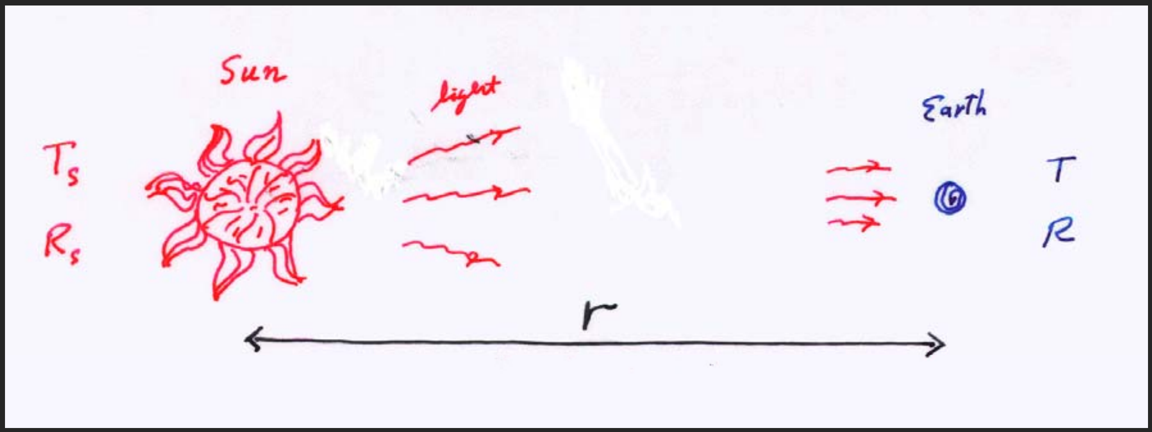
19. Solar Radiation and the Temperature of the Earth



Ts = 5800 K and $R_s = 6.96 \times 10^8$ m

$r = 1.50 \times 10^{11}$ m

T = ?? And $R = 6.37 \times 10^6$ m

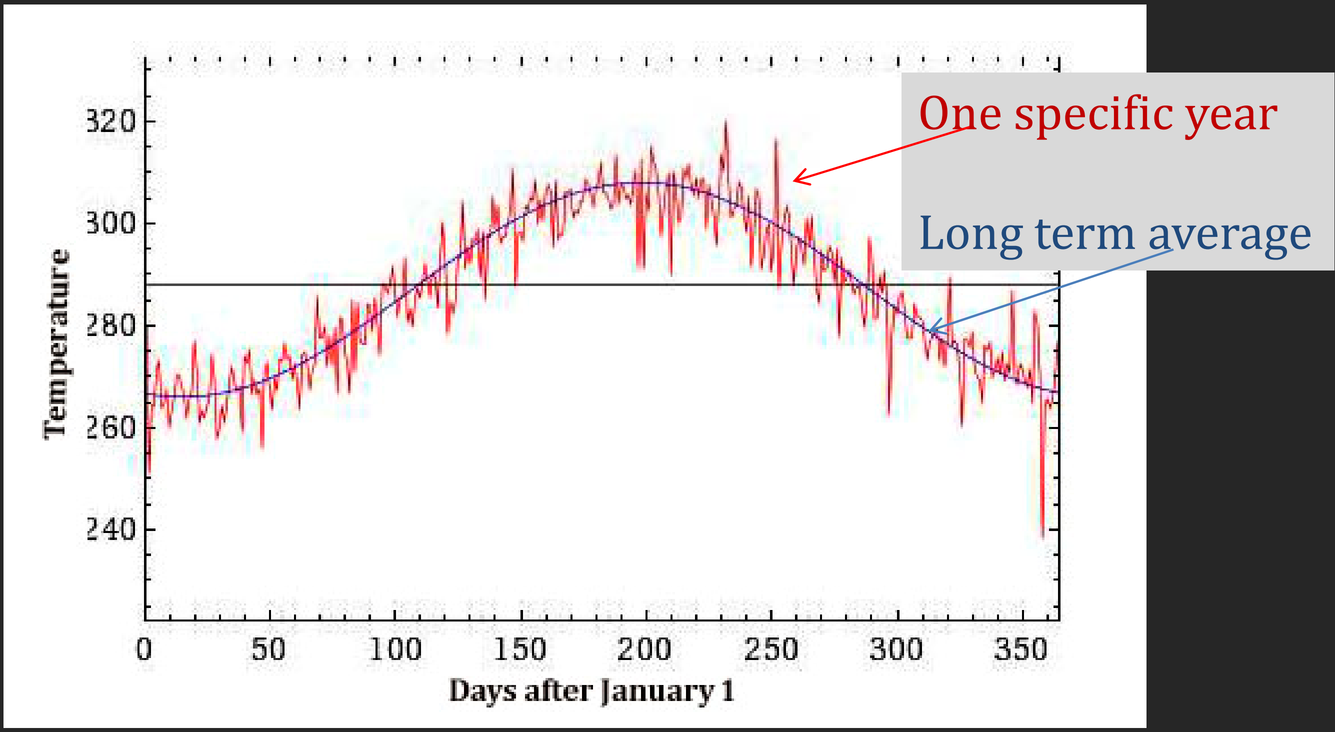
<u>What is the temperature of the Earth?</u>

