BAY AREA AIR QUALITY MANAGEMENT DISTRICT

AGENDA: 4

Climate Change Science Overview

Board of Directors
Climate Protection Committee
May 9, 2013

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Health & Science Officer

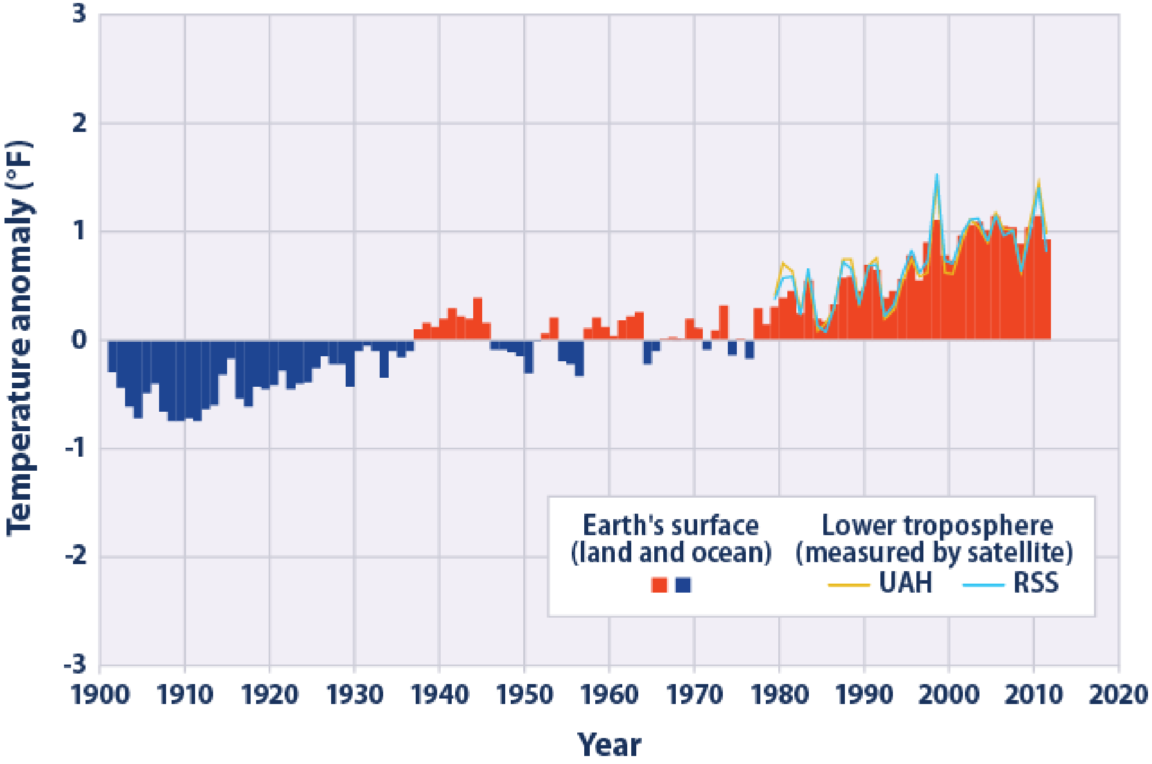
Presentation Outline

1. Definitions
2. Indicators of climate change
3. Milestones in the science of climate change
4. The climate system
5. The global energy balance and the Greenhouse Effect
6. The role of water vapor and clouds in the Greenhouse Effect
7. Greenhouse gases (GHGs)
8. Trends in atmospheric GHG levels
9. Radiative (Climate) Forcings
10. Climate Feedbacks
11. Projections of future global warming
12. Global Warming Potential (GWP) and carbon dioxide equivalent emissions (CO_2e)
13. GHG emissions by country (and for California)

Definitions

- Climate
  - The average pattern of weather (e.g., air temperature, winds, humidity, precipitation)
- Climate change
  - Changes in average weather conditions, and/or the variability in weather conditions (e.g., changes in the frequency and intensity of extreme weather events), that occur over a long period of time (30 years or more)
- Global warming
  - The rise in the average temperature of the atmosphere and the oceans that has occurred since the late 19th century, and its projected continuation

