Wednesday 27 September 2017
10:30-11:30
Class#13

Radiative importance of Carbon and Methane

Topics for today

- IPCC radiative forcing summary plot
- Radiative Forcing
- Greenhouse gases
- Carbon
- Methane

Project summary revisions due Friday 3PM

IPCC summary of Radiative forcing

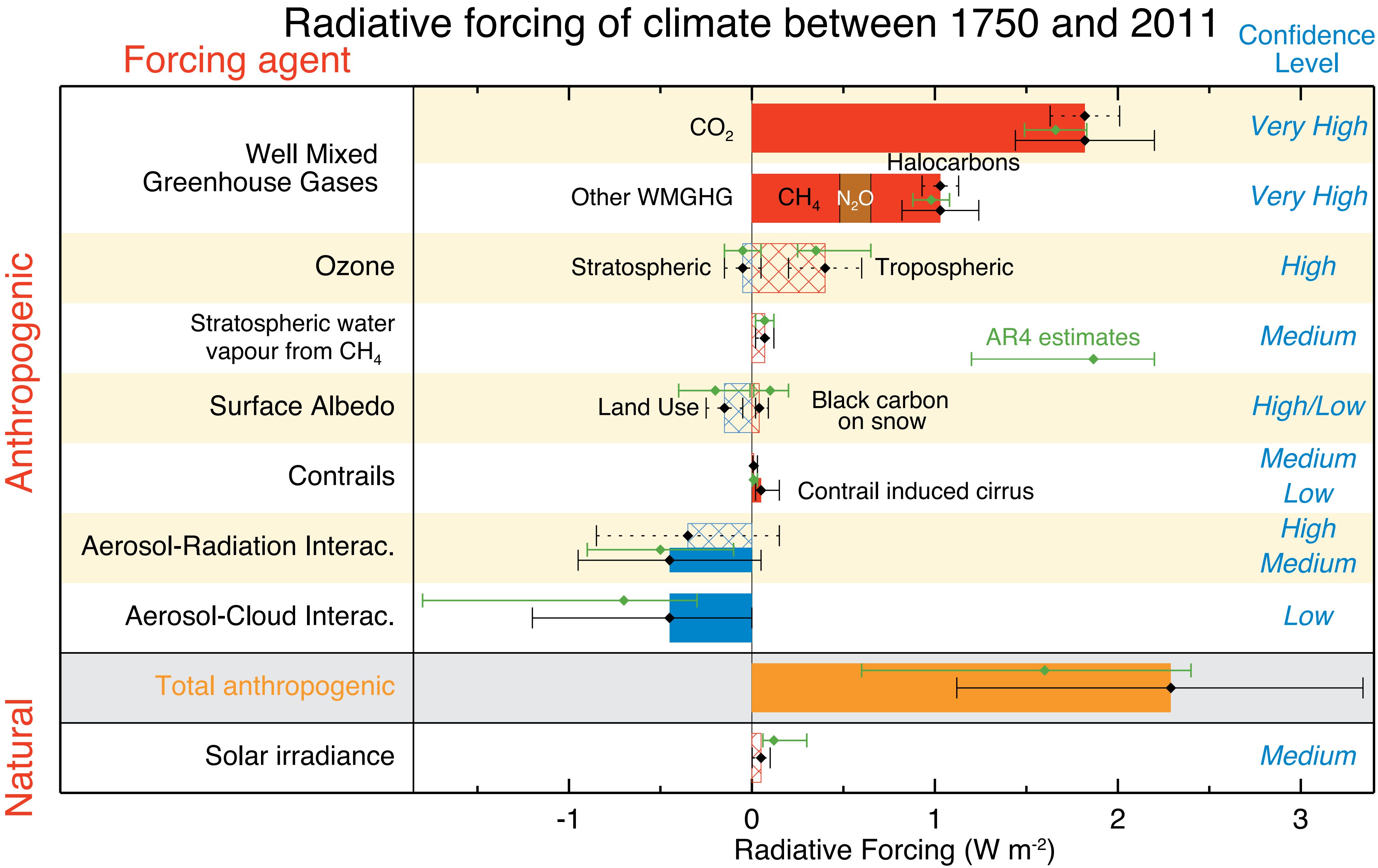


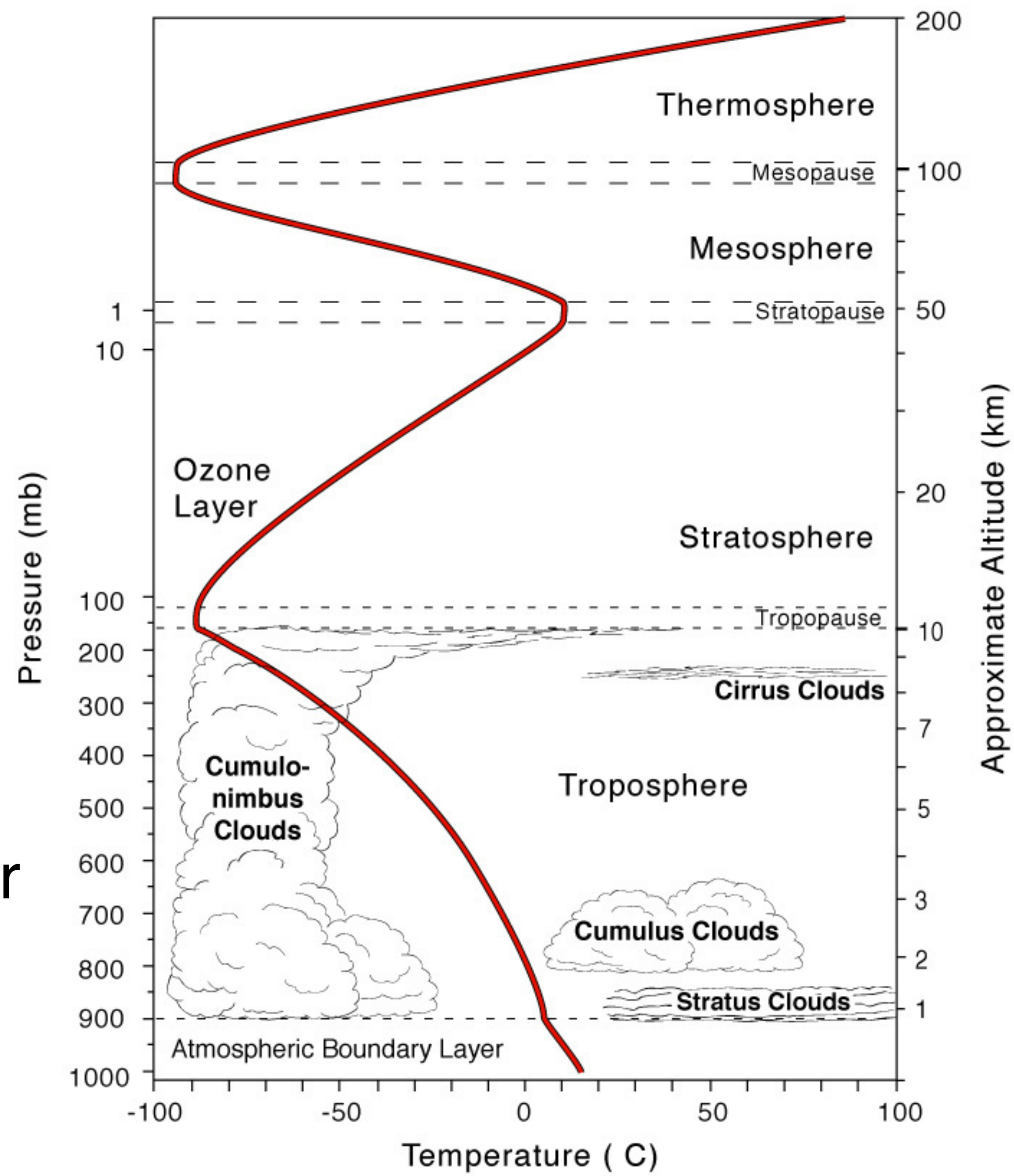
Figure TS.6, Technical Summary IPCC 2014

Definition of Radiative Forcing

- How do we determine the impact of a single greenhouse gas on climate?
- **Radiative Forcing** is the climate response to a single factor given in W/m^2
- Radiative Forcing represents a change in value between two periods of time.
- Radiative forcing (RF) is the **change in net irradiance at the tropopause** after allowing for stratospheric temperatures to readjust to radiative equilibrium, while holding surface and tropospheric temperatures and state variables such as water vapour and cloud cover fixed at the unperturbed values

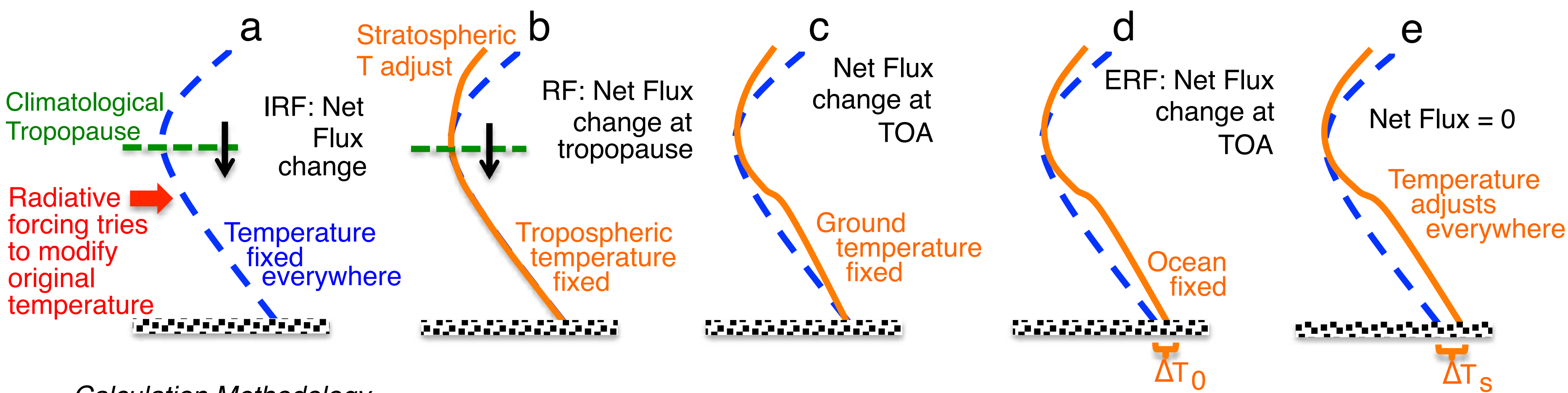
Atmospheric Temperature Profile

Review:
Tropopause
Lapse Rate
Boundary Layer



[Neelin 2011]

