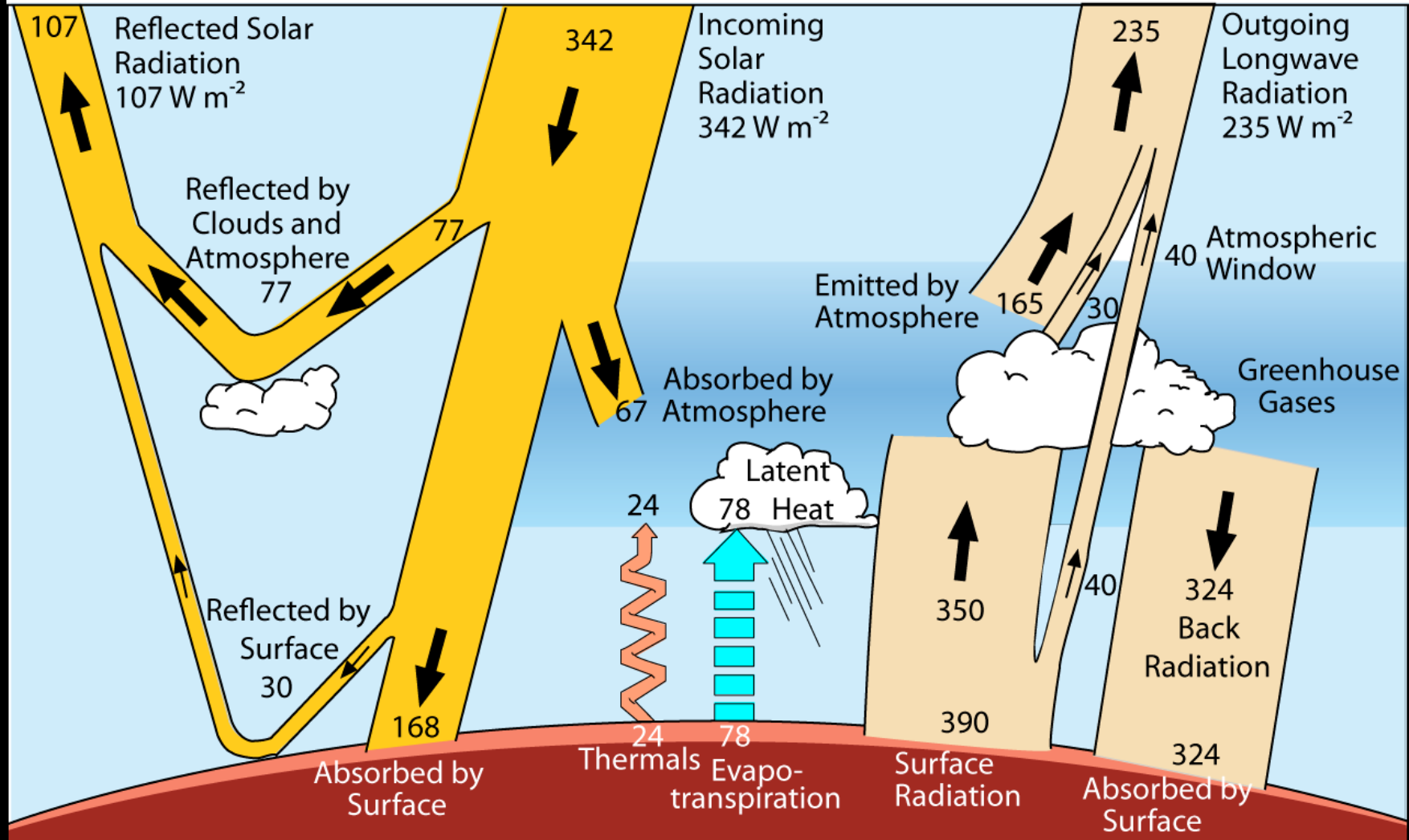


# GLOBAL Energy Flow Thru Atmosphere

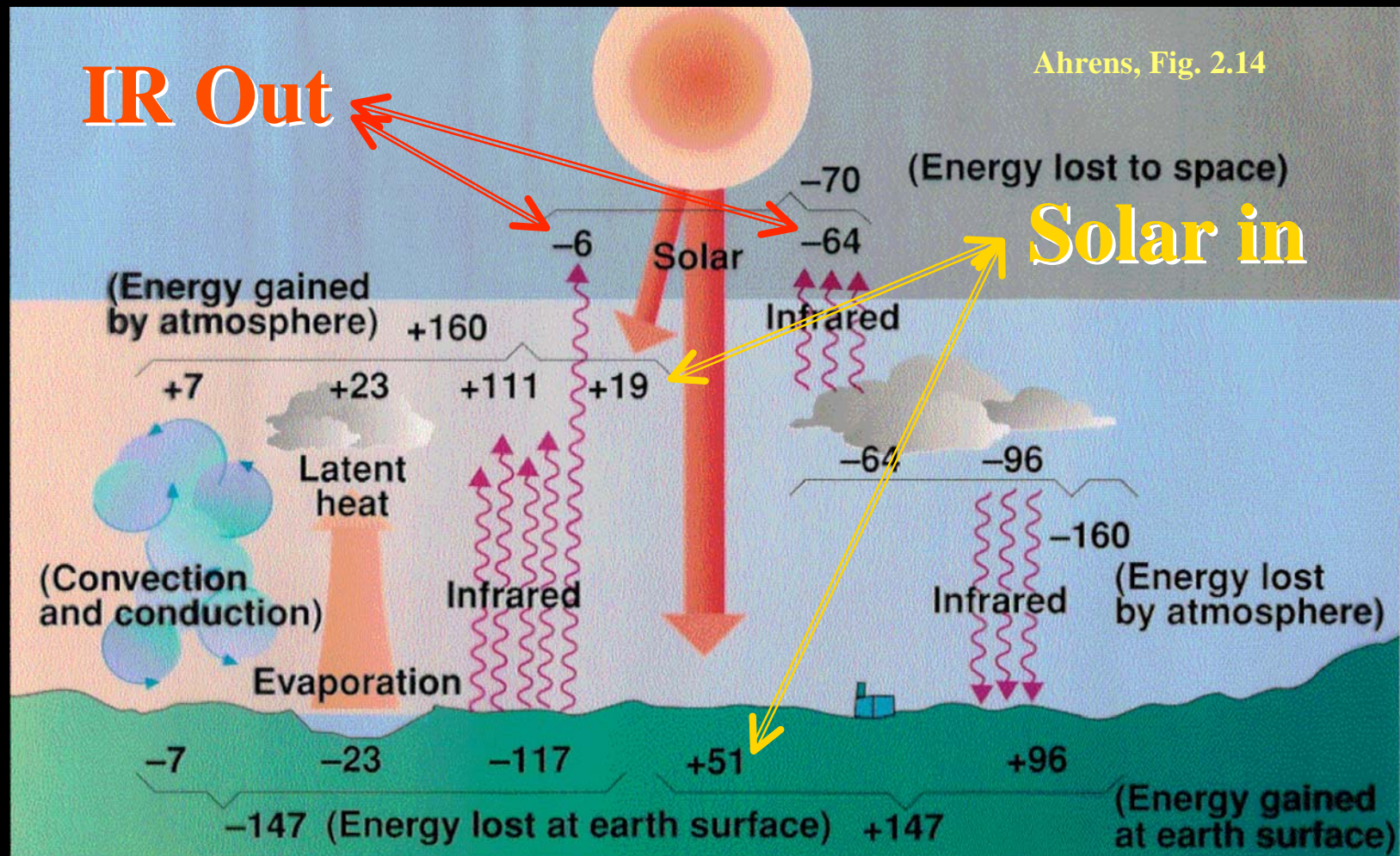
## Global Heat Flows



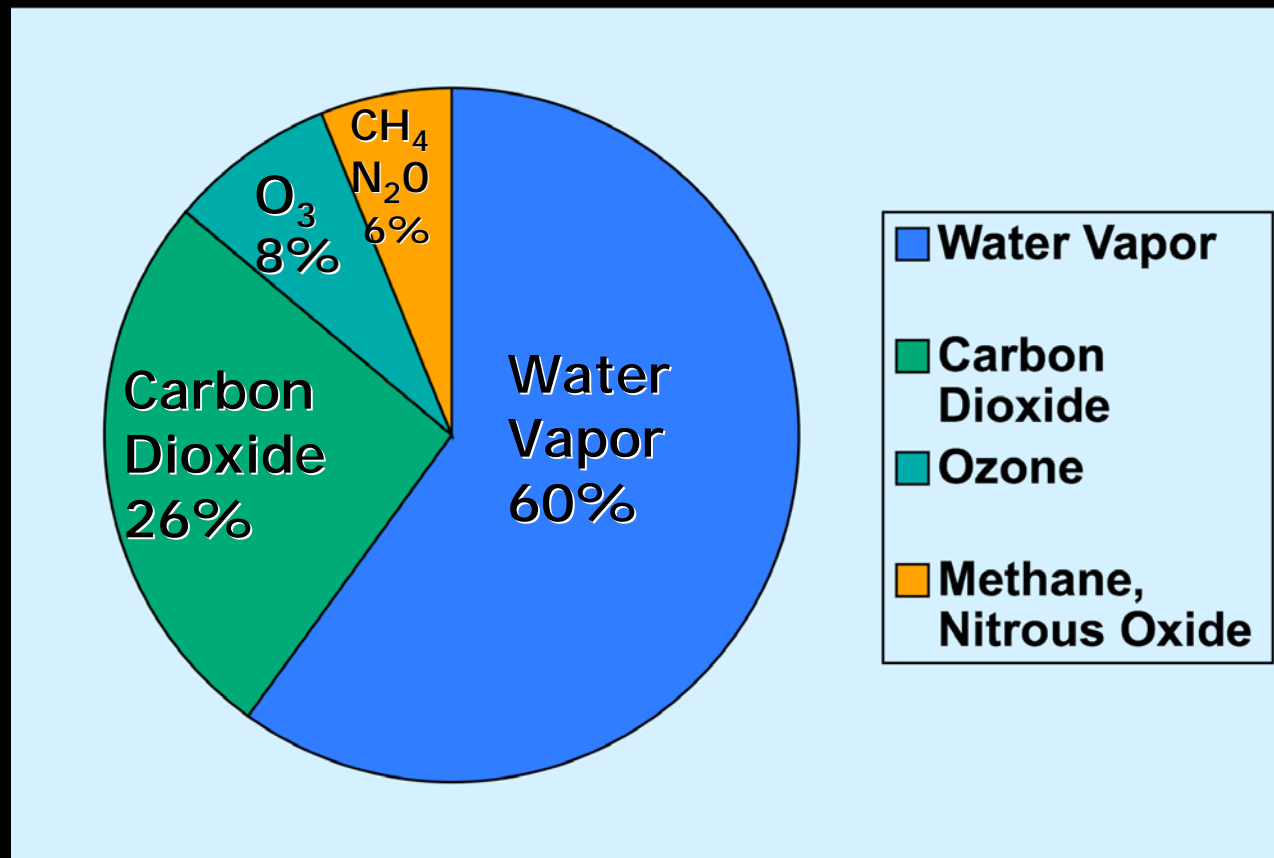
*Kiehl and Trenberth 1997*

