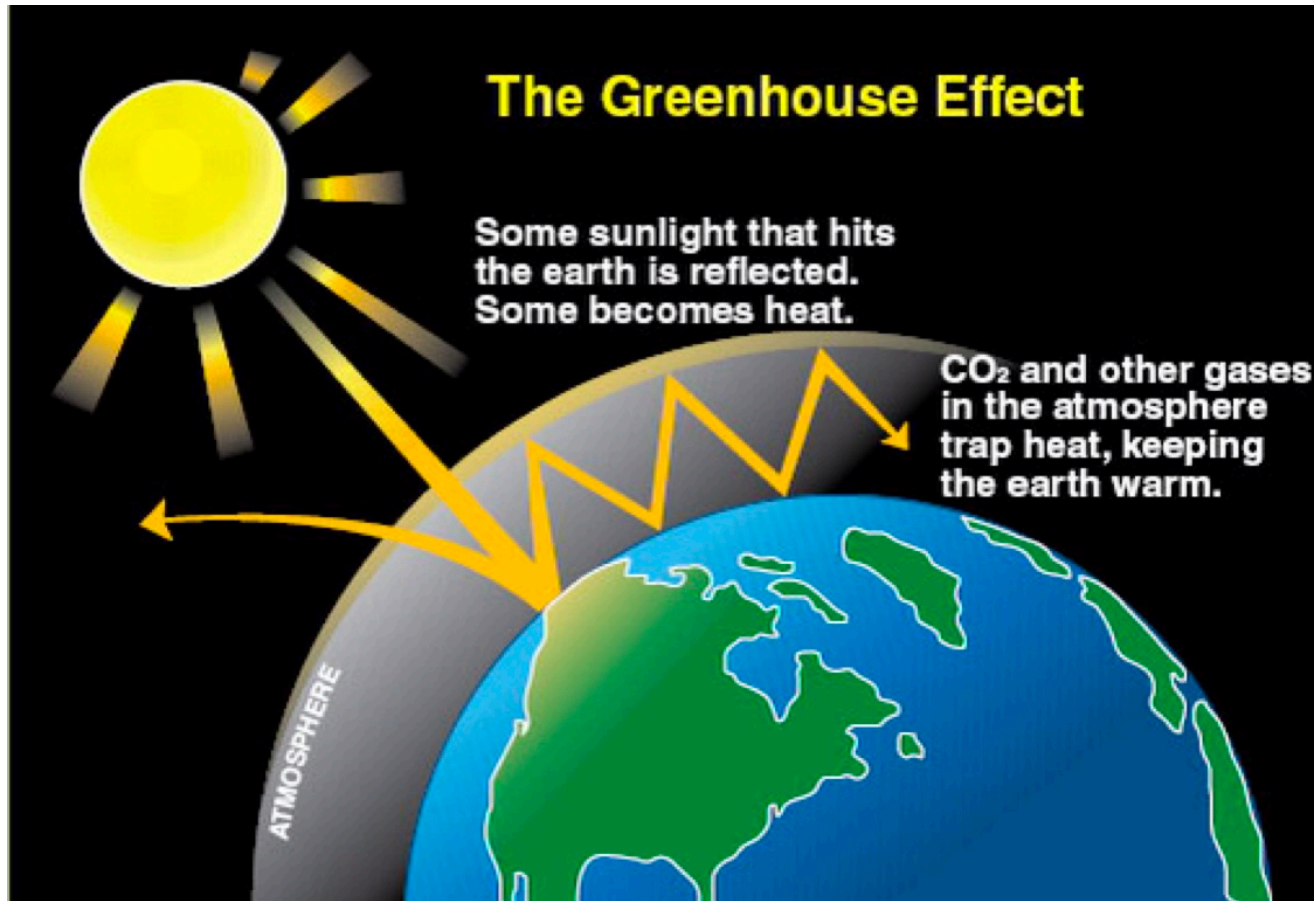


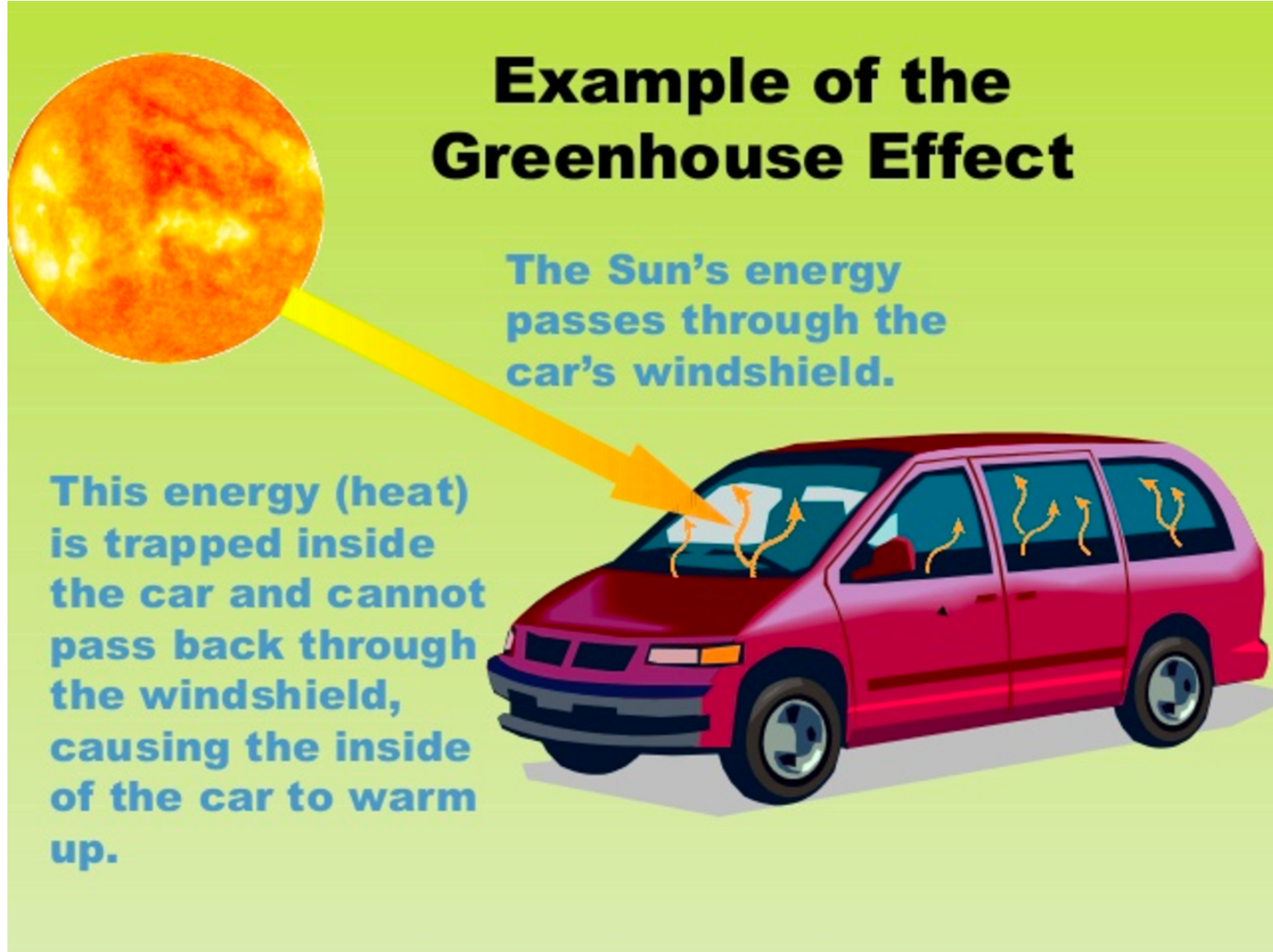
Understanding and Using Climate Data Resources



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Some basic physics

What is the Greenhouse Effect?



Greenhouse Effect (cont)

- Here is a somewhat more precise description
 - ◆ Sunlight carrying energy penetrates car windows (short-wavelength)
 - ◆ Solar energy heats the car interior
 - ◆ As car interior heats, it emits long-wavelength radiation (infrared)
 - ◆ But emitted IR waves are partially absorbed by windows!
 - ◆ So interior heats up more, increasing emitted IR waves
 - ◆ Interior warming stops once emitted energy = incoming energy
- So the car interior reaches *equilibrium* with incoming solar rays, but at a higher temperature than if the windows were open
- The same process works for planets with atmospheres
 - ◆ Consider Earth (next slide)

Greenhouse Effect and Global Warming

The Greenhouse Effect

Total warming is 33° C!

Some sunlight that hits the earth is reflected. Some becomes heat.

CO₂ and other gases in the atmosphere trap heat, keeping the earth warm.