Definition of Radiative Forcing



Calculation Methodology

Online or offline pair of radiative transfer calculations within one simulation

Difference between two offline radiative transfer calculations with prescribed surface and tropospheric conditions allowing stratospheric temperature to adjust

Difference between two full atmospheric model simulations with prescribed surface conditions everywhere or estimate based on regression of response in full coupled atmosphere-ocean simulation

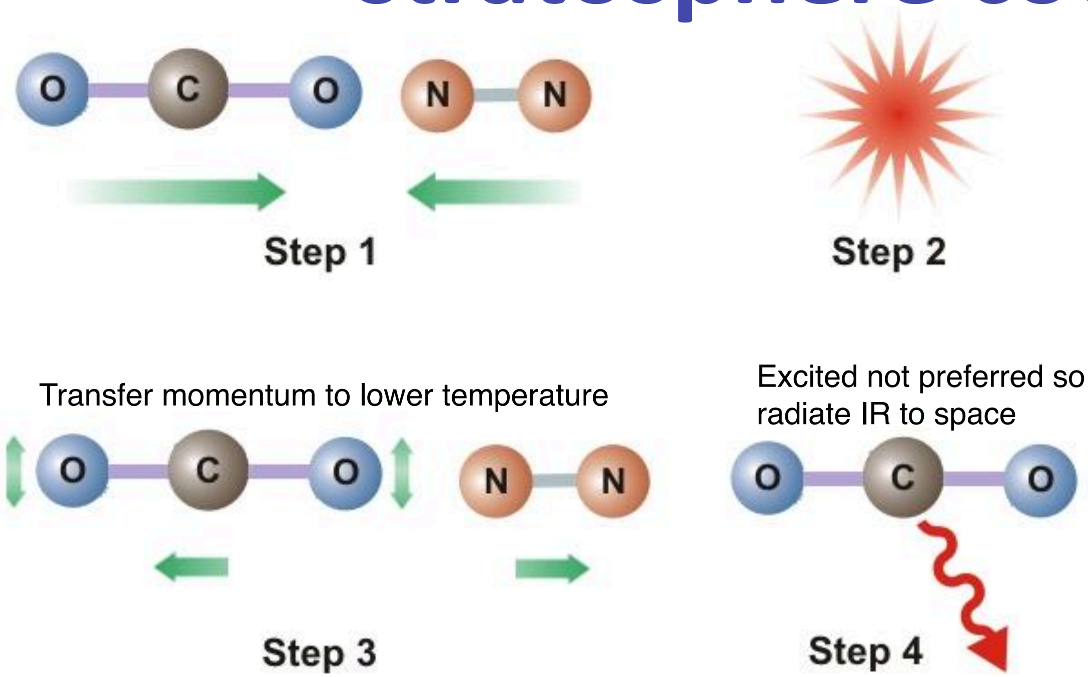
Difference between two full atmospheric model simulations with prescribed ocean conditions (SSTs and sea ice)

Difference between two full coupled atmosphere-ocean model simulations

Figure 8.1, Technical Summary IPCC 2014

Increased CO2, troposphere warms and stratosphere cools, why?

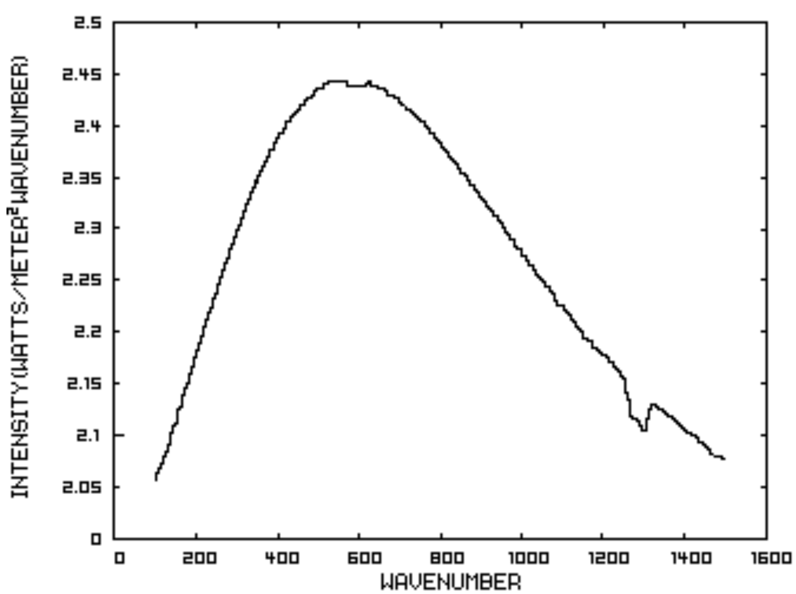
1

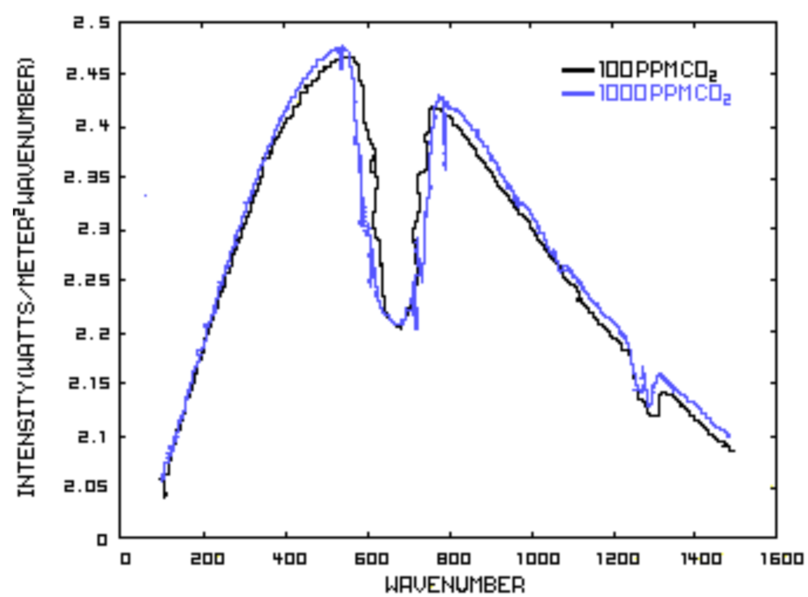


1) Conversion of the energy of motion of the particles in the atmosphere to IR radiation which escapes to space

2) Longwave going to stratosphere reduced so less radiation to interact with CO2 to warm it.

2





Composition of the Atmosphere

Constituent[a]	Molecular weight	Fractional concentration by volume	Major Sources
Nitrogen (N_2)	28.013	78.08%	Biological
Oxygen (O_2)	32.000	20.95%	Biological
Argon (Ar)	39.95	0.93%	Biological
Water vapor (H_2O)	18.02	0–5%	
Carbon dioxide (CO_2)	44.01	380 ppm	Biological, oceanic, combustion
Neon (Ne)	20.18	18 ppm	Volcanic?
Helium (He)	4.00	5 ppm	Radiogenic
Methane (CH_4)	16.04	1.75 ppm	Biological, anthropogenic
Krypton (Kr)	83.80	1 ppm	
Hydrogen (H_2)	2.02	0.5 ppm	Biological, anthropogenic
Nitrous oxide (N_2O)	56.03	0.3 ppm	soils, anthropogenic, lightning
Ozone (O_3)	48.00	0–0.1 ppm	Photochemical

[a] So called *greenhouse gases* are indicated by bold-faced type. For more detailed information on minor constituents, see Table 5.1.

[Wallace and Hobbs 2006]

Greenhouse Gas Absorption & Lifetimes

Table 4.1. Absorption of solar and terrestrial radiation by atmospheric molecules

	Spectral regions (μm)[a]		
Absorbing molecule	Solar wavelengths ~0.1–2.5 μm	Terrestrial wavelengths ~2.5–25 μm	Approximate atmospheric residence time[b]
Carbon dioxide (CO_2)	1.4, 1.6, 2.0, 0.78–1.24 (weak)	13.5–16.5, centered at 15 4.2–4.4, centered at 4.3 2.7, 5.2, 9.4, 10.4	5–200 years
Water vapor (H_2O)	0.72, 0.81, 0.94, 1.1, 1.4, 1.9	5.5–7.5, centered at 6.3 2.6–3.3 Water vapor continuum[c]	10 days
Ozone (O_3)	0.18–0.34, centered at 0.26 0.32–0.36, 0.44–0.74	2.7, 3.27, 3.59, 4.75, 5.75, 9.0 9.6, 14.1	2 months
Methane (CH_4)		3.3, 7.7	10 years
Nitrous oxide (N_2O)		4.5, 7.8, 17.0	100 years
Carbon monoxide (CO)	1.19, 1.57, 2.35	4.67 2.38–25.0	A few months

[a] Only absorption at wavelengths relevant for the climate system are listed. In general, these molecules will also have absorption lines and bands in other wavelengths, but this absorption does not directly influence the flow of radiative energy through the atmosphere.

[b] Residence times vary according to the atmospheric conditions. These values are estimates.

[c] Water vapor absorption is complicated (see text) because the combined vibrational and rotational modes give rise to tens of thousands of absorption lines.

