Lecture 2
9 January 2025

CM 615

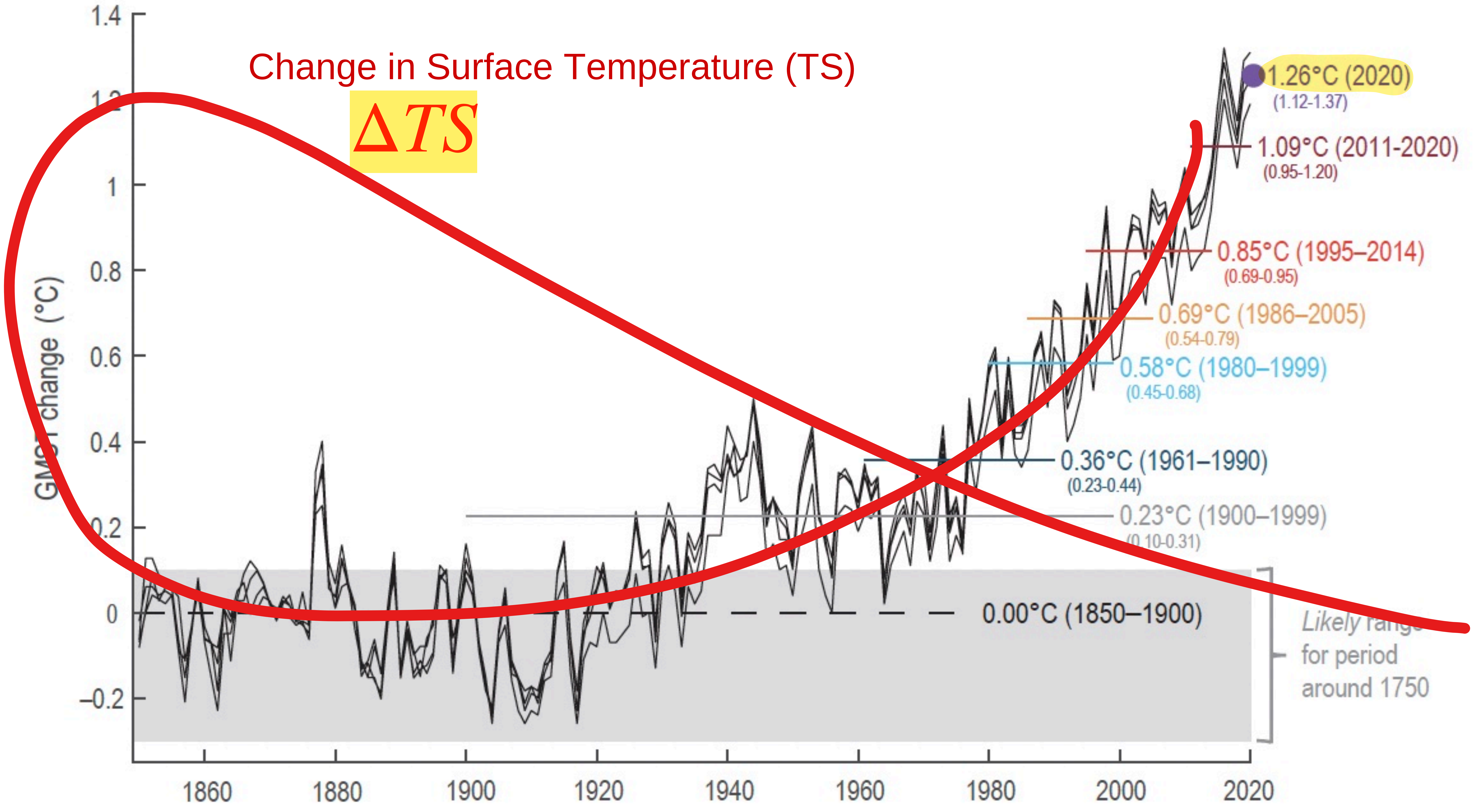
Climate change Impacts & Adaptation

Introduction to the course

Angshuman Modak
Climate Studies, IIT Bombay

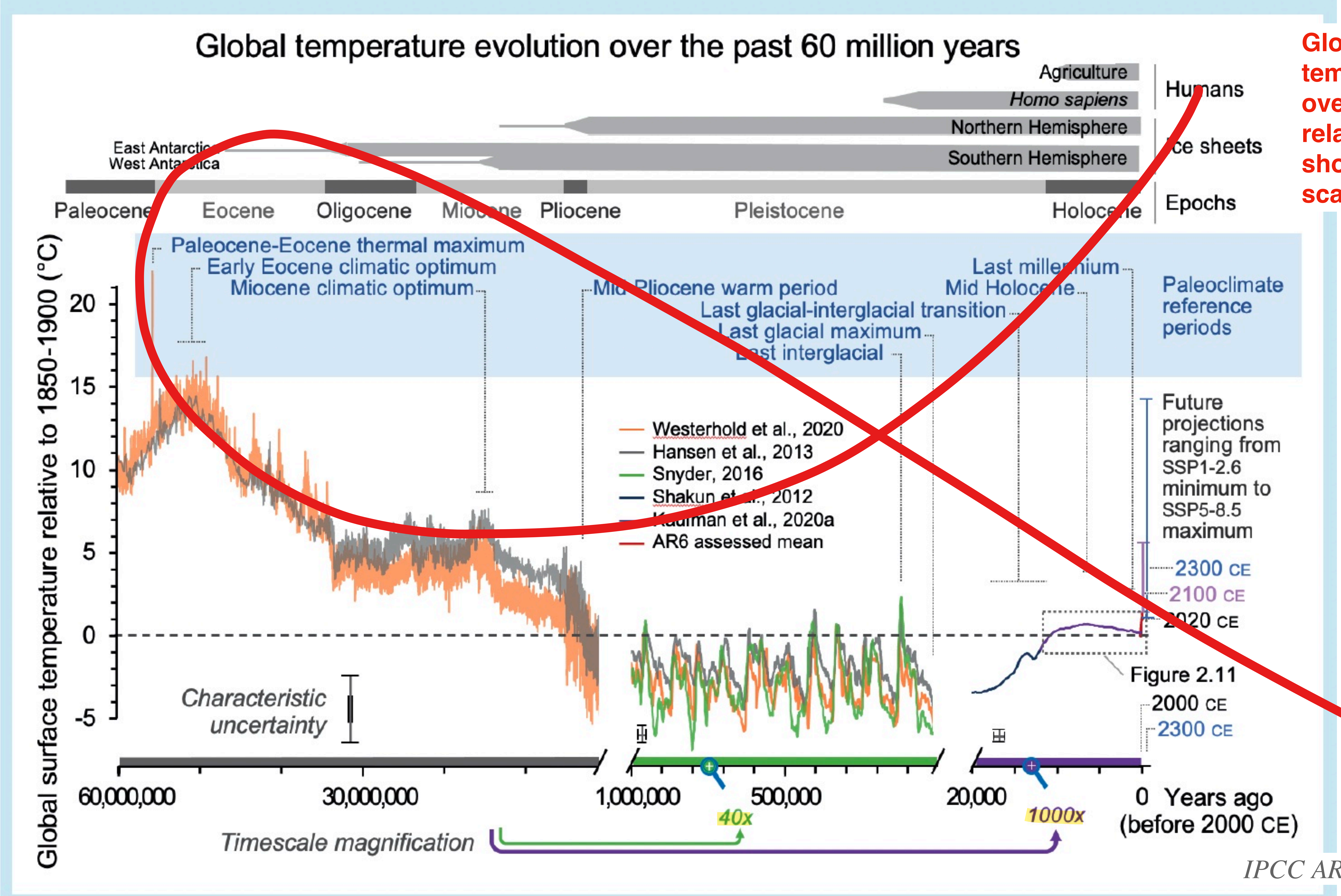
Observed global mean surface temperature change

