GEO409-FS2025 (3 credits)

Sep 10: Greenhouse Effects on Global Climate & Change

- Physical Foundations for Global Climate Change (finishing up)
- What is greenhouse effect?
- Major Greenhouse Gases (GHG)

Reading

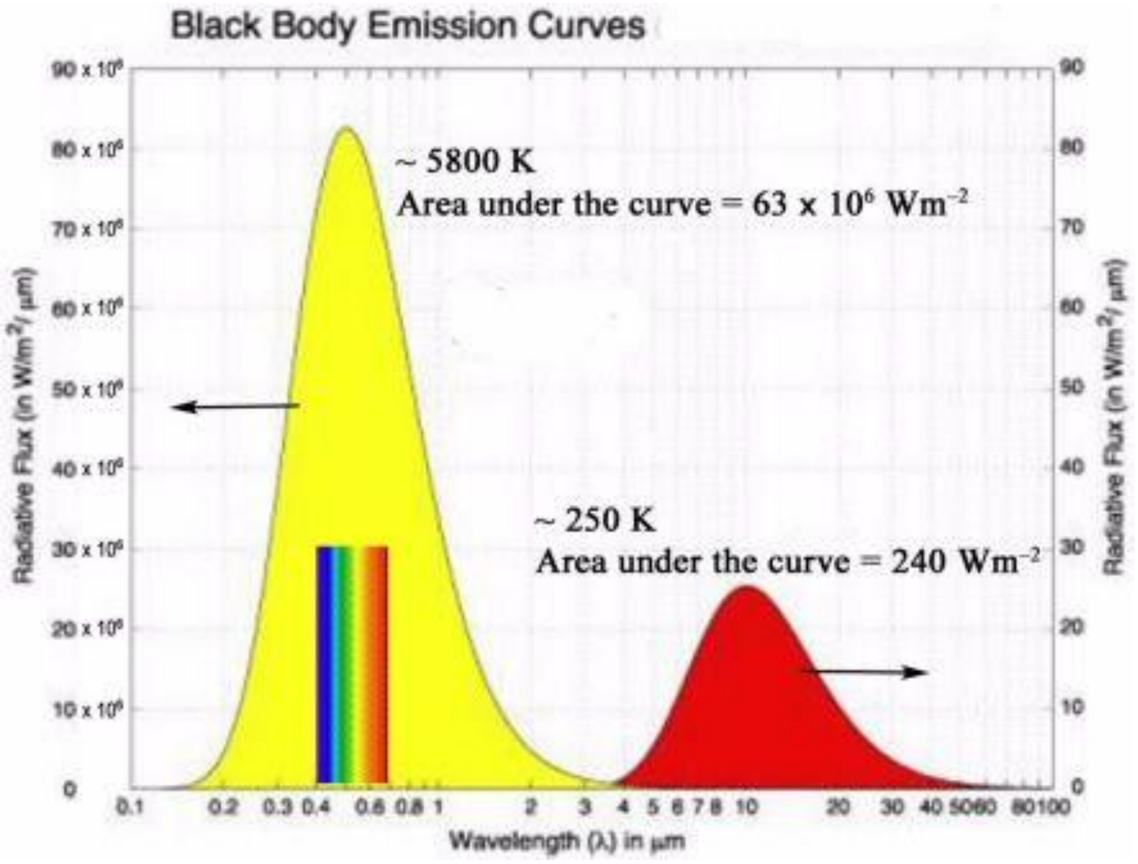
Chen, J., C. Lei, and P. Sciusco, 2021. Modeling Ecosystem Global Warming Potentials. In *Biophysical Models and Applications in Ecosystem Analysis* (pp. 121-126). MSU Press.

Next Quiz on Sept 17!

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").