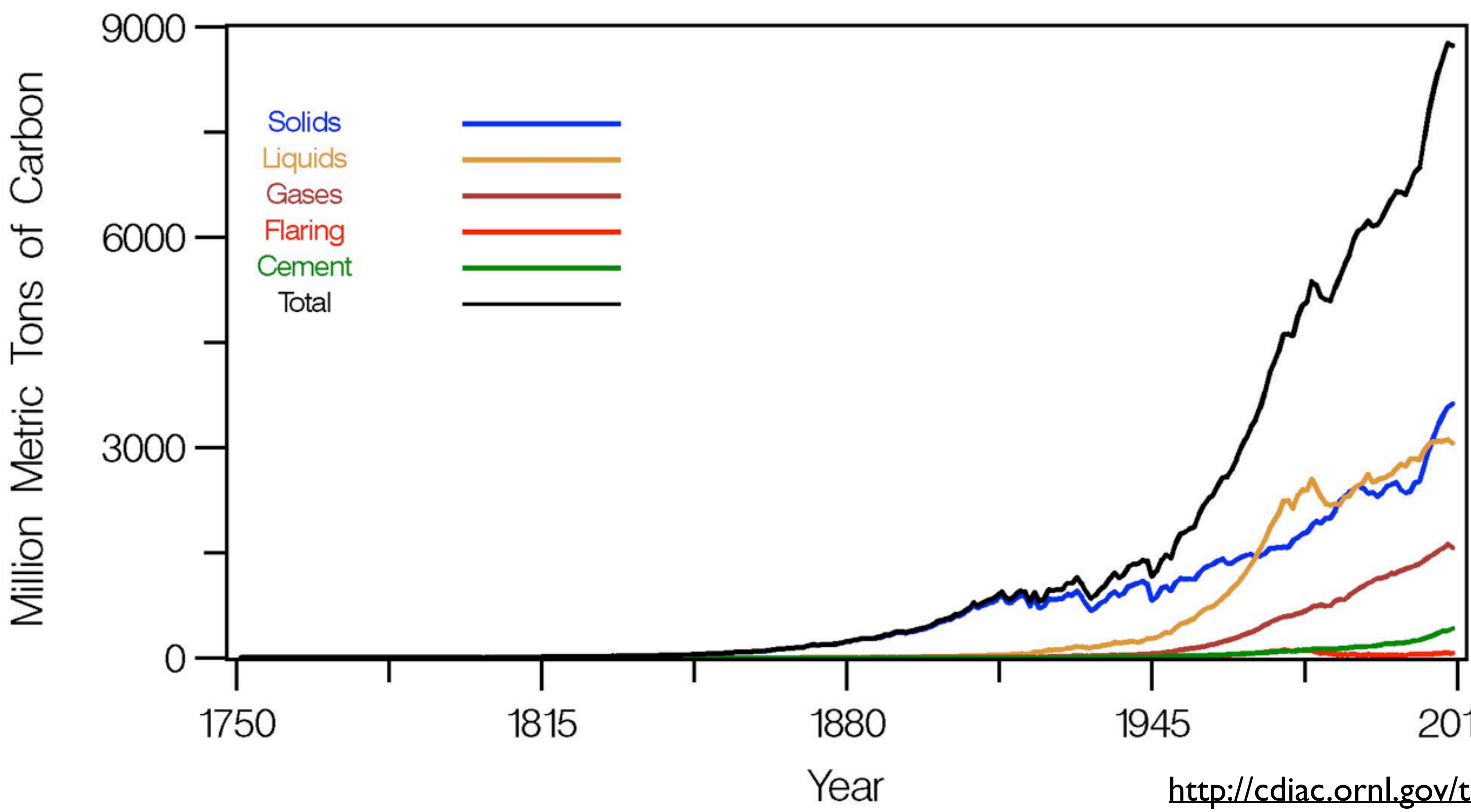
[Cook 2013]

Carbon Units

GtC = gigatons of carbon and giga = 10^9 Gt

In terms of mass, how much carbon does 1 part per million by volume of atmospheric CO_2 represent?
Use 5.137×10^{18} kg as the mass of the atmosphere (Trenberth, 1981 JGR 86:5238-46), **1 ppmv of CO_2= 2.13 Gt of carbon**.

Global Carbon Emissions from various sources



9000=9Gt

9

http://cdiac.ornl.gov/trends/emis/glo.html

Oxidation State

- Fundamental property of molecules is their oxidation state.
- Redox Chemistry for 3 sample types of Carbon (Archer Ch 8)

	Oxidized		Reduced
Simplest Example	CO_2	CH_4O	CH_4
Carbon Oxidation State	+4	0	-4
General Category	Inorganic Carbon	Carbonates	Hydrocarbons

- Oxidation is the surplus or deficit of electrons, so has to do with the bookkeeping of electrons.
- Organic versus Inorganic Carbon
- **Photosynthesis** is a reduction reaction, **Respiration** is the backward direction reaction

$$CO_2 + H_2O + energy \Leftrightarrow CH_4O + O_2$$

Carbon Highlights according to D. Archer

• Oxidation and Reduction has to do with bookkeeping of electrons
• Carbon at Earth's surface wants to be oxidized. It takes energy to make reduced carbon.
• Carbon is the structural backbone of life and the way life stores energy.
• Oxygen in the air and organic carbon in the ground are the poles of the battery of the planetary boundary biosphere. (There is enough organic carbon buried in the sediments to use up the O_2 in the atmosphere about 10 times.)

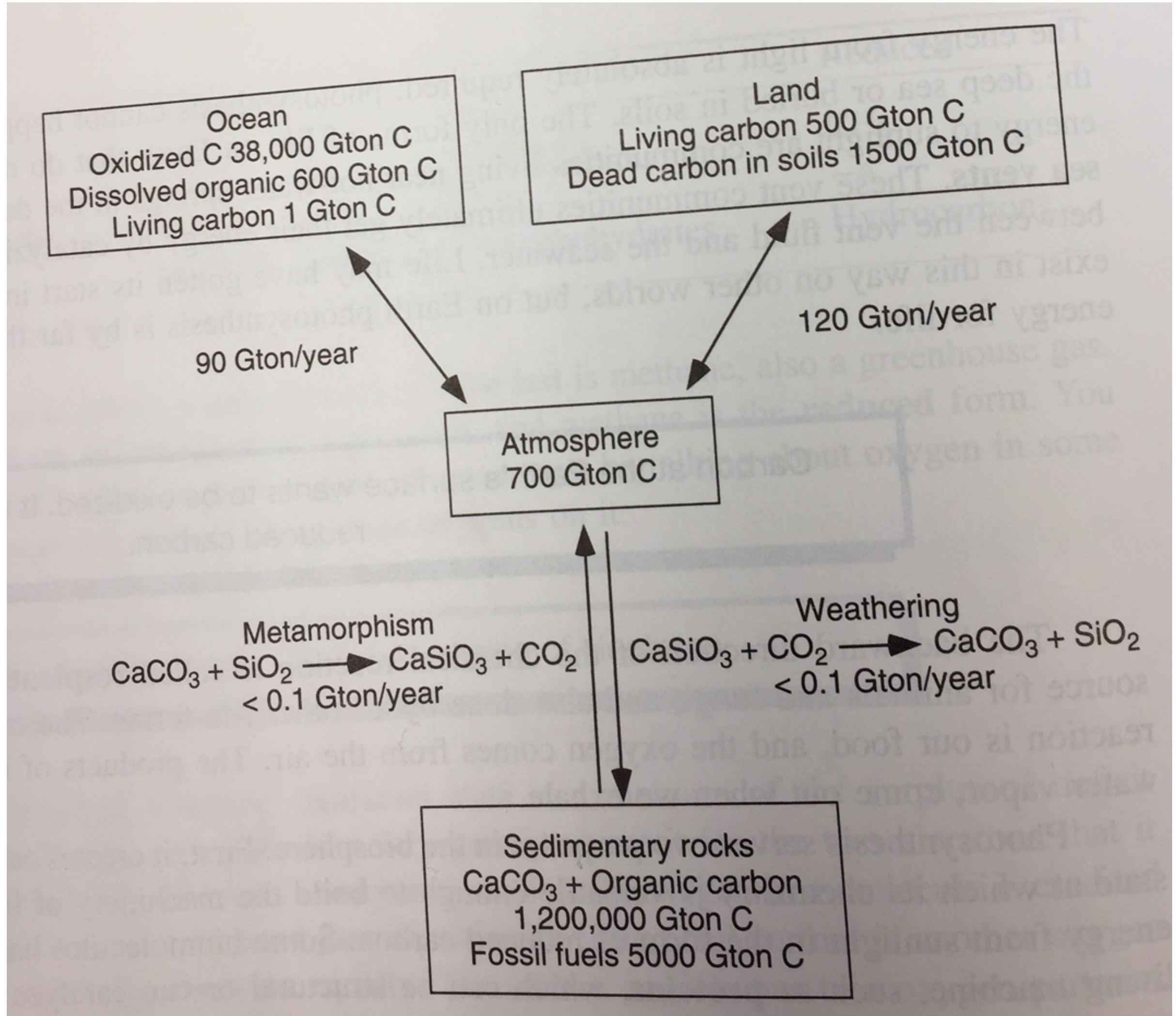
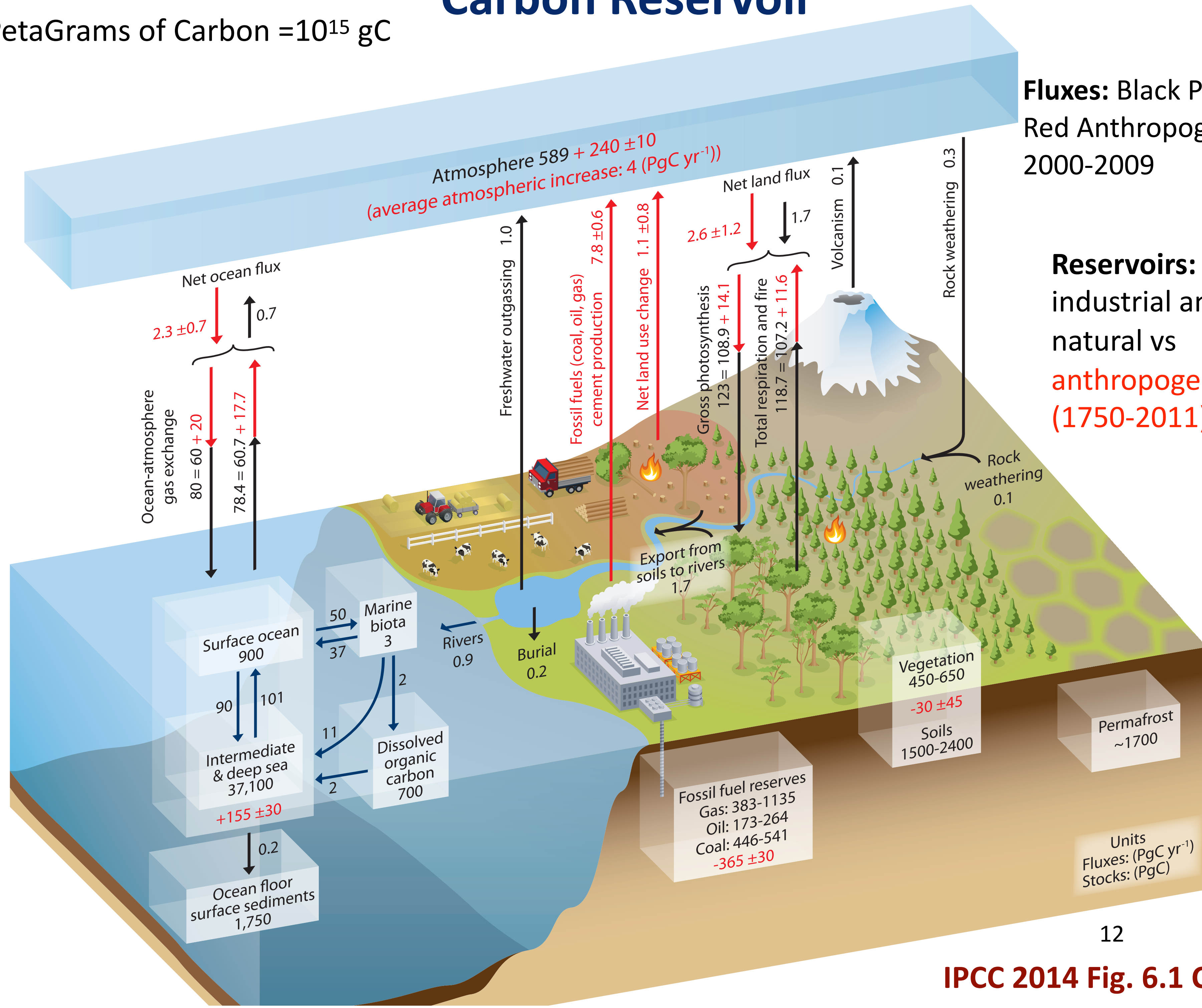