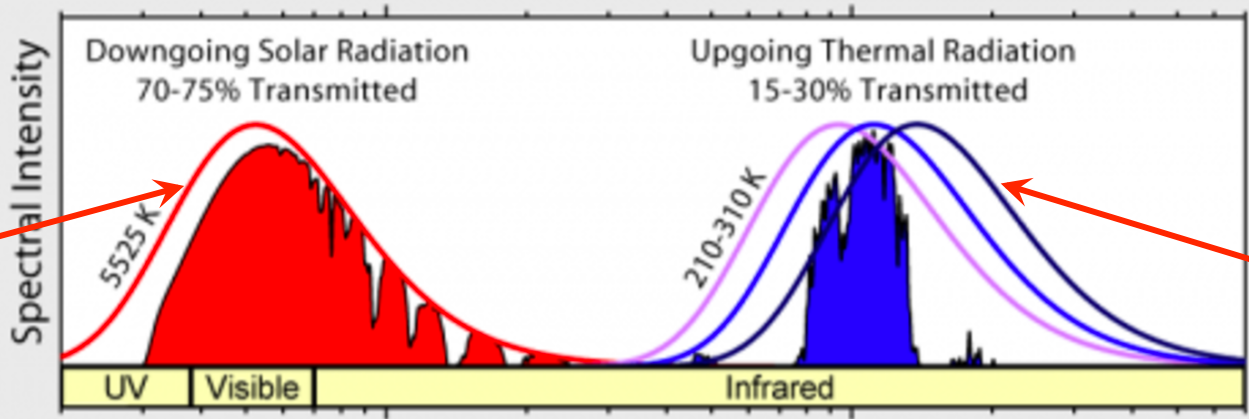
ATMOSPHERE

Which Gases Cause Greenhouse Effect?

- Most incoming solar radiation has wavelengths 0.4–1.5 μm
 - ◆ Visible and near infrared
 - ◆ Atmosphere is almost transparent to it
- Most emitted radiation by earth has wavelengths 5–40 μm
 - ◆ O₂ and N₂ are almost transparent to this radiation
 - ◆ But CO₂, CH₄, N₂O, CFCs, H₂O absorb heavily in this region
 - ◆ CO₂, CH₄, N₂O, CFCs are trace gases
 - ◆ H₂O comes from evaporation (which increases with CO₂, etc)
- (Next slide)

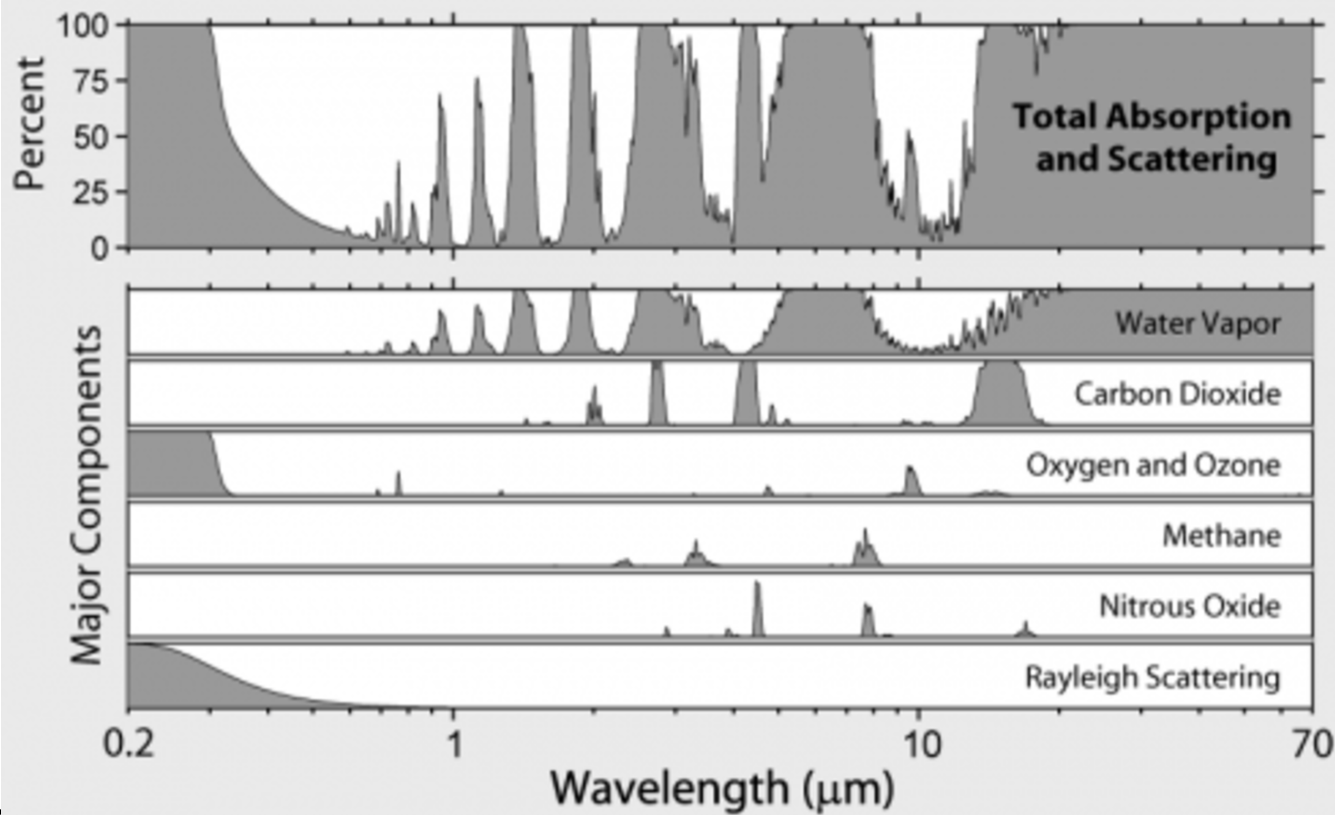
Radiation Transmitted by the Atmosphere

0.2 1 10 70



Sun radiation
 $T \sim 5600\text{K}$

Earth radiation
 $T \sim 300\text{K}$



Greenhouse Effect on Planet Temperatures

- First calculate planet surface temperature *without* atmosphere
 - ◆ Equilibrium: Total incoming solar power = total emitted power
 - ◆ Both sides determined by basic physics and planetary data!
- What data is needed to calculate this surface temperature?
 - ◆ Total solar power (same for all planets)
 - ◆ Distance of planet from Sun
 - ◆ Albedo of planet (reflectivity)
- Compare predicted vs observed temperatures to assess greenhouse warming
 - ◆ (Next slides)

Calculate Temperature Without Atmosphere

- Solar radiation intensity (at earth distance from Sun)

$$I_{\text{sun}} = 1362 \text{ W / m}^2$$

- Earth reflects $a \sim 30\%$ of incoming radiation (“albedo”)
- Equilibrium: radiation absorbed = radiation emitted
 - ◆ Use blackbody radiation law!

$$I_{\text{sun}} \times \pi r_{\text{earth}}^2 \times (1 - a) = \sigma T_{\text{earth}}^4 \times 4\pi r_{\text{earth}}^2$$

Absorbed radiation

Emitted radiation

- (See next slide)

Calculate Earth Temperature (2)

$$I_{\text{sun}} \times \pi r_{\text{earth}}^2 \times (1 - a) = \sigma T_{\text{earth}}^4 \times 4\pi r_{\text{earth}}^2$$

$$T_{\text{earth}} = \left(\frac{(1 - a) I_{\text{sun}}}{4\sigma} \right)^{1/4} \approx 255 \text{ K} \quad \text{Actual} = 288 \text{ K}$$