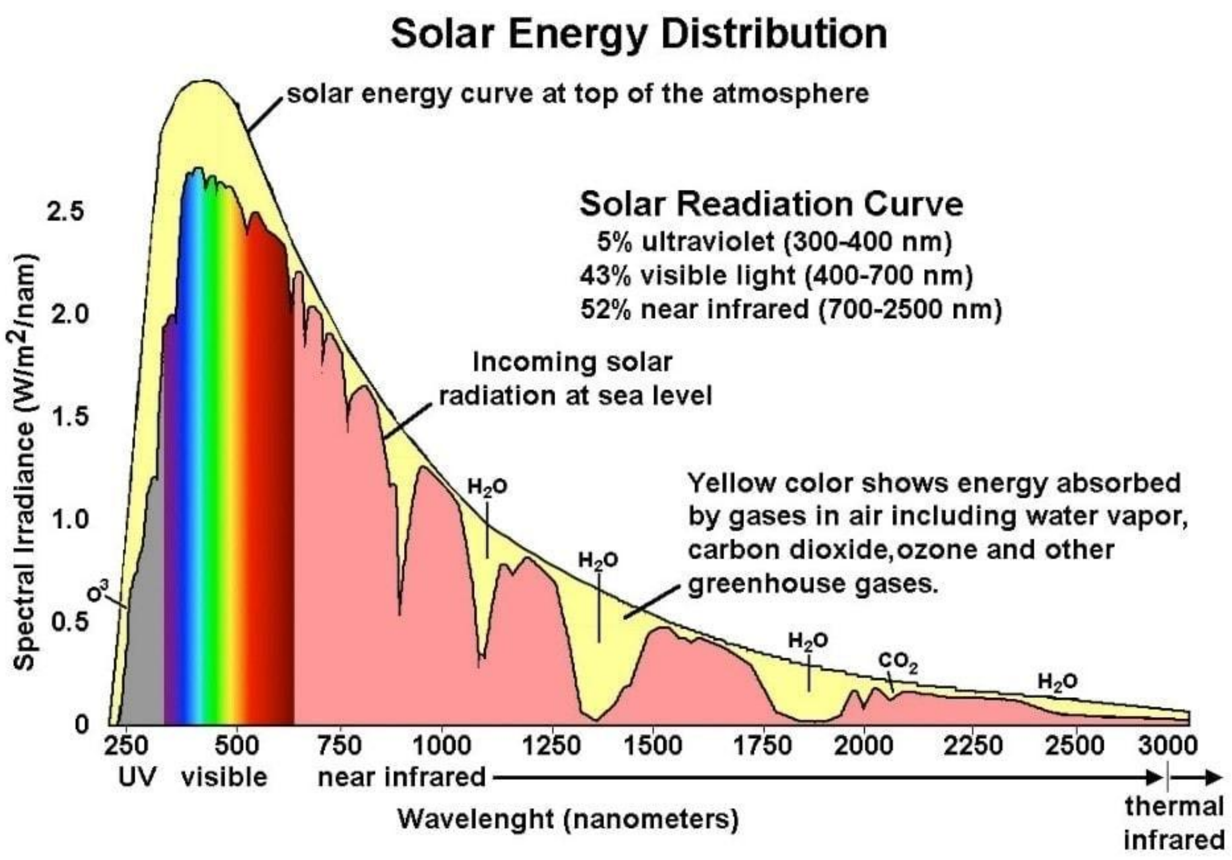
2) The Earth's (T = 288 K) peak emittance is 9.5-10.0 nm. In sum, Earth's temperature is mostly maintained by the balance of incoming shortwave radiation from the sun and outgoing longwave radiation from the Earth.

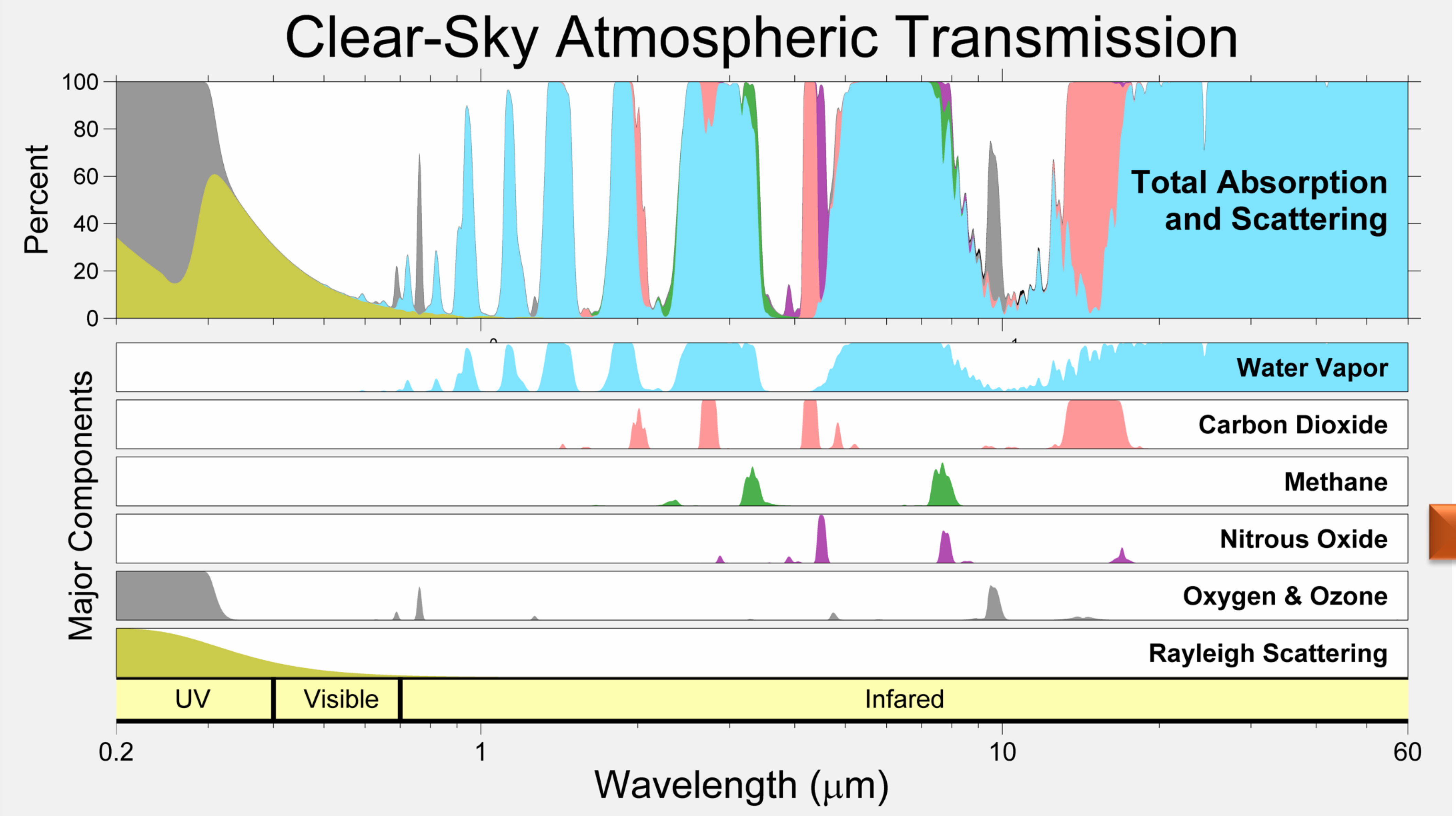
Quiz: How much energy does the earth receive from the sun?