Figure 8-1 Carbon reservoirs on Earth and carbon fluxes between them.

Carbon Reservoir

PetaGrams of Carbon =10^{15} gC

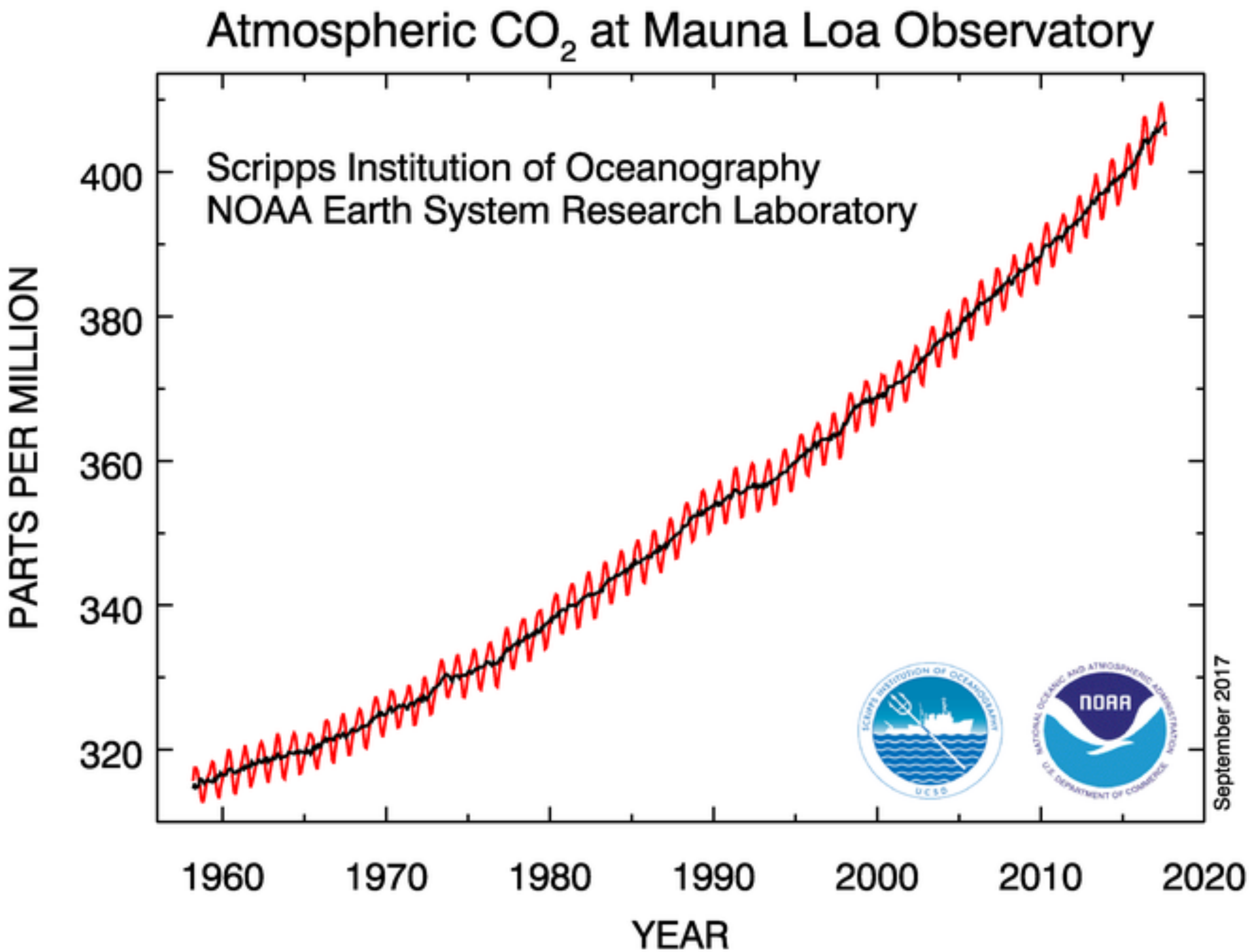


Fluxes: Black Prior to 1750, Red Anthropogenic fluxes 2000-2009

Reservoirs: Pre-industrial and natural vs anthropogenic (1750-2011)