Relative to 1850–1900 using four datasets



Created by
Angshuman Modak

IPCC AR6, Chen et al. 2021

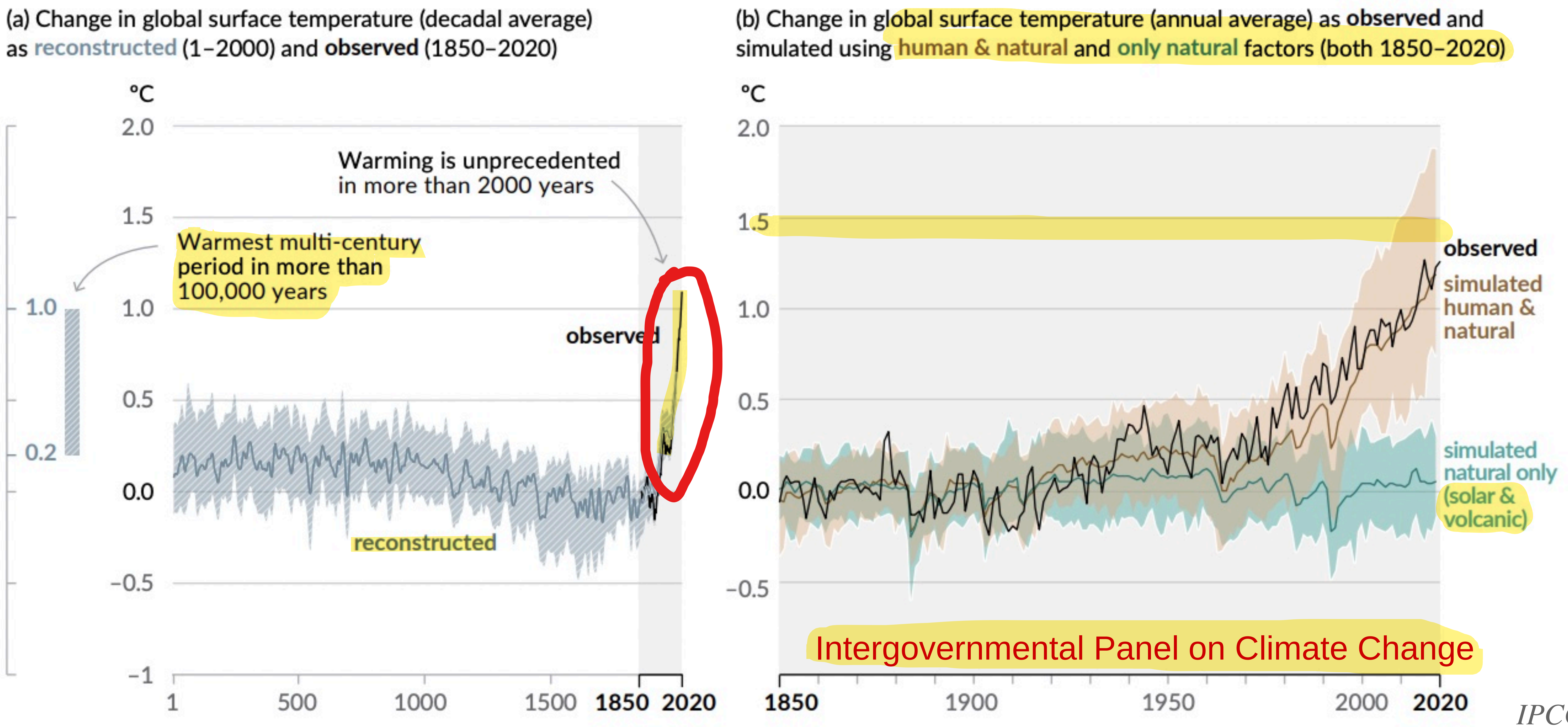


Global mean surface temperature (GMST) over the past 60 Myr relative to 1850–1900 shown on three time scales

IPCC AR6, Chen et al. 2021

Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years

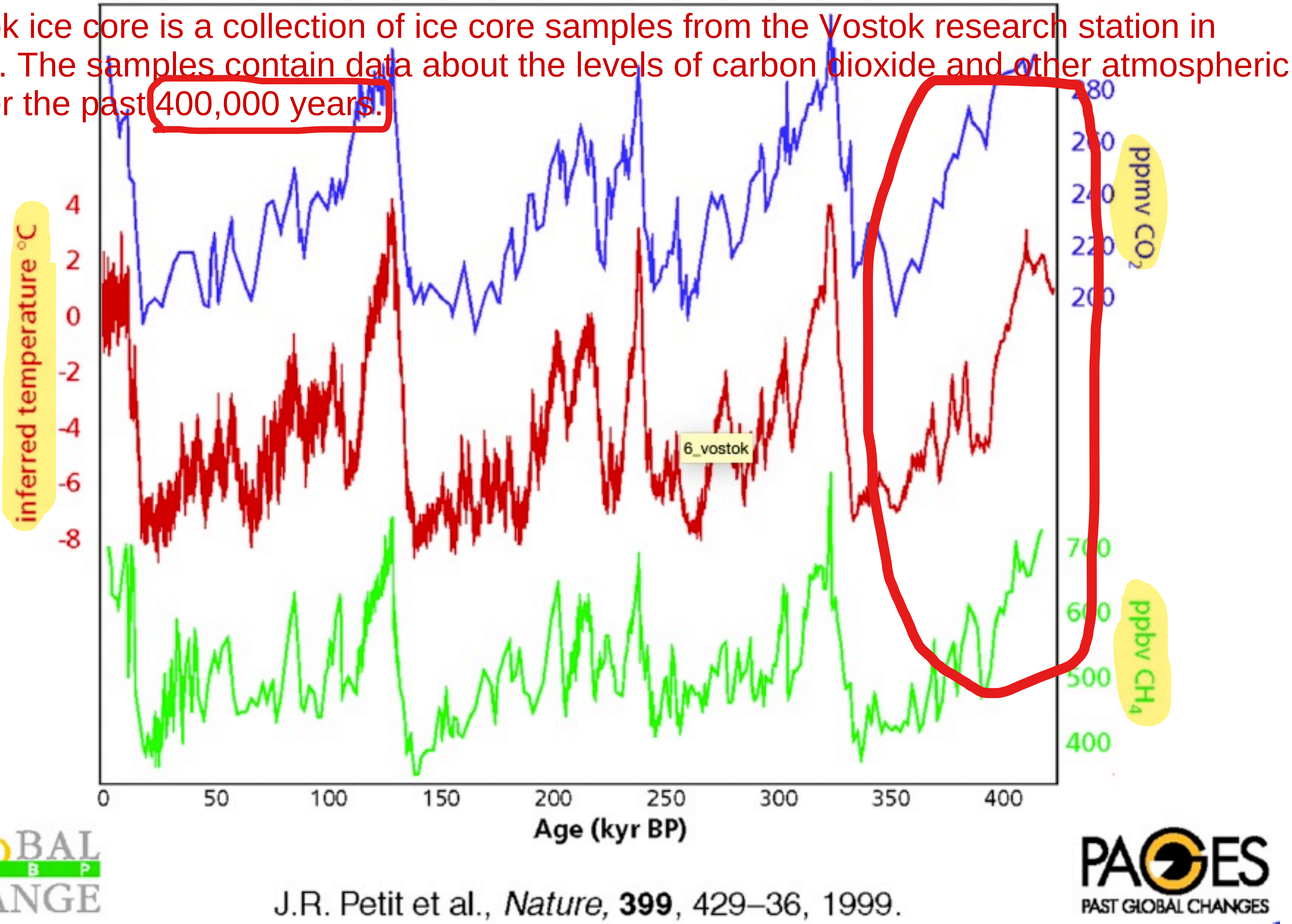
Changes in global surface temperature relative to 1850–1900



IPCC AR6, SPM

4 glacial cycles recorded in the Vostok ice core

The Vostok ice core is a collection of ice core samples from the Vostok research station in Antarctica. The samples contain data about the levels of carbon dioxide and other atmospheric gases over the past 400,000 years.



J.R. Petit et al., *Nature*, **399**, 429–36, 1999.