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.

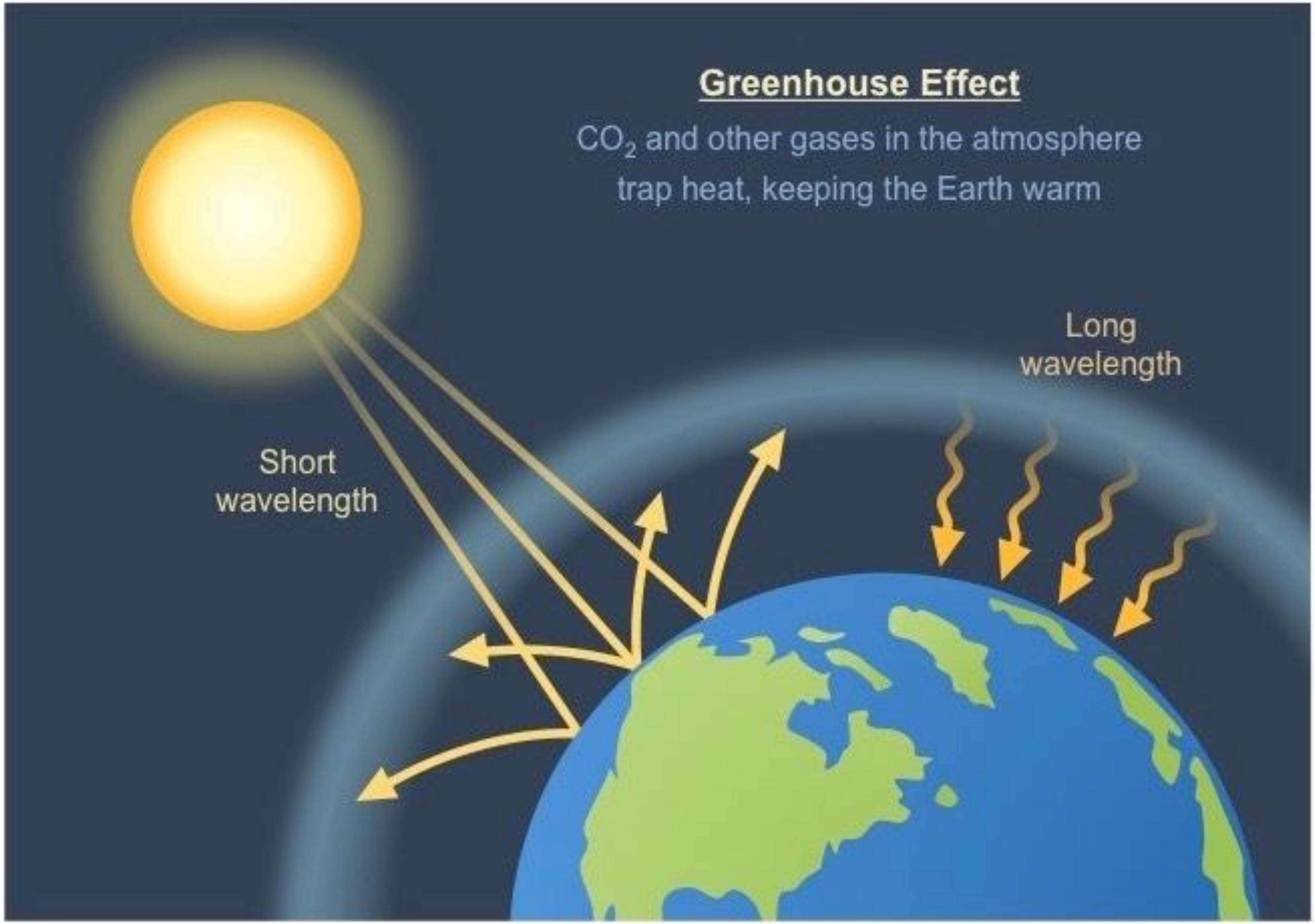




Greenhouse gases (GHG)

Chen, J. 2020

Why is temperature increasing?