IPCC 2014 Fig. 6.1 Chapter 6

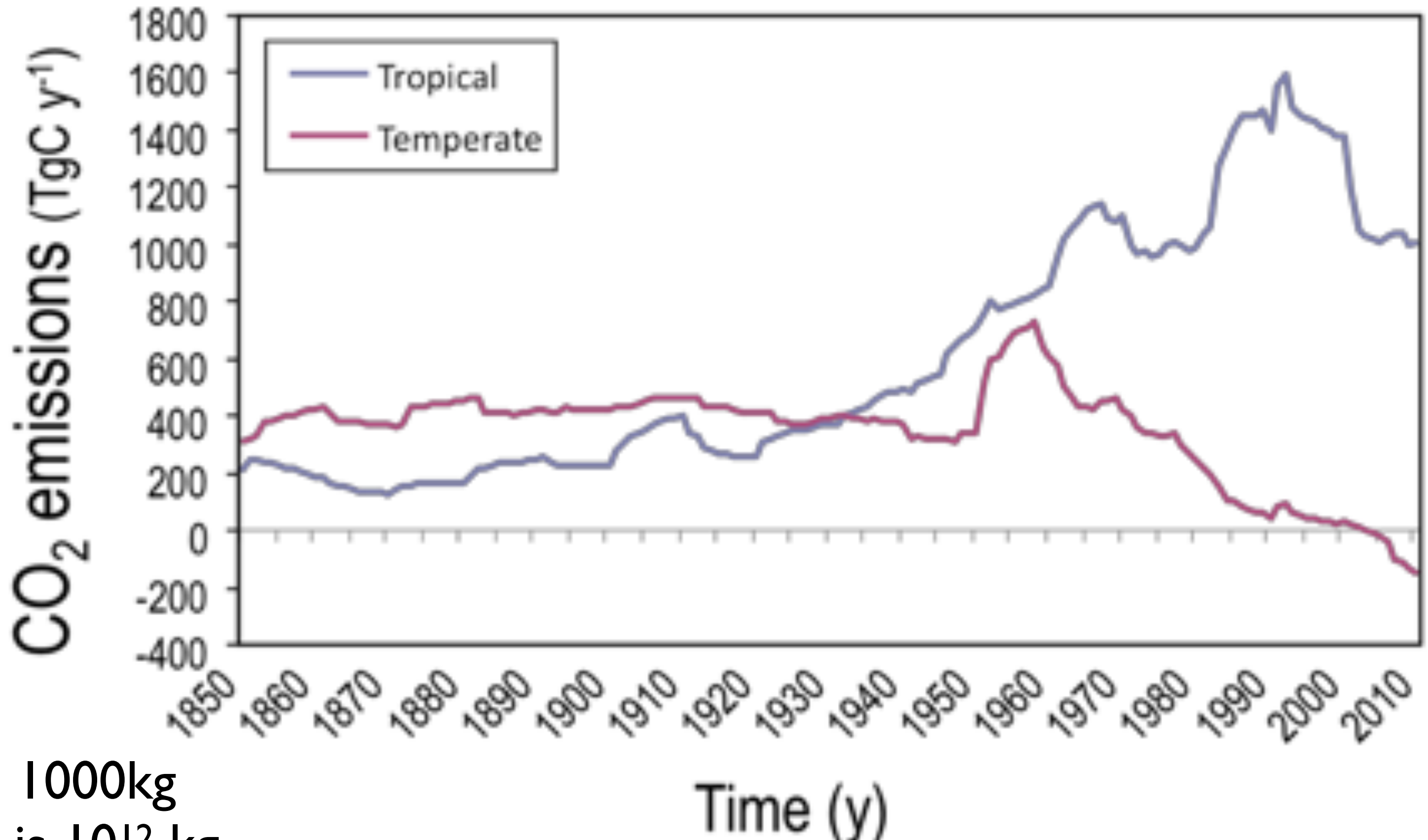
Carbon Dioxide Trends



https://www.esrl.noaa.gov/gmd/ccgg/trends/history.html

Carbon emissions from land surface changes

1400 Tg is 1.4 Gigatons



Giga is 10^9
Tera is 10^{12}

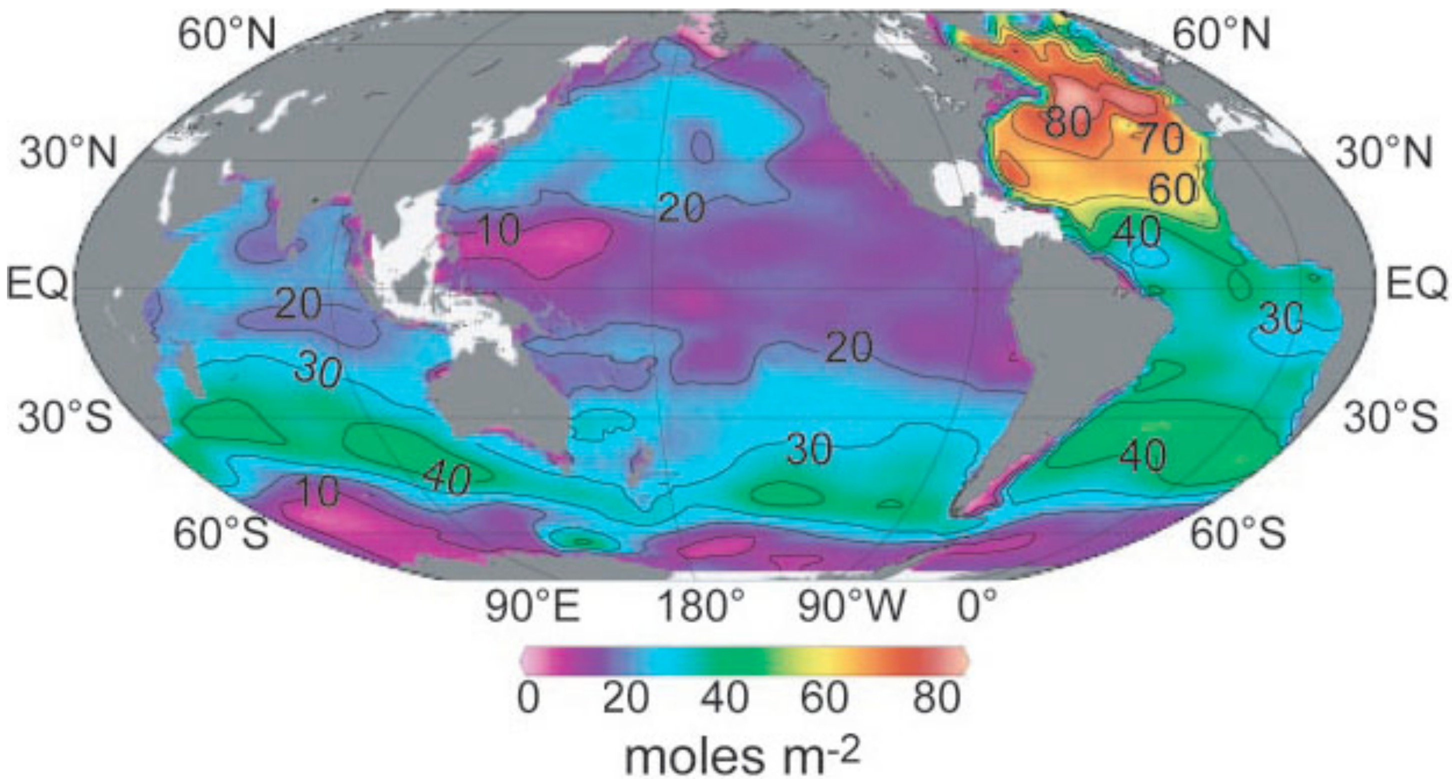
1 Tonne is 1000kg
1 Gigaton is 10^{12} kg

CO2 emission from land use modification. Figure taken from Global Carbon Project 2010. Data source: R.A. Houghton 2010 (personal communication); GFRA (2010).

http://carboncycle2.lbl.gov/resources/experts-corner/annual-cycles-of-atmospheric-co2-concentration.html

Ocean Carbon Reservoir

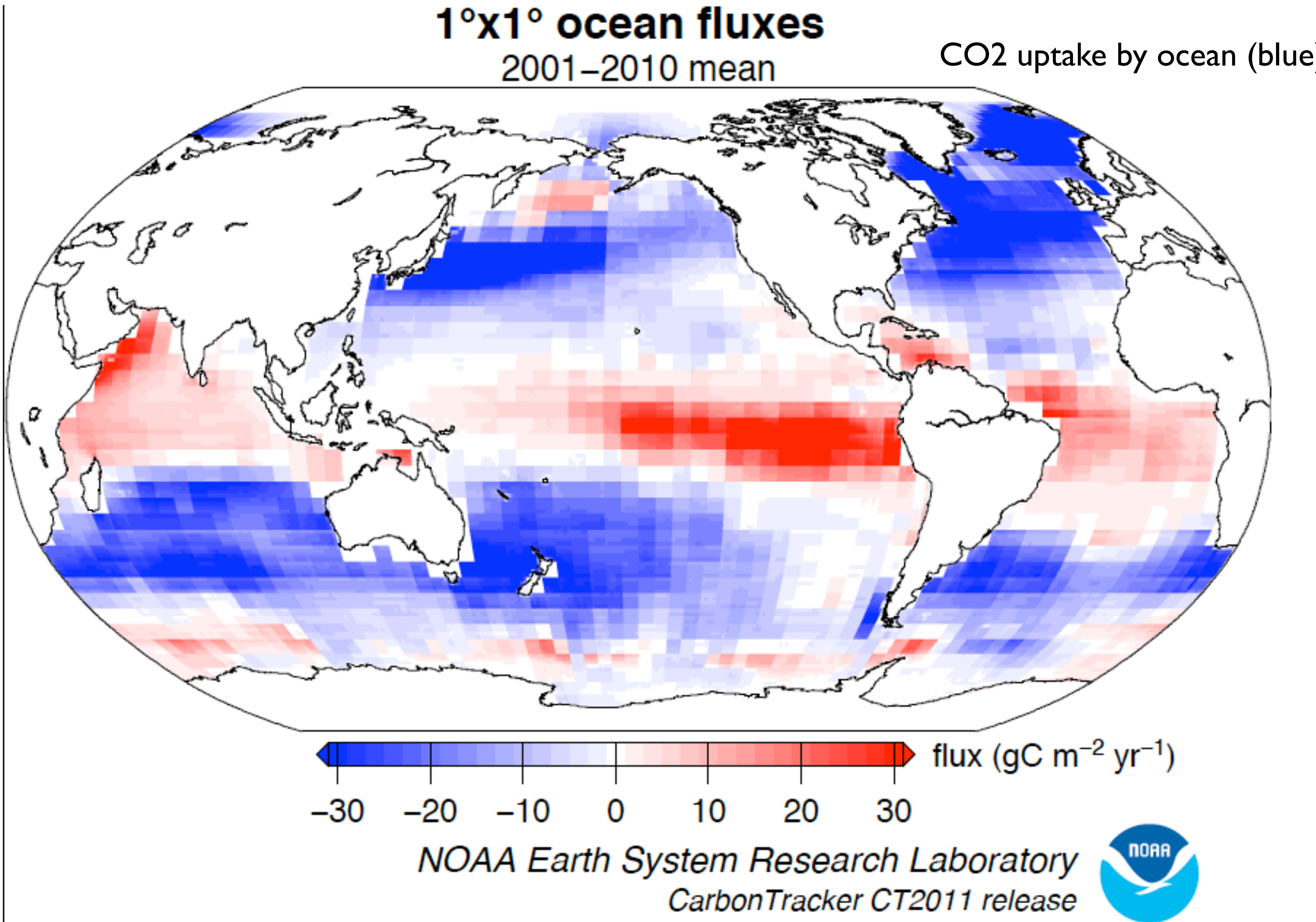
- Ocean carbon has the largest reservoir and it is mainly dead (energetically and biologically) since it is oxidized
- Dissolved inorganic carbon (DIC)
- 1 Gt of the ocean carbon is in living things
- Summary data from global ocean measurements in 1990s



[Sabine et al. Science 2004]

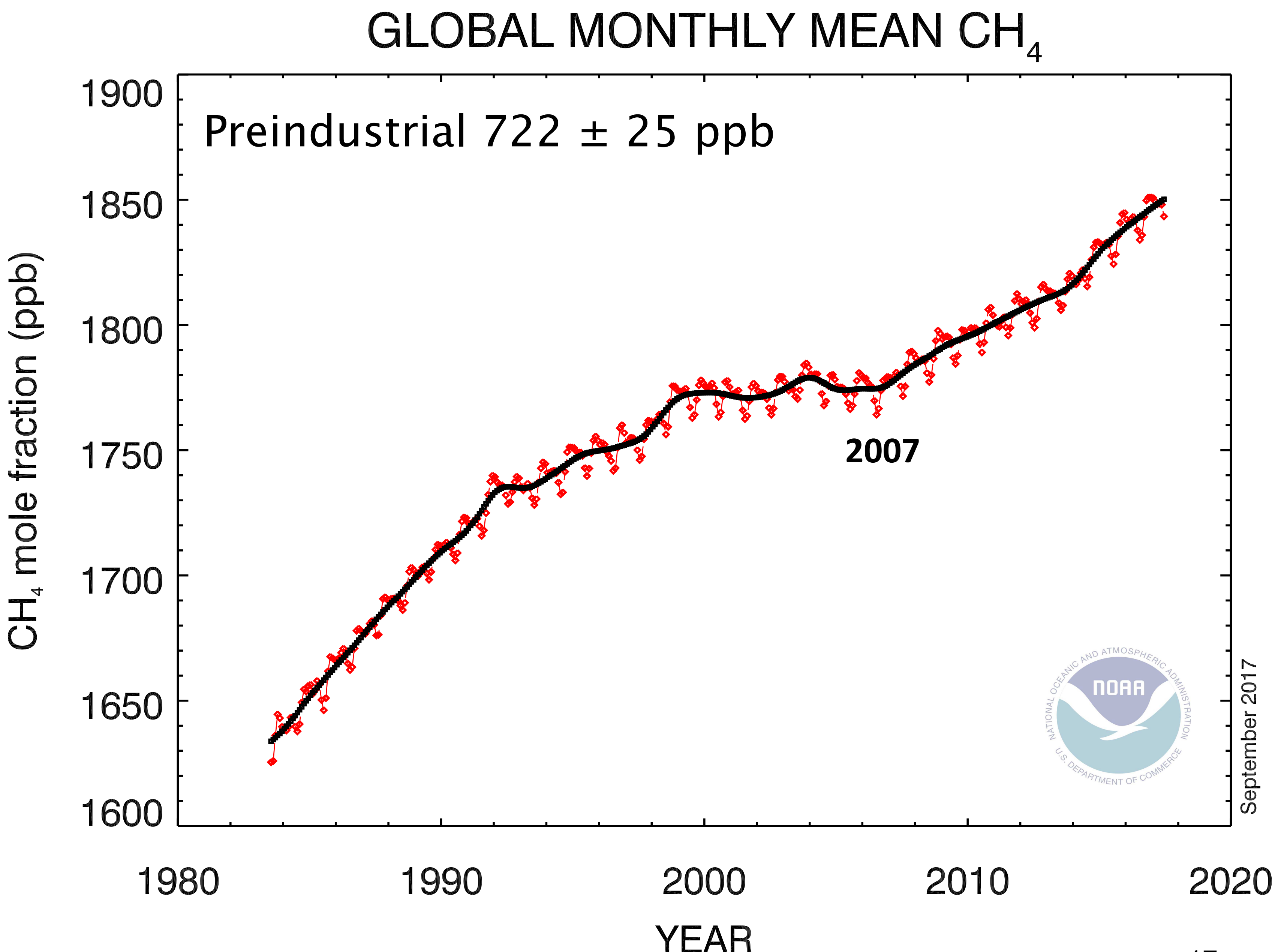
- 1Gigatonne = 1 Pg, total is 106 PgC in plot (106 GtC of human origin is in the ocean)