➤ +33° C difference is due to atmospheric greenhouse effect

Predicted and Observed Temperatures

All temps in °C

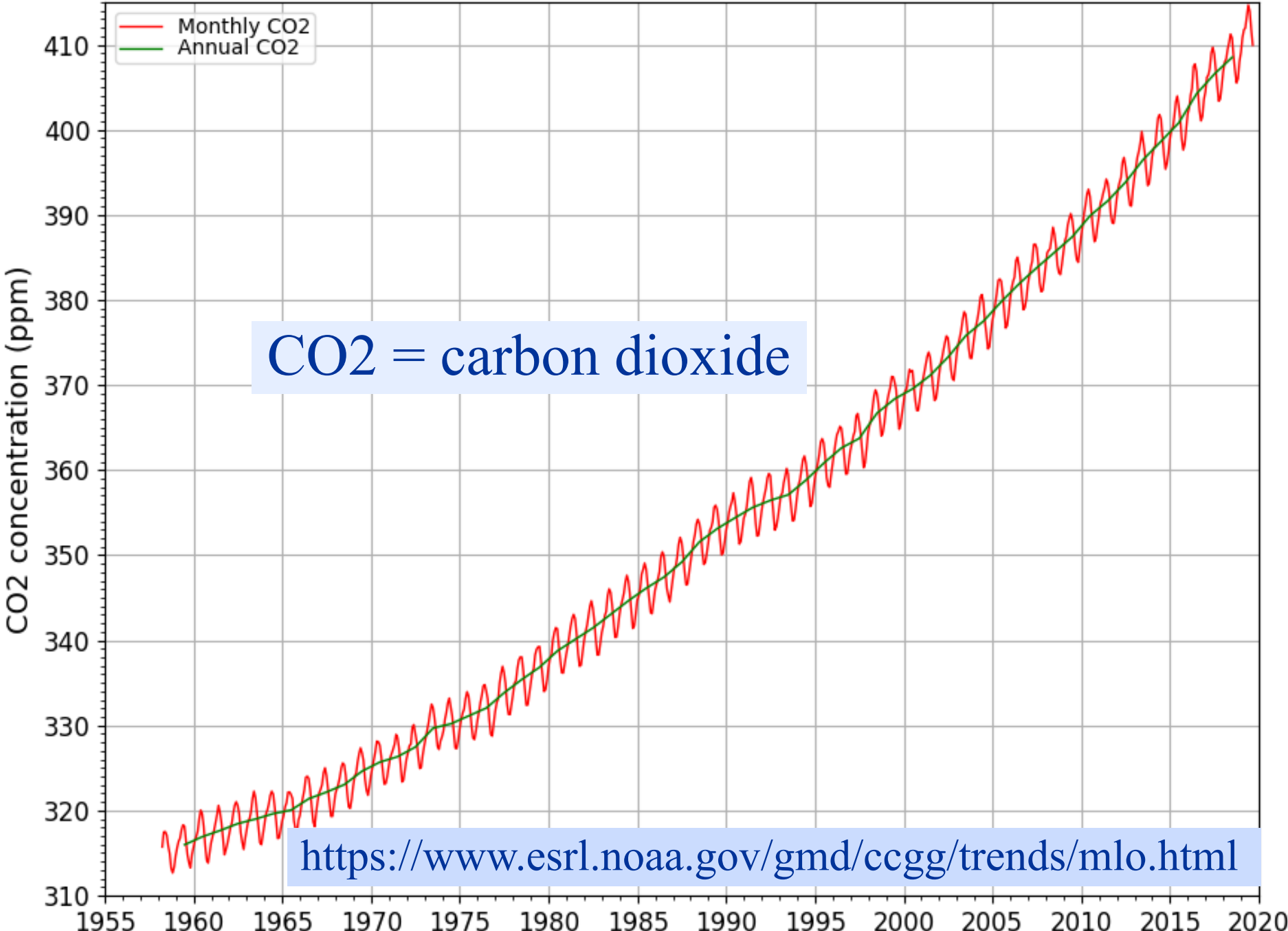
Planet	Solar Distance	Albedo	T_{pred}	T_{obs}	T_{obs} - T_{pred}
Mercury	0.39	0.068	165	167	+2
Venus	0.73	0.90	-91	462	+553
Earth	1.00	0.30	-18	15	+33
Mars	1.52	0.25	-63	-58	+5
Titan	9.56	0.27	-190	-179	+11

- Mercury has ~0 greenhouse effect (no atmosphere)
- Venus has huge effect (very dense atmosphere)
- Earth has significant effect (CO₂, CH₄, H₂O, ...)
- Mars has small effect (little atmosphere, but some dust)

So What is the “Controversy”?

- Earth warming of +33°C is not controversial
 - ◆ This is a huge greenhouse gas effect, but sometimes forgotten
- Climate scientists predict human-caused *additional* increases (~2–4 °C) from continued increases in greenhouse gases
 - ◆ CO₂, CH₄, CFCs, N₂O
 - ◆ But some people dispute these additional temperature increases
- Effects of rising temperatures
 - ◆ Rising sea levels (melting ice, thermal expansion of water)
 - ◆ Increased severity of hot weather
 - ◆ Increase in hurricane frequencies & intensities
 - ◆ Displacement of people!!
- Next slides show increases in greenhouse gases in recent times

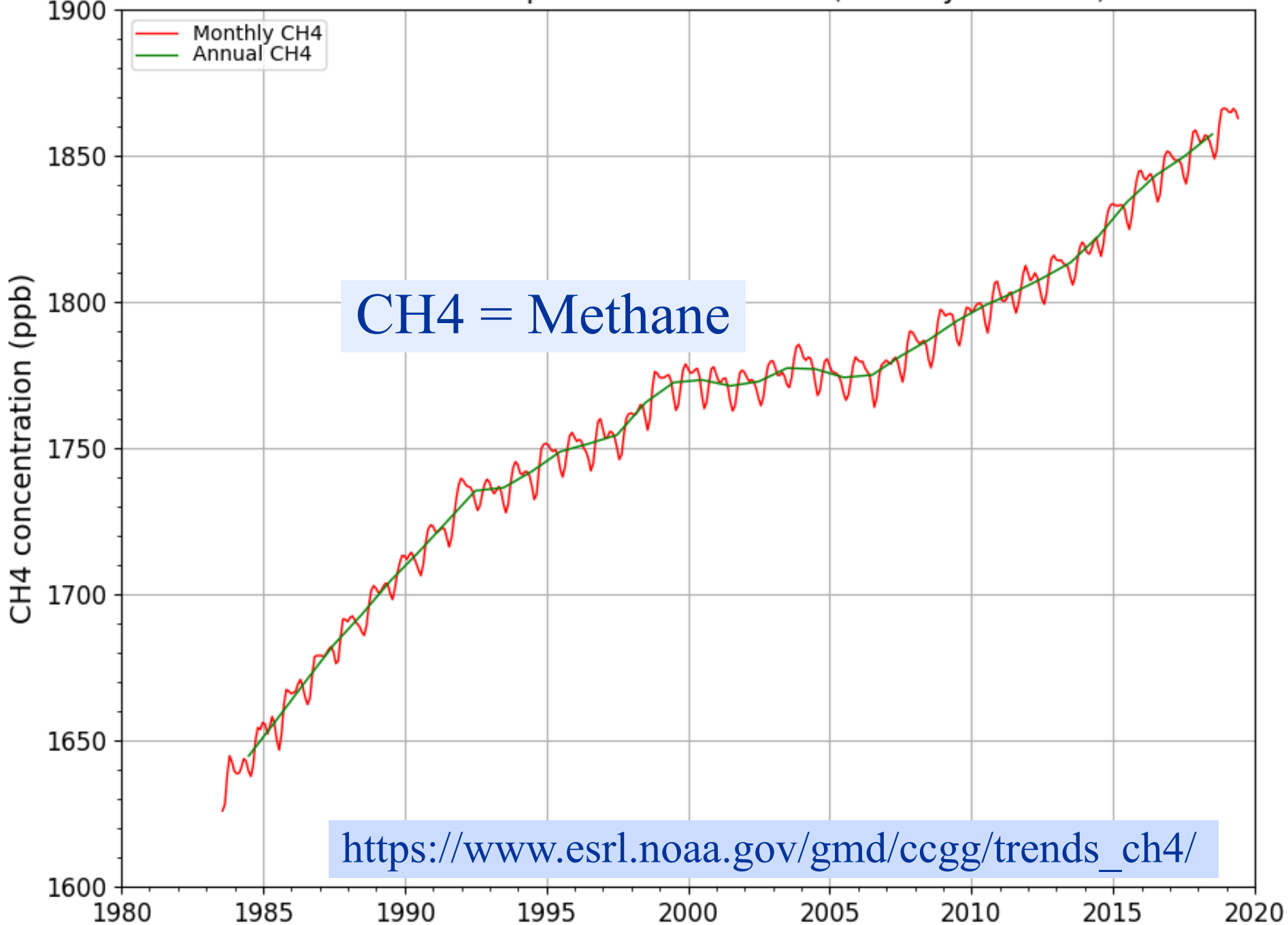
MLOA CO2 atmospheric concentration (monthly & annual)