The glacial cycles are triggered by the changes in the earth's orbit

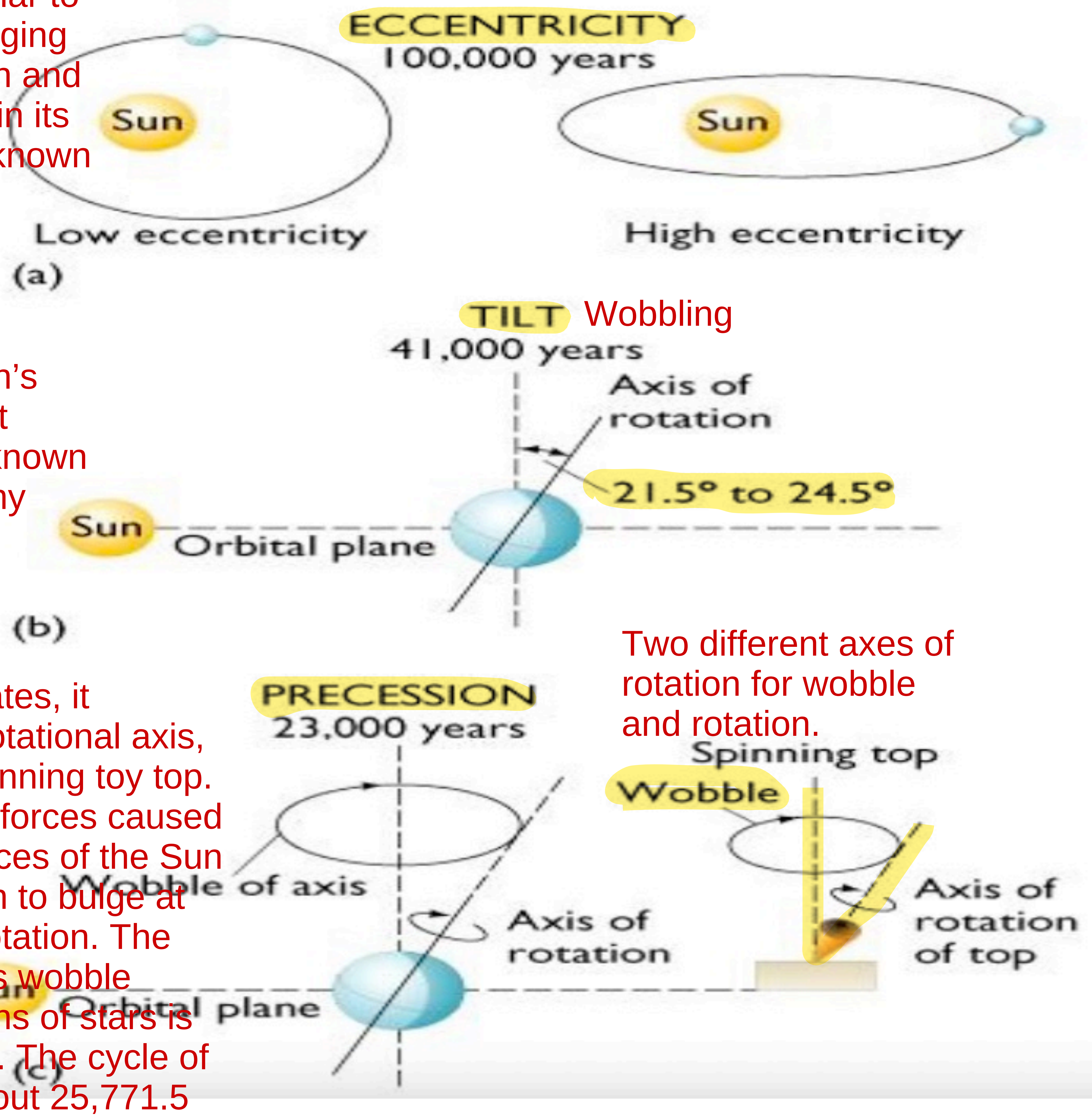
Pilgrimage - A pilgrim's journey

Earth's eccentricity changes primarily due to the gravitational pull exerted by other planets in our solar system, most notably Jupiter and Saturn, which cause the shape of Earth's orbit to vary over time from nearly circular to slightly elliptical, thus changing the distance between Earth and the Sun at different points in its orbit; this phenomenon is known as a Milankovitch cycle.

$0.0034 < e < 0.058$

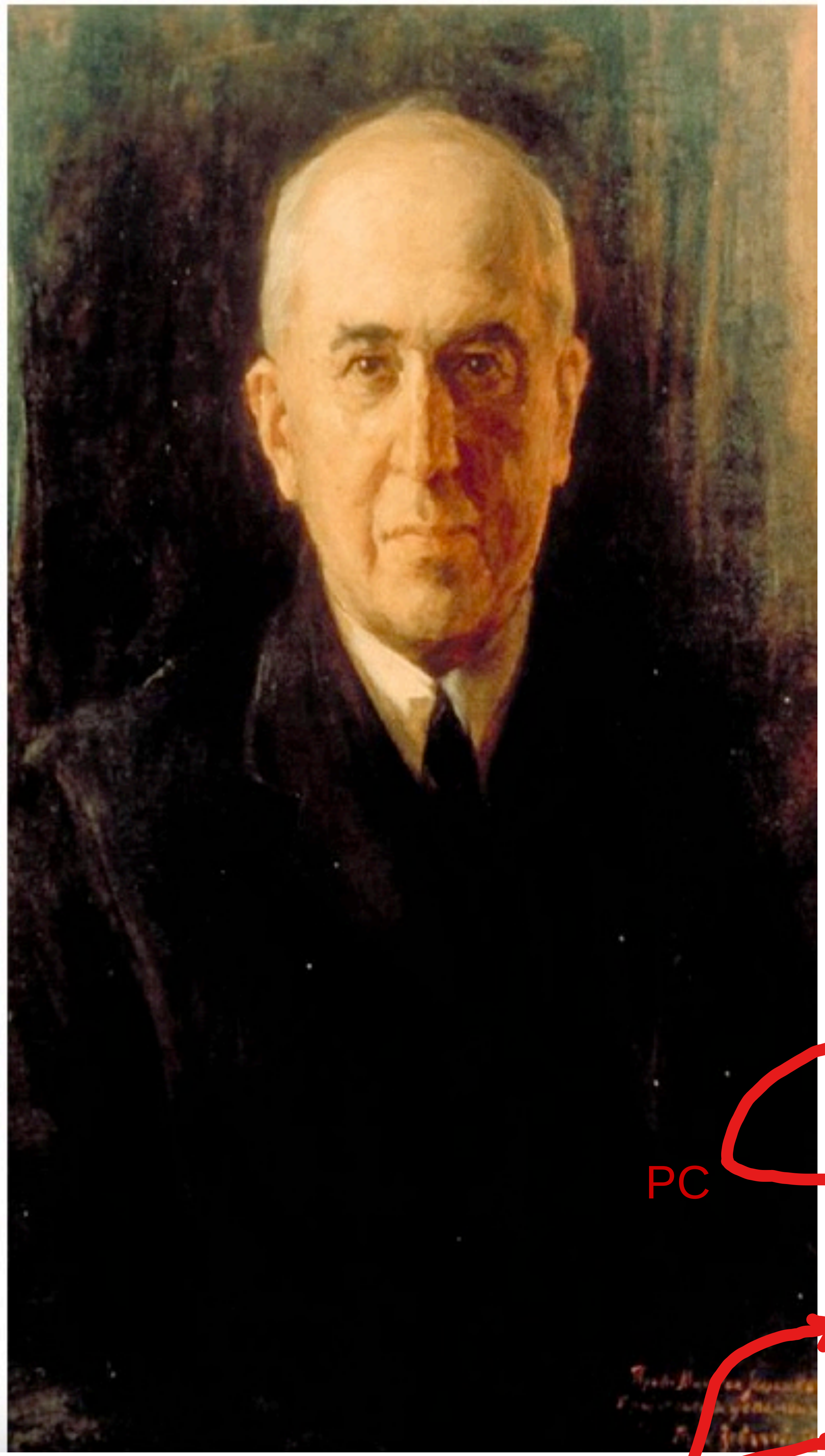
Obliquity – The angle Earth's axis of rotation is tilted as it travels around the Sun is known as obliquity. Obliquity is why Earth has seasons.

Precession – As Earth rotates, it wobbles slightly upon its rotational axis, like a slightly off-center spinning toy top. This wobble is due to tidal forces caused by the gravitational influences of the Sun and Moon that cause Earth to bulge at the equator, affecting its rotation. The trend in the direction of this wobble relative to the fixed positions of stars is known as axial precession. The cycle of axial precession spans about 25,771.5 years.



