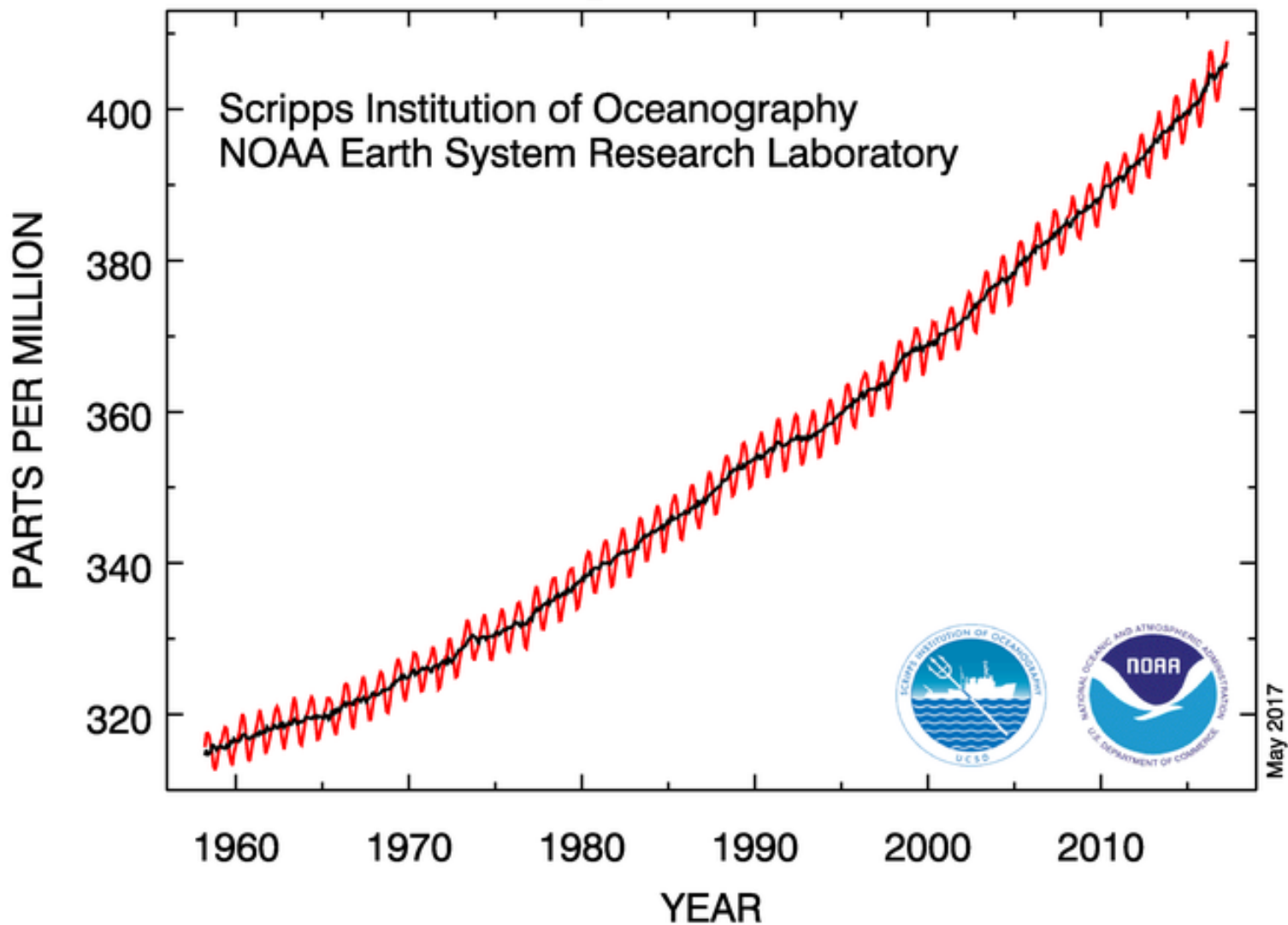


# How we know that human activities are driving climate change

*Pieter Tans  
NOAA Earth System Research Laboratory  
Boulder, Colorado*

*23 May 2017  
Global Monitoring Annual Conference  
Boulder, Colorado*

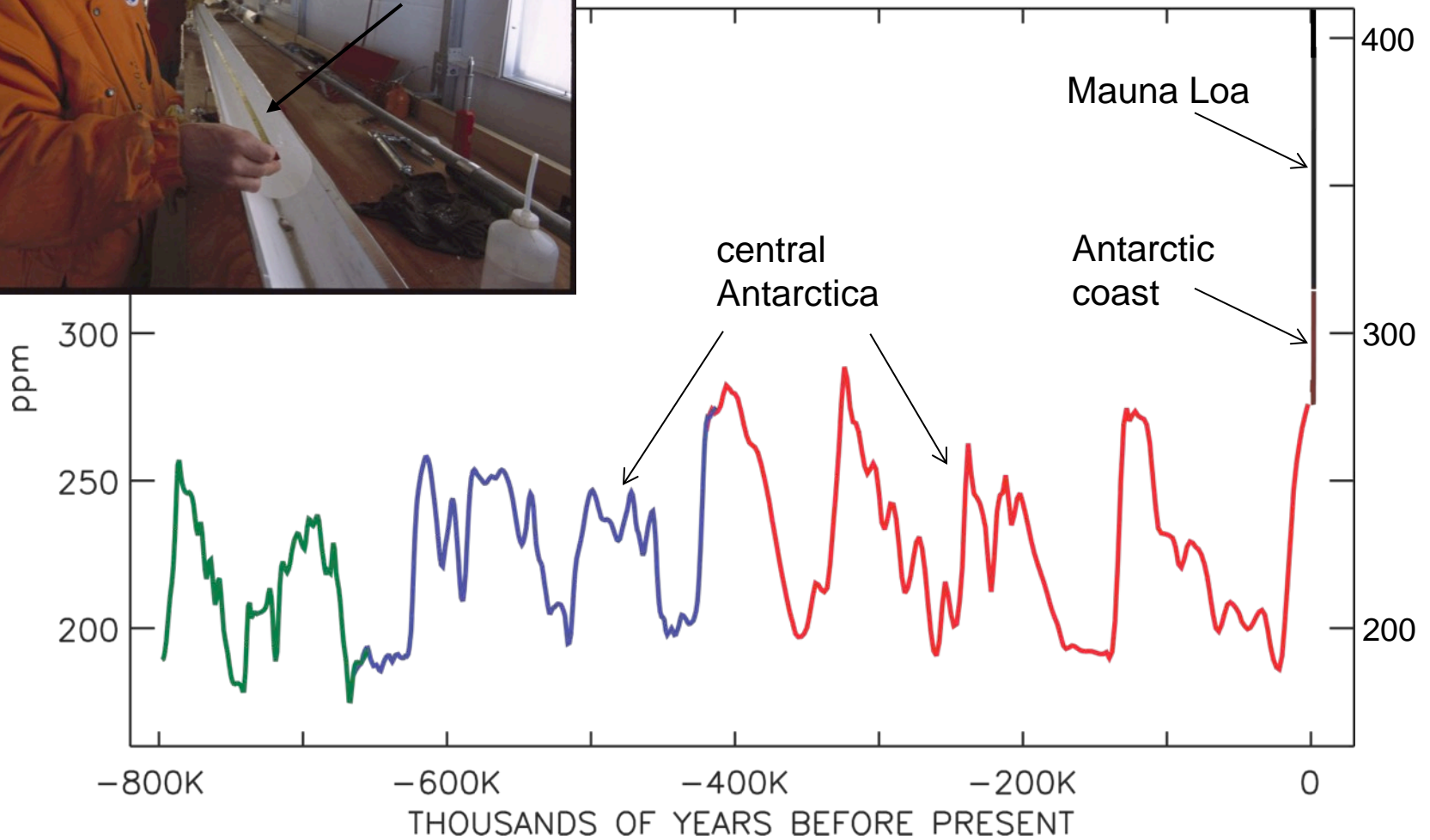
# Atmospheric CO<sub>2</sub> at Mauna Loa Observatory



