Chapter 3: Radiation and Energy Balance

Feb 4 & 9

3.1. Temperature and Energy
3.2. Electromagnetic Radiation
3.3. Blackbody Radiation
3.4. Energy Balance
Terms
Problems

Take-Home Messages

- Major physical laws on radiation energy
- Solar radiation and distribution
- Short- and Long-wave radiation (all waves)
- Amount of energy by wavelength

3.4. Energy Balance

First Law of Thermodynamics = energy is conserved.

- Since photons are packets of energy, first law tells us that when object emits photon, emitting object's internal energy must decrease.
- Since temperature is measure of internal energy, emission of photons causes object to cool.
- Opposite occurs as photon absorbed by object - internal energy and temperature increase.
- Objects always absorbing and emitting photons.

Net change in internal energy of object is amount of energy-in (E_{in}) from absorbing photons minus energy-out (E_{out}) from emitting photons:

- ***ENERGY-IN (E_{in}):*** *Energy gained by absorbing photons =>* temperature increases.
- ***ENERGY-OUT (E_{out}):*** *Energy lost by emitting photons =>* temperature decreases.
- ***EQUILIBRIUM:*** *when internal energy and temperature are unchanging,*

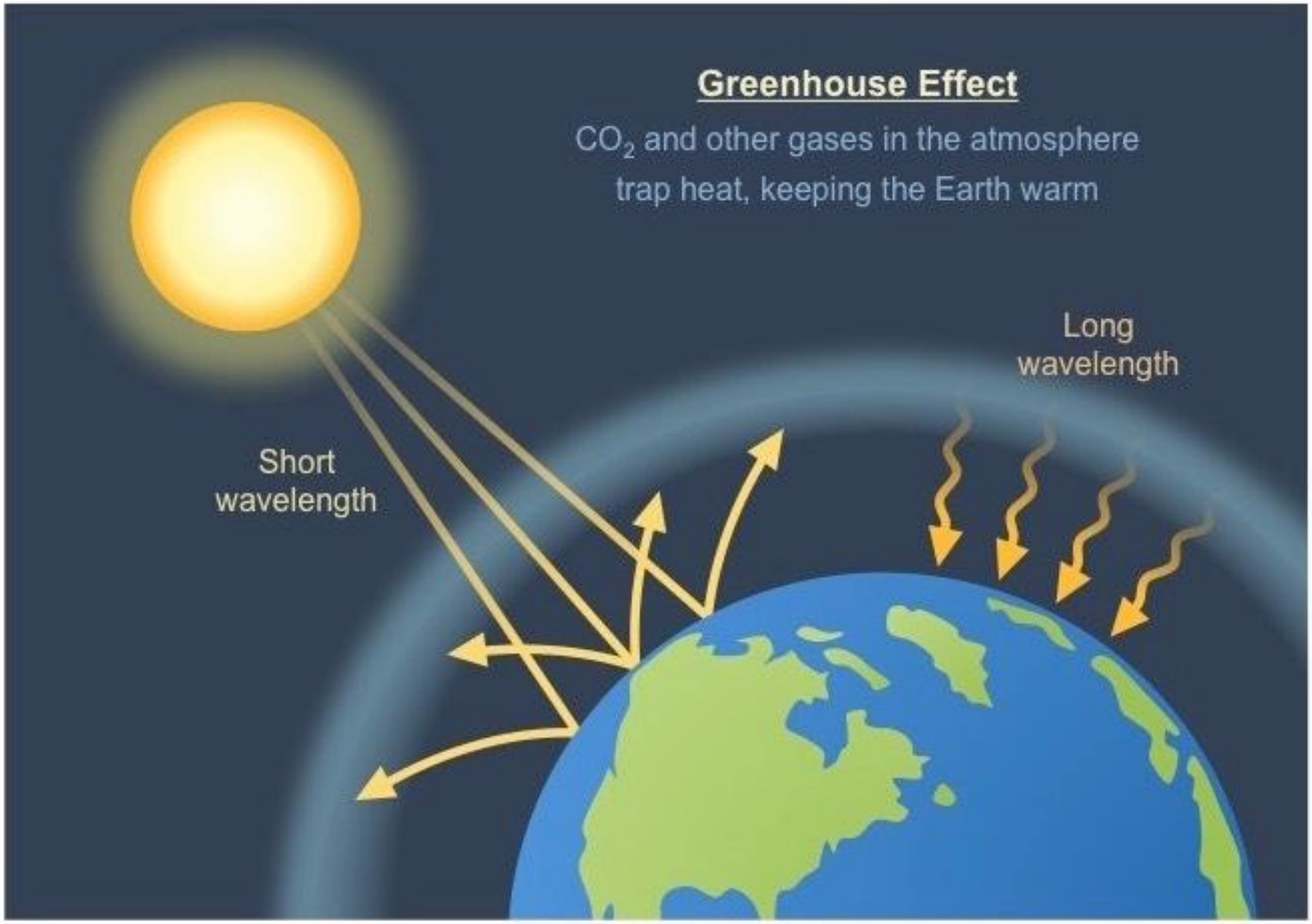
$$E_{in} = E_{out}$$

Table 3.1 Energy balance summary

Condition	Effect on internal energy	Effect on temperature
If $E_{in} > E_{out}$ for an object	Internal energy of that object increases	Temperature of that object increases
If $E_{out} > E_{in}$ for an object	Internal energy of that object decreases	Temperature of that object decreases
E_{in} equals E_{out} for an object	Internal energy of that object is not changing	Temperature of that object is not changing

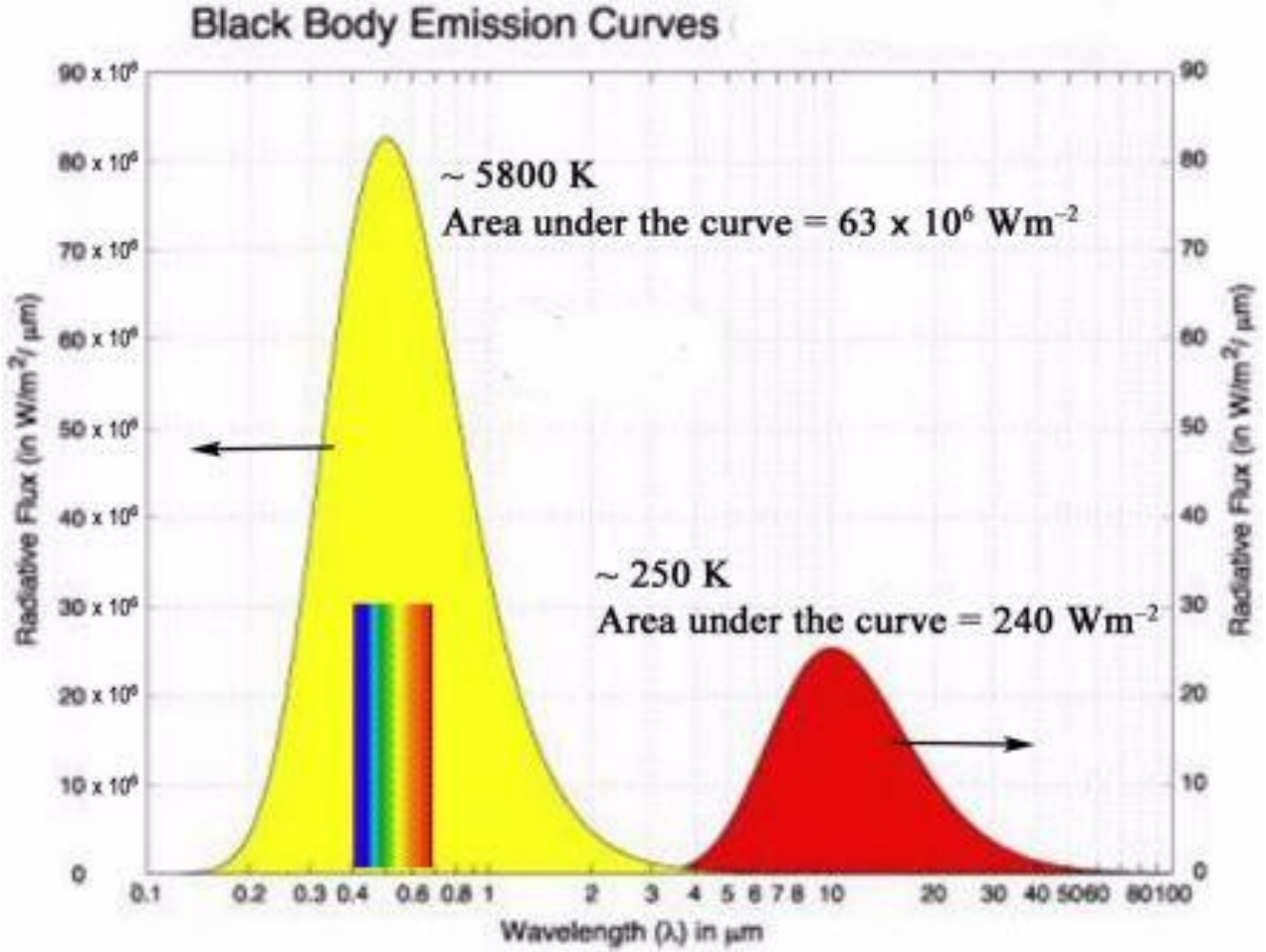
This is the foundation explaining global warming!