Wobbling

Two different axes of rotation for wobble and rotation.



https://science.nasa.gov/science-research/earth-science/milankovitch-orbital-cycles-and-their-role-in-earths-climate/

Glaciation periods = Ice Ages

Solar Radiation = Insolation

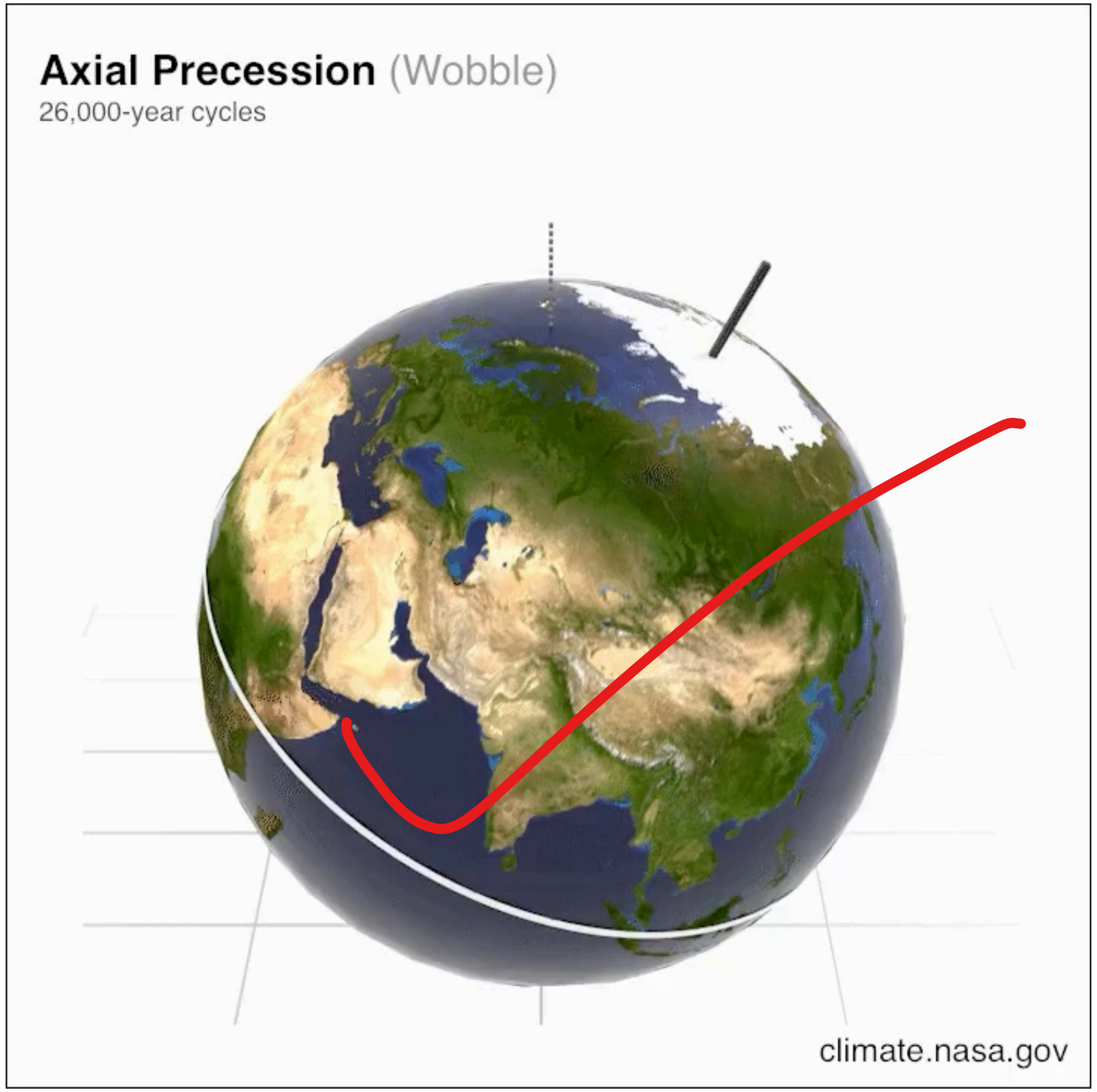
Mid-Latitudes = The areas of our planet located between about 30 and 60 degrees north and south of the equator

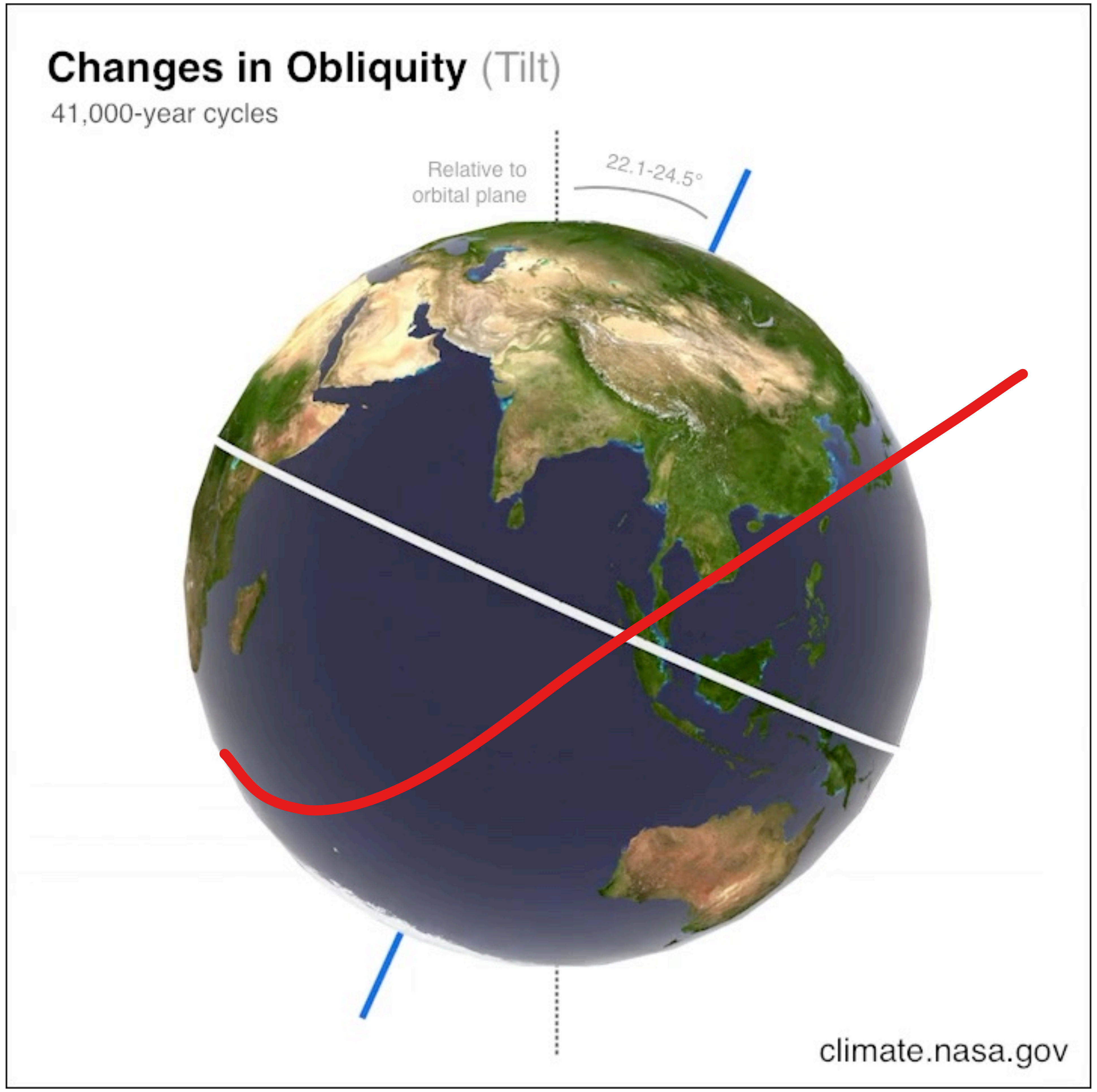
PC

Earth's closest approach to the Sun = Perihelion (about January 3 each year)