Of course the temperature on Earth is highly variable, in both location and time ….

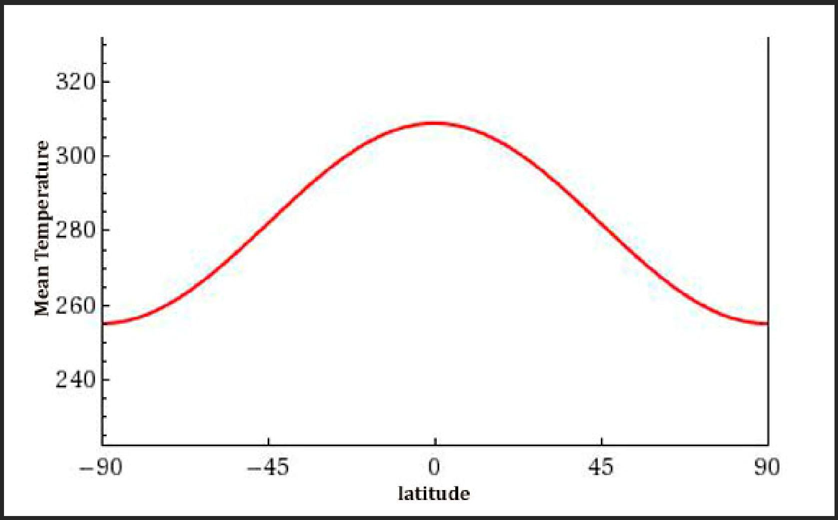
What're the hottest and coldest temperatures you ever experienced?

What is meant by “mean temperature”?

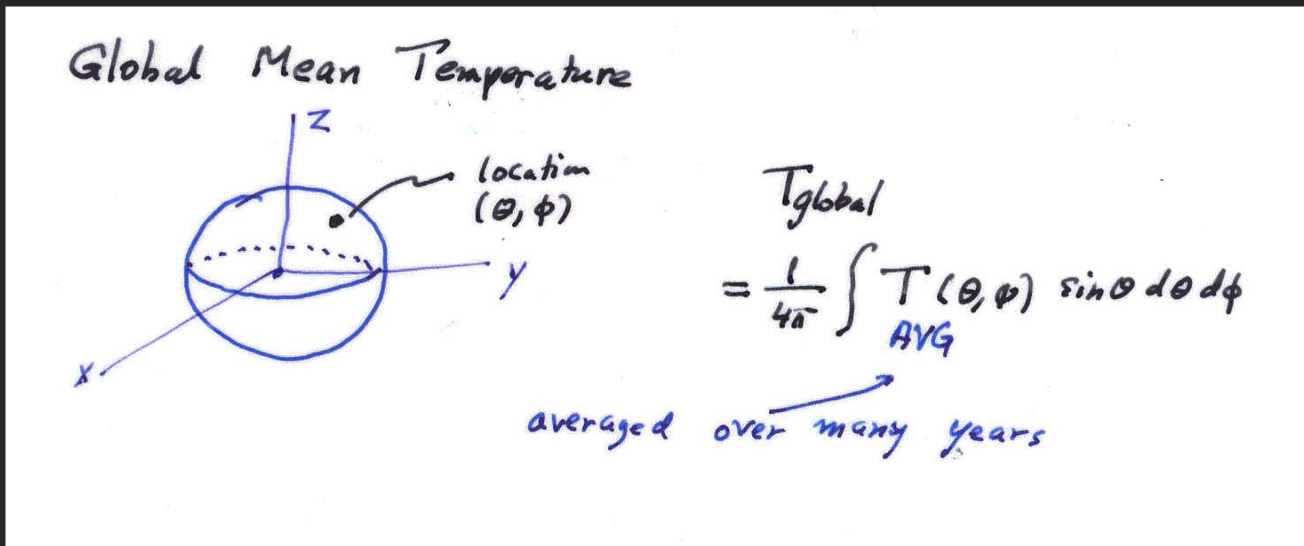
<u>Variation in time.</u> Take some location (e.g., MI)