How does ocean effect atmospheric CO_2?



http://www.esrl.noaa.gov/gmd/ccgg/carbontracker/documentation_ocn.html

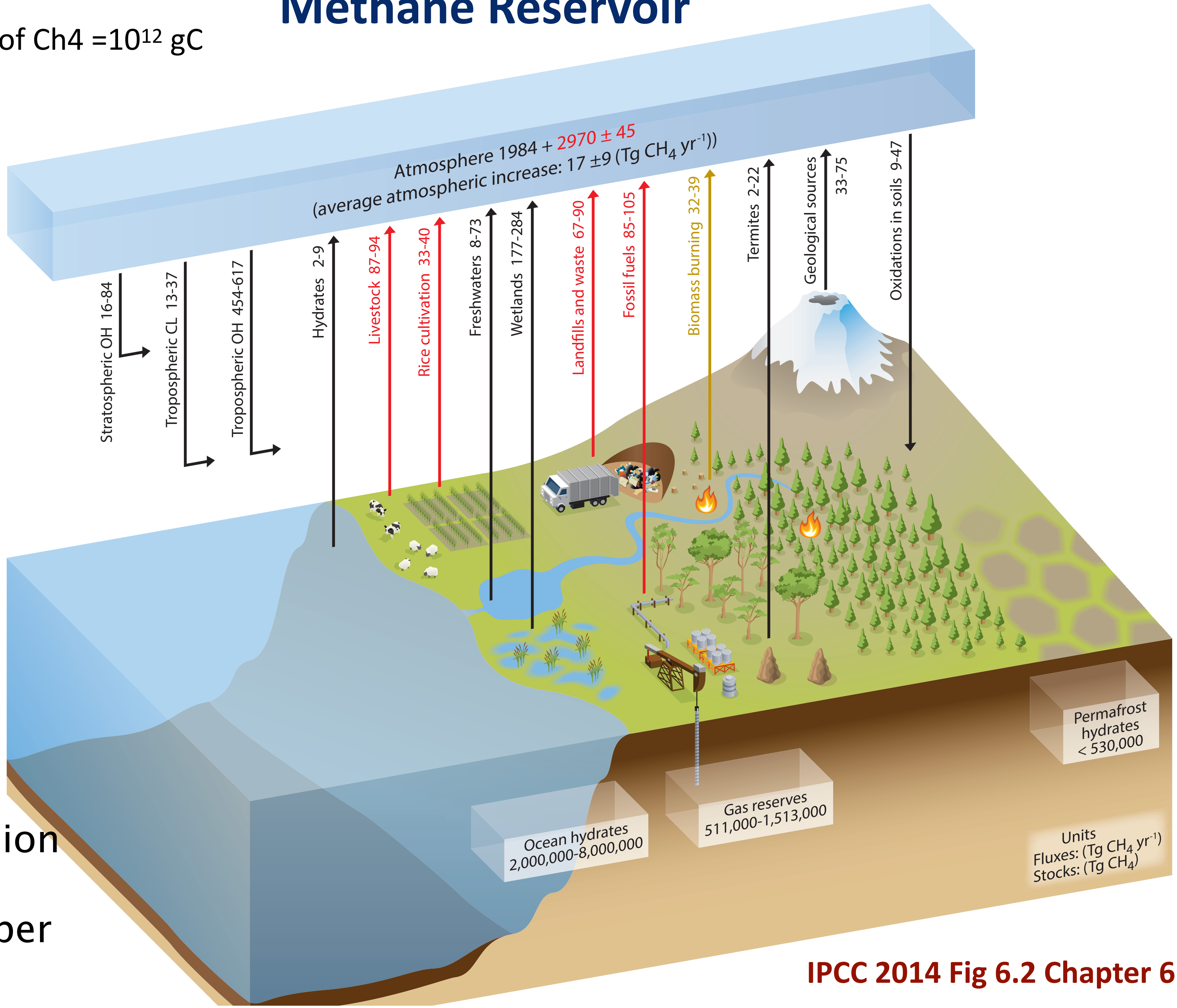
Methane Trends



https://www.esrl.noaa.gov/gmd/ccgg/trends_ch4/

Methane Reservoir

TeraGrams of Ch4 =10[12] gC



Conversion 2.7476 TgCH4 per ppb

IPCC 2014 Fig 6.2 Chapter 6

Isotope analysis: higher FF mean & increase microbes

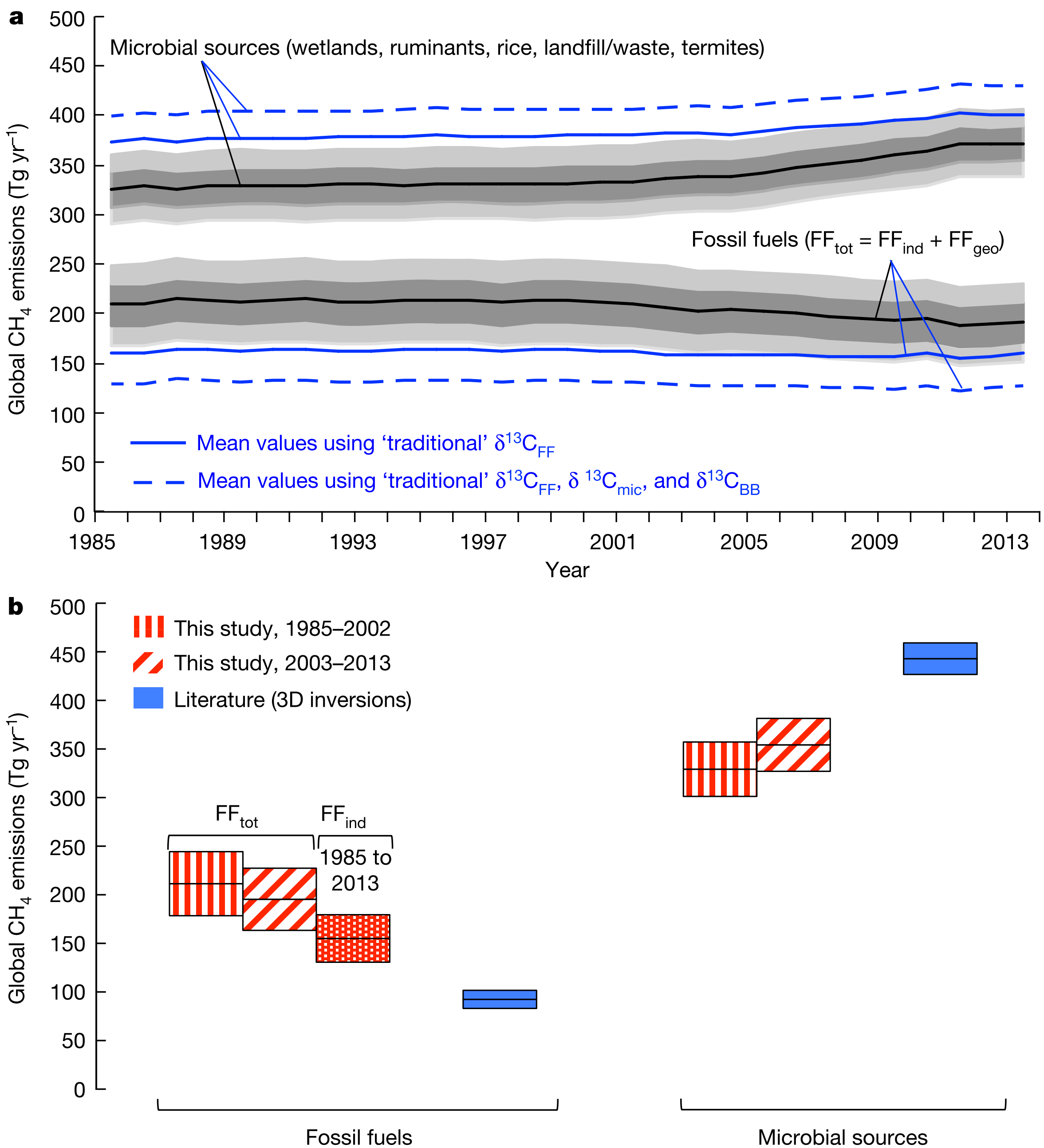
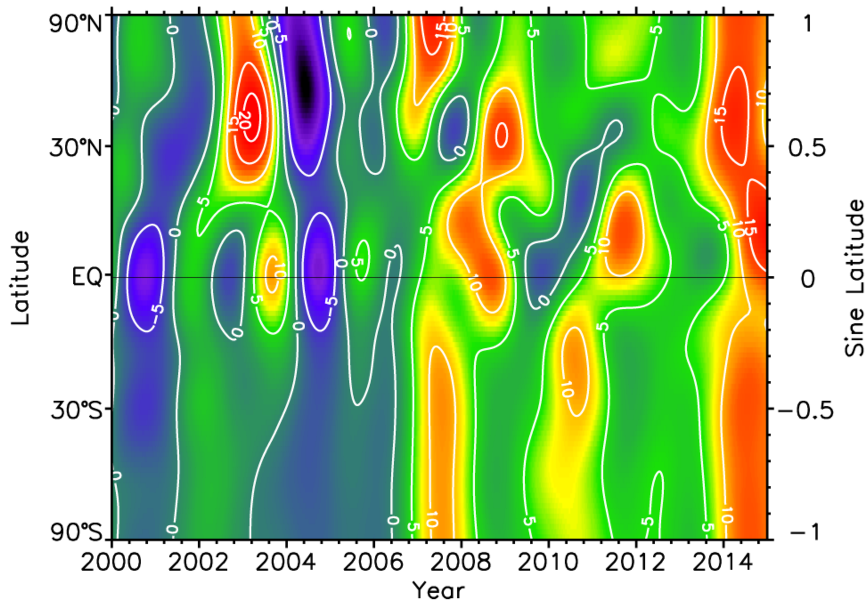
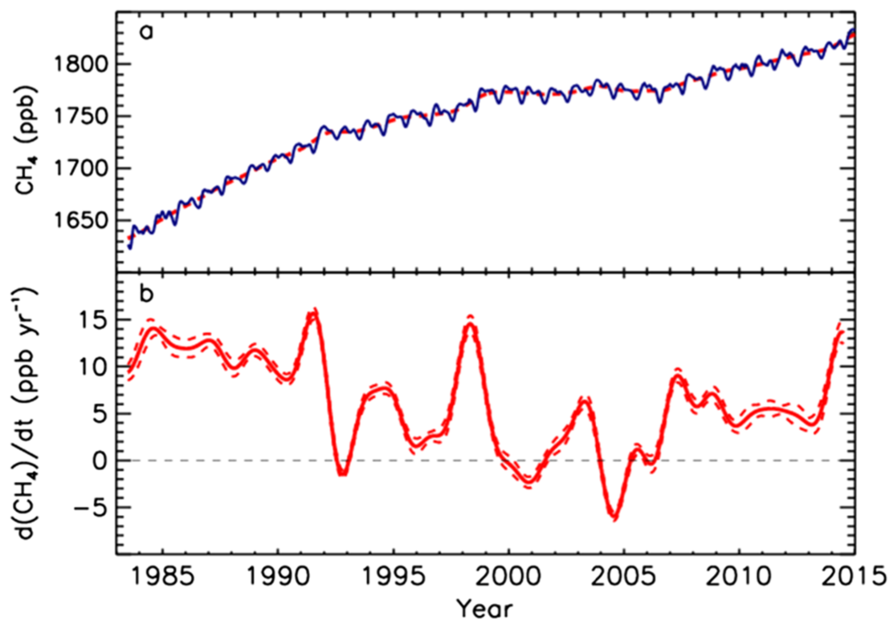