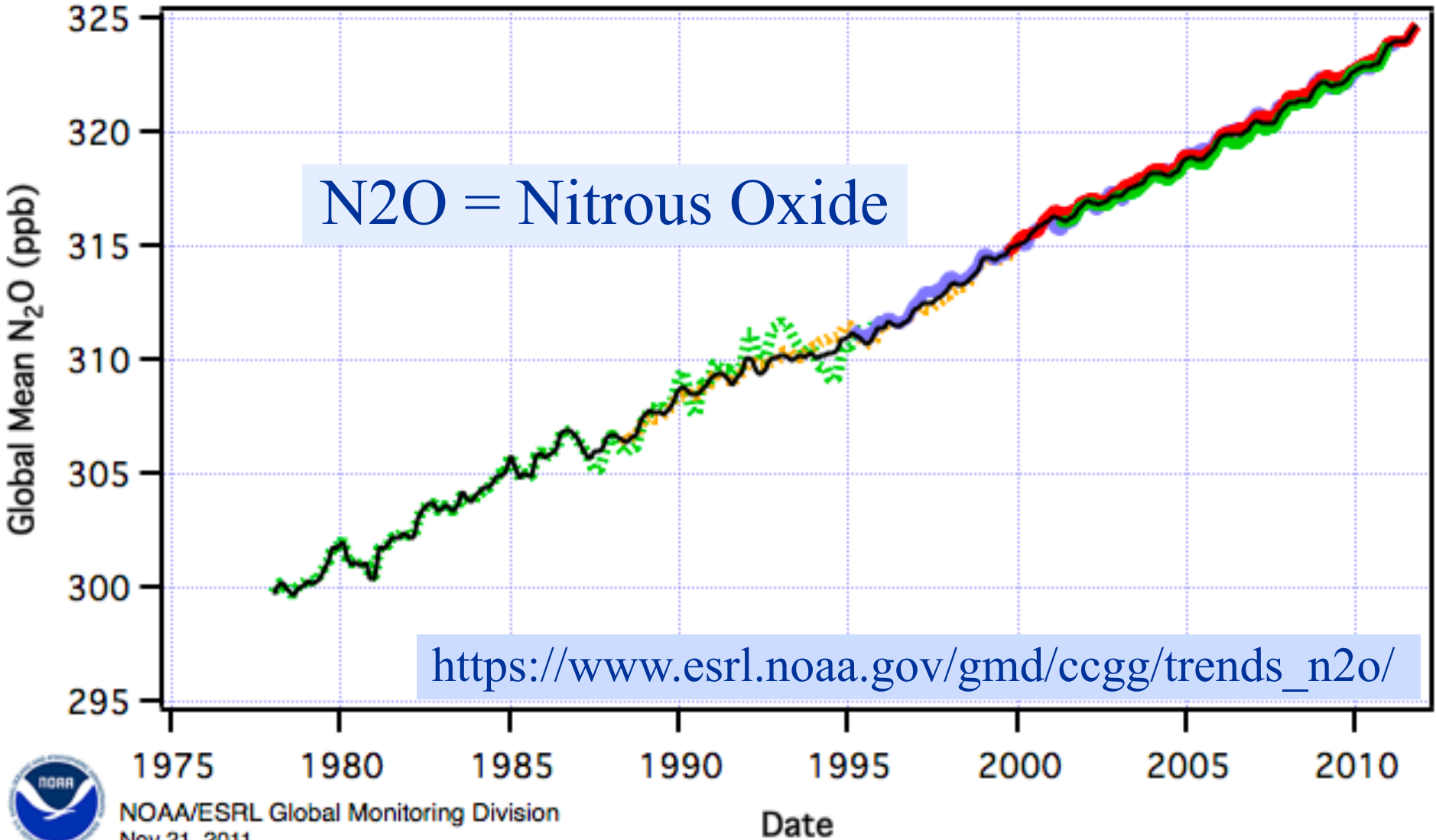
CO2 = carbon dioxide

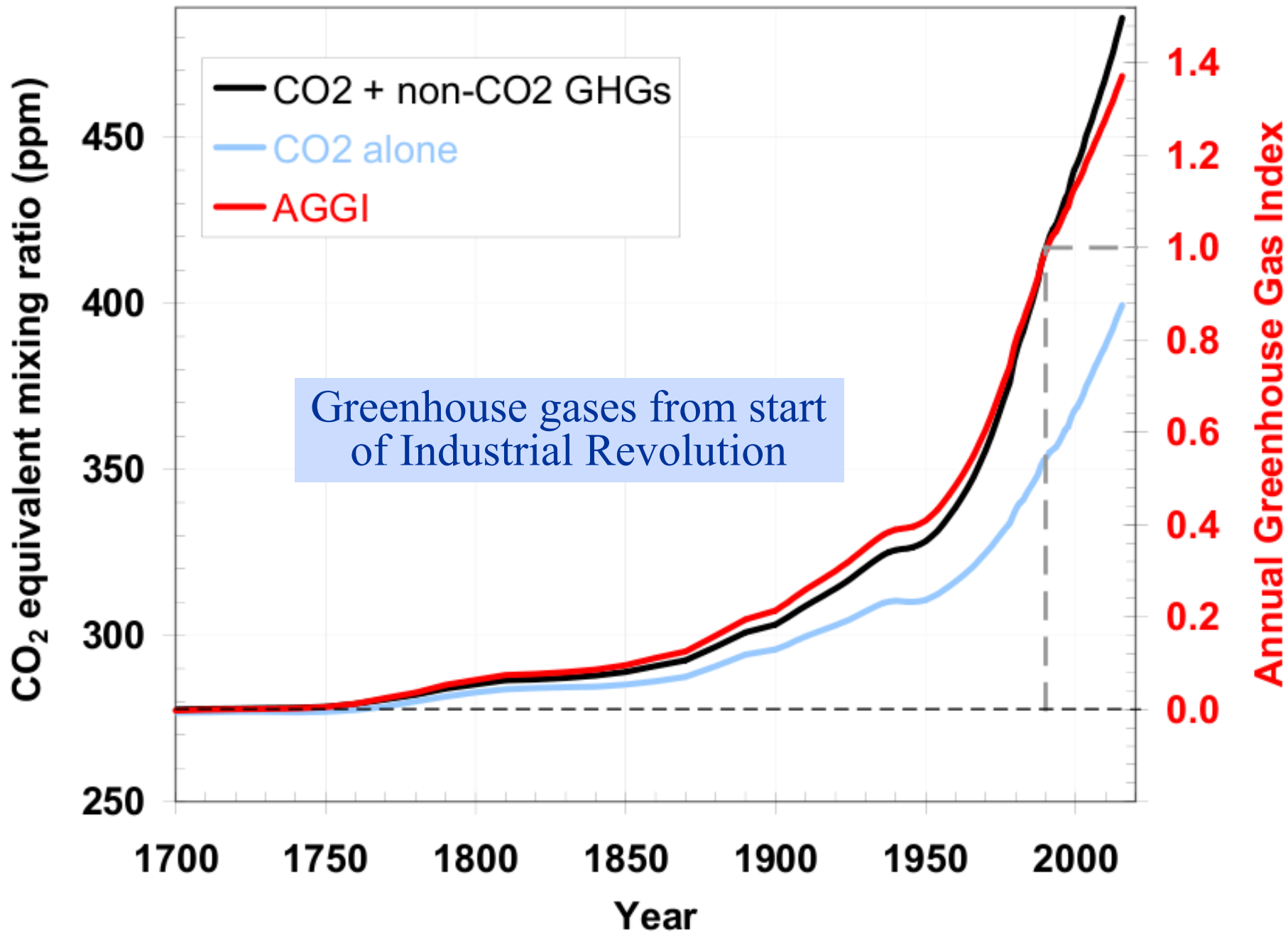
<https://www.esrl.noaa.gov/gmd/ccgg/trends/mlo.html>

Global CH₄ atmospheric concentration (monthly & annual)



— Combined Global mean ■■■■ Original flask ECD program ■■■■ Current flask ECD program
■ Carbon Cycle Gas Group (CCGG) flask program
■■■■ RITS in situ program ■■■■ CATS in situ program





Some resources

Types of Climate Data Resources

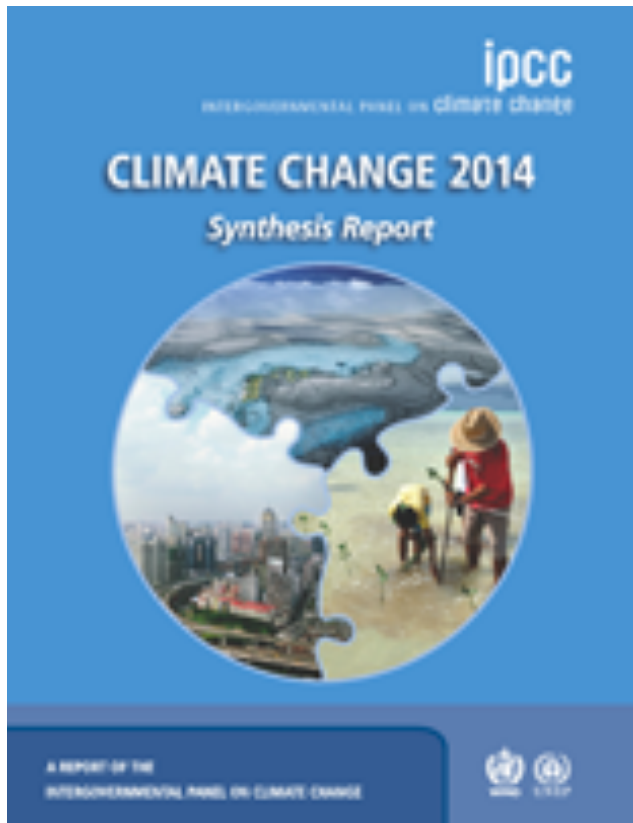
- International Panel on Climate Change (IPCC)
 - ◆ No research → but summarizes current state of climate science
 - ◆ IPCC issues report every few years (2014 most recent)
 - ◆ Many useful graphs, tables and useful summary reports