Why is temperature increasing?



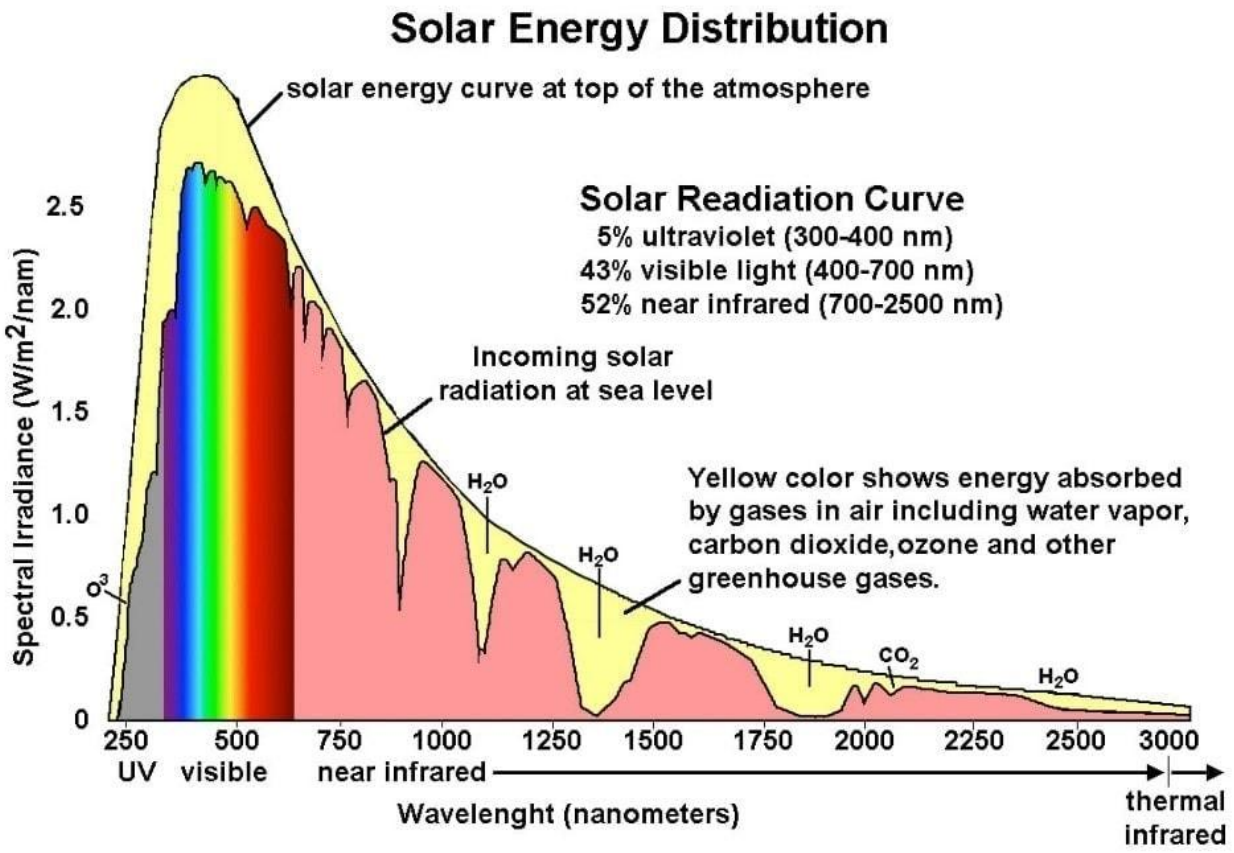
1) Radiant emittance from the sun (T = 6000 K) varies from 0.2 nm to 3.0 nm and peaks at spectra of ~0.55 nm, with most energy coming from a wavelength of 0.3-0.7 nm (>50%). These wavelengths are loosely called “shortwave radiation” or “visible light”).