# TODAY'S CO2 IS HIGHLY ANOMALOUS

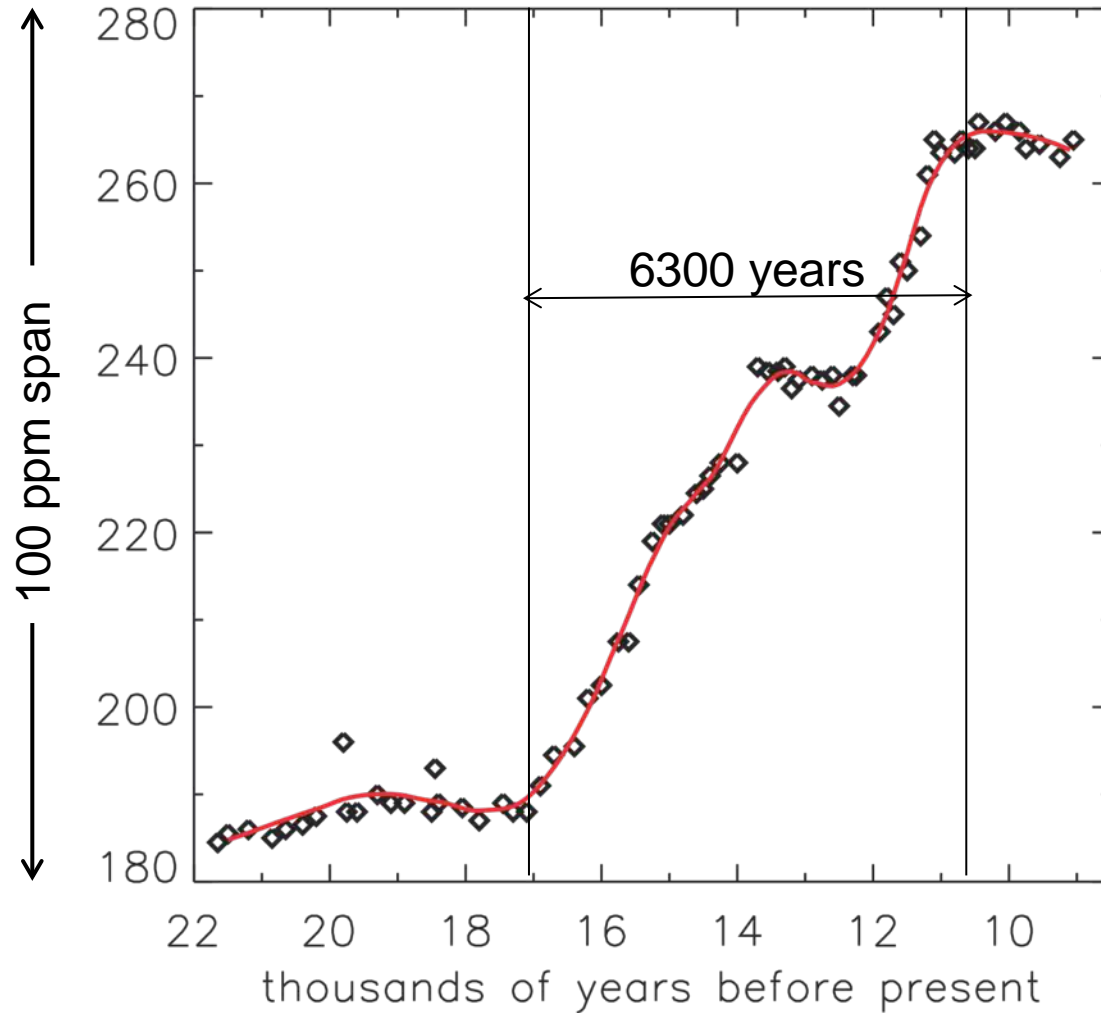


800,000 year history of atmospheric carbon dioxide

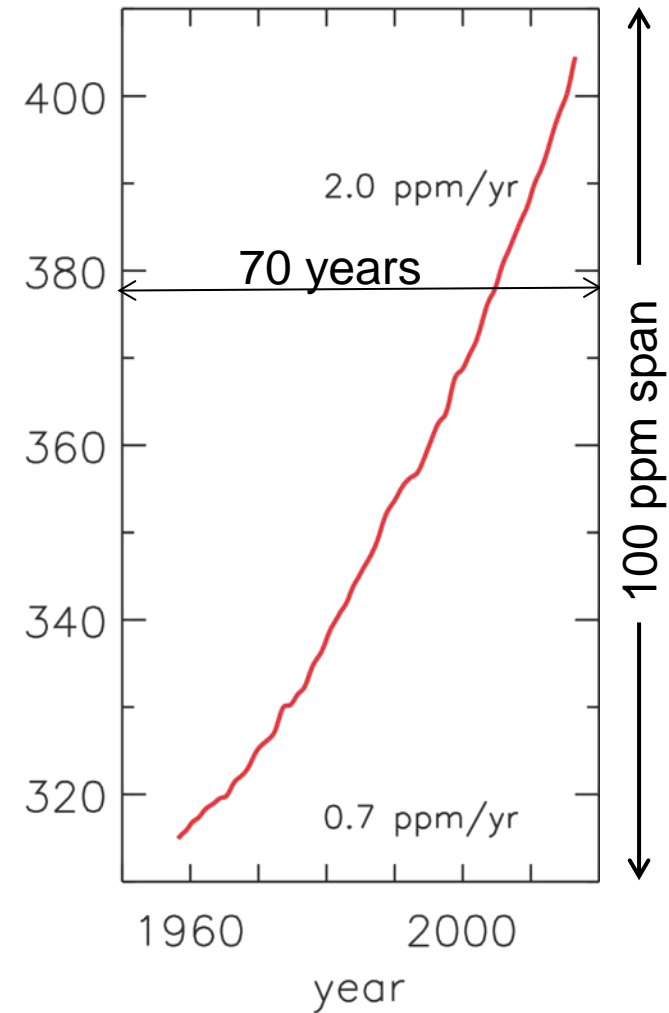


# TODAY'S CO2 IS HIGHLY ANOMALOUS

## CO2 at the end of last ice age



## Mauna Loa CO2



# ISOTOPIC EVIDENCE FOR THE SOURCES OF TODAY'S INCREASE

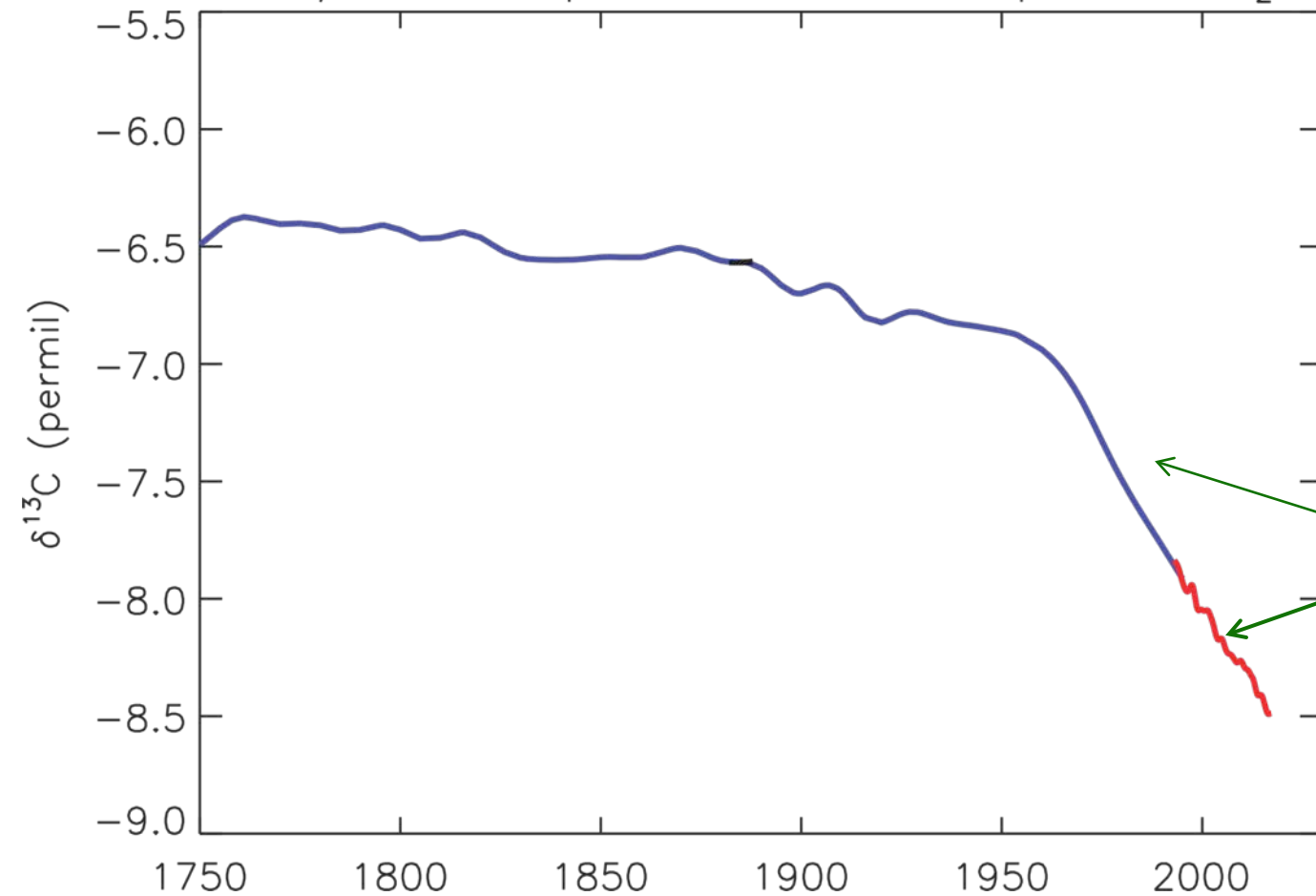
$$\delta^{13}\text{C} \equiv \frac{^{13}\text{C}/^{12}\text{C}_{\text{sample}} - ^{13}\text{C}/^{12}\text{C}_{\text{reference}}}{^{13}\text{C}/^{12}\text{C}_{\text{reference}}}$$

$$\frac{^{14}\text{C}/\text{C}_{\text{sample}}}{^{14}\text{C}/\text{C}_{\text{reference}}}$$