# Global Atmo Energy Balance

In a stable climate, Solar Energy IN = IR Energy OUT



# The Natural Greenhouse Effect: clear sky

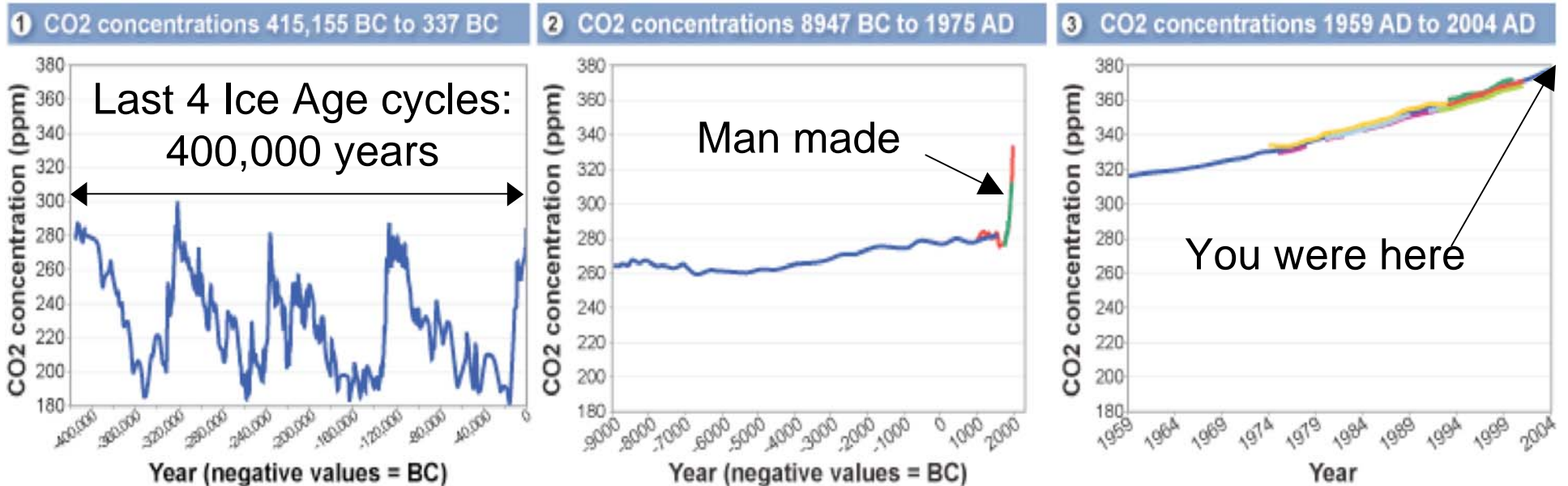


Clouds also have a greenhouse effect

Kiehl and Trenberth 1997