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.

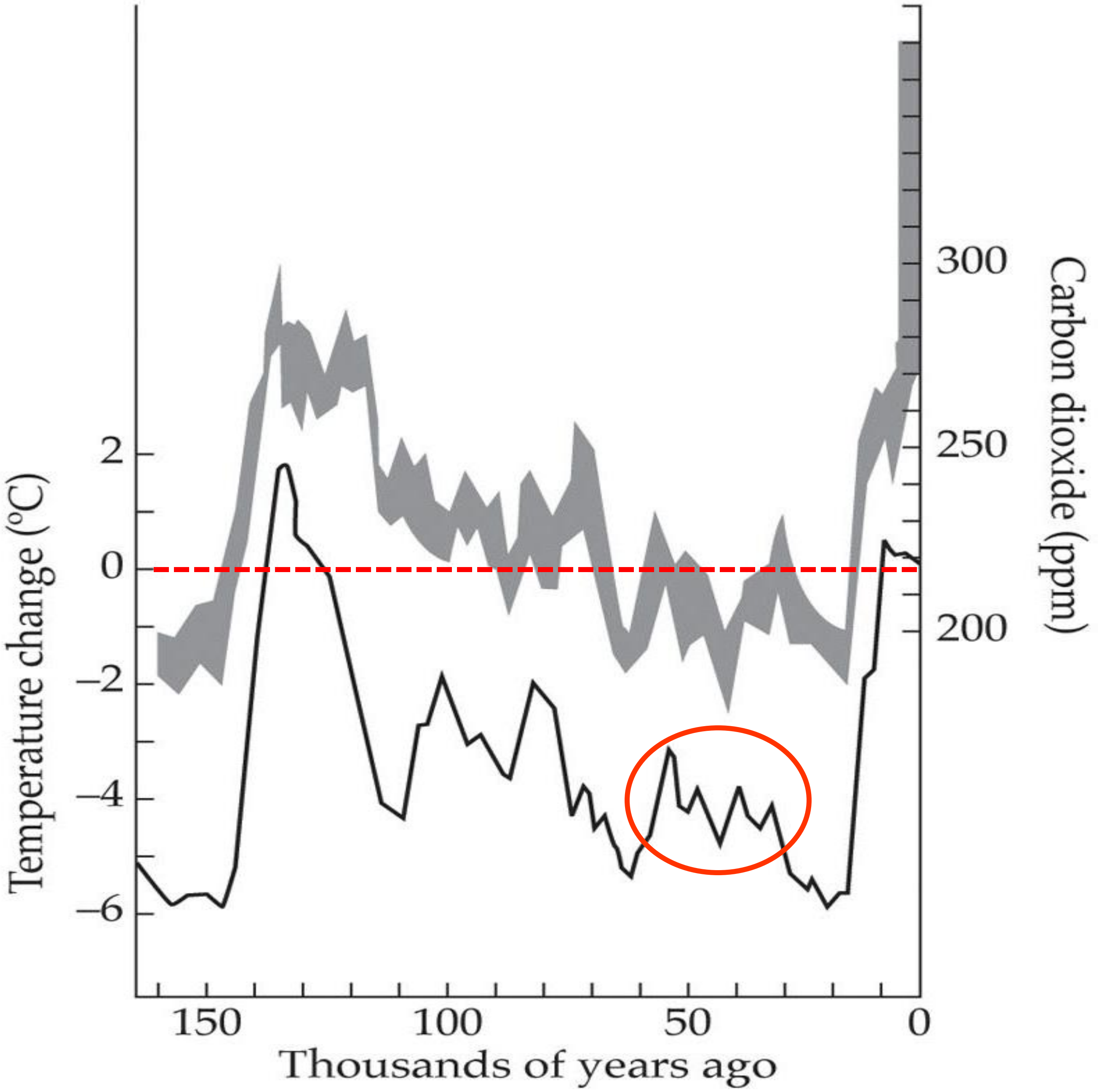
- Roger R.D. Revelle and other pioneering scholars started scientific investigations on anthropogenic influences on global warming (see more detailed history in Archer & Pierrehumbert 2011). However, they hypothesized that oceans would absorb all the CO_2.

- 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.

Increasing in emission of GHG and air pollution

The relationship between temperature and carbon dioxide over the past 160,000 years



PRINCIPLES OF CONSERVATION BIOLOGY, Third Edition, Figur

It takes time for any GHG species to diminish (decomposition), with varying resident time in the atmosphere!

Table 5.1 Global warming potential (GWP) of greenhouse gases (GHGs) based on the fourth Assessment Report (AR_4) of the IPCC (2007). The release of 1 kg CH_4, for example, is equivalent to 25 kg of CO_2 (from Forster *et al.* 2007).