	$\delta^{13}\text{C}$ (approximate)	$^{13}\text{C}/^{12}\text{C}$ ratio	(approximate)
Carbonate rock	0 ‰	0.011237	0
Atmosphere	-8 ‰	0.011147	1.04
From oceans	-8 ‰	0.011147	1.06
Terrestrial biosphere	-26 ‰	0.010945	1.07
Coal	-24 ‰	0.010967	0
Oil	-28 ‰	0.010923	0
Natural gas	-45 ‰	0.010732	0

# ISOTOPIC EVIDENCE FOR THE SOURCES OF TODAY'S INCREASE

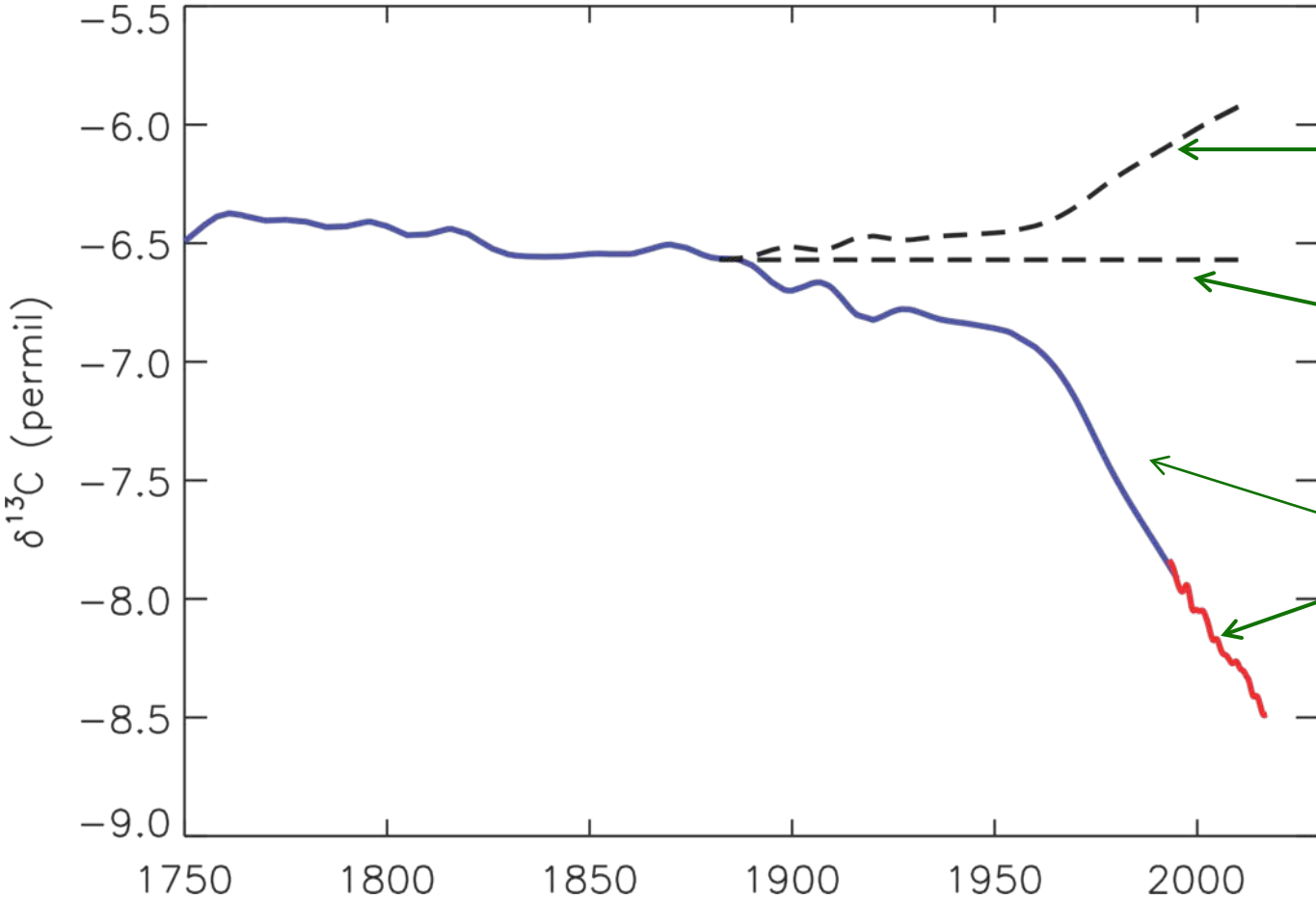
$^{13}\text{C}/^{12}\text{C}$  isotopic ratio of atmospheric  $\text{CO}_2$