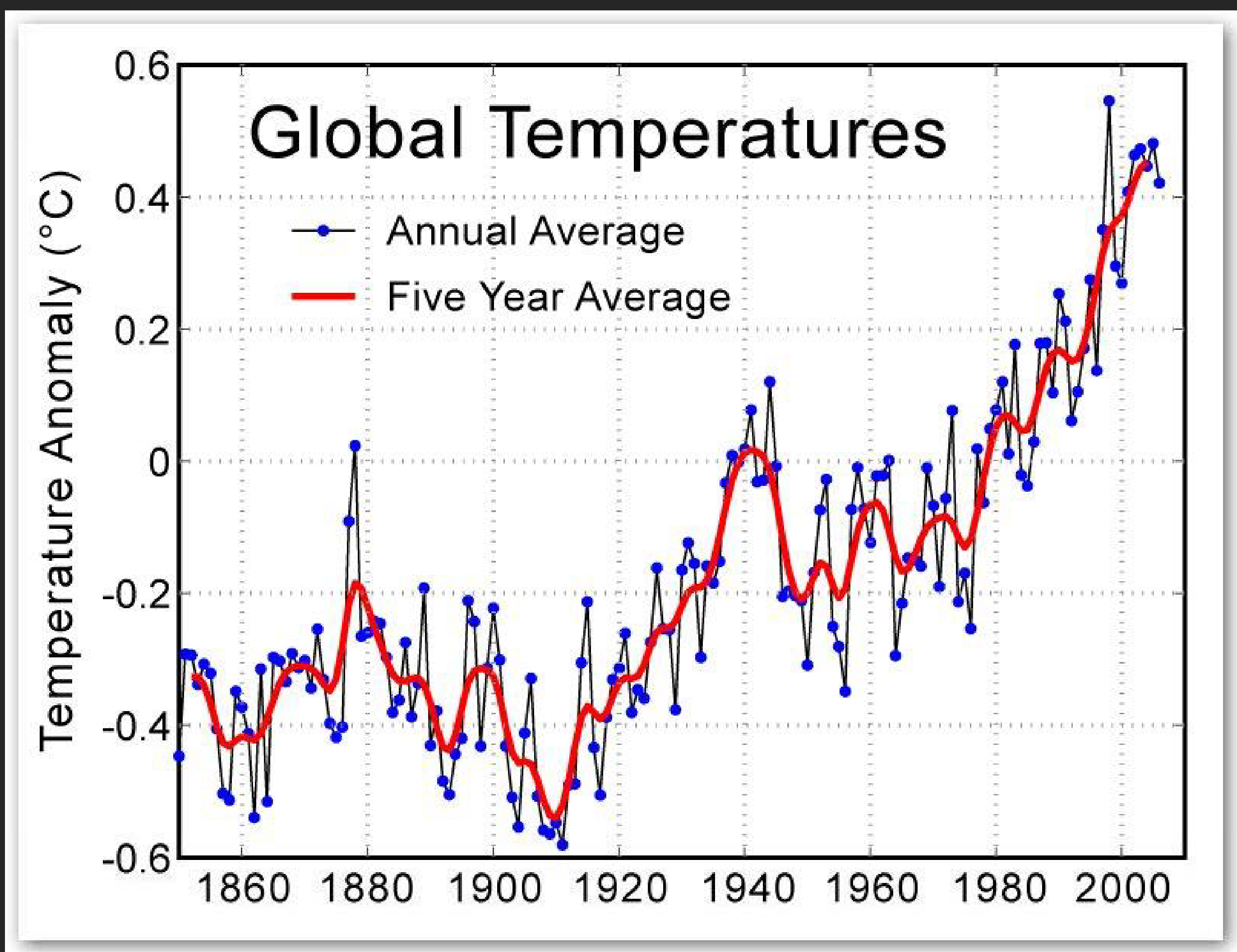


<u>Variation in location</u>



South Pole equator North Pole


Global Mean Temperature
z
location
(θ, φ)
y
x
T_global
= 1/4π ∫ T(θ, φ) sinθ dθ dφ
AVG
averaged over many years


Global Temperatures
Annual Average
Five Year Average
Temperature Anomaly (°C)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1860
1880
1900
1920
1940
1960
1980
2000

Let's try to calculate the temperature of the Earth

- Power from sun $= P_s = \sigma T_s^4 \cdot 4\pi R_s^2$

  $P_s = 3.91 \times 10^{26}$ W

- Energy flux at distance $r = S = \frac{P_s}{4\pi r^2}$

  $S = 1380$ W/m²

  (conservation of energy)

- Power incident on Earth $= P = S \cdot \pi R^2$ (projected area)

  $P = 1.76 \times 10^{17}$ W

Albedo

Let a = albedo = reflectivity = fraction of incident radiation that gets directly reflected back into space.
Note range: $0 \le a \le 1$ ***(pure black → → pure white)***
Over the surface of the Earth, a varies widely.
The global average is 0.31 .

- Power absorbed by Earth $P' = (1-a)\,P$

  $P' = 1.23 \times 10^{17}$ W a = albedo = 0.3 average

- Power radiated by the Earth $P_{rad.} = \sigma T^4 \cdot 4\pi R^2$

