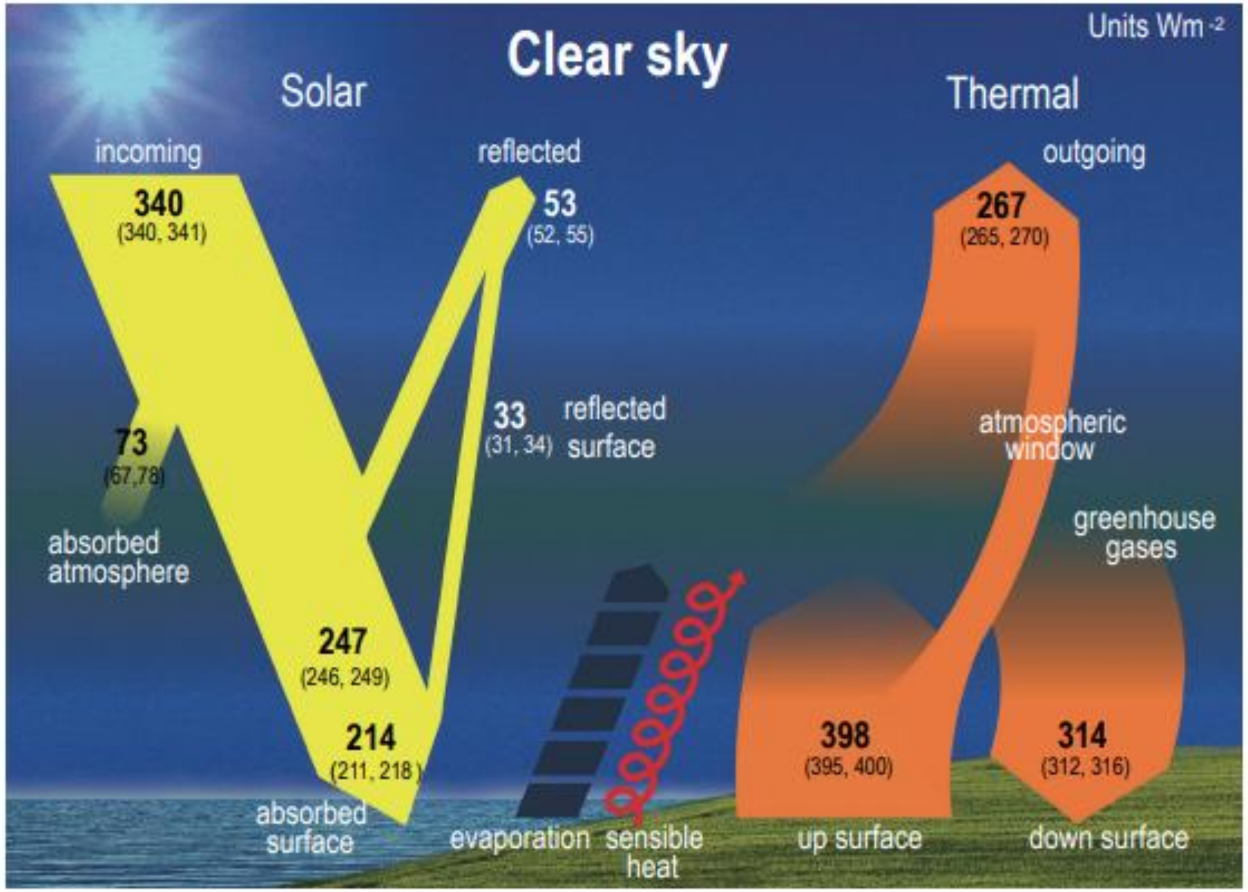
https://www.pinterest.com/pin/561964859722645297/



61964859722645297/

Figure 7.2 | Schematic representation of the global mean energy budget of the Earth. Numbers indicate best estimates for the magnitudes of the globally averaged energy balance components in W m^{-2} together with their uncertainty ranges in parentheses (5–95% confidence range), representing climate conditions at the beginning of the 21st century.





Major Terminology

Global Warming Potential (GWP)

Greenhouse Gases (GHG)

Earth System Models (ESMs)

Global Surface Air Temperature (GSAT)

Radiation Forcing (RF)

https://www.pinterest.com/pin/561964859722645297/

Study Questions

- How is the energy balance at the top of the atmosphere (TOA) determined?
- How are the Stefan–Boltzmann Law and Planck's Radiation Law applied to understanding Earth's temperature?
- Why is it difficult to accurately quantify the TOA energy budget?
- What is the greenhouse effect from a radiation perspective?
- Do volcanoes, or large wildfires, keep the Earth warmer or cooler?

GEO409-FS2026 (3 credits)

Sep 14: Greenhouse Effects on Global Climate & Change

- What is greenhouse effect?
- Major Greenhouse Gases (GHG)

Reading

Chen, J., C. Lei, and P. Sciusco, 2021. Modeling Ecosystem Global Warming Potentials. In *Biophysical Models and Applications in Ecosystem Analysis* (pp. 121-126). MSU Press.