# Changing CO<sub>2</sub> concentrations

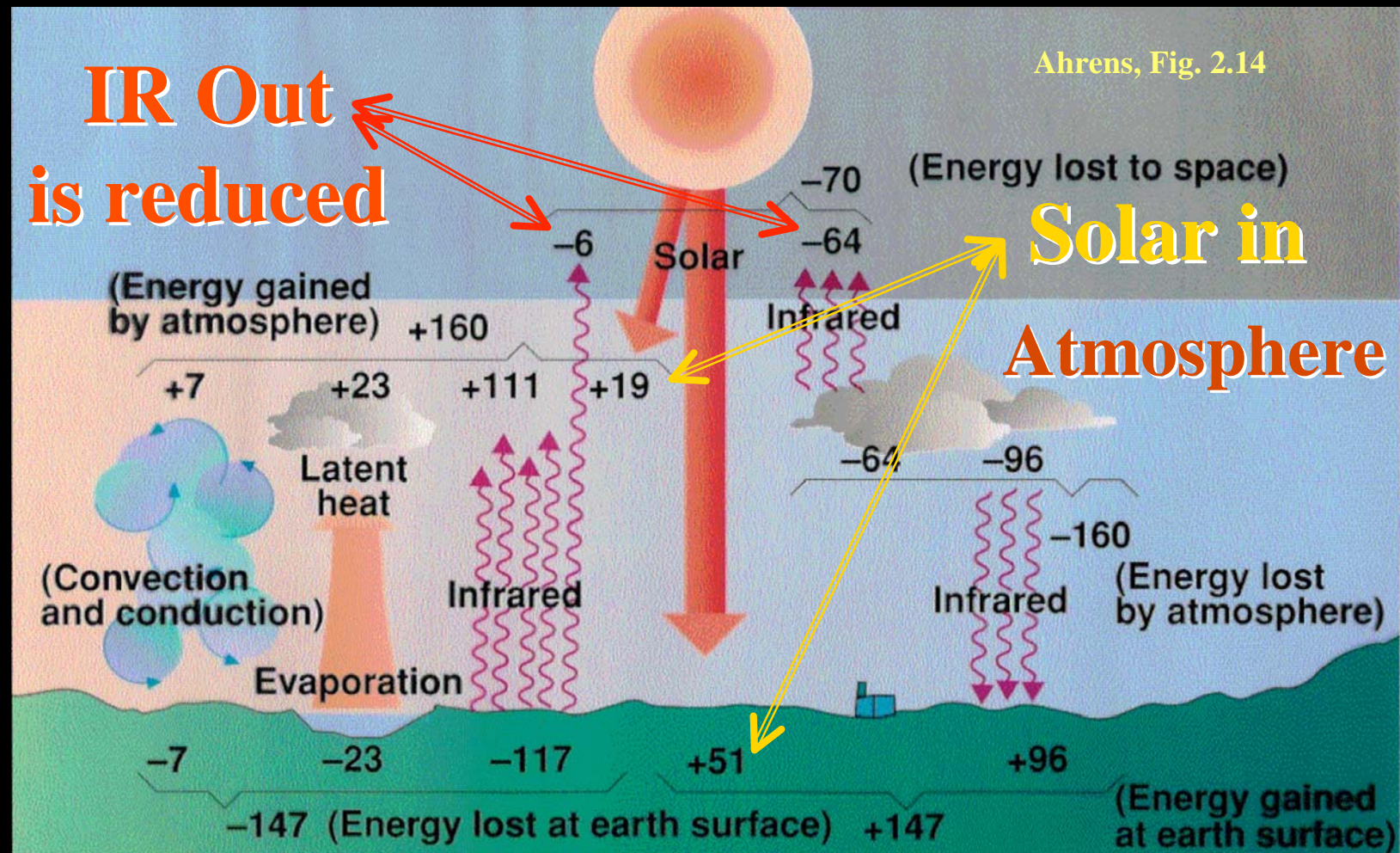
- CO<sub>2</sub> concentrations have varied naturally by a factor of 2 over the past few hundred thousand years
- Fossil fuel burning since the industrial revolution has created a sharp increase in CO<sub>2</sub> concentrations
- CO<sub>2</sub> concentrations are now higher than at any time in past few hundred thousand years
- And concentrations are increasing faster with time