  (blackbody radiation)

Now, in the steady state

power in = power out

$$(1-a)\,P = \sigma T^4 \cdot 4\pi R^2$$

Thus
$$T = \left[\frac{(1-a)\,P}{4\pi R^2 \sigma}\right]^{1/4} = 255\ \text{K}$$

T of the Earth = 255 K ← prediction of the theory

What went wrong?

$$T_{observed} = 288 \text{ K} \qquad = 59\ °F$$

$$T_{calculated} = 255 \text{ K} \qquad = 0\ °F$$

$$(\Delta T)_{\substack{greenhouse\\ effect}} = +33 \text{ K} \qquad = 59\ °F$$

The greenhouse effect is a big deal.

Certain atmospheric molecules absorb infrared radiation from the Earth's surface. Therefore the temperature of the atmosphere is higher than the naive calculation.

We could apply the same calculation to other planets

	Earth	Venus	Mars	units
Mean orbital radius (r)	1.50×10^{11}	1.08×10^{11}	2.28×10^{11}	m
albedo (global average)	0.31	0.75	0.22	-
calculated T	254	232	212	K
observed T	288	740	218	K
greenhouse effect	+34	+508	+6	K

Naive calculation of T ...

$$(1-a)\, P_{\text{from sun}} = P_{\text{radiated}}$$

$$(1-a)\, \frac{\sigma T_s^4 \cdot 4\pi R_s^2}{4\pi r^2}\, \pi R^2 = \sigma T^4 \cdot 4\pi R^2$$

$$T^4 = \frac{(1-a)\, T_s^4 R_s^2}{4 r^2}$$

(SIMPLEST CALCULATION)