GHG Species	Formula	Lifetime (years)	20-year	100-year	500-year
Carbon Dioxide	CO_2	Variable	1	1	1
Methane	CH_4	12±3	72	25	7.6
Nitrous Oxide	N_2O	120	289	298	153

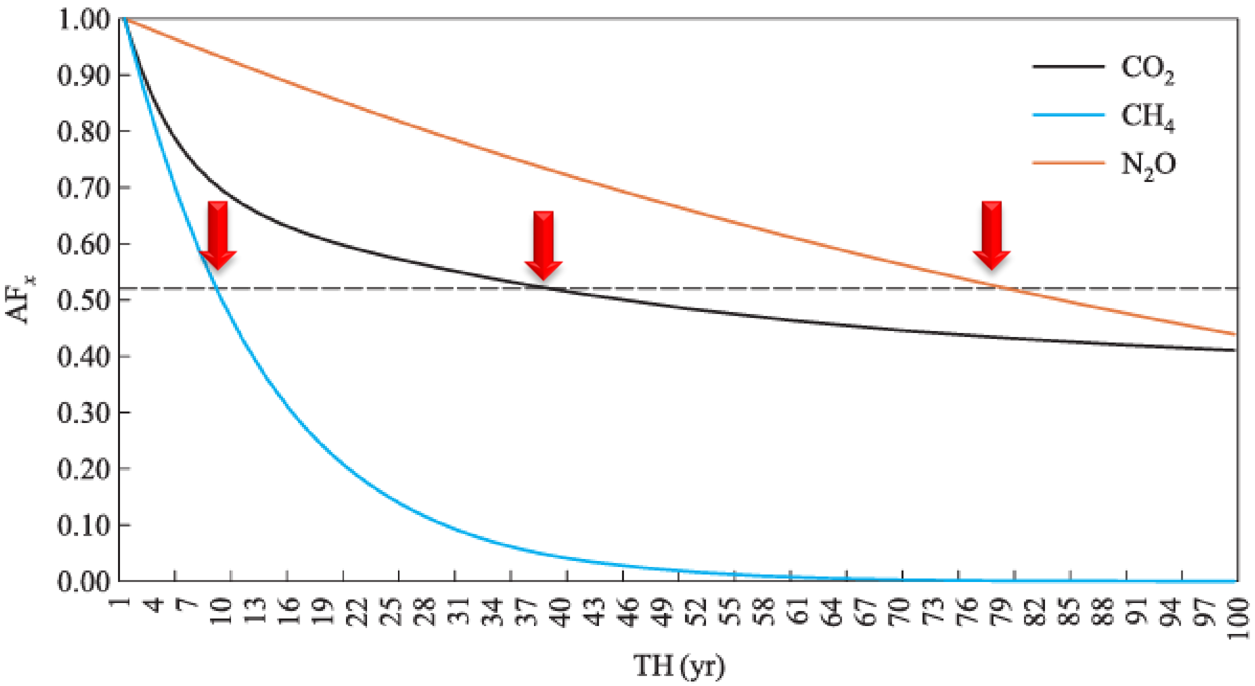


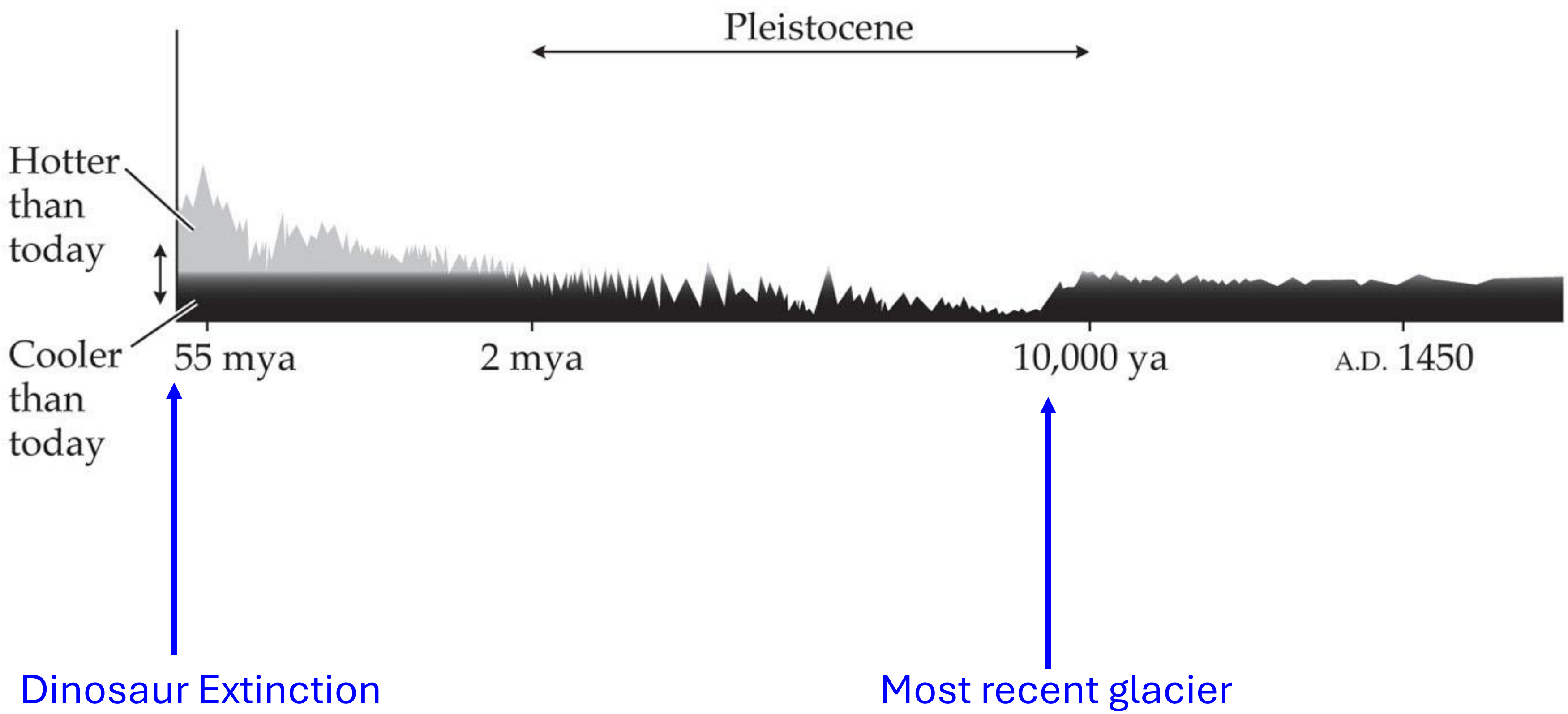
Fig. 5.4 The impulse response functions from the fifth IPCC Annual Report (AR_5) for calculating AF_x of CO_2, CH_4 and N_2O (Eqs. 5.5 and 5.6). The horizontal dashed line indicates the average AF_{CO_2} (0.52) over 100 years (TH = 100) (IPCC 2014 SM). This means that 52% of the emitted CO_2 pulse remains in the atmosphere after 100 years.