- Data resources
 - ◆ Land/sea temperature records
 - ◆ CO₂, CH₄, N₂O atmospheric concentration
 - ◆ Sea ice area (Arctic & Antarctic)
 - ◆ Sea ice volume & thickness (Arctic)
 - ◆ <http://berkeleyearth.org/>

- Many graphs, maps, videos exist online
 - ◆ Some of these are explicitly educational

IPCC Reports

- 5th Assessment Report (AR5) finished in 2014
 - ◆ <http://www.ipcc.ch/>
 - ◆ <http://www.ipcc.ch/report/ar5/>

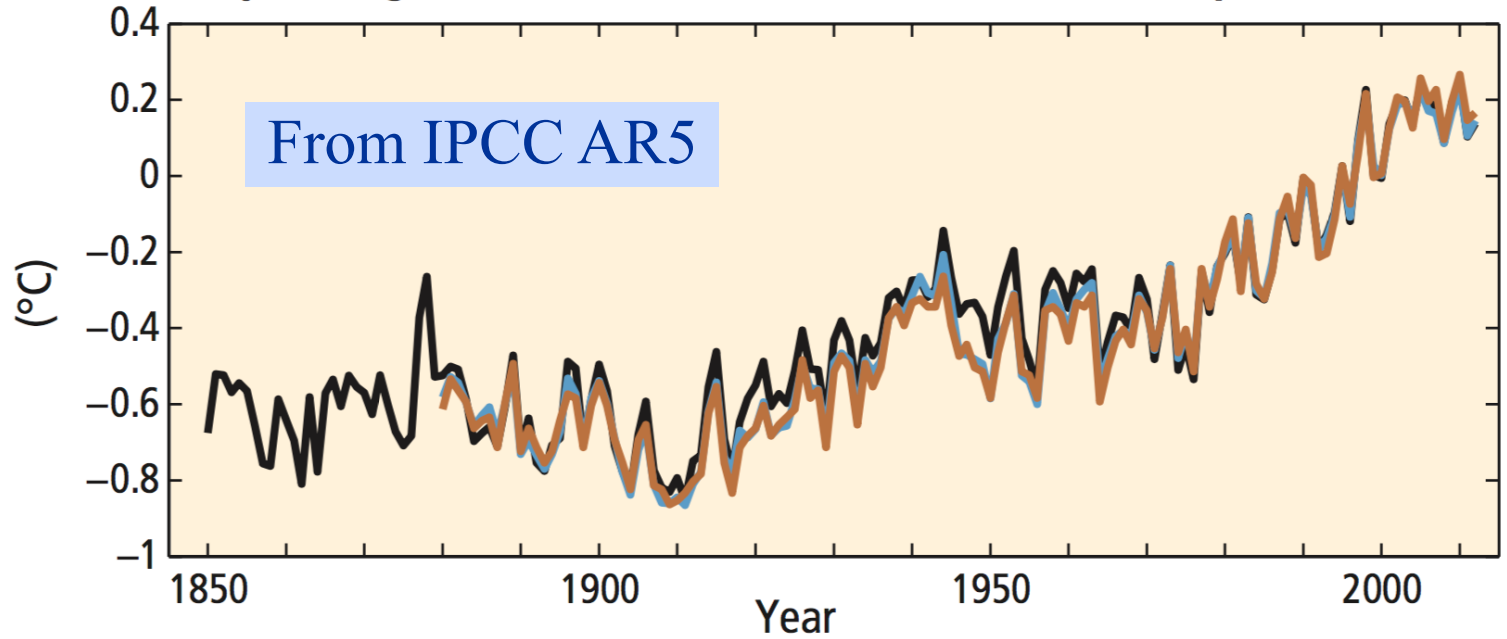


AR5 is most recent IPCC report

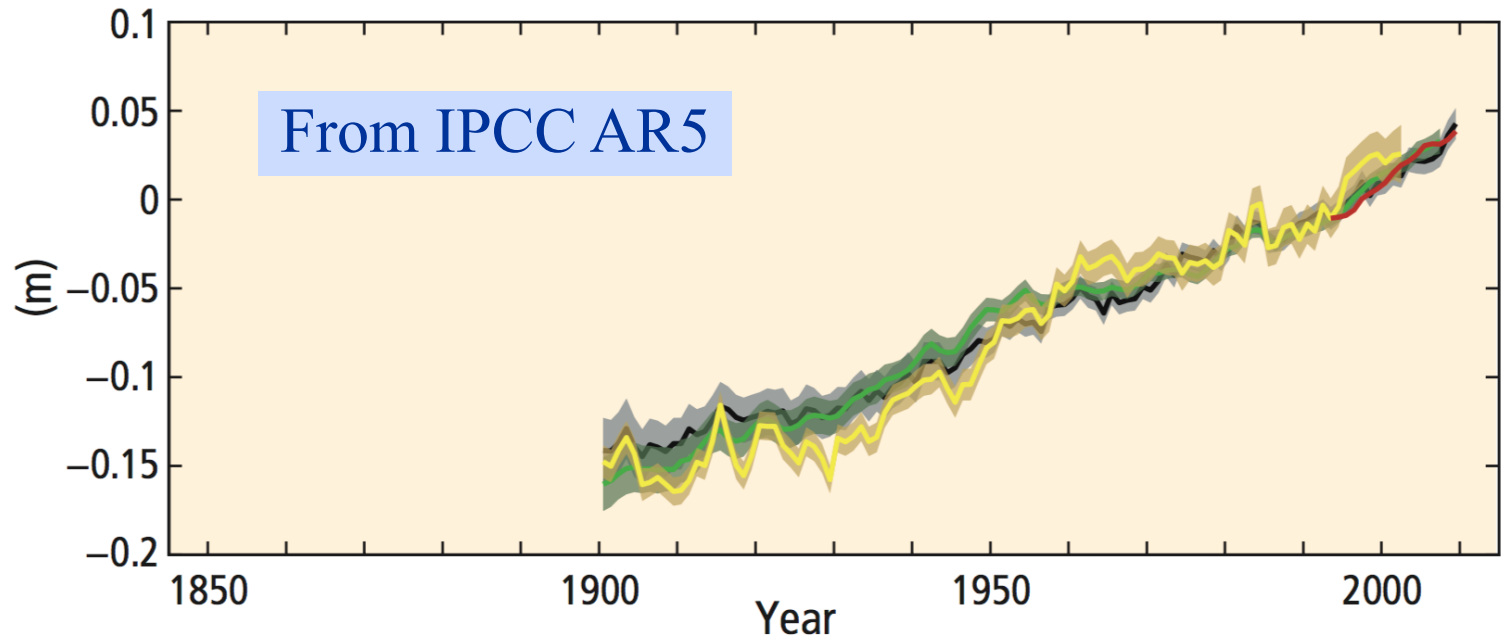
- 80 page Synthesis Report
- 32 page Summary for Policymakers