**Observations: the added  $\text{CO}_2$  is depleted in  $^{13}\text{C}$**

The CO<sub>2</sub> added to the atmosphere is of organic origin

<sup>13</sup>C/<sup>12</sup>C isotopic ratio of atmospheric CO<sub>2</sub>

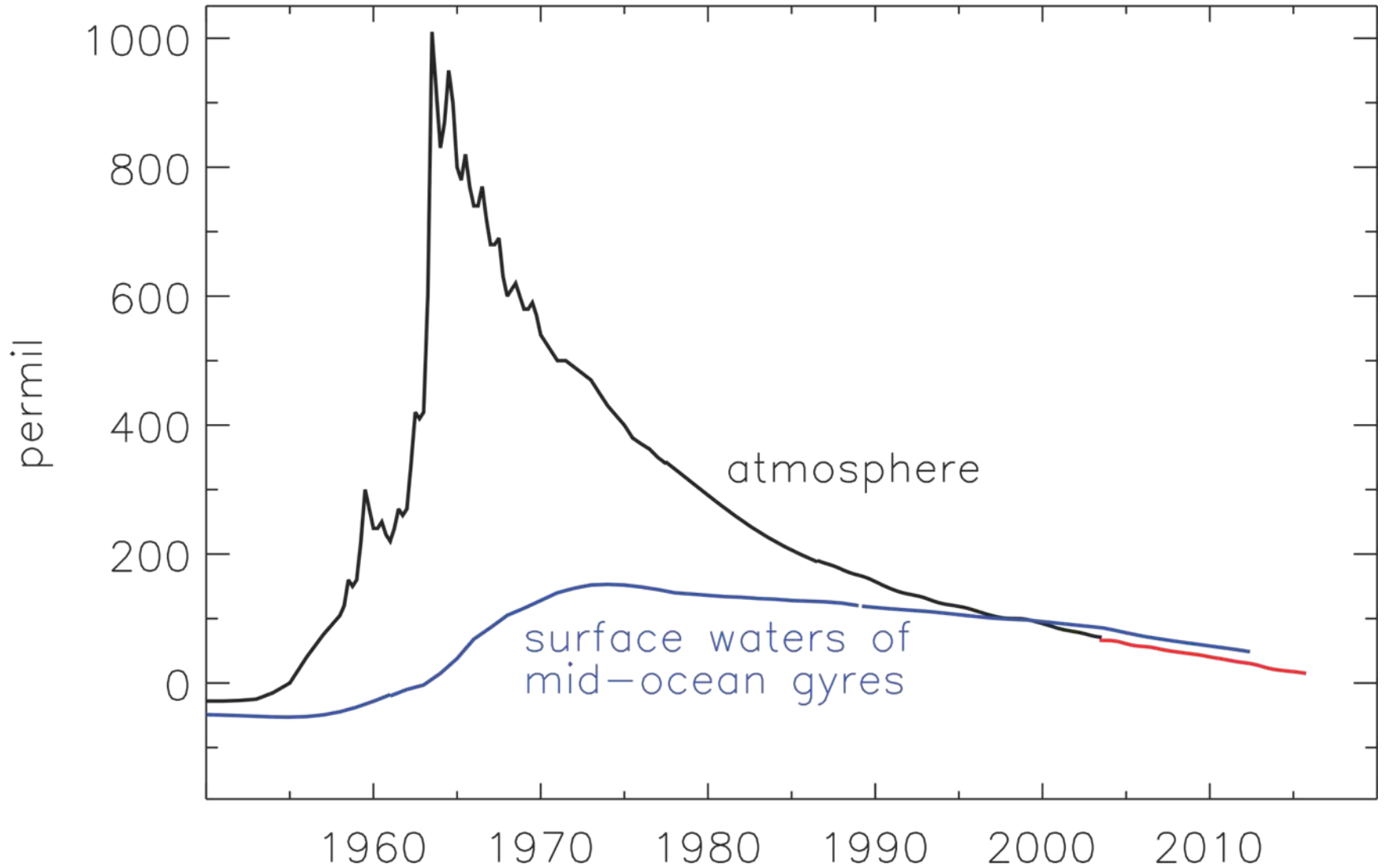


This would have been observed if the extra CO<sub>2</sub> had come from volcanoes or from the oceans....

Observations: the added CO<sub>2</sub> is depleted in <sup>13</sup>C

The organic material is very old

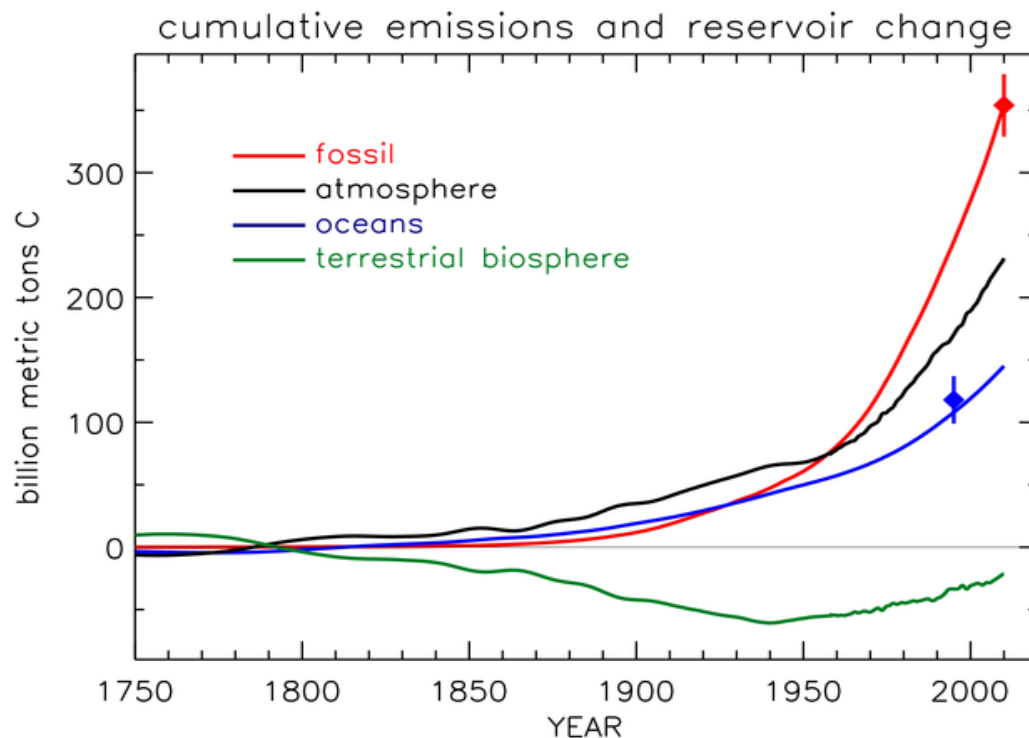
$^{14}\text{C}$  in atmosphere and surface oceans





