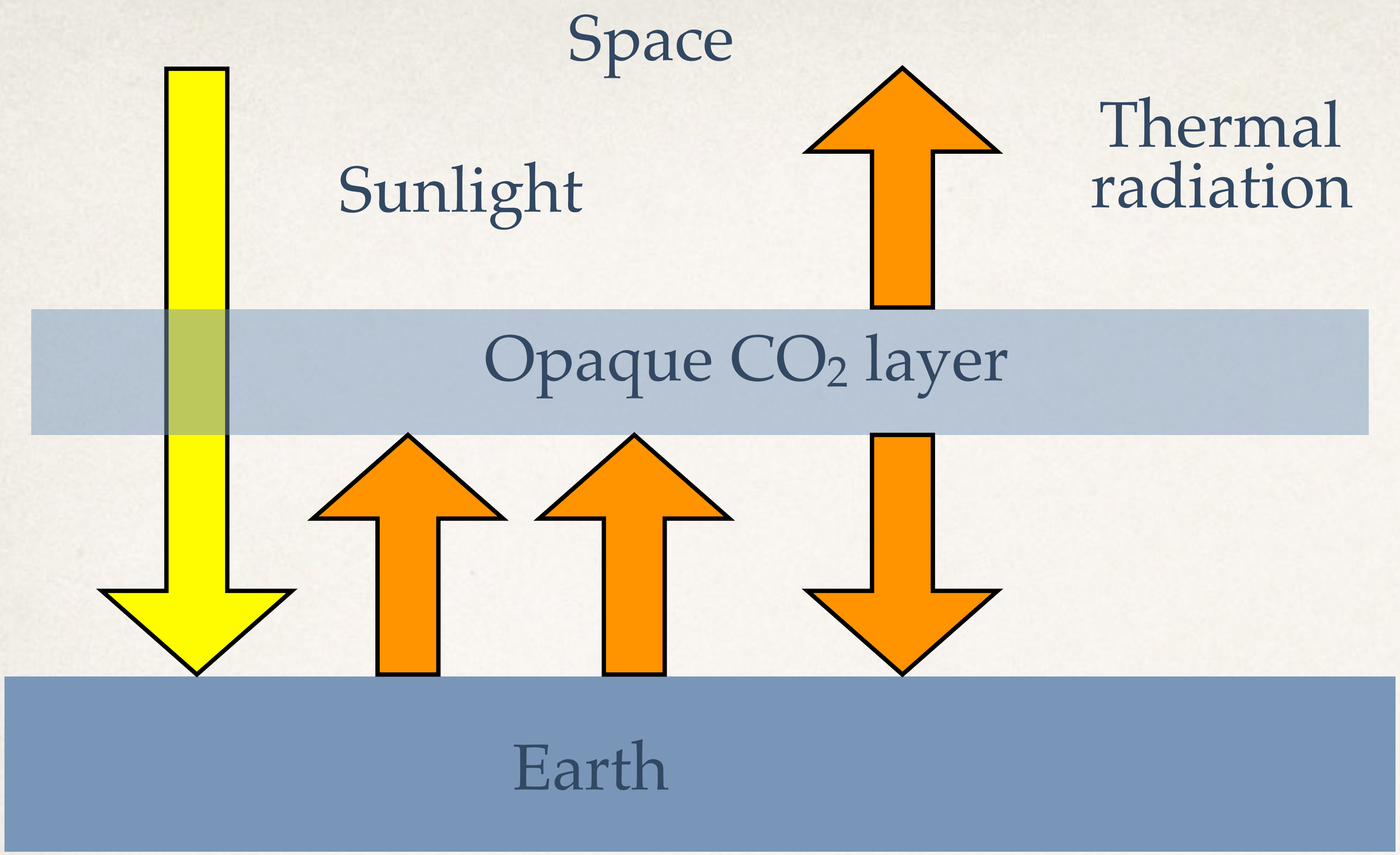

Climate Change in the Introductory Course

Chapter T10 in *Six Ideas* 3/e!