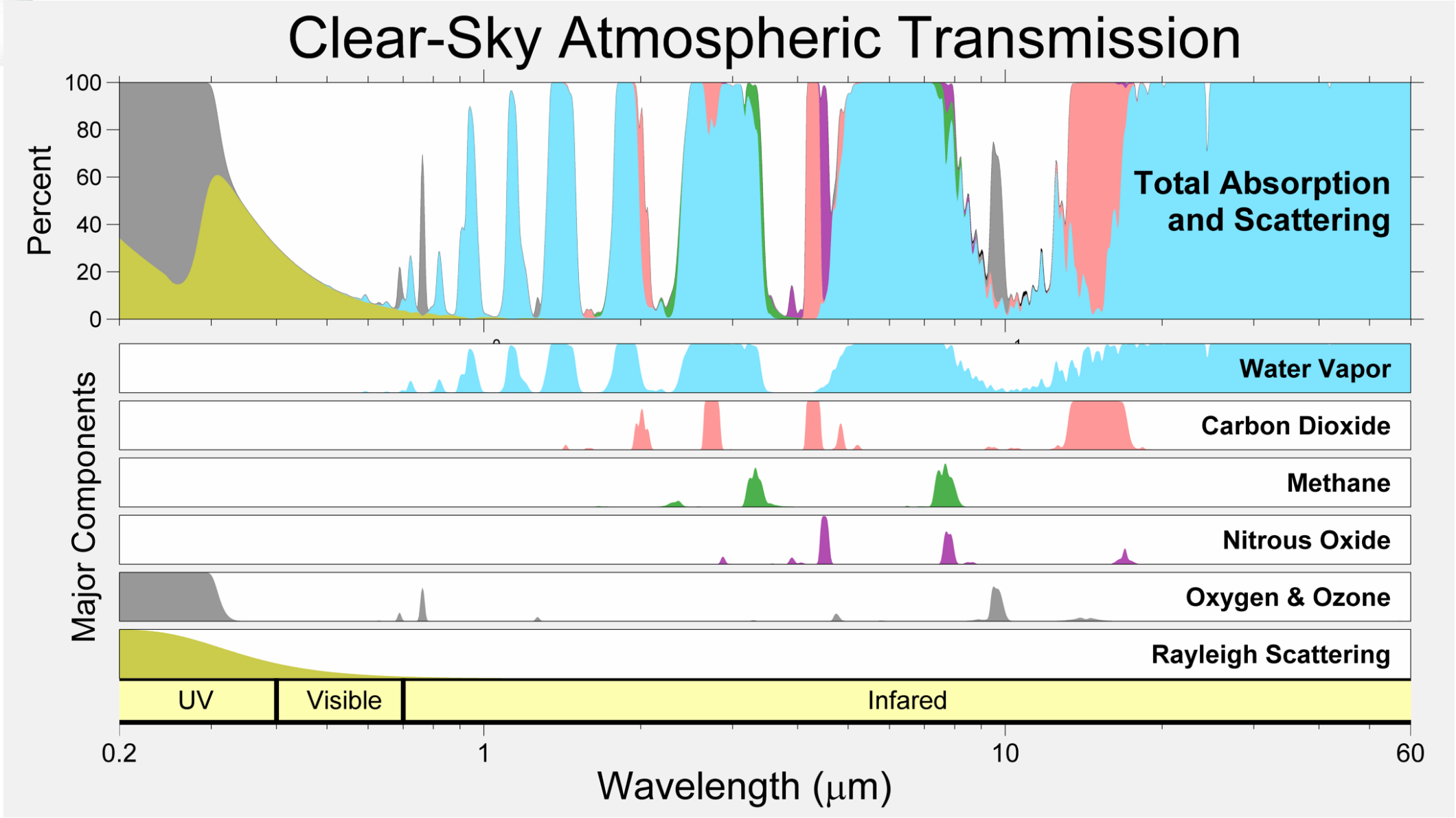
2) The Earth’s (T = 288 K) peak emittance is 9.5-10.0 nm. In sum, Earth’s temperature is mostly maintained by the balance of incoming shortwave radiation from the sun and outgoing longwave radiation from the Earth.