See <http://epa.gov/climatechange/science/recentac.html>

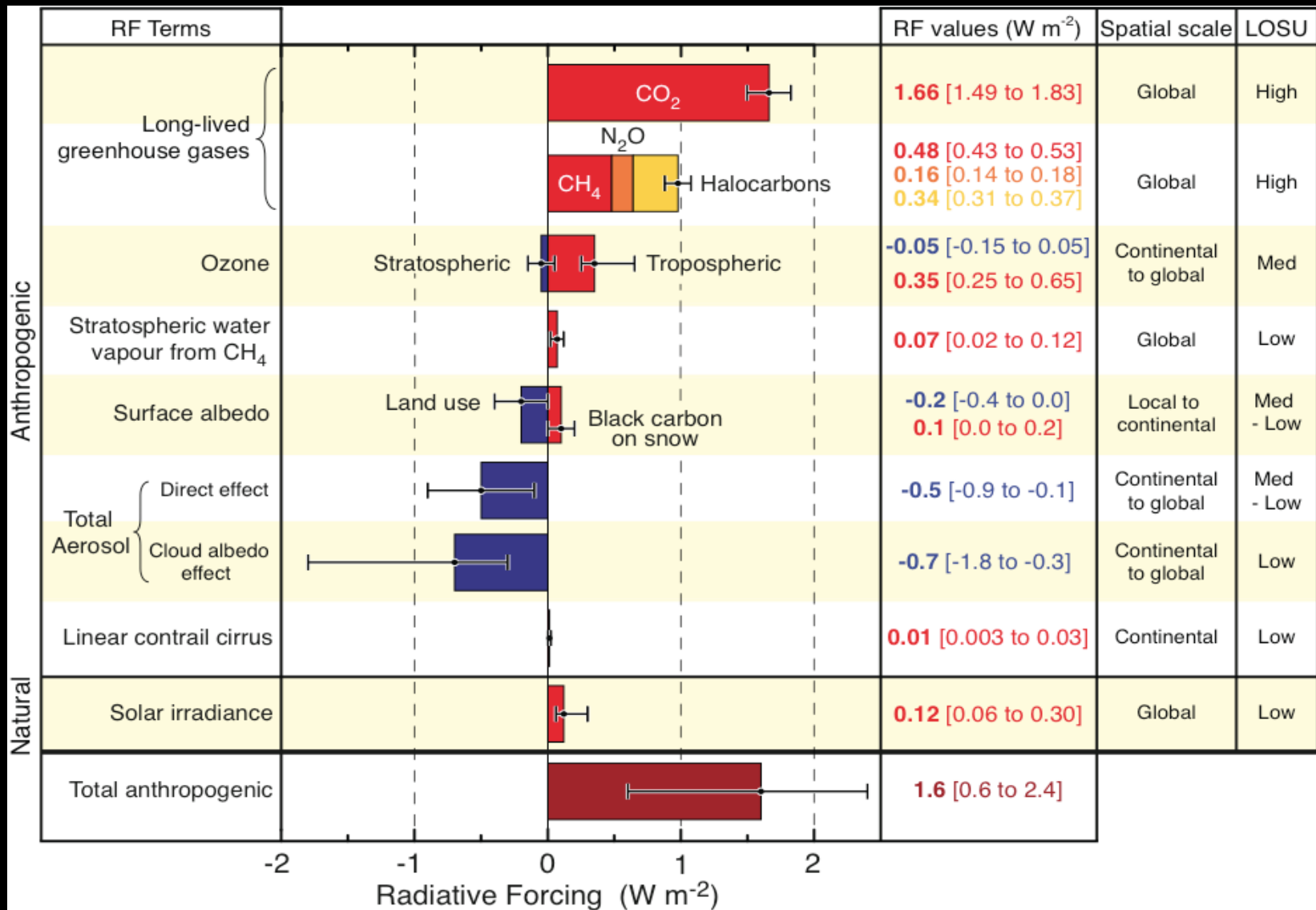
# Global Atmo Energy Imbalance

Increasing GHG concentrations decrease Energy out  
So Energy IN > Energy OUT and the Earth warms



# Radiative Forcing (RF) Components

{Global-average estimates and ranges; typical geographical extent and assessed level of scientific understanding}



# Stefan-Boltzmann's Law

(review from Lecture 5)