AR6 already started, due in 2022

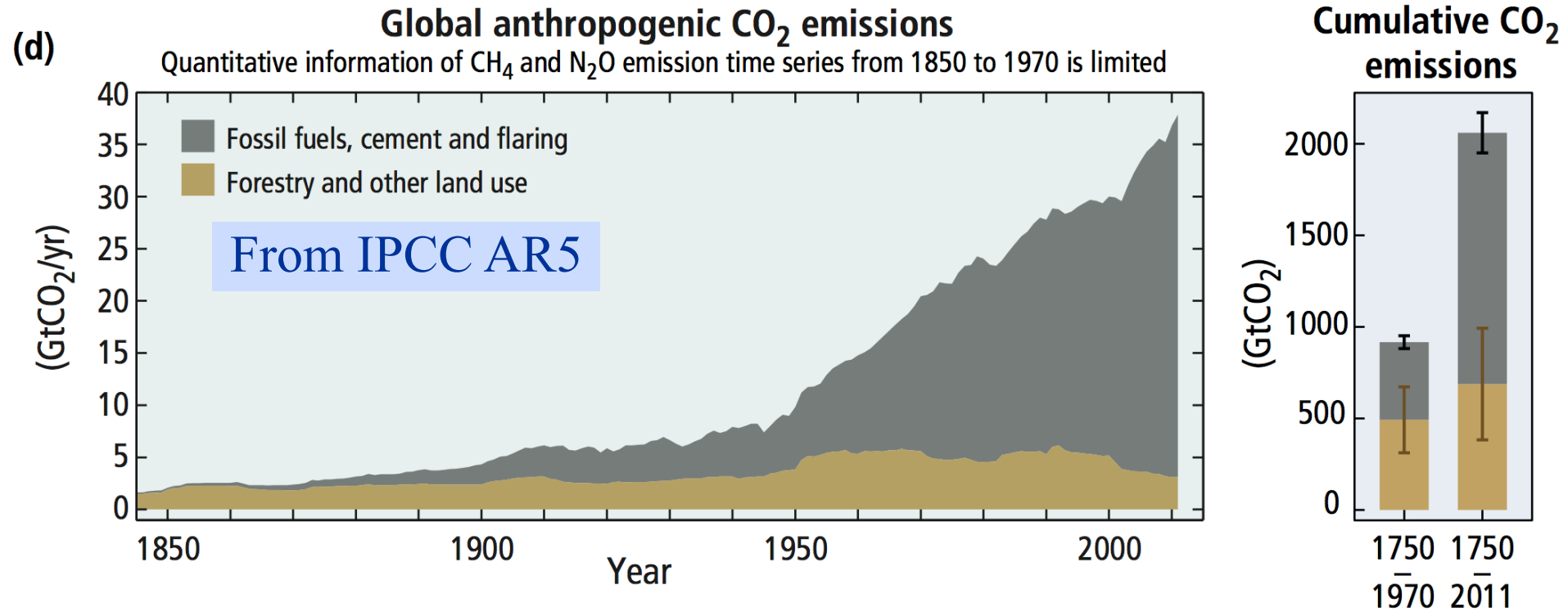
(a) Globally averaged combined land and ocean surface temperature anomaly



(b) Globally averaged sea level change

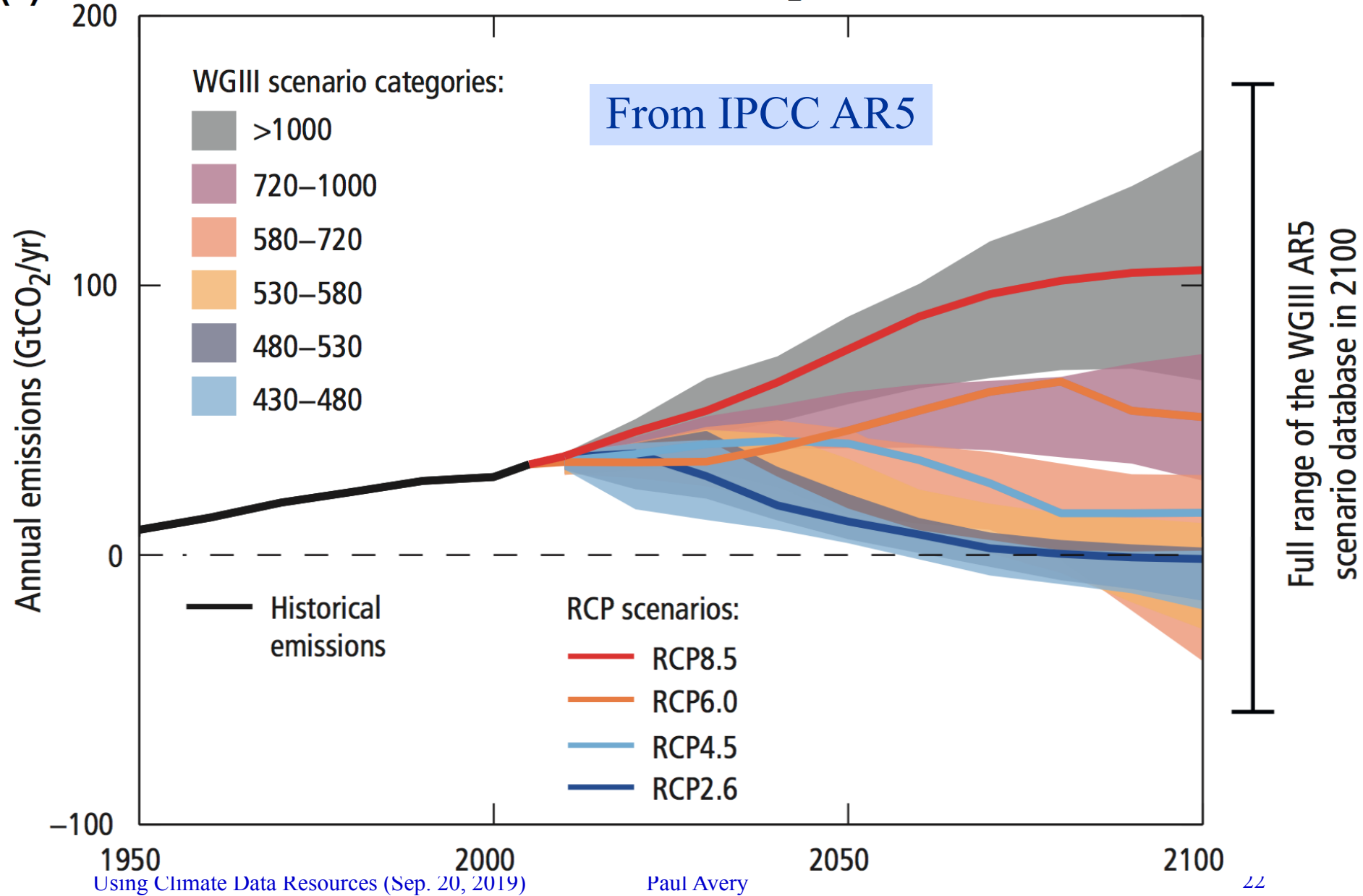


CO₂ Emissions



(a)

Annual anthropogenic CO₂ emissions



ESRL: CO₂, CH₄, N₂O, etc. Resources

- Earth Systems Research Lab (under NOAA)
 - ◆ <https://www.esrl.noaa.gov/gmd/ccgg/trends/>
 - ◆ https://www.esrl.noaa.gov/gmd/ccgg/trends_ch4/
 - ◆ <https://www.esrl.noaa.gov/gmd/hats/combined/N2O.html>
 - ◆ <https://www.esrl.noaa.gov/gmd/hats/data.html>
 - ◆ Lots of data, graphs (+ interactive), and even movies

- CO₂ data files
 - ◆ Measured monthly since 1959 (Mauna Loa) & globally since 1980
 - ◆ <ftp://aftp.cmdl.noaa.gov/products/trends/co2/>

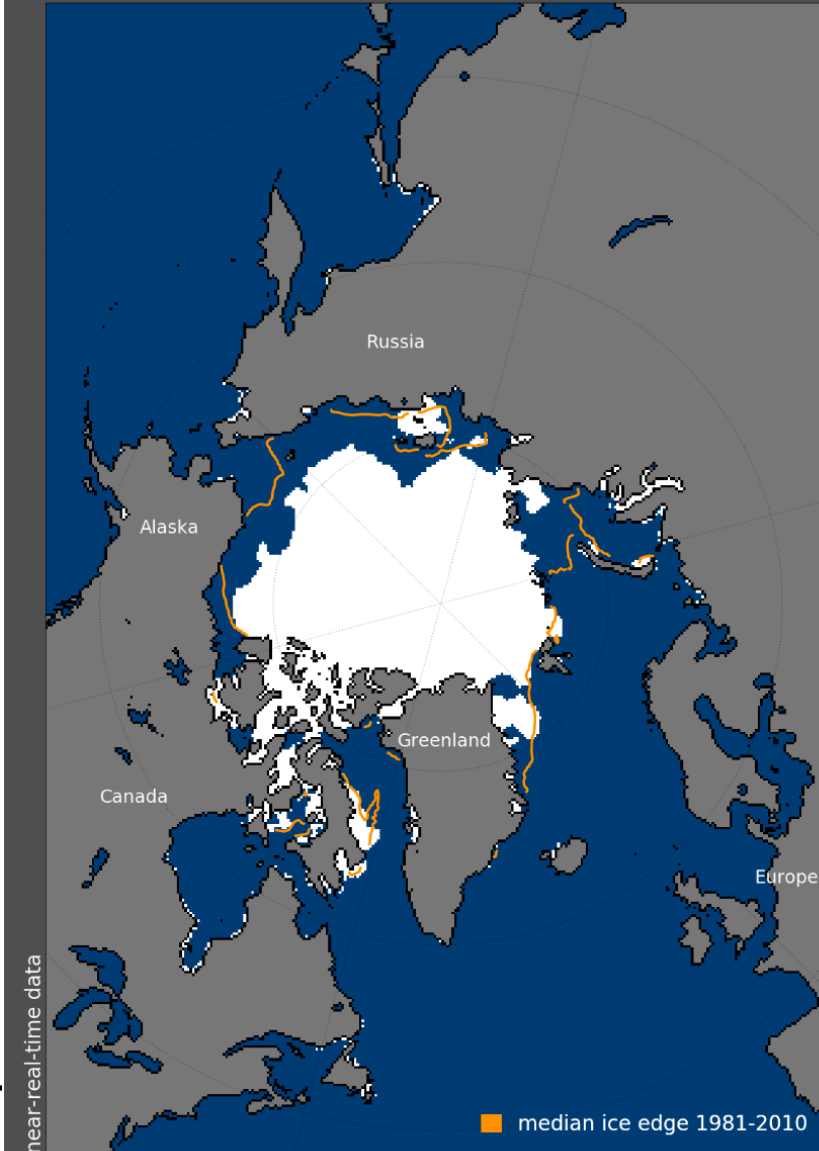
- CH₄ data files
 - ◆ Measured monthly since 1983
 - ◆ <ftp://aftp.cmdl.noaa.gov/products/trends/ch4/>