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

- Earth's atmosphere is composed of many gases and particles. Nitrogen (~78%) and oxygen (~21%) are the two major chemical species. Other species, including water, argon, carbon dioxide, neon, helium, methane, krypton, hydrogen, nitrous oxide, xenon, ozone, carbon monoxide, and ammonia, account for <1%.
- The atmosphere also contains a large amount of particulate matters and biological materials that can affect the energy balance of the Earth. For example, an increase in the amount of aerosol deposition on snow and glacier surfaces will reduce and, consequently, keep more energy within the Earth system. Volcanic eruptions, large-scale fires, and industrial production are major sources of aerosols at global scale.





H_2O

CO_2

CH_4

N_2O

O & O_3

Chen, J. 2020

Fig. 2.13: Temperature anomaly of southern polar region (blue) over past 410,000 yr, relative to today's temperature. Constructed from an Antarctic ice core. Carbon dioxide (orange) from air bubbles trapped in ice.

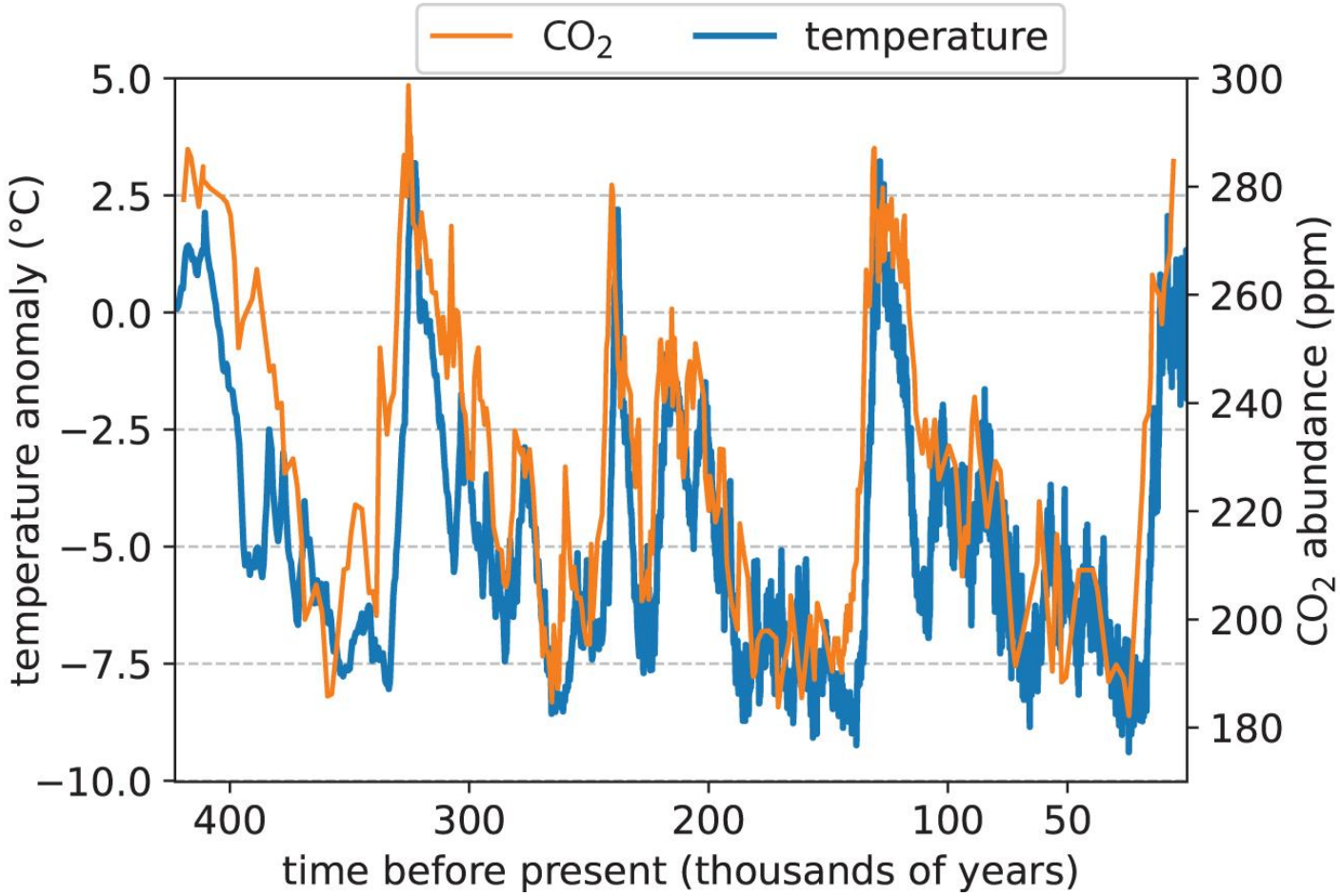
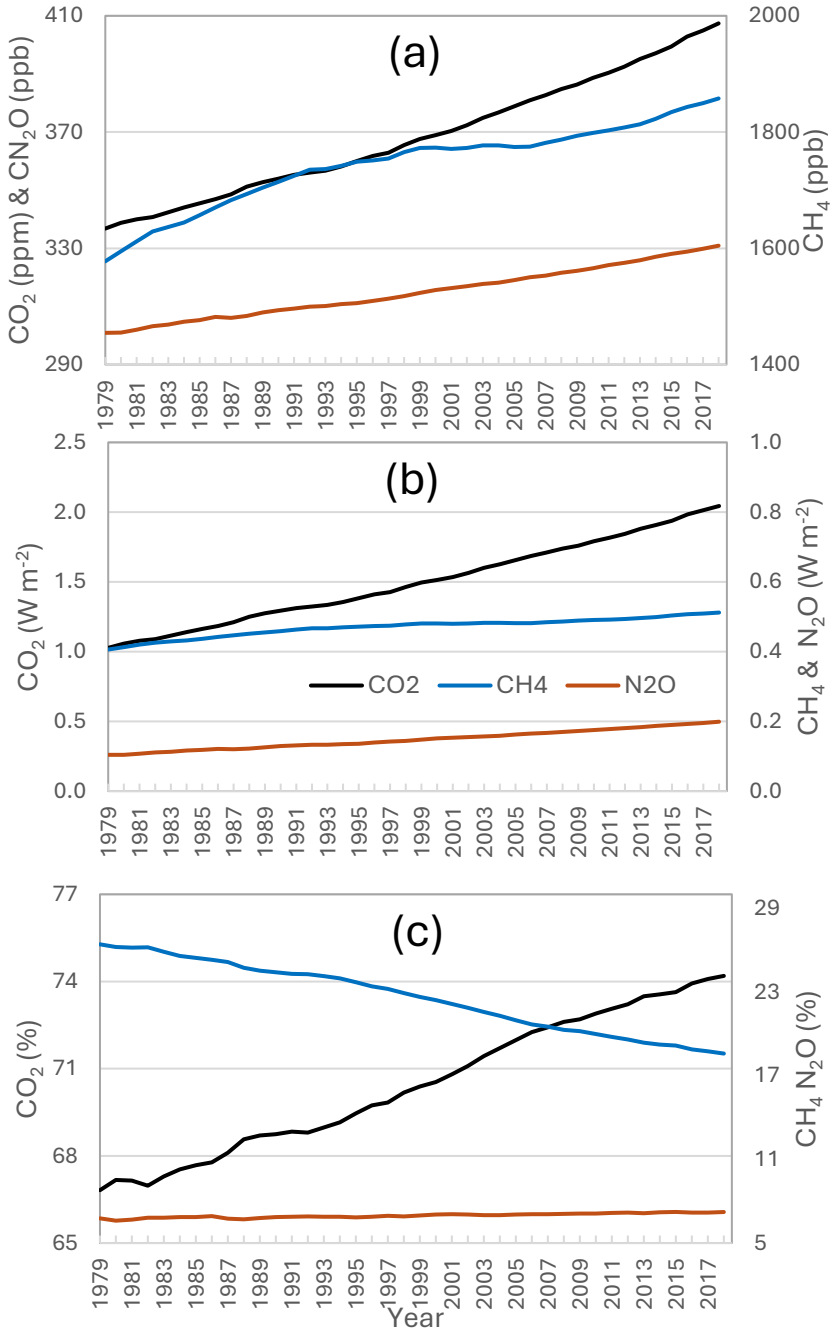