Figure 2 | Fossil fuel and microbial source CH_4 budget terms. a, Long-term trend in global microbial and total FF_{tot} CH_4 emissions from 1985 to 2013. Moving averages are shown; see Supplementary Fig. 18 for original mass balance results including inter-annual variability due to multiple components not accounted for in this model (see text). Mean values are shown in solid black. Dark and light grey bands mark the 25th/75th percentile and the 10th/90th percentiles, respectively. Blue lines assume the mean $\delta^{13}C_{source}$ values from the literature (as in Fig. 1, blue values). See Supplementary Information section 7 for sensitivity analyses. **b**, The box plot compares means and 1 s.d. uncertainties between this study (red) and the recent literature[3–8] 3D inversions (blue). The box-model temporal split marks approximately when the $\delta^{13}C_{atm}$ increase stopped and $\delta^{13}C_{FF}$ decreased; literature periods vary. The literature budget terms were scaled to match this study's mean total CH_4 budget (see Supplementary Information section 8 for individual literature study means). Industrial FF (FF_{ind}) represents total FF (FF_{tot}) minus natural geological seepage (FF_{geo}). Literature $FF_{tot} = FF_{ind}$ because these studies exclude FF_{geo}.

[Schwietzke et al. Nature 2016]

Rising atmospheric methane: 2007–2014 growth and isotopic shift





Nisbet et al. 2016, Global Biogeochemical Cycles
Volume 30, Issue 9, pages 1356-1370, 27 SEP 2016 DOI: 10.1002/2016GB005406
http://onlinelibrary.wiley.com/doi/10.1002/2016GB005406/full#gbc20468-fig-0001

Do these Methane trends matter?

- While CO_2 has risen ~40% since pre-industrial times, while methane levels have **more than doubled**, rising from 700 parts per billion to almost 1,800 ppb.
- Increased agricultural activity in India & China, but also more rain/bogs increased microbial production. Tropics have been wetter recently.
- In 2007, there was a peak emission from the Arctic when it was warm.

Methane vs Carbon Dioxide

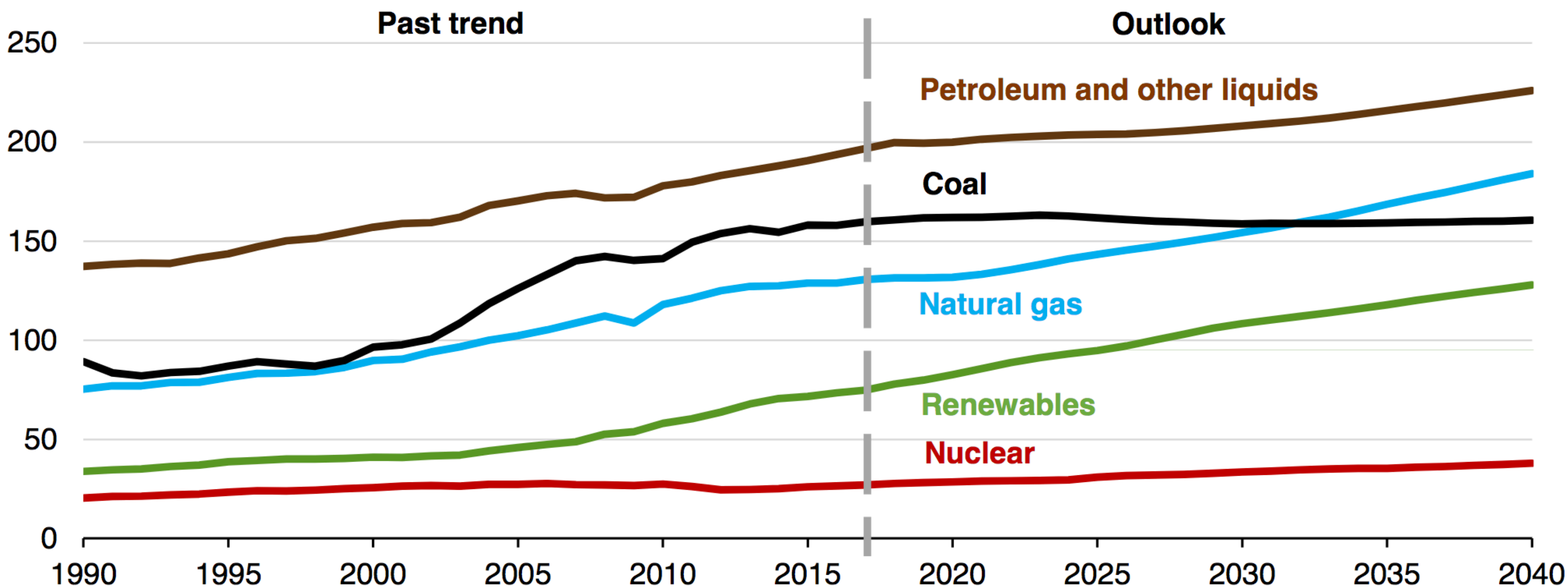
- While CO_2 persists in the atmosphere for centuries, or even millennia, methane warms the planet on steroids for a decade or two before decaying to CO_2.
- In those short decades, methane warms the planet by 86 times as much as CO_2, according to the Intergovernmental Panel on Climate Change.
- Methane is a more potent gas because it absorbs much more energy than CO_2.
- According to EPA Global Warming Potential (GWP), CO_2=1, Methane=28–36 over 100 years, and Nitrous Oxide (N_2O) has a GWP 265–298 times that of CO_2 for a 100-year timescale.

Energy Consumption Past and Future

Energy consumption increases over the projection for all fuels other than coal in the Reference case with renewables being the fastest-growing energy source