# WHAT HAPPENED TO CO2 EMITTED FROM FOSSIL FUEL BURNING?

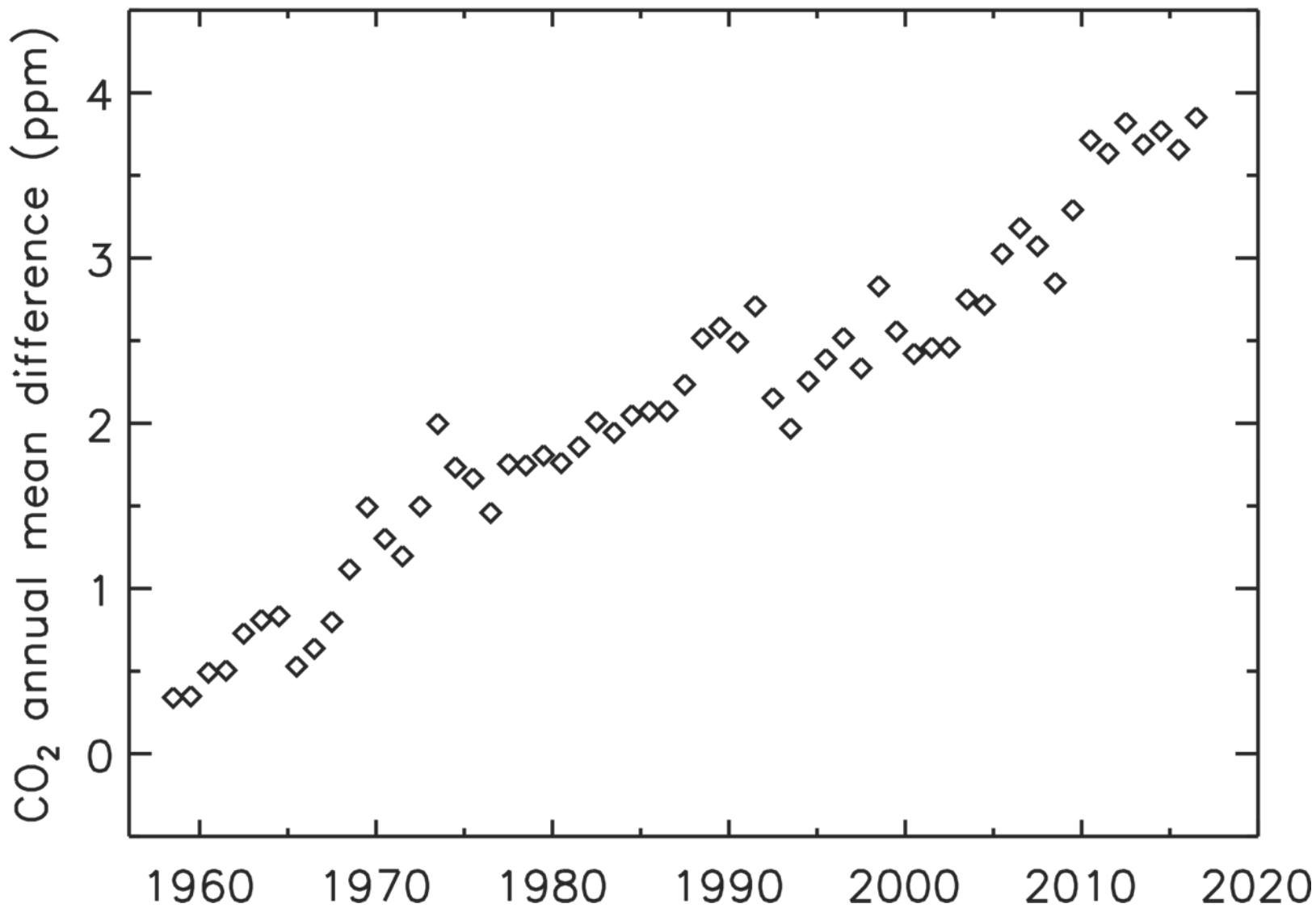
Cumulative fossil fuel emissions (Jan. 2010) <i>(source: CDIAC)</i>	Gton C $355 \pm 25$
Observed atmospheric increase (Jan. 2010) <i>(source: ESRL)</i>	$231 \pm 10$
Observed ocean increase through 1994 <i>(Sabine et al., Science 2004)</i>	$118 \pm 19$
modeled oceans, extrapolated through 2009	145



mass balance:

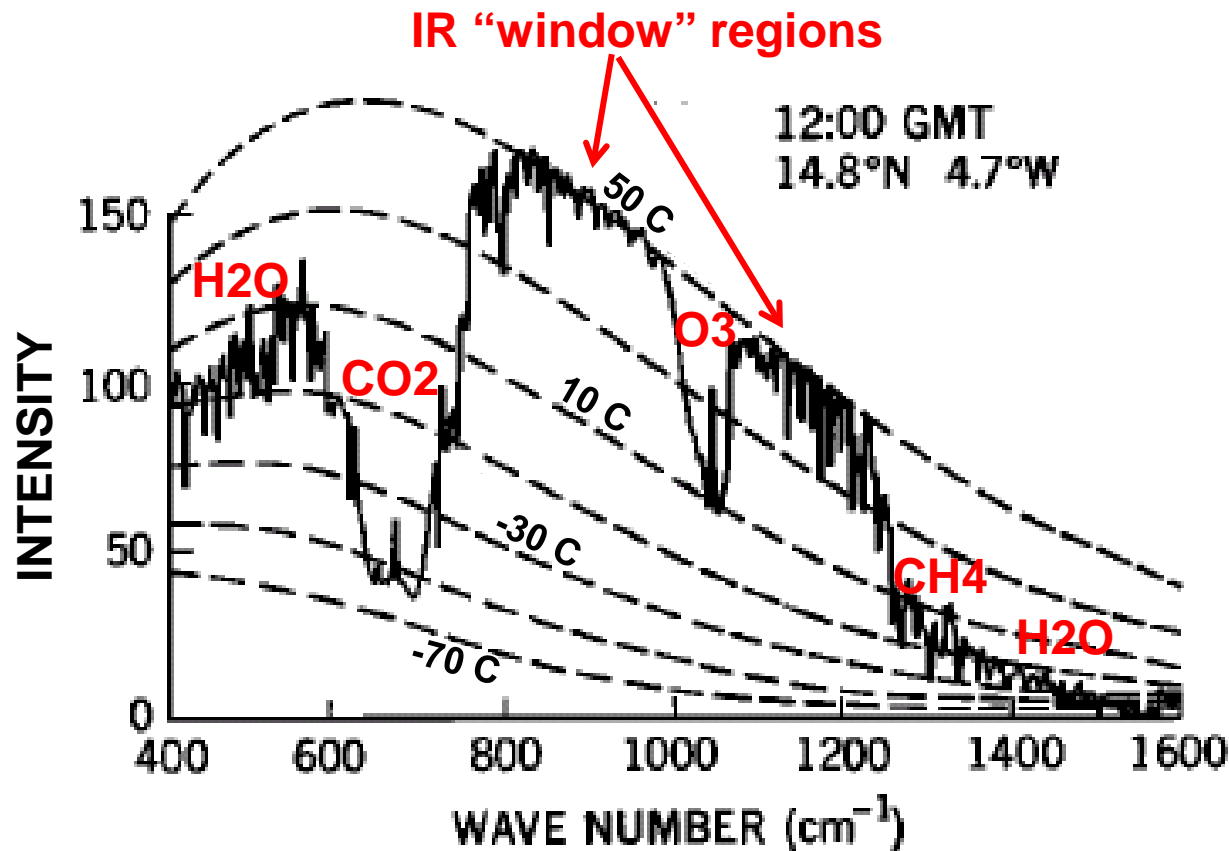
**fossil fuel emissions** =  
**atmos increase** +  
**ocean increase**  
**+ terrestrial biosphere**

Mauna Loa minus South Pole



# THE GREENHOUSE EFFECT IS WELL UNDERSTOOD, AND OBSERVED

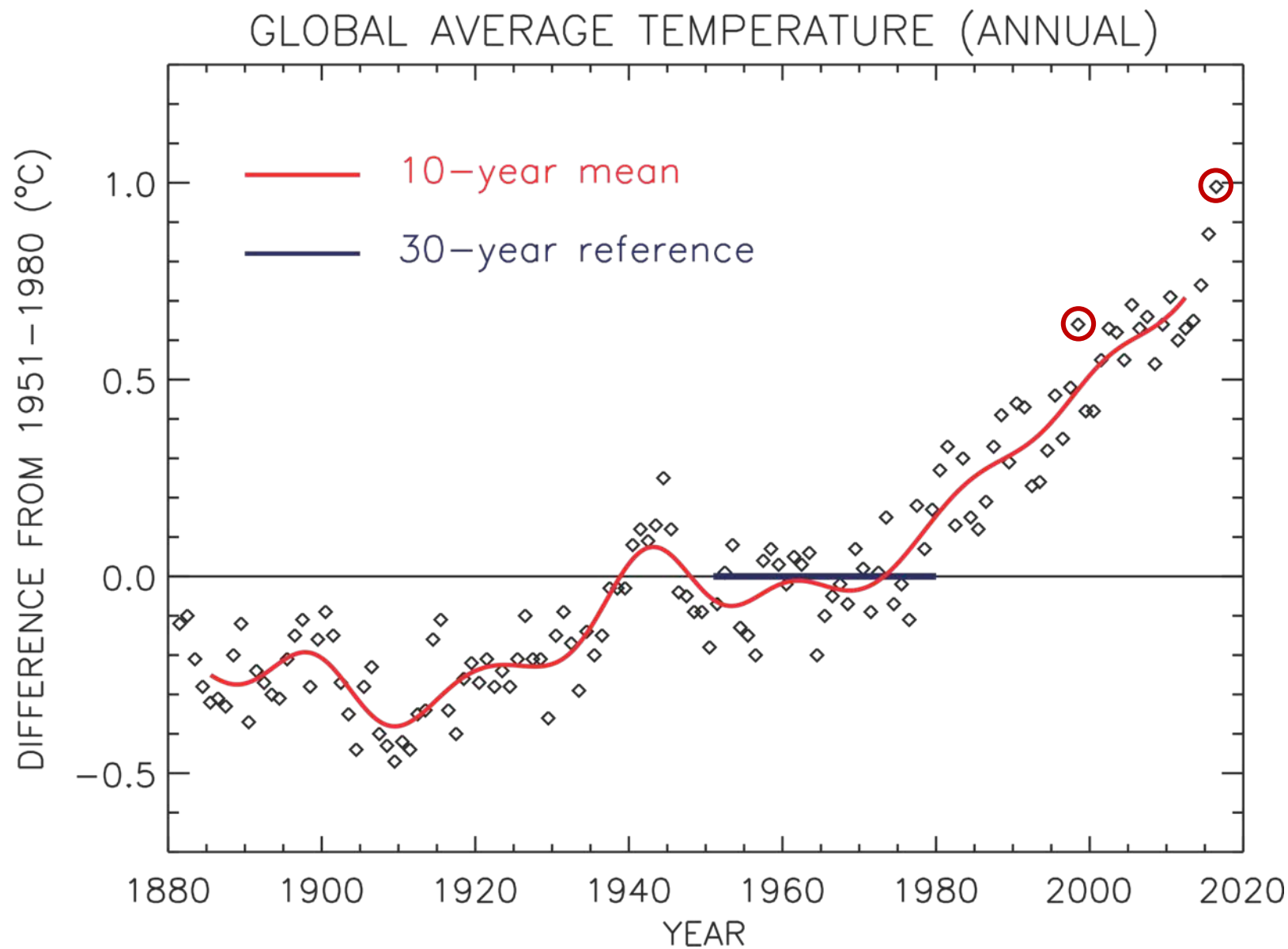
Outgoing infrared radiation (clear skies) from Earth to space as a function of wavelength over the Sahara desert. Measured by Nimbus 4 satellite in 1970