Trends in Global Average Surface Temperatures

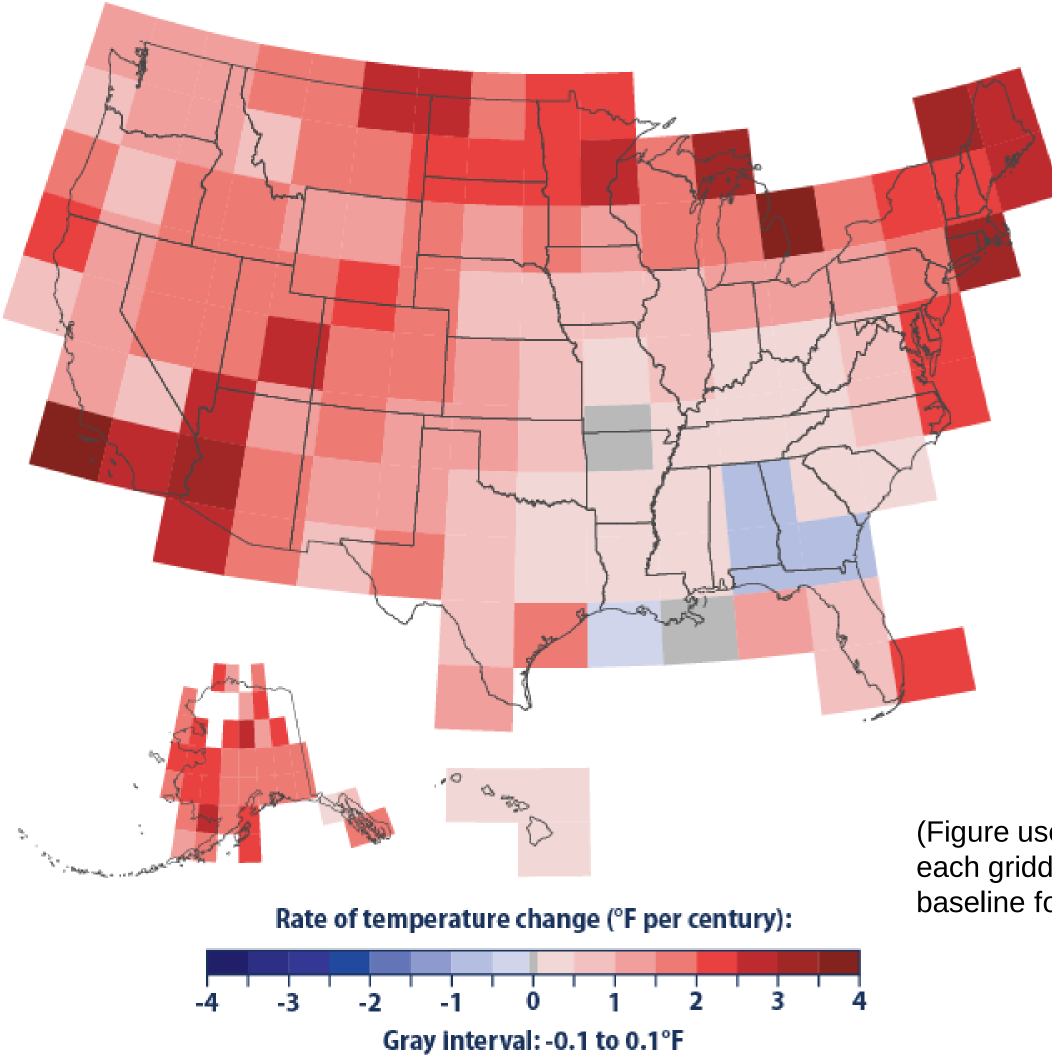


Data source: NOAA (National Oceanic and Atmospheric Administration). 2012. National Climatic Data Center. Accessed April 2012. www.ncdc.noaa.gov/oa/ncdc.html.