World energy consumption by energy source

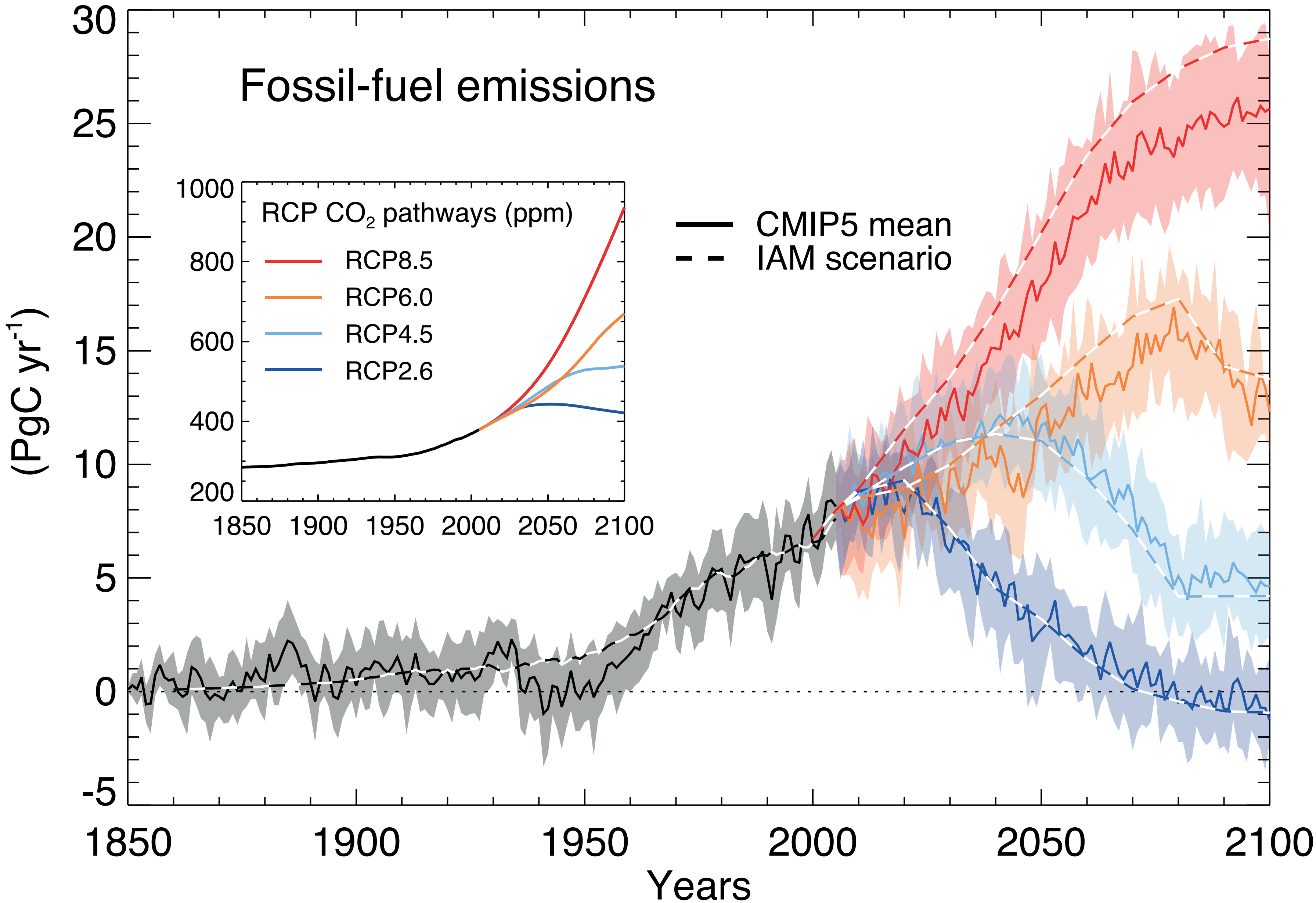
quadrillion Btu



Source: EIA, International Energy Outlook 2017

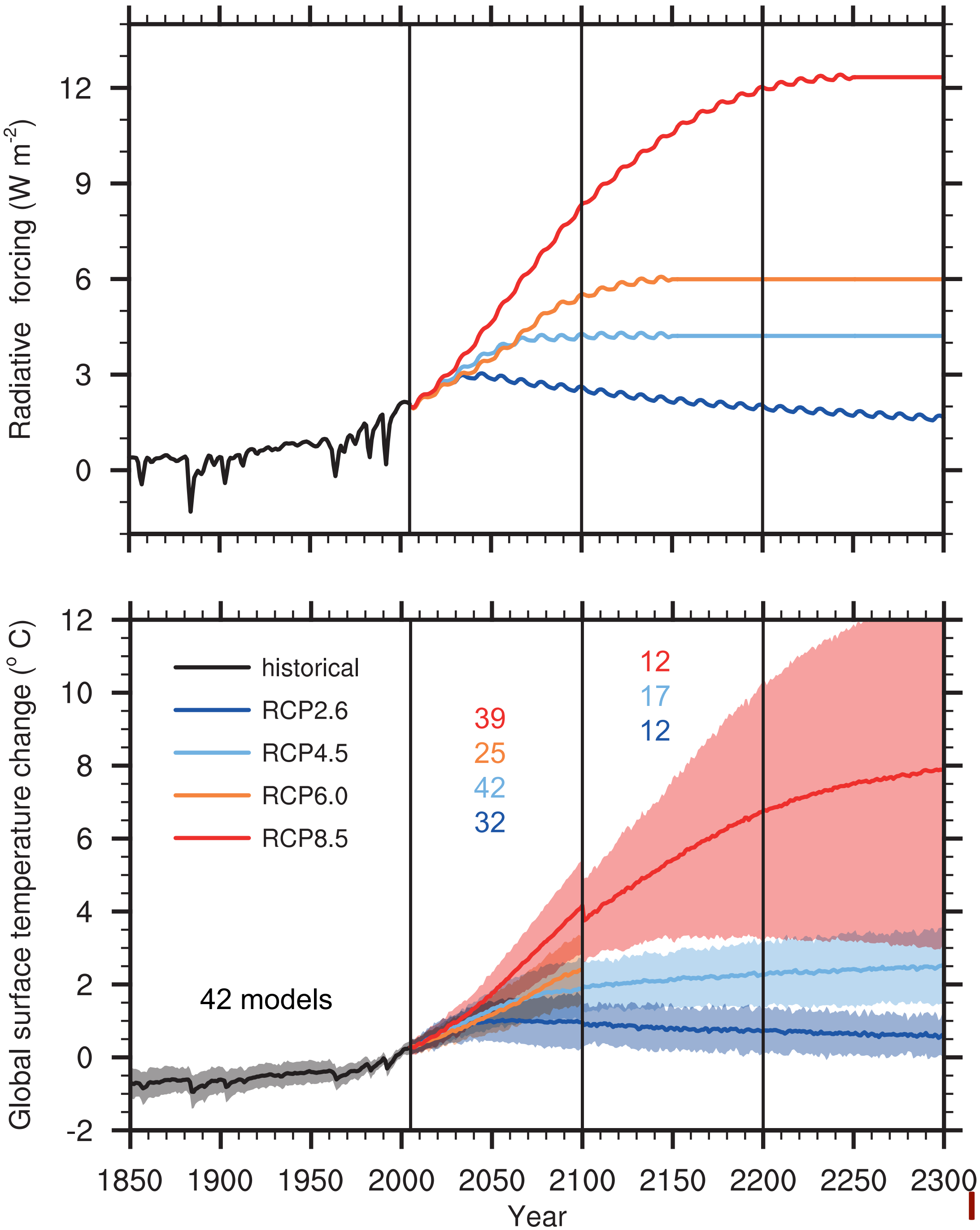
https://www.eia.gov/outlooks/ieo/exec_summ.php

Emissions from different scenarios



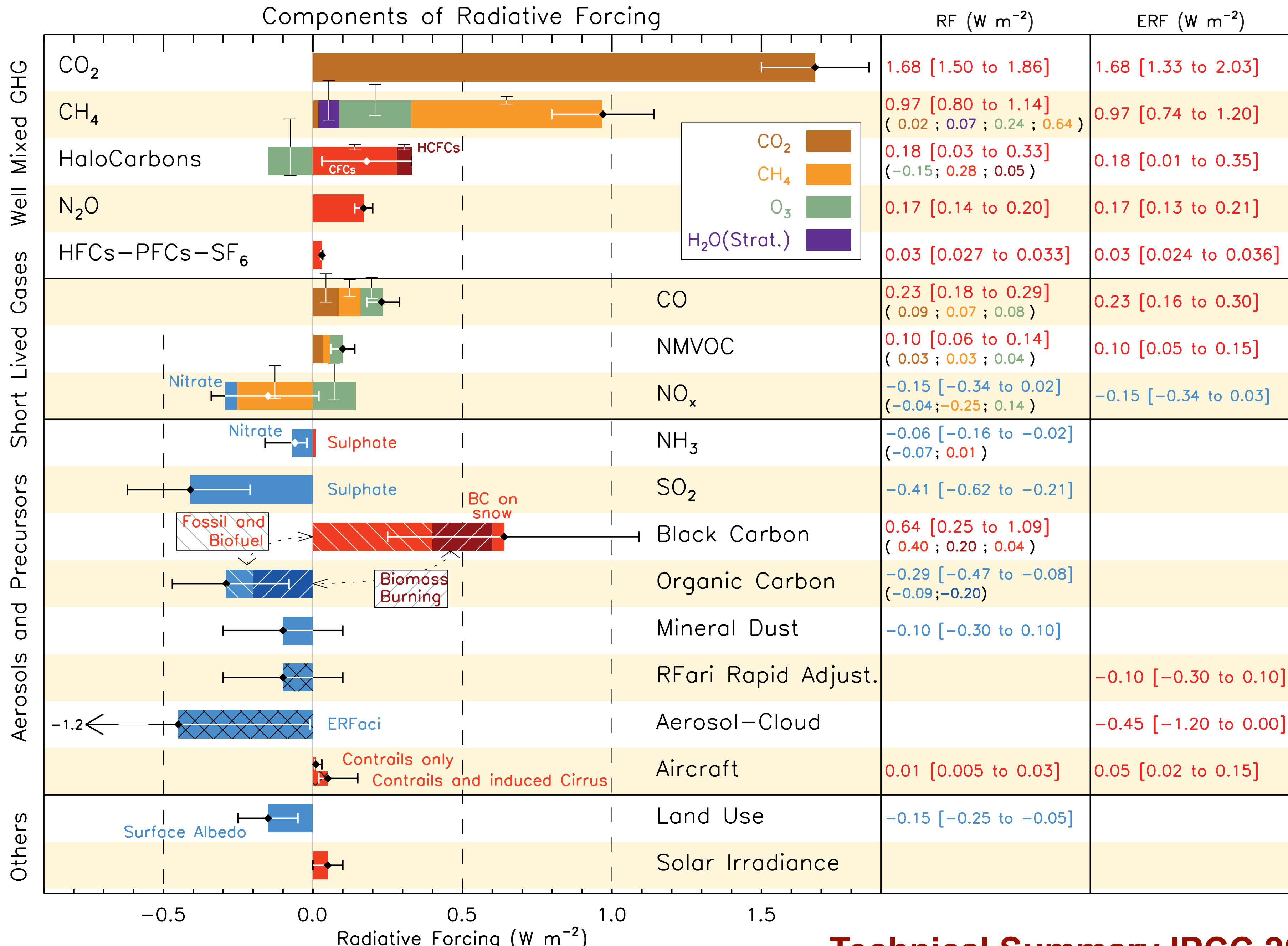
IPCC 2014 Fig TS.19 Technical Summary

Projected Temperatures from different scenarios



IPCC 2014 Fig TS.15 Technical Summary

IPCC summary of Radiative forcing



Technical Summary IPCC 2014

Summary

- Radiative impacts of increased CO_2 and CH_4
- Radiative Forcing, a way to generalize and compare the impacts on temperature of different GHGs
- Methane sources and Methane hiatus
- Methane vs Carbon Dioxide
- Climate RCPs, Scenarios used to make future projections
- IPCC summary of radiative forcing