NSIDC: Satellite Images and Data

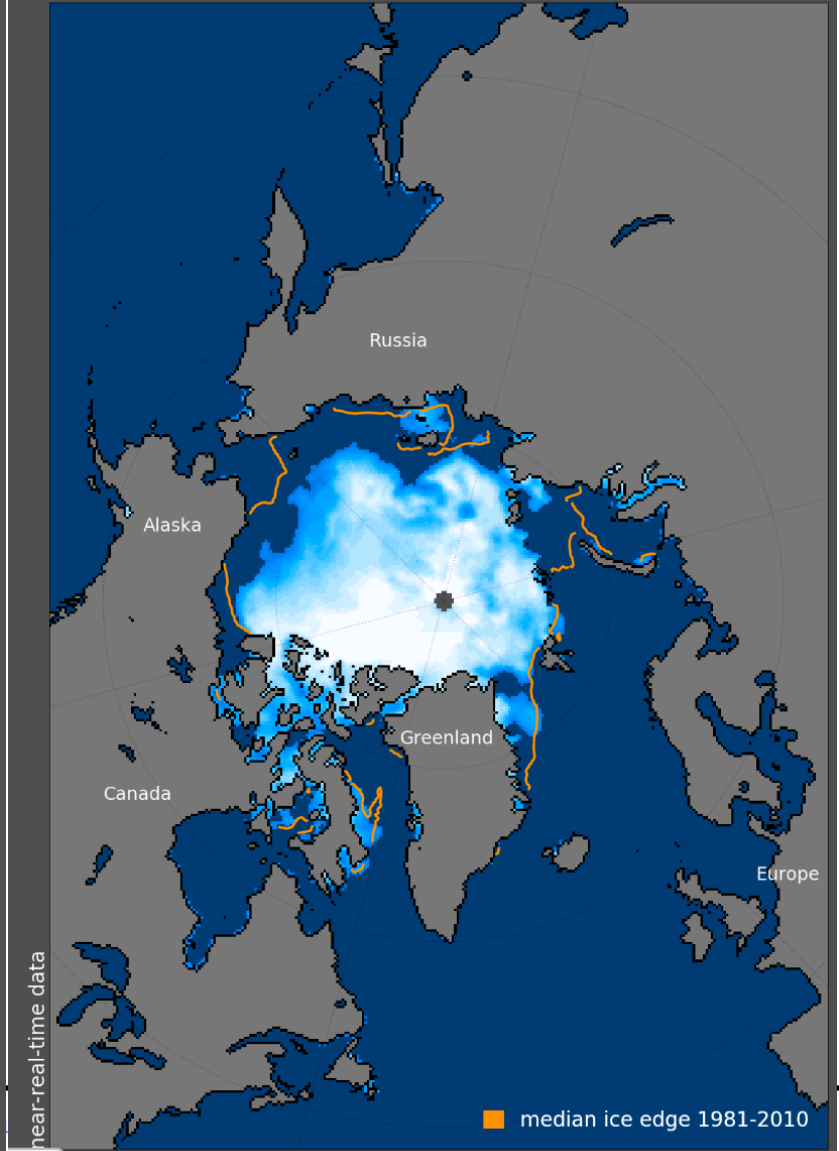
- National Snow and Ice Data Center
 - ◆ <https://nsidc.org/>
 - ◆ Why? → Polar regions are sensitive to effects of warming
 - ◆ But must track ice over decades
- NSIDC provides many satellite images & data products
 - ◆ Arctic and Antarctic regions
 - ◆ Most useful are measurements of sea ice “extent” (area)
- NSIDC has a very extensive website
 - ◆ Lots of data, images, information
 - ◆ ... but somewhat tricky to find what you want

NSIDC Satellite Views

Sea Ice Extent, 30 Jul 2017



Sea Ice Concentration, 30 Jul 2017



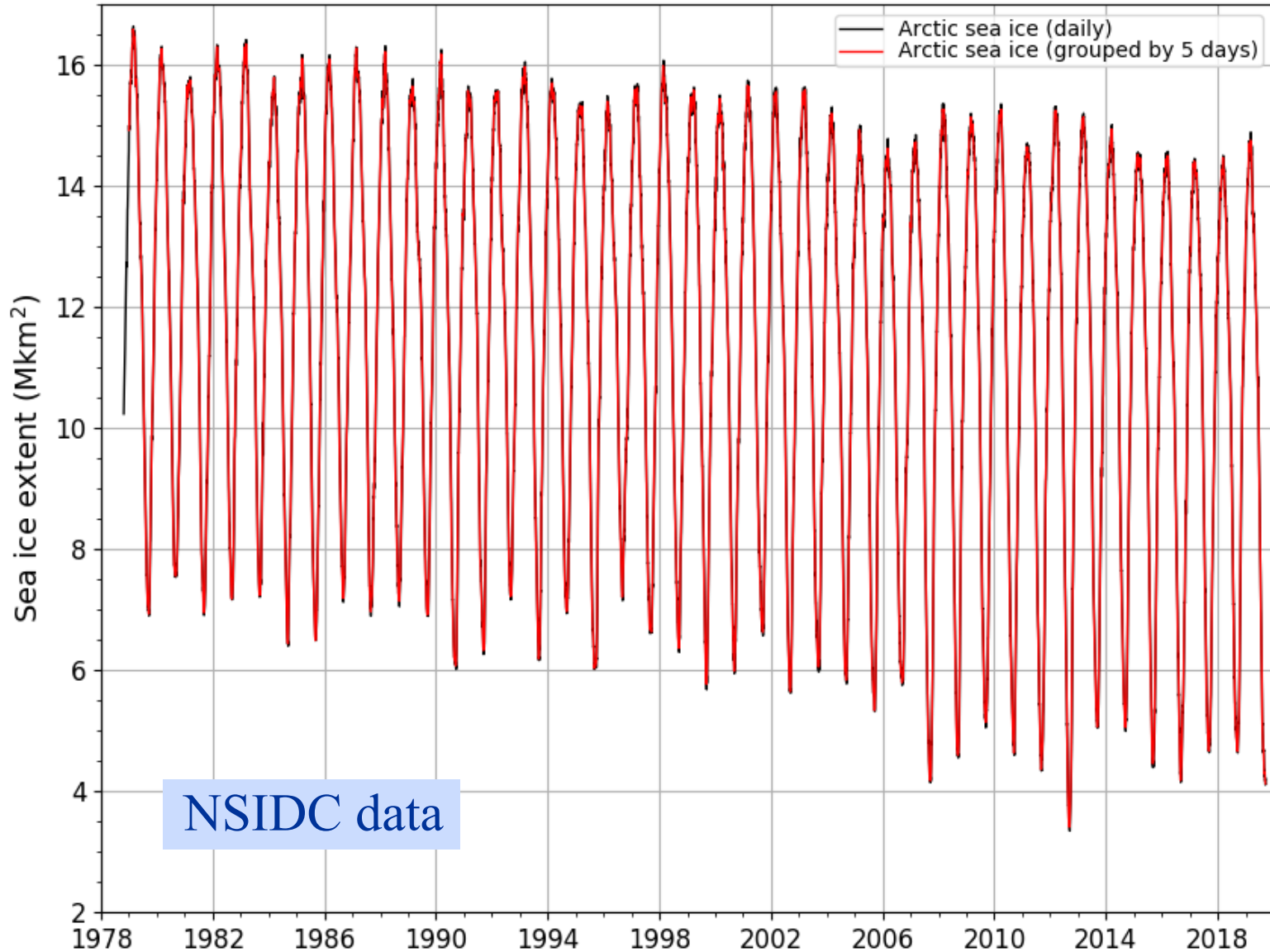
PIOMAS: Sea Ice Volume & Thickness

- Pan-Arctic Ice Ocean Modeling and Assimilation System
 - ◆ <http://psc.apl.uw.edu/>
 - ◆ <http://psc.apl.uw.edu/research/projects/arctic-sea-ice-volume-anomaly/>
- Measures Arctic sea ice volume and thickness
 - ◆ Combination of observations that have are assembled into a total sea ice volume and thickness using a model
 - ◆ Summary: Volume is shrinking faster than area
 - ◆ (Next slides)