Global average surface temperature has risen at an average rate of 0.14°F per decade since 1901.

(Figure uses average global surface temperature from 1901 – 2000 as a baseline for depicting change).

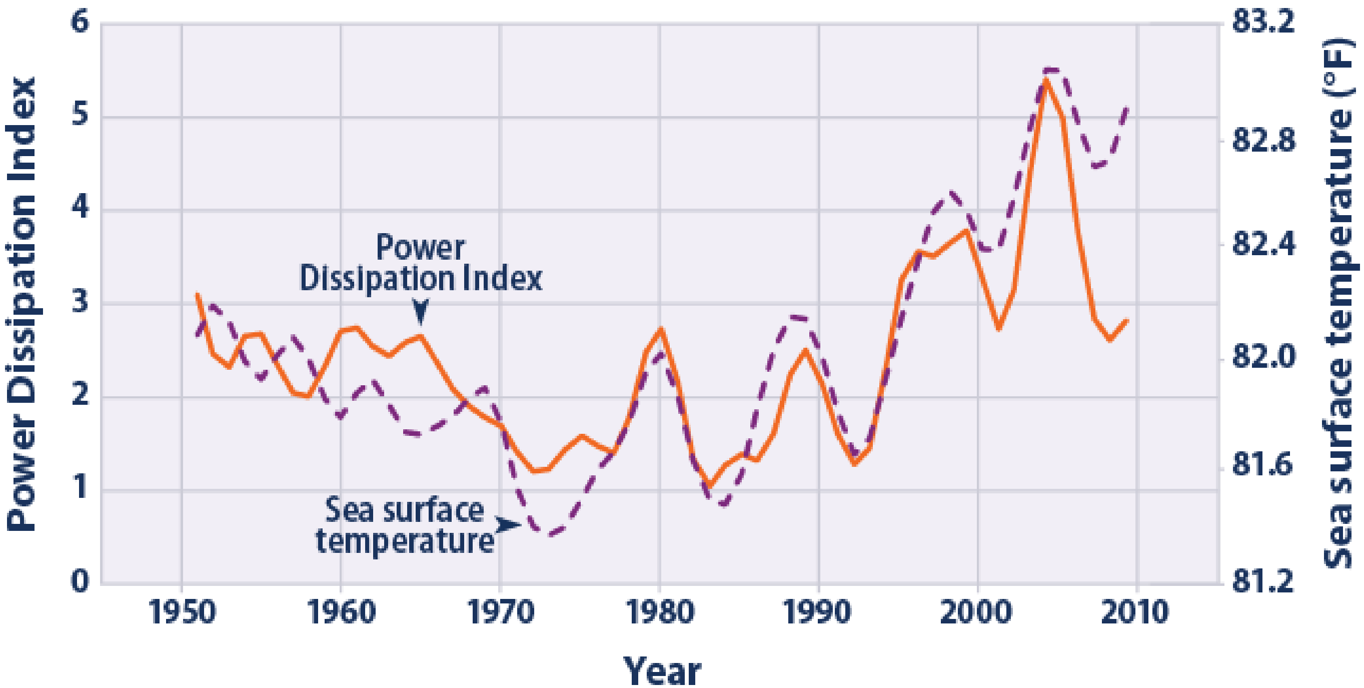
Trends in Air Temperatures in the U.S. (1901-2011)



(Figure uses average air temperature in each gridded area from 1901 – 2000 as a baseline for depicting change).

Data source: NOAA (National Oceanic and Atmospheric Administration). 2012. National Climatic Data Center. Accessed April 2012. www.ncdc.noaa.gov/oa/ncdc.html.