FA

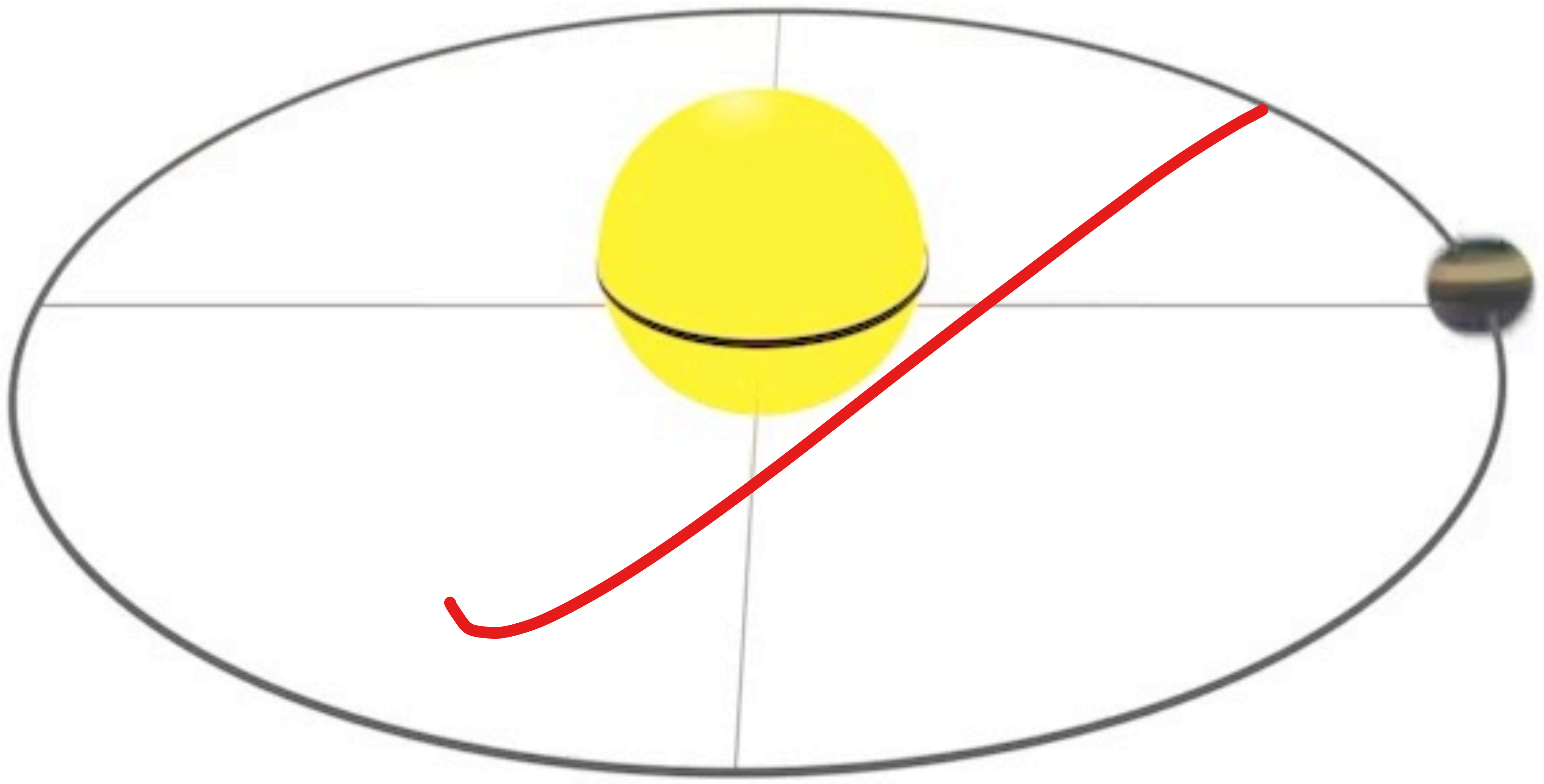
Farthest departure from the Sun = Aphelion (on or about July 4)


Axial Precession (Wobble)
26,000-year cycles
climate.nasa.gov


Changes in Obliquity (Tilt)
41,000-year cycles
Relative to orbital plane
22.1-24.5°
climate.nasa.gov

Changes in Eccentricity (Orbit Shape)

100,000-year cycles

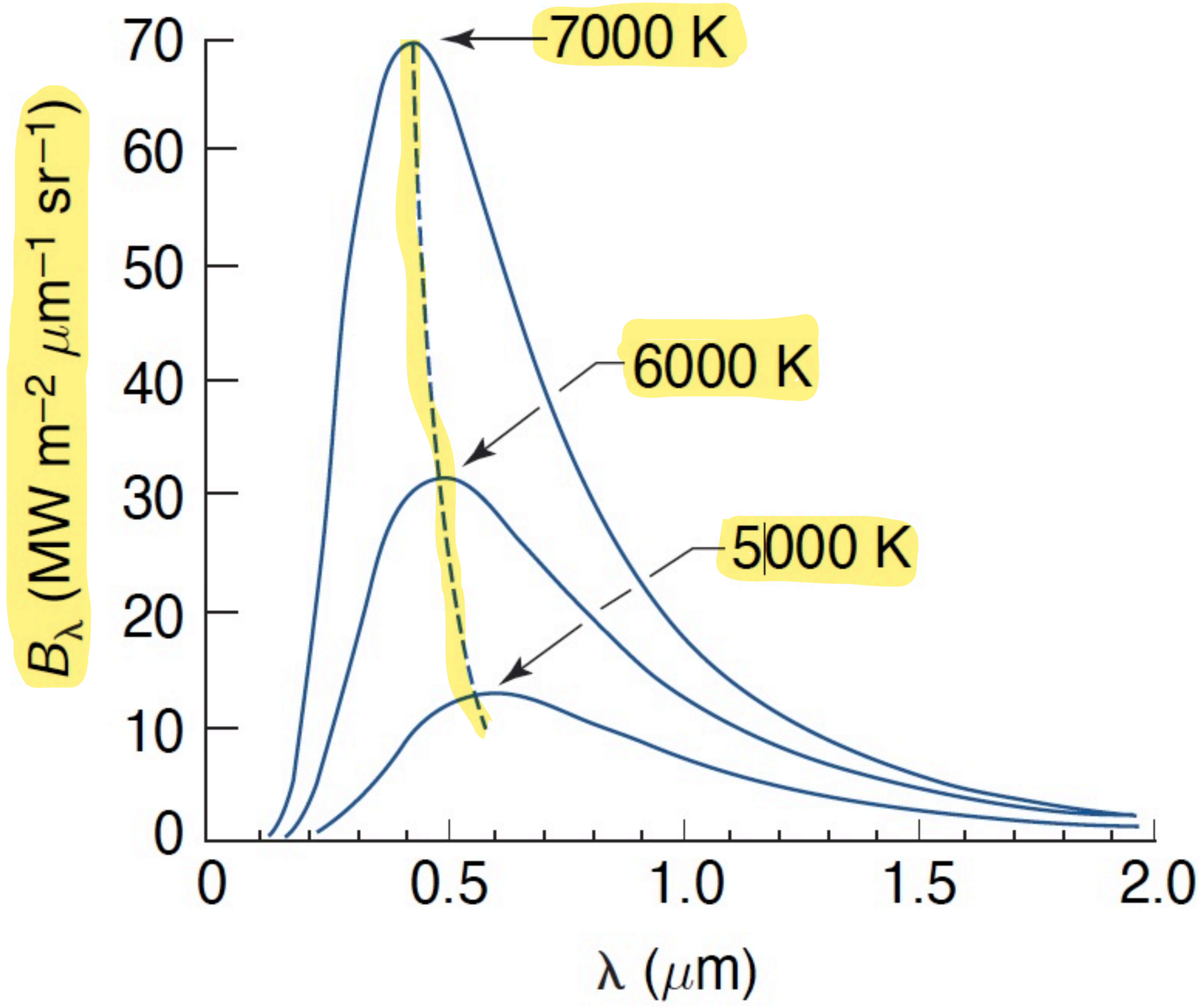


*Changes in eccentricity exaggerated so the effect can be seen. Earth's orbit shape varies between 0.0034 (almost a perfect circle) to 0.058 (slightly elliptical).