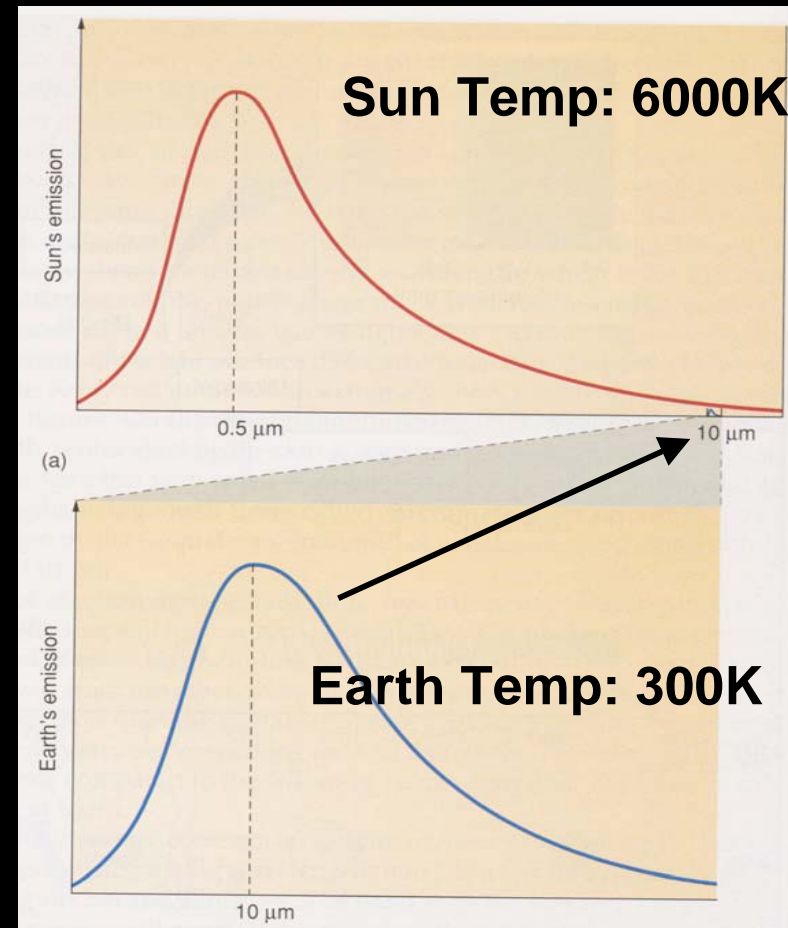
- The hotter the object, the more radiation emitted.
- When the temperature is doubled, the emitted energy increases by a factor of **16**
- Stefan-Boltzmann's Law

$$E = (5.67 \times 10^{-8} \text{ Wm}^{-2}\text{K}^{-4}) \times T^4$$

$$E = 2 \times 2 \times 2 \times 2 = 16$$

4 times

(T is temperature in Kelvin)