Thomas A. Moore, Pomona College (tmoore@pomona.edu)

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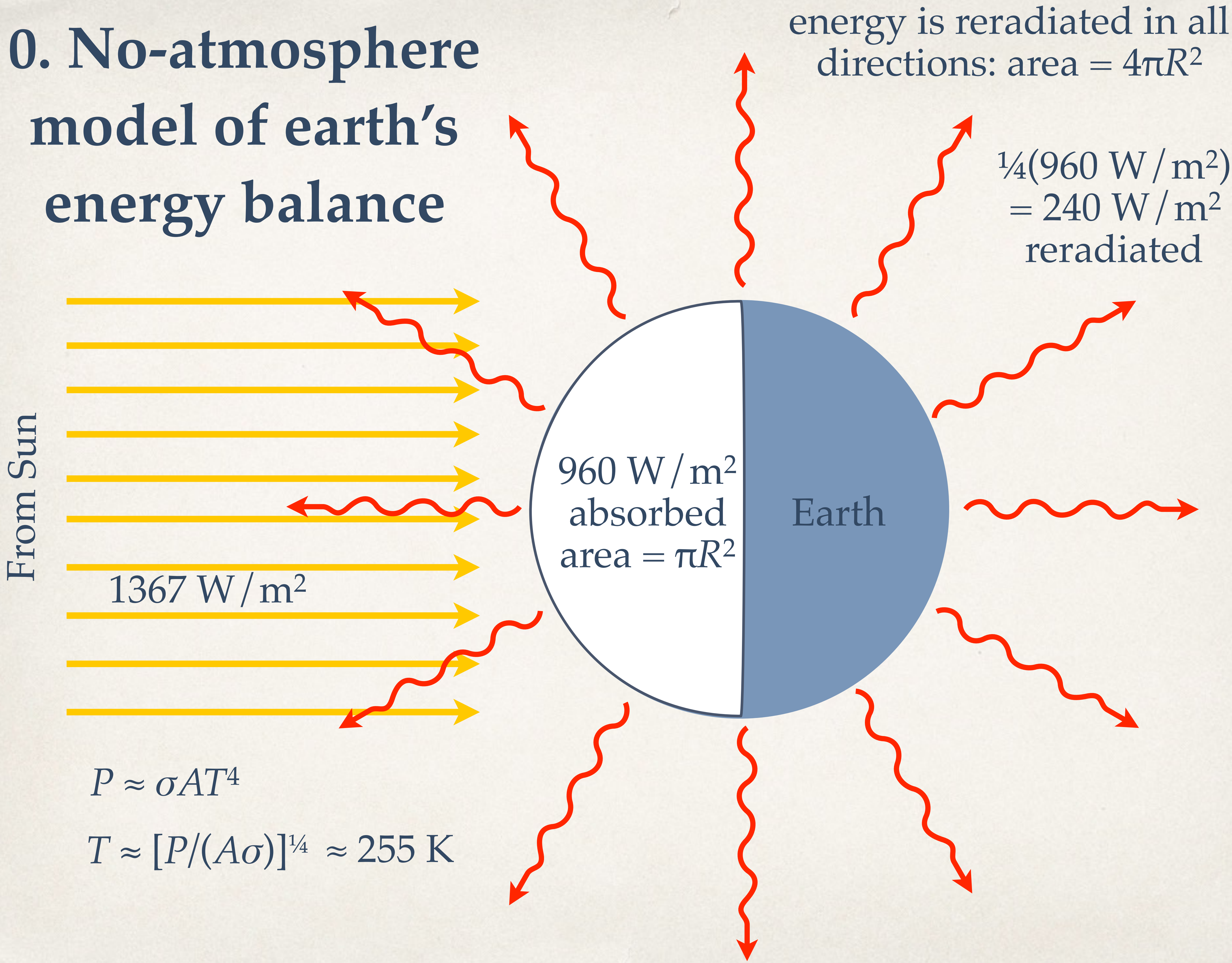
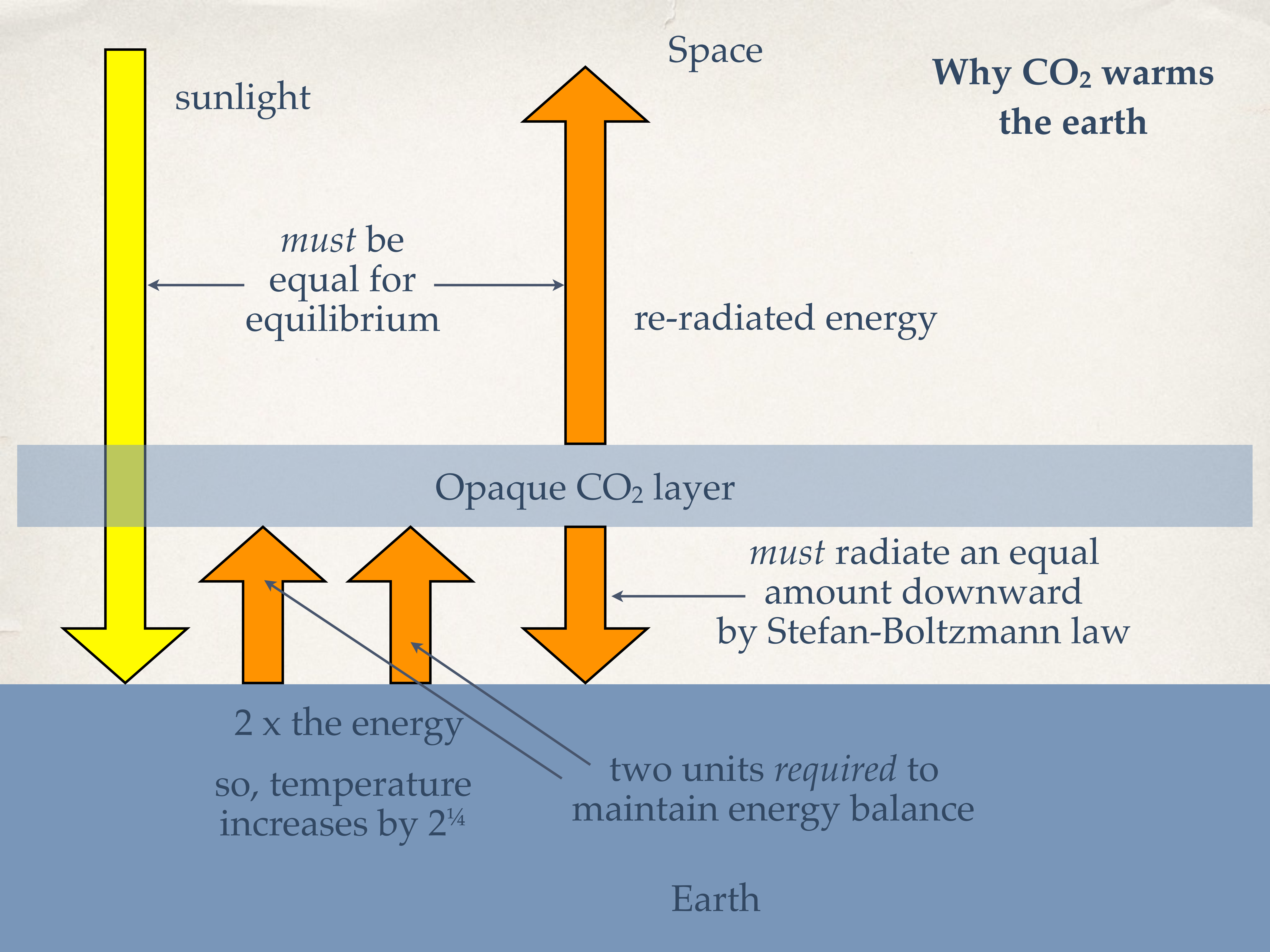