GWPs provide a common unit of measure, which allows analysts to add up emissions estimates of different gases (e.g., to compile a national GHG inventory) and allows policymakers to compare emissions reduction opportunities across sectors and gases. Other than H_2O, these are the major greenhouse gases (GHG):

- **CO_2**, by definition, has a GWP of 1 regardless of the time period used, because it is the gas being used as the reference. CO_2 remains in the climate system for a very long time: CO_2 emissions cause increases in atmospheric concentrations of CO_2 that will last thousands of years.
- **Methane (CH_4)** is estimated to have a GWP of 28–36 over 100 years (Learn why EPA's U.S. Inventory of Greenhouse Gas Emissions and Sinks uses a different value.). CH_4 emitted today lasts about a decade on average, which is much less time than CO_2. But CH_4 also absorbs much more energy than CO_2. The net effect of the shorter lifetime and higher energy absorption is reflected in the GWP. The CH_4 GWP also accounts for some indirect effects, such as the fact that CH_4 is a precursor to ozone, and ozone is itself a GHG.
- **Nitrous Oxide (N_2O)** has a GWP 265–298 times that of CO_2 for a 100-year timescale. N_2O emitted today remains in the atmosphere for more than 100 years, on average.
- Chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), hydrochlorofluorocarbons (HCFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) are sometimes called high-GWP gases because, for a given amount of mass, they trap substantially more heat than CO_2. (The GWPs for these gases can be in the thousands or tens of thousands.)

https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

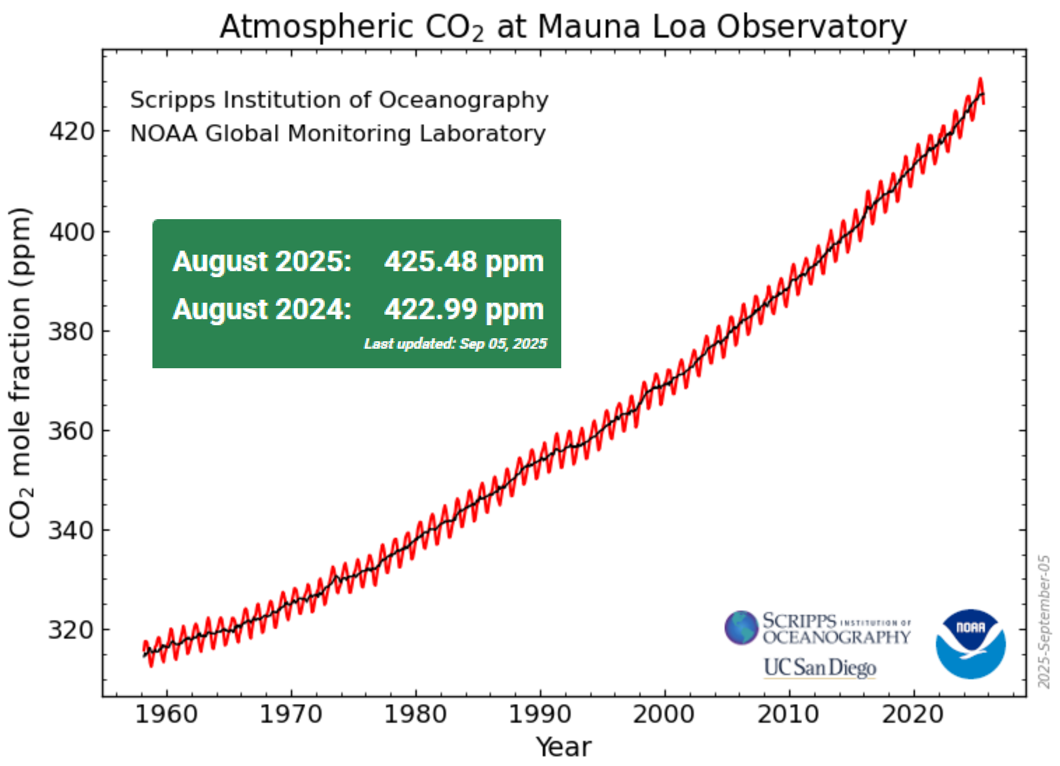
Average global temperature over the last 65 million years