climate.nasa.gov

Stefan-Boltzmann Law

Connecting the peaks => The maxima of subsequent curves shift right



Insolation

Intensity of radiation emitted by a blackbody

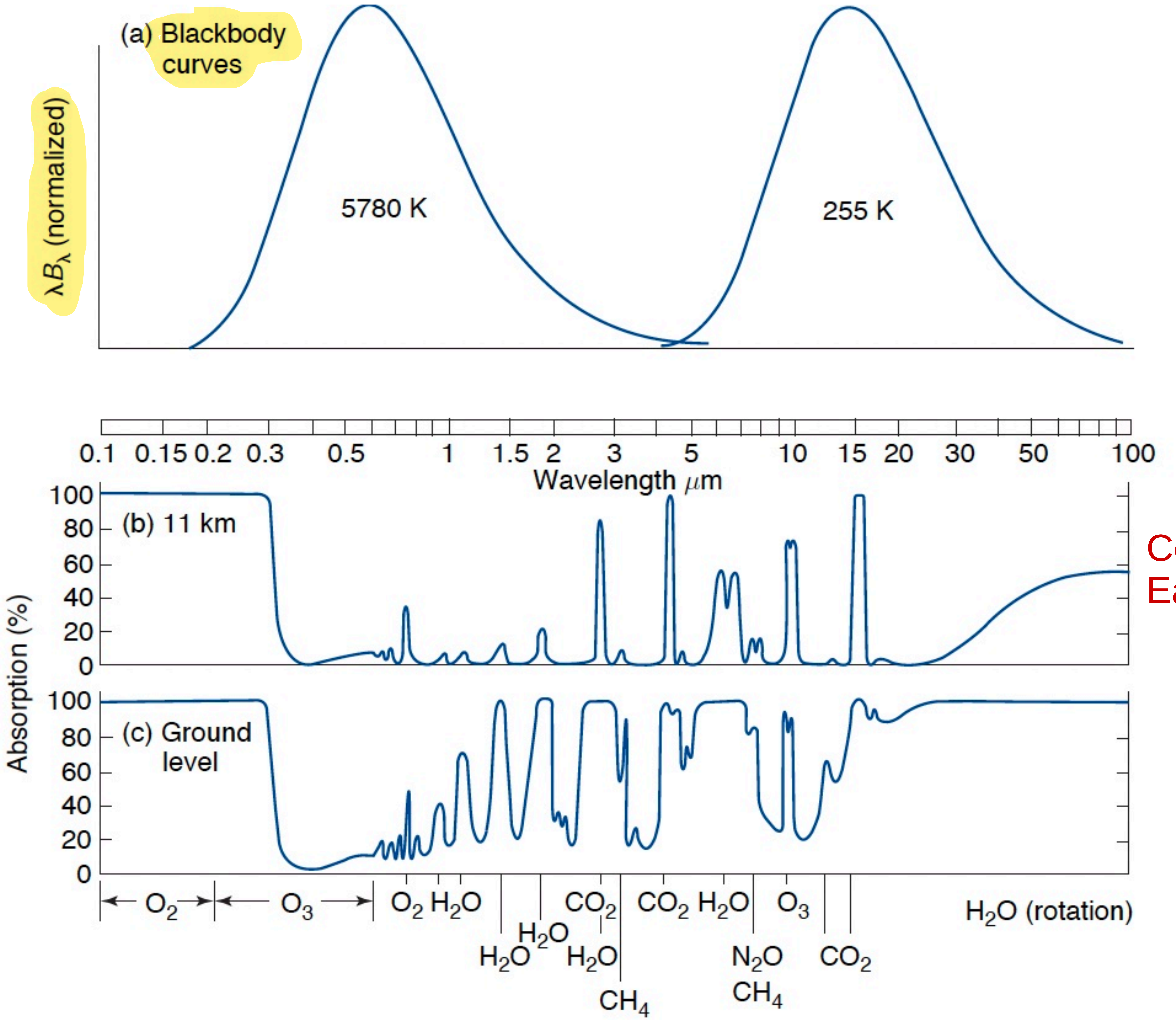
The Planck's Function

$$\boxed{e_{\lambda b} = \frac{2\pi hc^2}{\lambda^5[e^{hc/\lambda kT} - 1]}}$$

E = hc/lambda

Wallace and Hobbs

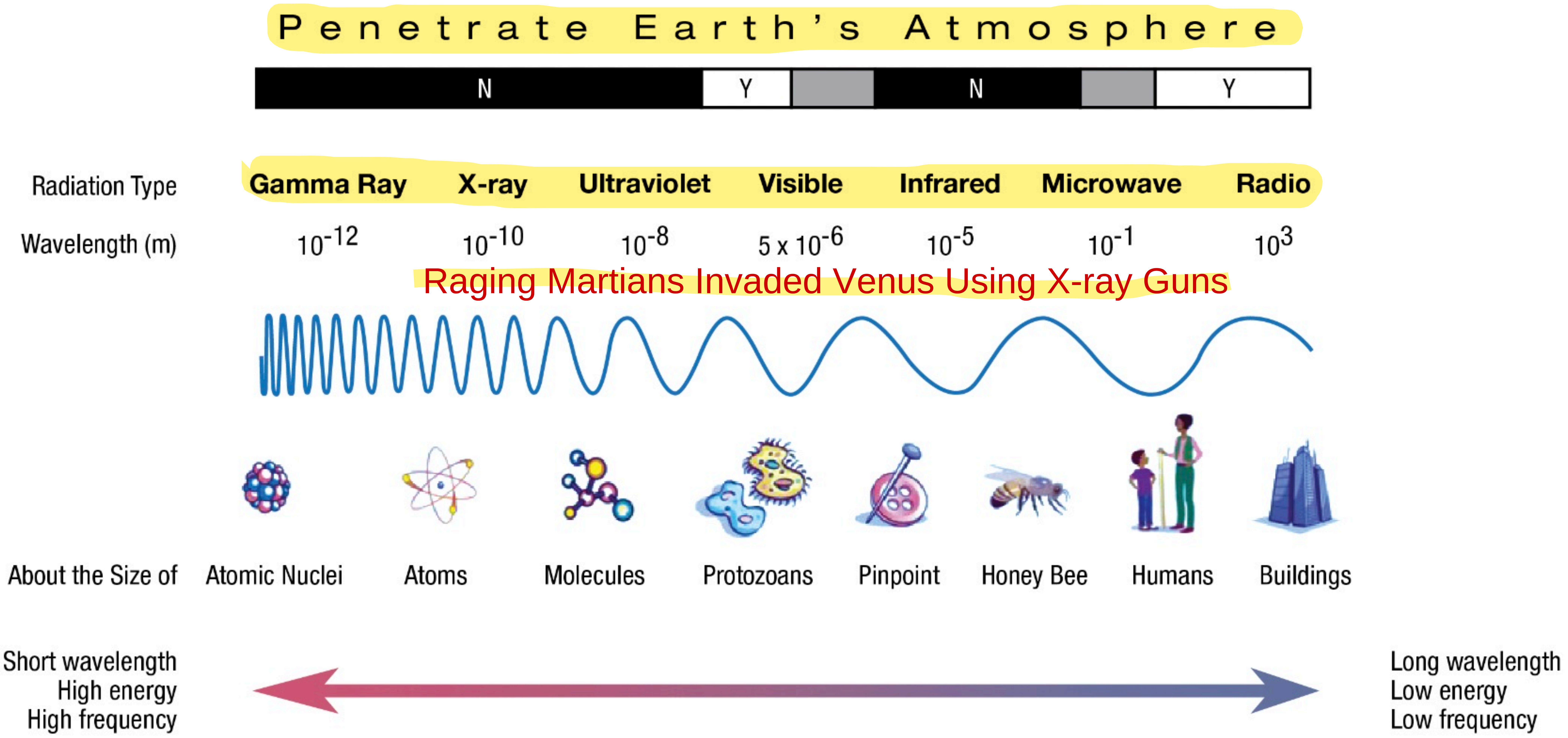
Stefan-Boltzmann Law



Concentration of various species within Earth's ecosystem.

Wallace and Hobbs

THE ELECTROMAGNETIC SPECTRUM



The Electromagnetic Spectrum. Image Credit: NASA

Wavelength ranges

0.1 - 0.2 μm - Far UV

0.2 - 0.4 μm - UV

0.4 - 0.7 μm - Visible

0.7 - 4.0 μm - Near-IR

4.0 - 40.0 μm - Middle IR

40.0 - 500 μm - Far IR

500 - 10^6 μm - Microwave

> 10^6 μm - Radiowaves

?