## Climate forcing by long lived GHGs (Watt m<sup>-2</sup>)

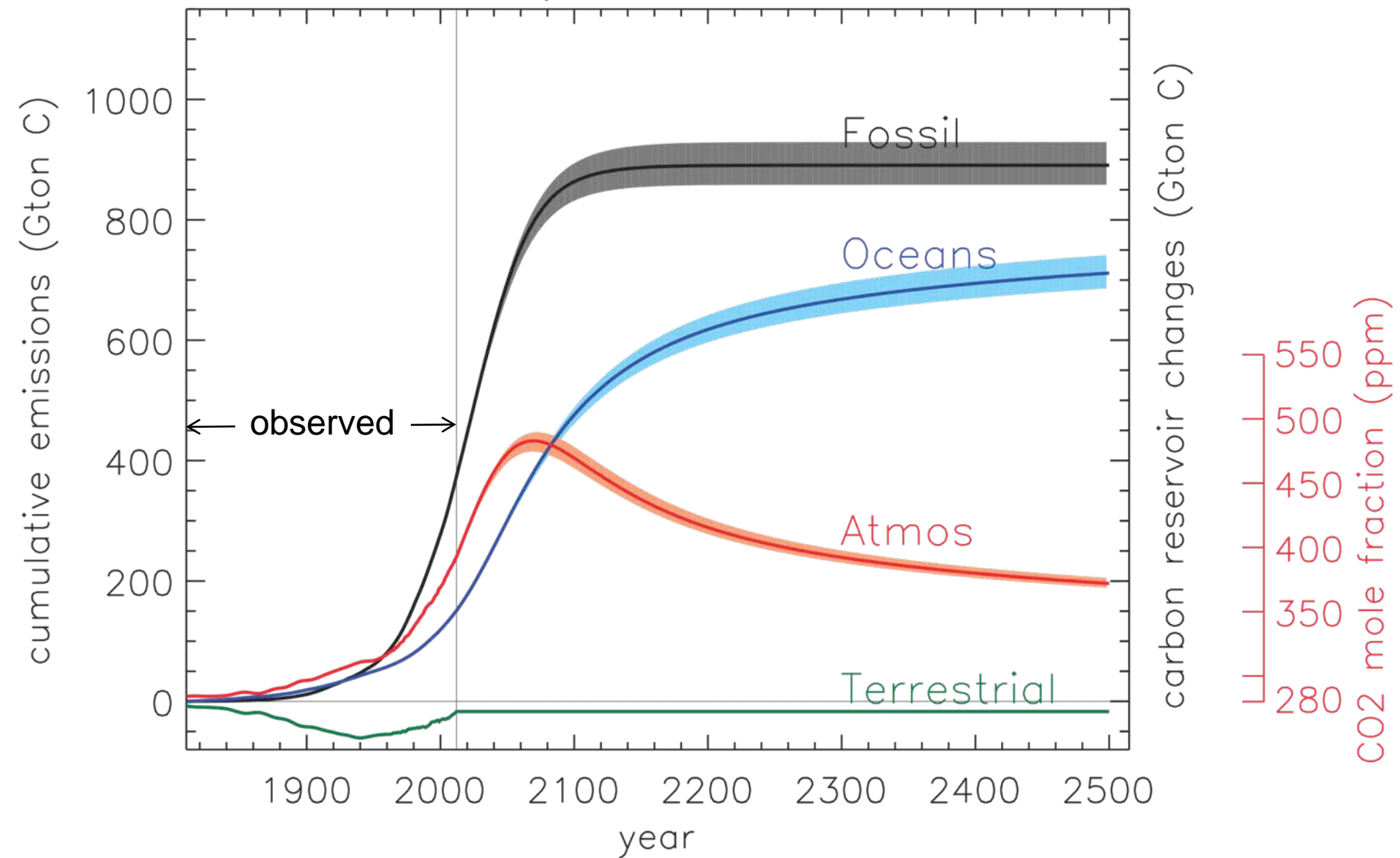
	CO2	CH4	N2O	F-12	F-11	minor	TOTAL	%solar
1950	0.572	0.244	0.059				0.875	0.348
1980	1.058	0.413	0.104	0.097	0.042	0.034	1.747	0.728
2000	1.512	0.481	0.151	0.173	0.066	0.083	2.467	1.028
2013	1.882	0.496	0.184	0.167	0.059	0.114	2.901	1.209
2014	1.908	0.499	0.187	0.166	0.058	0.116	2.935	1.223
2015	1.939	0.504	0.190	0.165	0.058	0.118	2.974	1.293

# WHAT DO WE OBSERVE? INDEED, THE EARTH IS WARMING, AS EXPECTED



# INTO THE FAR FUTURE, THOUSANDS OF YEARS

## carbon cycle mass balance



Total retained energy by enhanced CO<sub>2</sub> alone, 1750-2500, would be enough to raise the temperature of the upper 1000 m of the oceans by 12 degree C

Total retained energy by *all* GHGs, 1750-2100, raises T by 5 degree C

*Not considered: negative climate forcings (cooling) such as fine particles (haze, also called aerosols) and their effects on clouds. Increased aerosols are **also** due to human activities.*

Earth's observed heat budget 1950-2004 (D. Murphy, JGR 2009):

(Excess retained heat by GHGs ~half of one solar radiation-year)

- 12% for heating of oceans
- 21% for increased IR radiation to space (cooling from warmed surface)
- 18% compensating cooling from stratospheric aerosols (volcanoes)
- ~50% compensating residual cooling, mostly by human-caused aerosols

Based on observations and well understood physics and chemistry, human actions have committed the Earth to significant climate change for thousands of years.

Additional commitment is growing at a record pace.

Modeled predictions of climate change span a large range but do not negate the above conclusions in any way.