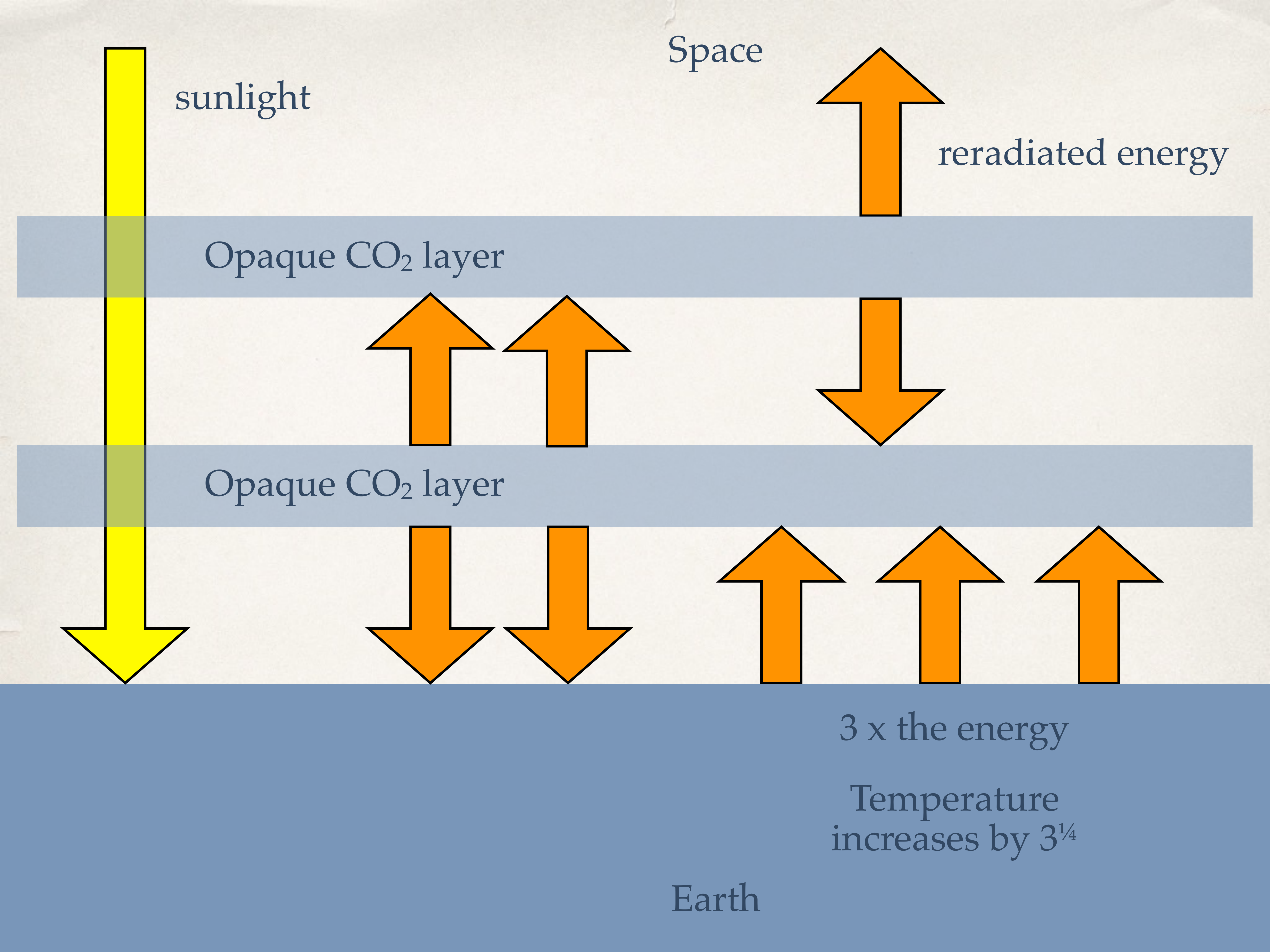
0. No-atmosphere model of earth's energy balance