Aguado, Fig. 2-7

# Change in IR Emission to Space

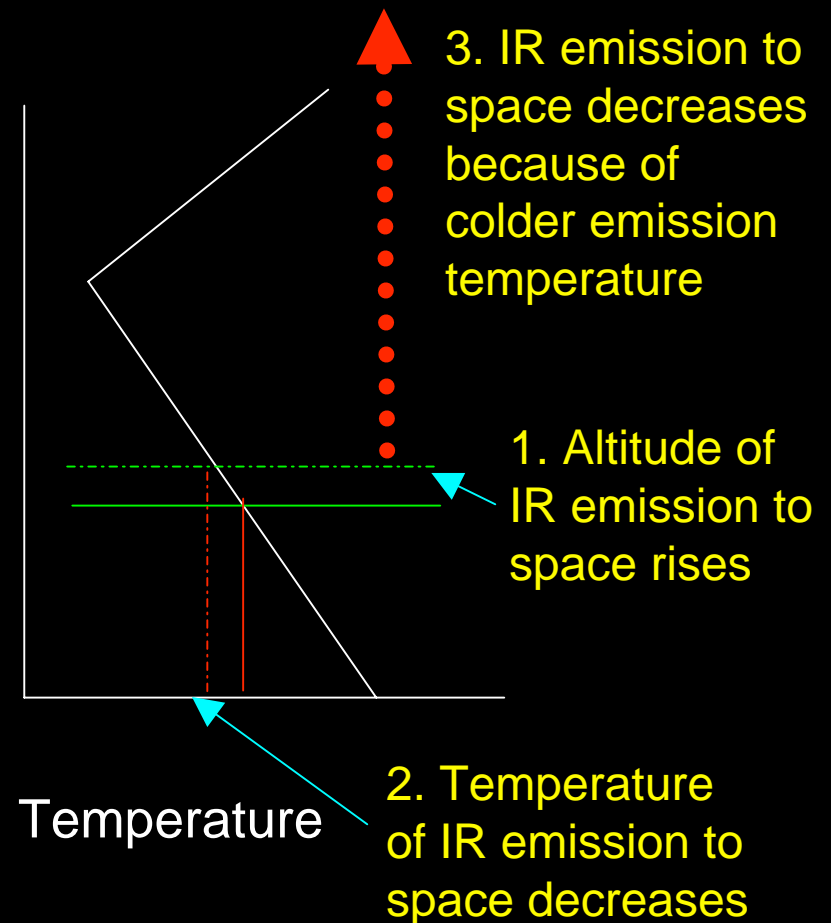
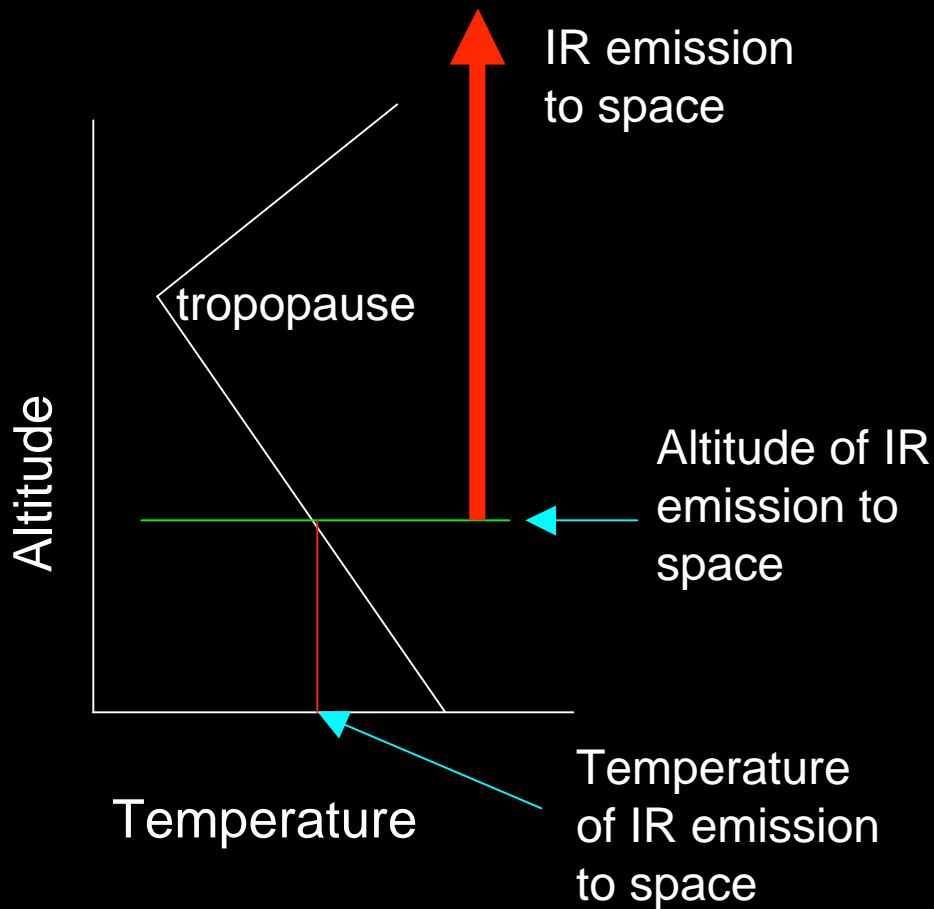
- Notice that because of Earth's greenhouse gases, 91% (=64/70) [195/235 = 83%] of the IR emitted to space comes from the atmosphere and only 9% (=6/70) [40/235 = 17%] comes from the surface
- When GHG's are added to the atmosphere, the altitude of IR emission to space rises
- In the troposphere, air temperature decreases with altitude
- So the temperature of the emission to space decreases
- So the energy emission to space decreases because the emission energy decreases with decreasing temperature