Plots (1): Arctic Sea Ice Extent Data

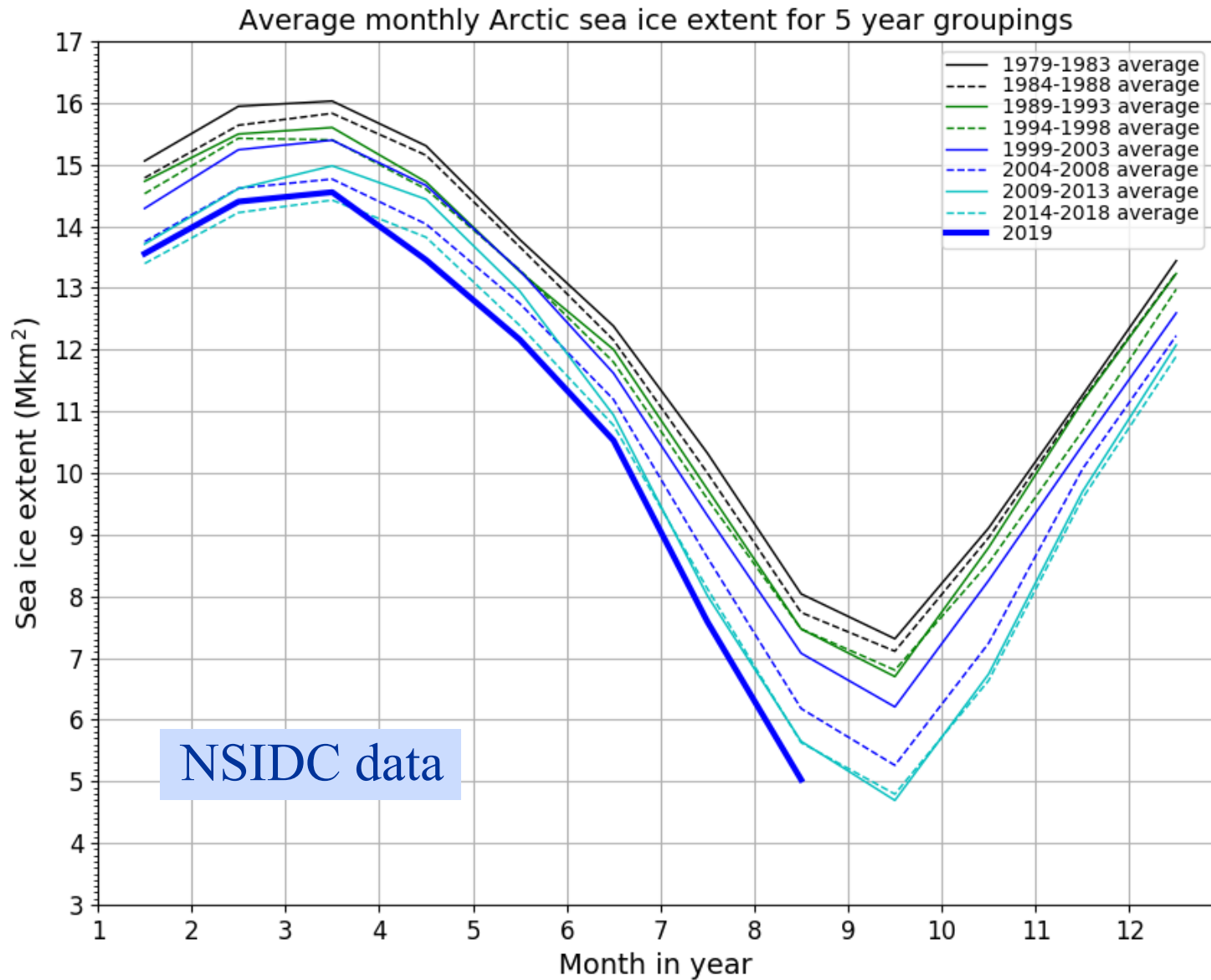
1979 - Now

Arctic sea ice extent

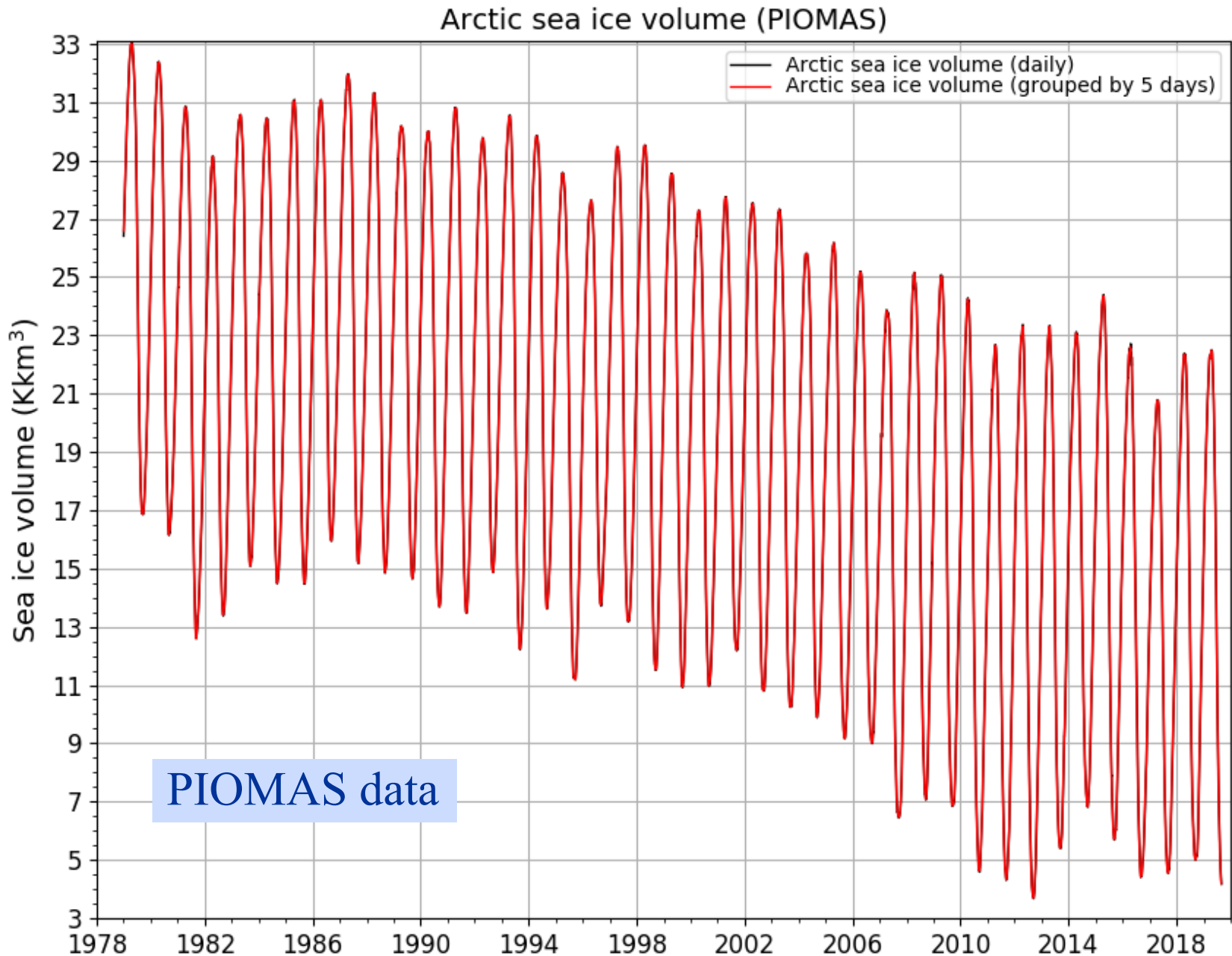


Plots (2): Annual Sea Ice Extent Cycle

5 year averages for each month



Plots (3): Arctic Sea Volume Data



Plots (4): Annual Sea Ice Volume Cycle

5 year averages for each month