Figure 5-1. Long-term changes in three major greenhouse gas (GHG) species (CO_2, CH_4 and N_2O) concentrations (a), their radiative forcing (RF) (b), and their RF portion of the total during 1979-2018. Data source: https://www.esrl.noaa.gov/gmd/aggi/NOAA_MoleFractions_2019.csv (downloaded on 29 March 2020).



Brief History:

- In 1896 Swedish scholar Svante Arrhenius concluded that fossil fuel combustion may eventually result in enhanced global warming. He predicted that a doubling of CO_2 concentration would lead to a 5 ^oC increase in global temperature. His warning was mostly ignored until the late 1950s.

- Roger R.D. Revelle and other pioneering scholars started scientific investigations on anthropogenic influences on global warming (see more detailed history in Archer & Pierrehumbert 2011). However, they hypothesized that oceans would absorb all the CO_2.

- In late 1980s, there was a general hypothesis that terrestrial ecosystems can be managed effectively to reduce GHG to slow down global warming.

- Since 1990s, IPCC and other organizations have been calling for reductions in GHG.

In sum,

1) Global temperatures have risen in recent decades as a result of the rapid increase in greenhouse gas (GHG) emissions, commonly referred to as the greenhouse effect (more in Chapter 4)

2) This is explained by the energy balance: $[E_{in} - E_{out}]$

3) CO_2 concentration in the atmosphere is the primary GHG agent for global warming (Chapter 5)

“The climate system is an angry beast and we are poking it with sticks.”

Dr. Wallace Broecker

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Quiz 2 on Feb 11

- Chapter 2 & 3
- Similar format to Quiz 1, w/ one optional question

TERMS

Blackbody
Electromagnetic radiation
Energy
Equilibrium
~~Incandescent light bulb~~
Infrared radiation
Internal energy
Joule
Kelvin scale
Micron
Photons
Power
Temperature
Ultraviolet
Visible photons
Watt
Wavelength
Wien's displacement law

GHG
GHG species

Chapter 4: A Simple Climate Model

Feb 11 & 16

4.1. The Source of Energy for Our Climate System
4.2. Energy Loss to Space
4.3. The Greenhouse Effect
4.4. Testing Our Theory with Other Planets
Terms
Problems