$P \approx \sigma A T^4$

$T \approx [P/(A\sigma)]^{1/4} \approx 255$ K


Why CO_2 warms the earth
Space
sunlight
must be equal for equilibrium
re-radiated energy
Opaque CO_2 layer
must radiate an equal amount downward by Stefan-Boltzmann law
2 x the energy
so, temperature increases by $2^{1/4}$
two units *required* to maintain energy balance
Earth


Space
sunlight
reradiated energy
Opaque CO_2 layer
Opaque CO_2 layer
3 x the energy
Temperature increases by $3^{1/4}$
Earth

1. Pre-Industrial Model (for 280 ppm CO_2)

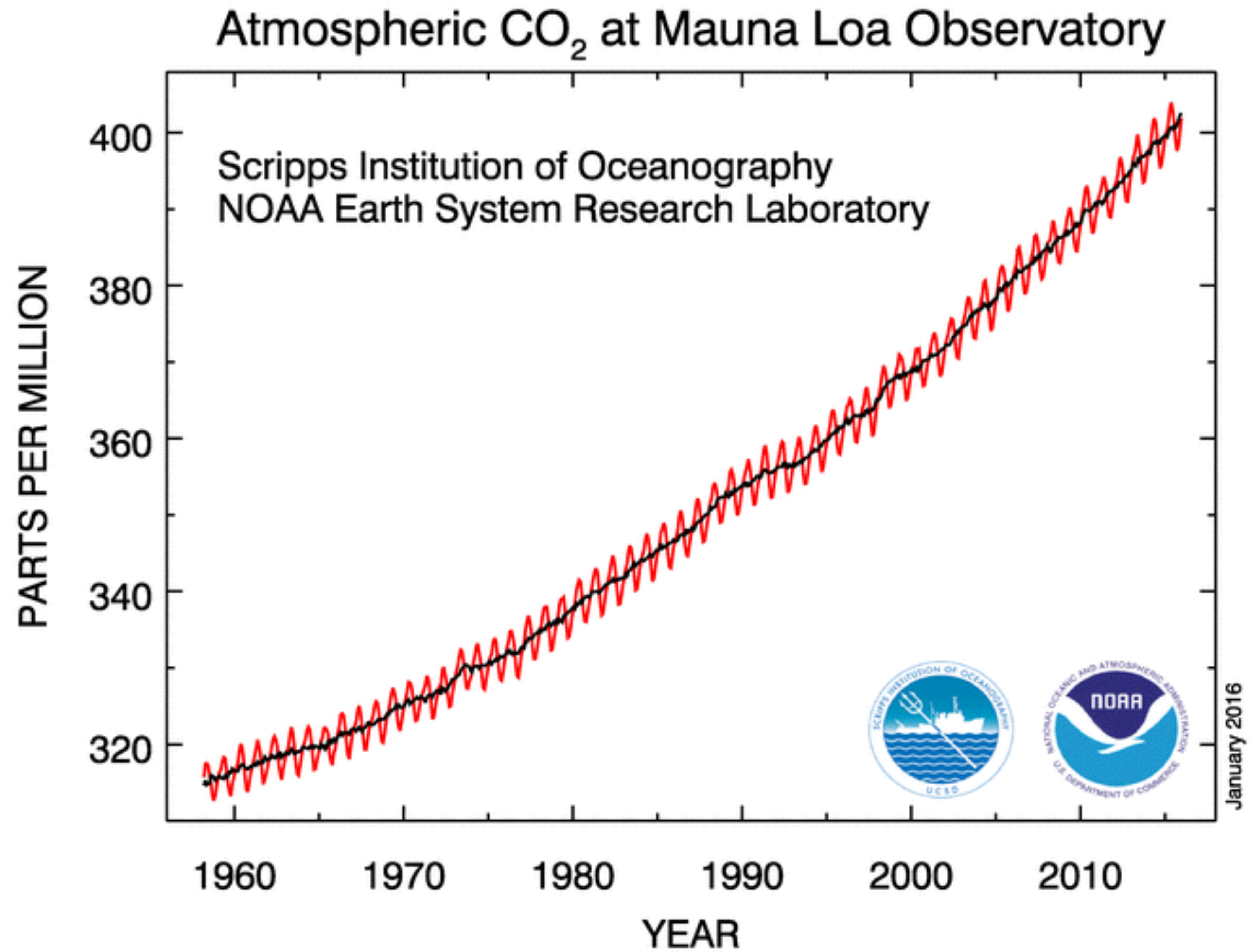
number of layers ↓

So, $$T = (255\text{ K})(x + 1)^{1/4}$$

Let's *assume* this applies for non-integer x, but note that the true formula *should* match when x is an integer.