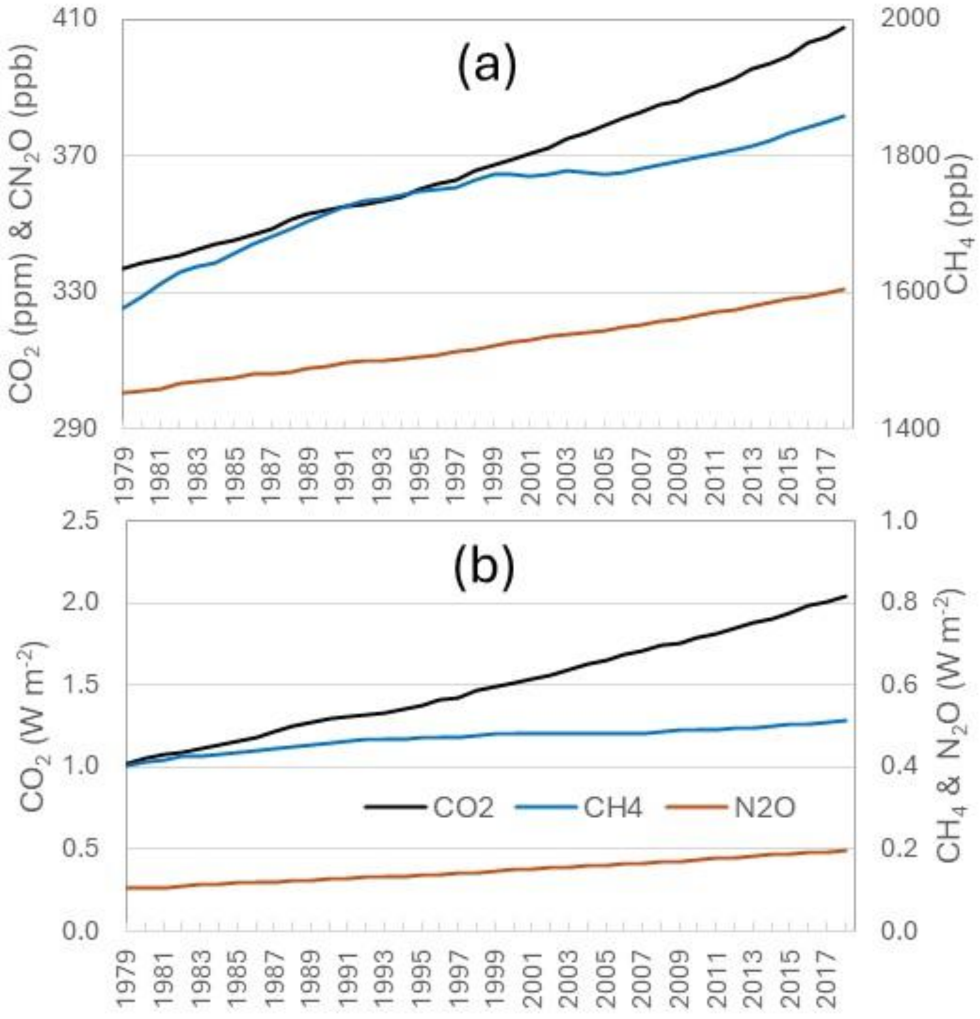


PRINCIPLES OF CONSERVATION BIOLOGY, Third Edition, **Figure 10.2**

5.1 Introduction

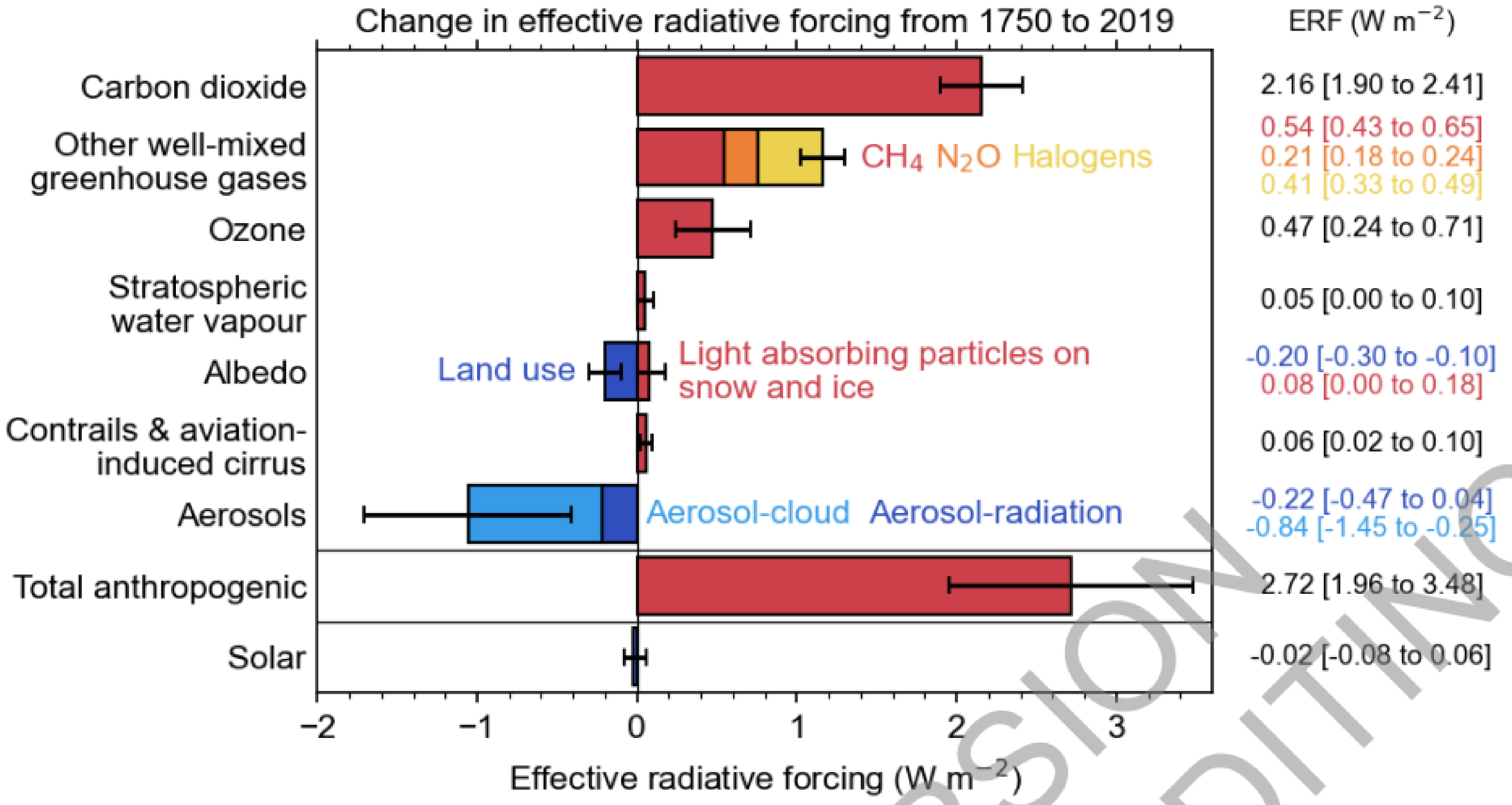
Long-term changes in three major GHG species (CO_2, CH_4 & N_2O) concentrations (a), their radiative forcing (RF) (b during 1979-2018. Data source: https://www.esrl.noaa.gov/gmd/aggi/NOAA_MoleFractions_2019.csv (downloaded on 29 March 2020).





https://gml.noaa.gov/ccgg/trends/

Contributions of Major Warming/Cooling Species (IPCC 2021)



1) Another frontier in quantifying GWP of terrestrial ecosystems is resulted from the changes in albedo ($\Delta\alpha_s$) that reflect more solar radiation back to outer space (*e.g.*, lighter canopies) or keep more radiation energy within Earth systems (*e.g.*, taller and denser canopies) (Chapter 1). This is known as the radiative forcing (RF_s) of land surface.

2) Imagine an area that can reflect 1% more solar radiation (*i.e.*, an increase of albedo by 1%). With an atmospheric transmission of 0.854, the total amount of solar energy that reaches the ground will be ~1170 W m^{-2} (*i.e.*, solar constant times 0.854).

3) Assuming the same transmittance for the outgoing shortwave radiation, 1% more reflection is equivalent to ~10 W m^{-2} (*i.e.*, 1170*0.854*0.01). This value is equivalent to a cooling effect of ~11 $kgCO_2$, or ~3 kgC m^{-2} (see Section 5.2 for conversion).

Next Lecture

Sep 15: Albedo Effects on Earth's Climate: Warming and Cooling

- Albedo of terrestrial ecosystems
- Land use and albedo
- Albedo measurements
- Albedo and GWP

Reading

Chen, J., Lei, C., Chu, H., Li, X., Torn, M., Wang, Y. P., ... & Robertson, G. P. (2024). Overlooked cooling effects of albedo in terrestrial ecosystems. *Environmental Research Letters*, *19*(9), 093001.