Stefan-Boltzmann Law

The blackbody flux density/irradiance obtained by integrating the Planck's function over all wavelengths is given by the Stefan–Boltzmann law $e_b = \sigma T^4$

$$\sigma = \frac{2\pi^5 k^4}{15 h^3 c^2}$$

Planck's function basis for quantum mechanics

(Hemispherical) Emissive power of a blackbody —> $e_{\lambda b} = \dfrac{2\pi h c^2}{\lambda^5 [e^{hc/\lambda kT} - 1]}$

Solar constant

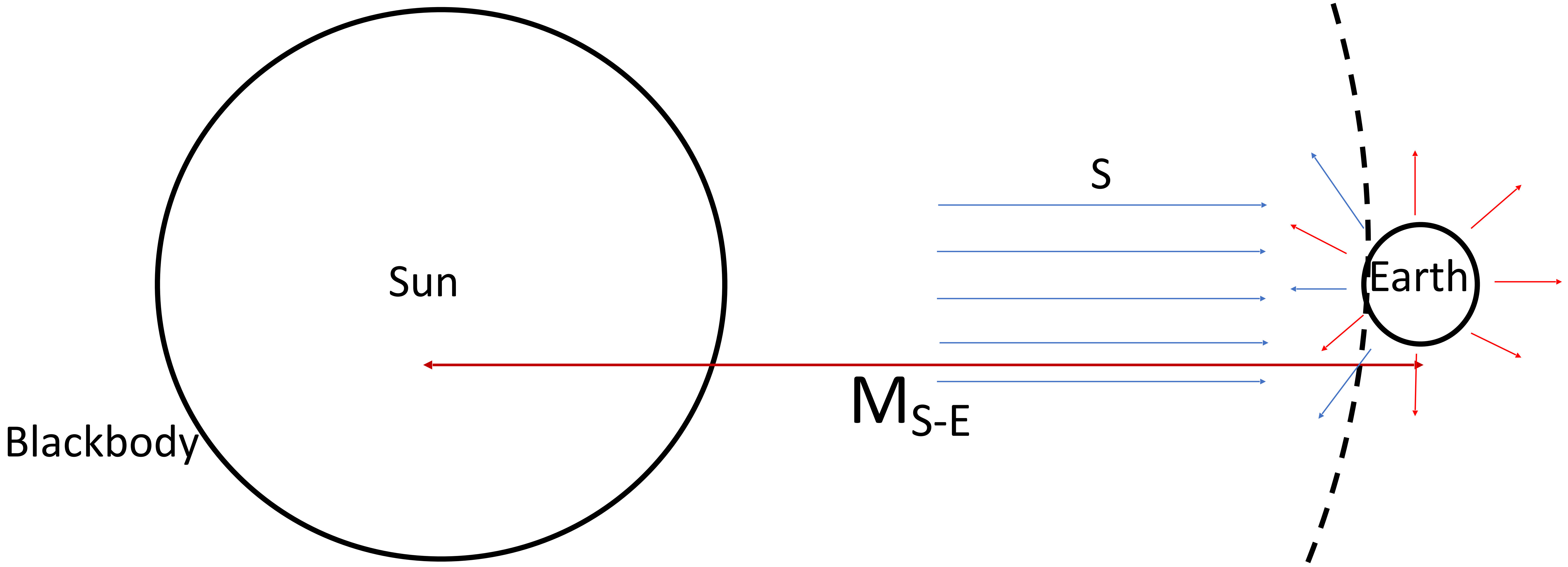
Radiation incident − reflected back radiation = radiation emitted by Earth

$$S\,\pi R_E^2 - \alpha\,S\,\pi R_E^2 - \sigma T_E^4\,4\pi R_E^2 = 0$$

$$\underset{(S)}{Solar\ constant} = \frac{4\pi R_{SUN}^2 \cdot \sigma T_{SUN}^4}{4\pi M_{S-E}^2}$$

$$= 1365\ Wm^{-2}$$

S = 1365 W/m2



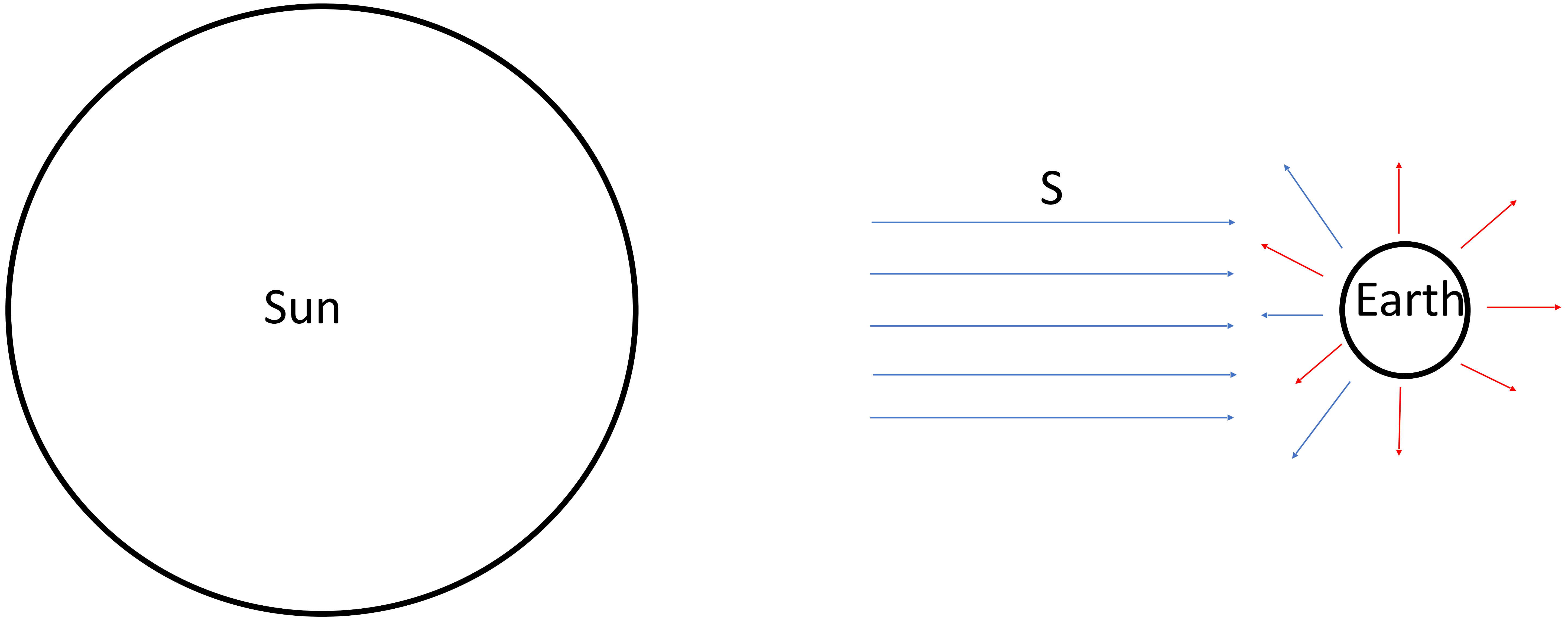
$T_{SUN} = 5778K \approx 6000K$

$$R_S = 6.96\ \times\ 10^8\ m$$

$$M_{S-E} = 1.496\ \times\ 10^{11}\ m$$

Energy balance (N)

$$\boxed{\frac{S}{4}(1-\alpha) = \sigma T_E^4}$$



Here, T_E is the effective radiating temperature of Earth or emission temperature.

Assuming a single uniform temperature.

$$S = 1365\ Wm^{-2}$$

$$\alpha = 0.29$$

$T_E = 255\ K$

Currently, the global mean temperature of earth is around

$T_S = 288\ K$

$T_S - T_E = 33\ K$

Greenhouse effect

Greenhouse effect and greenhouse gases

Currently, the global mean surface temperature of earth is around

$T_S = 289K, T_E = 255K$

Greenhouse effect

$\sigma T_S^4 - \sigma T_E^4 \approx 150Wm^{-2}$

Atmosphere, with interesting gases. The major gases like the Nitrogen, Oxygen, Argon 99.9% but the minor gases play the role of this effect, H2O, CO2, CH4, N2O,… As these gases have strong absorptions

So, we need to develop our simple model. Perhaps we can start with a model with single layer atmosphere.


Solar Insolation
(1 month)
340Wm − 2
Insolation (W/m²)
0
275
550
Jul 2006
2006
2013

Reflected Shortwave Radiation
(1 month)

$100Wm-2$

Albedo
(1 month)

30 %


Outgoing Longwave Radiation
(1 month)
239Wm – 2
Outgoing Longwave Radiation (W/m²)
85
218
350
Jul 2006
2006
2013

Net Radiation
(1 month)

$\approx 1Wm - 2$

The Inter-Tropical Convergence Zone (ITCZ) is a low-pressure band of clouds that encircles the Earth near the equator. It's where the trade winds of the Northern and Southern Hemispheres meet.