$$T = 14.0°\text{C} = 287.0\text{ K before 1900}$$

$$\Rightarrow \quad x = 0.605 \quad \text{at 280 ppm } CO_2$$


Atmospheric CO_2 at Mauna Loa Observatory
Scripps Institution of Oceanography
NOAA Earth System Research Laboratory
PARTS PER MILLION
400
380
360
340
320
1960
1970
1980
1990
2000
2010
YEAR
January 2016

2. Linear Increase Model

$$\text{at } 400 \text{ ppm } CO_2,\ \ x = (400/280)0.605 = 0.864$$

$$\Rightarrow\ \ T = (255\text{ K})(1 + 0.864)^{1/4} = 298\text{ K} = 25°\text{C}$$

$$\Rightarrow\ \ T \text{ increases by } 11°\text{C}\quad (!)$$

This is inconsistent with the the **actual measured** (and not really disputed) rise of ~ 0.8°C.[1]

3. Square Root Increase Model[2]

$$\text{at } 400 \text{ ppm } CO_2, \; x = (400/280)^{1/2} 0.605 = 0.723$$

$$\Rightarrow \; T = (255 \text{ K})(1 + 0.723)^{1/4} = 292 \text{ K} = 19°\text{C}$$

$$\Rightarrow \; T \text{ increases by } 5°\text{C} \quad (!)$$

This is inconsistent with the the **actual measured** (and not really disputed) rise of ~ 0.8°C.[1]

4. Adjust for CO_2 fraction

Pre-industrial CO_2 actually only contributes 27% of opacity (H_2O most of the rest).[3] Now, 0.27(0.605) = 0.163, so this is the effective thickness of the pre-industrial CO_2 layer and 0.442 is the thickness of the the other stuff ≈ constant.