# Change in IR Emission to Space

BEFORE GHG increase IN=OUT

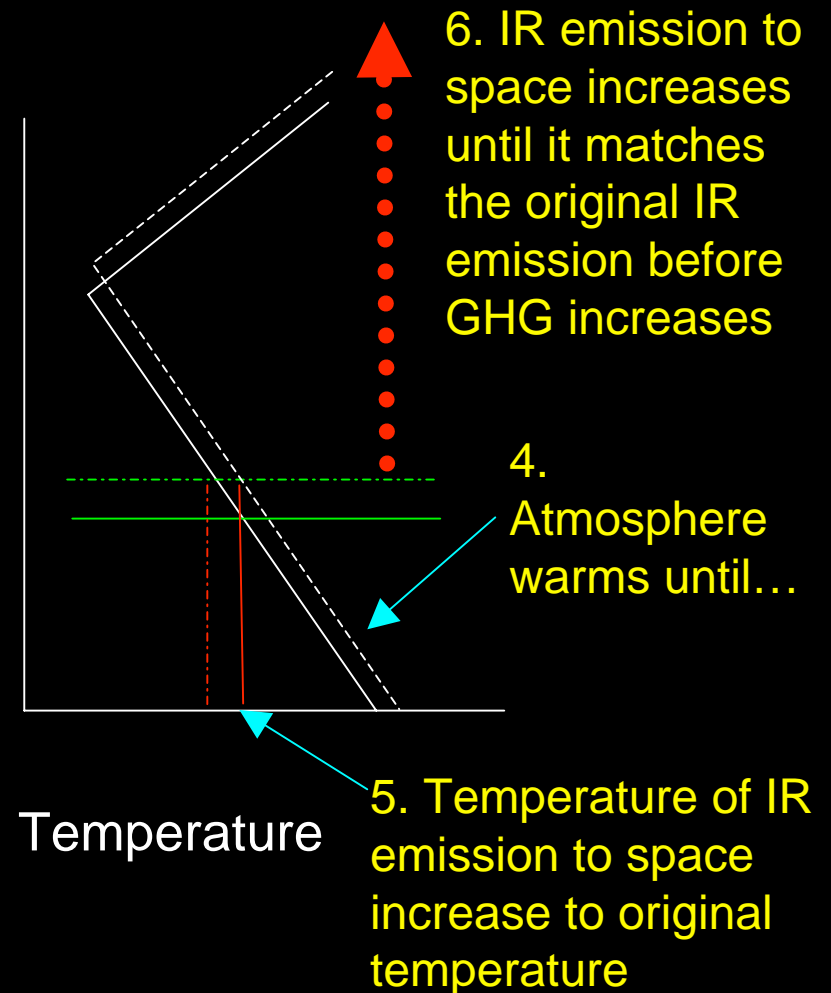
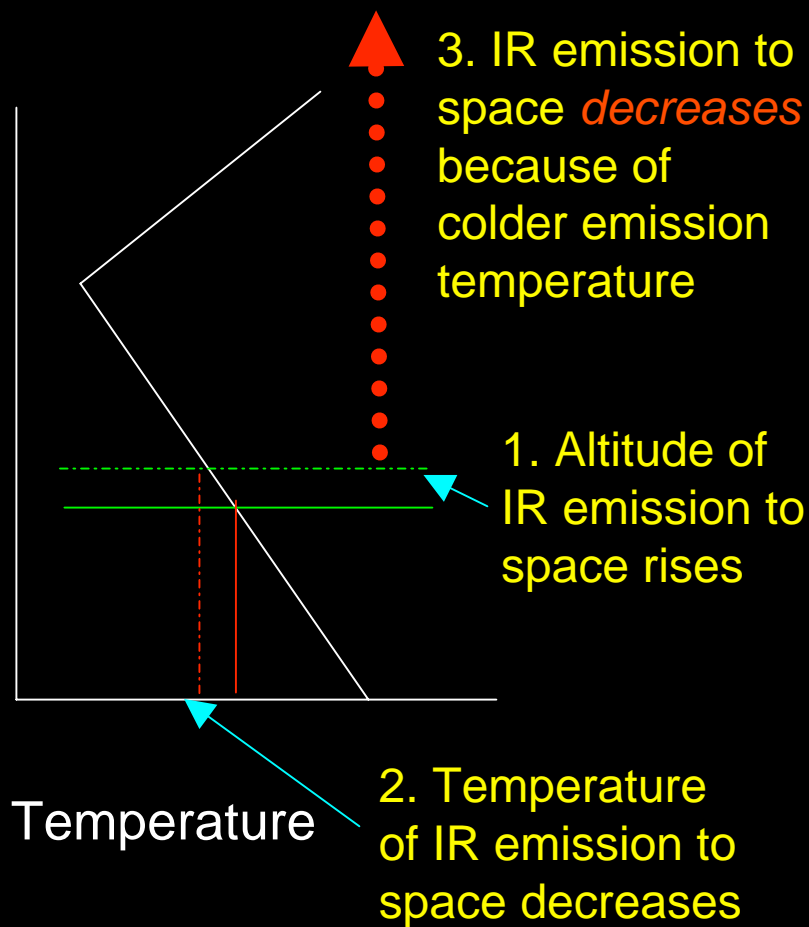
AFTER GHG increase IN>OUT



# Change in IR Emission to Space (cont'd)

AFTER GHG increase IN>OUT

Eventual solution IN=OUT



# Anthropogenically-Caused Warming

- Initially after increasing GHG concentrations, the IR radiation to space decreases, such that

$$\text{Solar in} > \text{IR out}$$

- Causing the Earth to start warming

- IF GHG concentrations level off at some point, then eventually the Earth warms enough that

$$\text{Solar in} = \text{IR out}$$

- “*Eventually*” depends on how fast the oceans warm

- The warmer Earth represents a new climate regime
  - With bad and good consequences that we partially understand