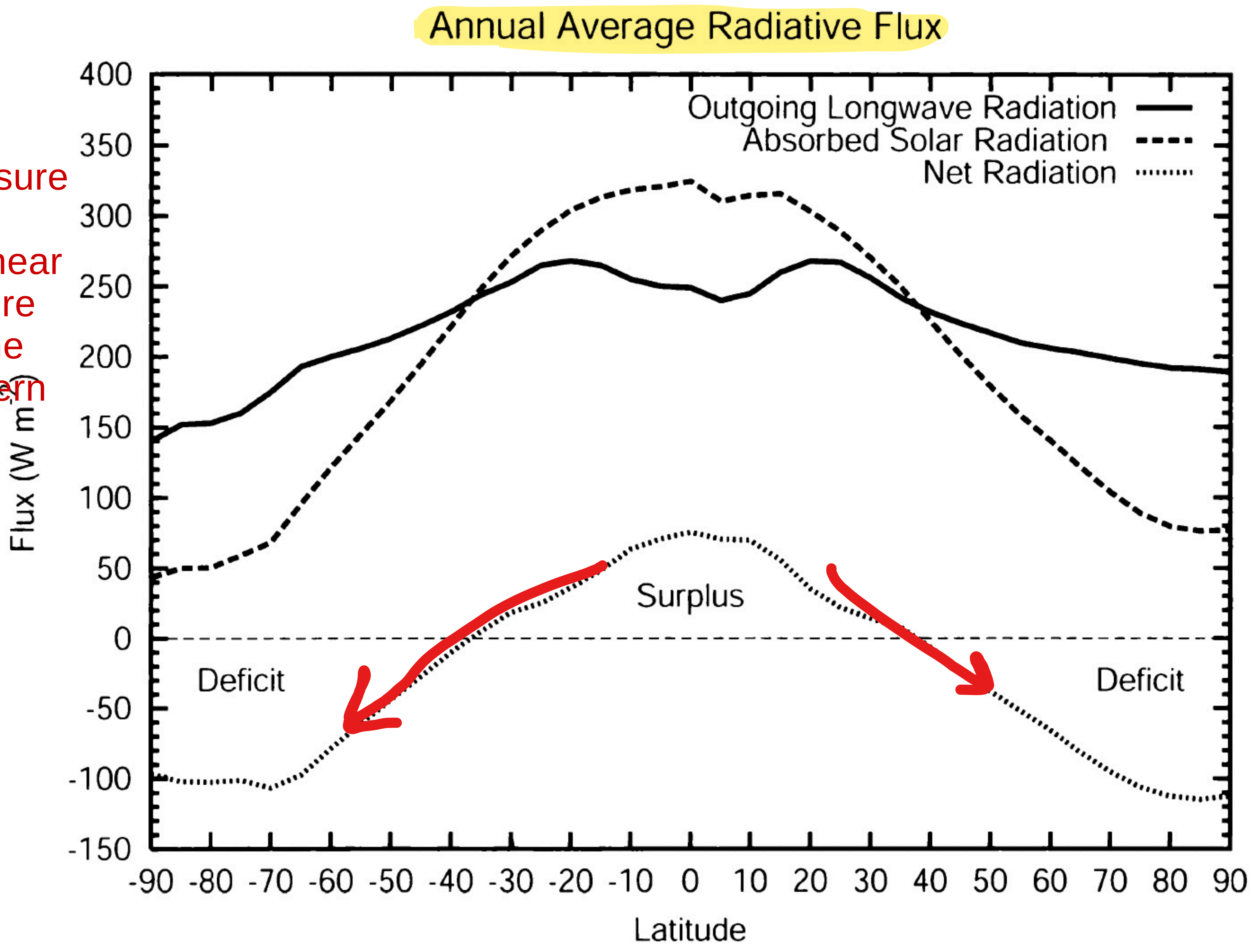


Fig. 1.1: Annual average radiation budget as a function of latitude.

What effect does the ITCZ have?

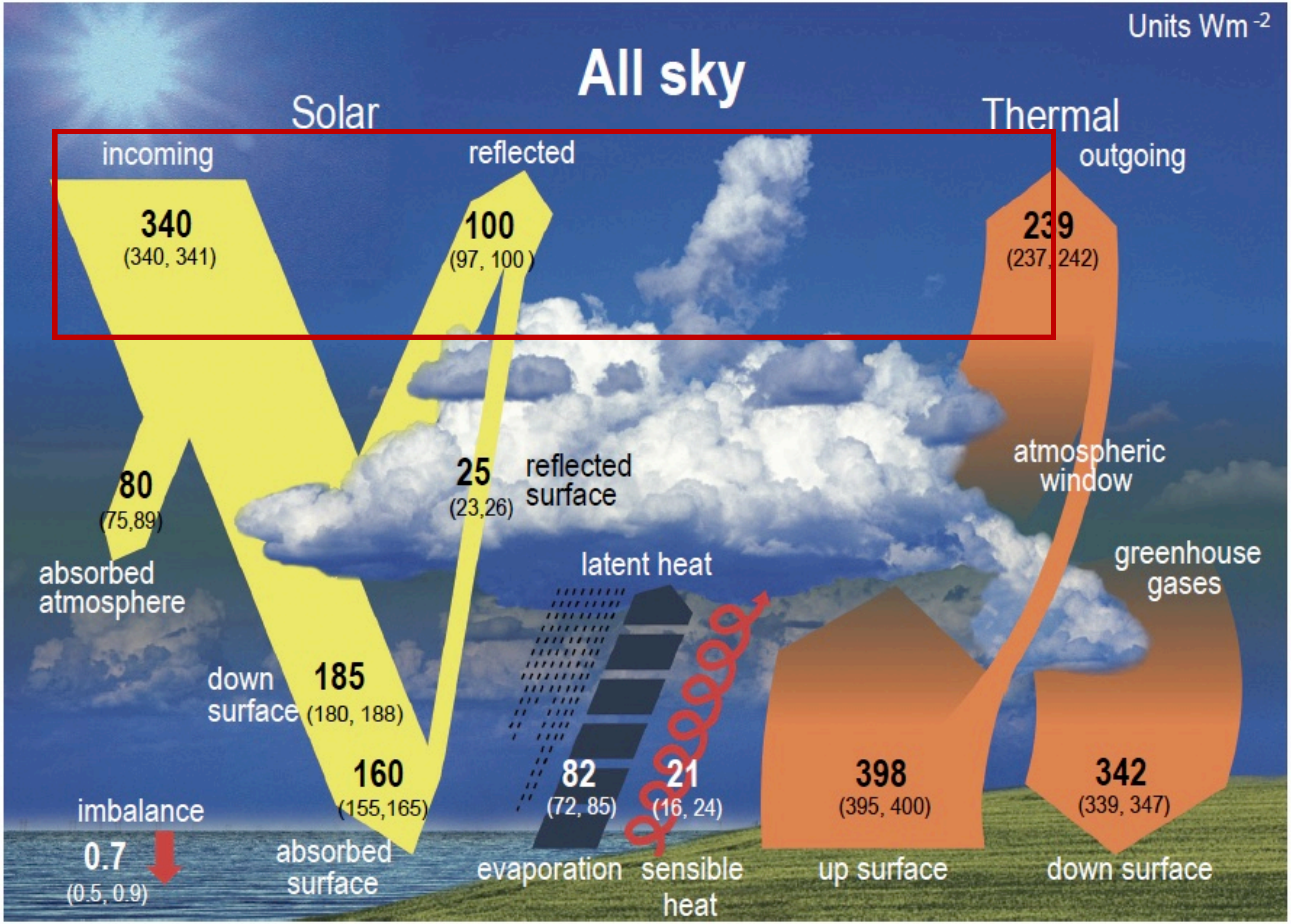
Wet and dry seasons: The ITCZ's seasonal shifts cause wet and dry seasons in the tropics.

Doldrums: Sailors call the ITCZ the doldrums because the area can be calm for weeks, making it difficult to sail.

Severe droughts or flooding: Longer term changes in the ITCZ can cause severe droughts or flooding.

IPCC AR6

Energy flows in the climate system



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Energy flows in the climate system