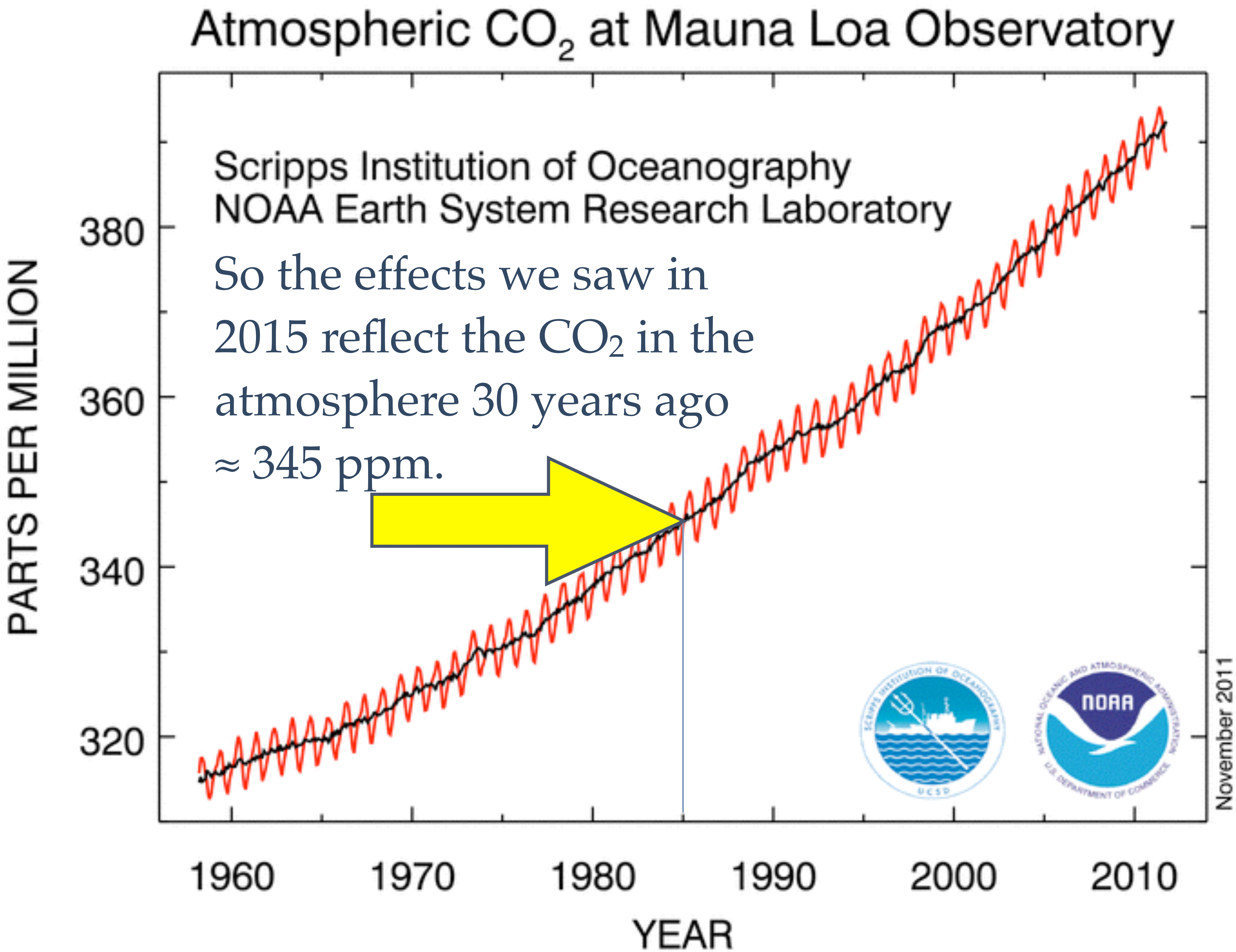
$$x = (400/280)^{1/2}(0.163) + 0.442 = 0.637$$

$$\Rightarrow \; T = (255\text{ K})(x+1)^{1/4} = 288.4\text{ K} = 15.4°\text{C}$$

$$\Rightarrow \; \sim 1.4°\text{C temperature increase}$$

5. Add Ocean Delay

- Model assumes equilibrium
- But Earth is currently *not* in equilibrium
- The ocean's large heat capacity delays equilibrium
- Simple model: effective delay is 30 years[4]



So the effects we saw in 2015 reflect the CO_2 in the atmosphere 30 years ago ≈ 345 ppm.

Calculating the temperature rise for 345 ppm:

$$x = (345/280)^{1/2}(0.163) + 0.442 = 0.623$$

$$\Rightarrow \; T \; = \; (255\text{ K})(x+1)^{1/4} = 287.8\text{ K} = 14.8°\text{C}$$

$$\Rightarrow \; \sim 0.8°\text{C temperature increase}$$

This is basically spot on.

Endnotes

1. http://www.ncdc.noaa.gov/sotc/global/2015/11/supplemental/page-2

2. For more information about why the square root, go to

   http://scienceofdoom.com/roadmap/co2/

read CO_2 parts 3 and 4, and note that I am assuming that the "strong condition" applies (as claimed in the article) and that the "optical depth" is proportional to x (the number of layers).

3. Part 5 of the above discusses the 27% figure. (In general, scienceofdoom.com (in spite of the silly name) is a useful website for exploring the science of climate modeling at a significantly more sophisticated level than I am assuming here.)

4. I got this figure from a talk by climate scientist James Hansen. See also http://arxiv.org/abs/1307.6821 and http://meteora.ucsd.edu/cap/pdffiles/Hansen-04-29-05.pdf

Chapter T10 in

Six Ideas That Shaped Physics, 3rd edition

(McGraw-Hill, available February 2016)

http://www.physics.pomona.edu/sixideas/

(I have posted this talk there)