Trends in North Atlantic Tropical Cyclone Activity

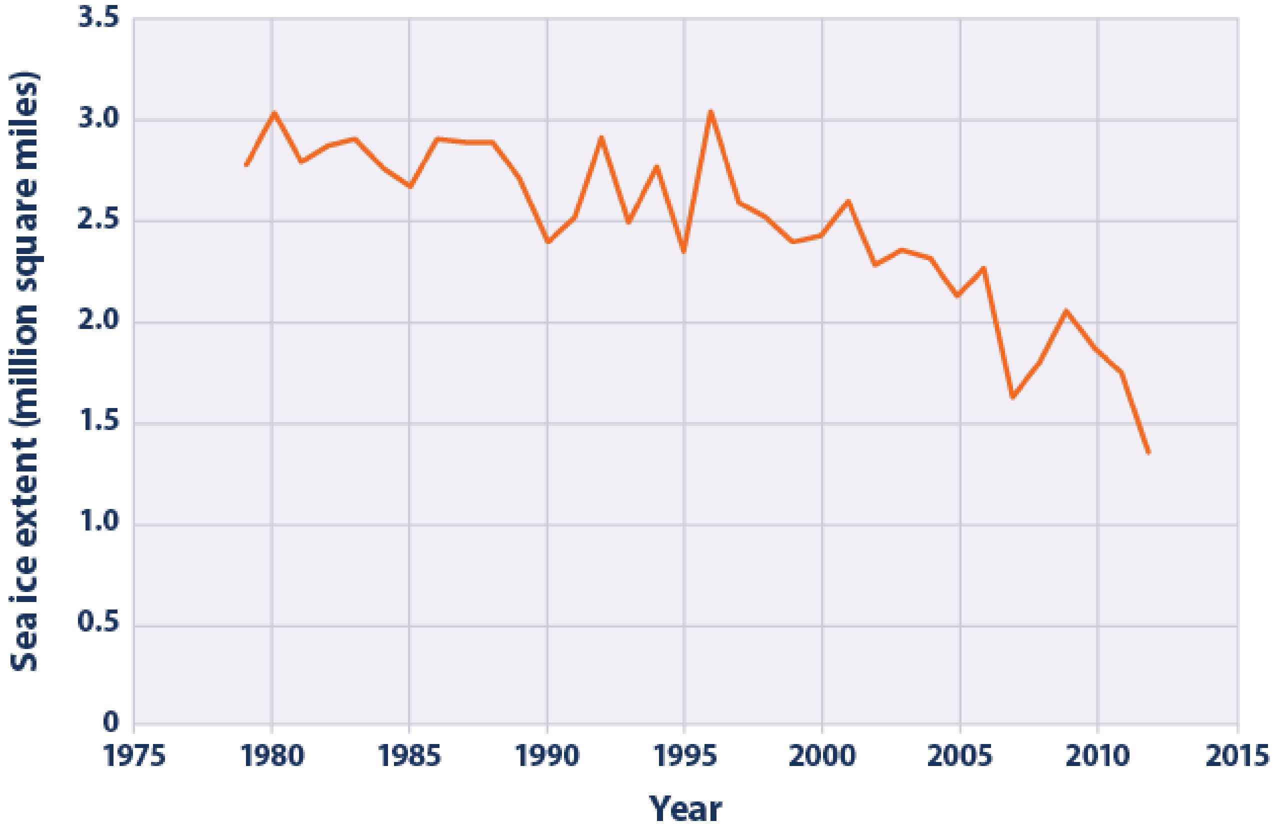


Data source: Emanuel, K.A. 2012 update to data originally published in: Emanuel, K.A. 2007. Environmental factors affecting tropical cyclone power dissipation. J. Climate 20(22):5497–5509.

Cyclone intensity has risen noticeably over the past 20 years. Changes in observation methods over time make it difficult to know for certain whether tropical storm activity has actually shown a long-term increase.

(Power Dissipation Index (PDI) is a measure of storm intensity and is based on measurements of wind speed. The figure shows trends in annual PDI values, which represent the sum of PDI values for all named storms during the year).

Trends in September Monthly Average Arctic Sea Ice Extent

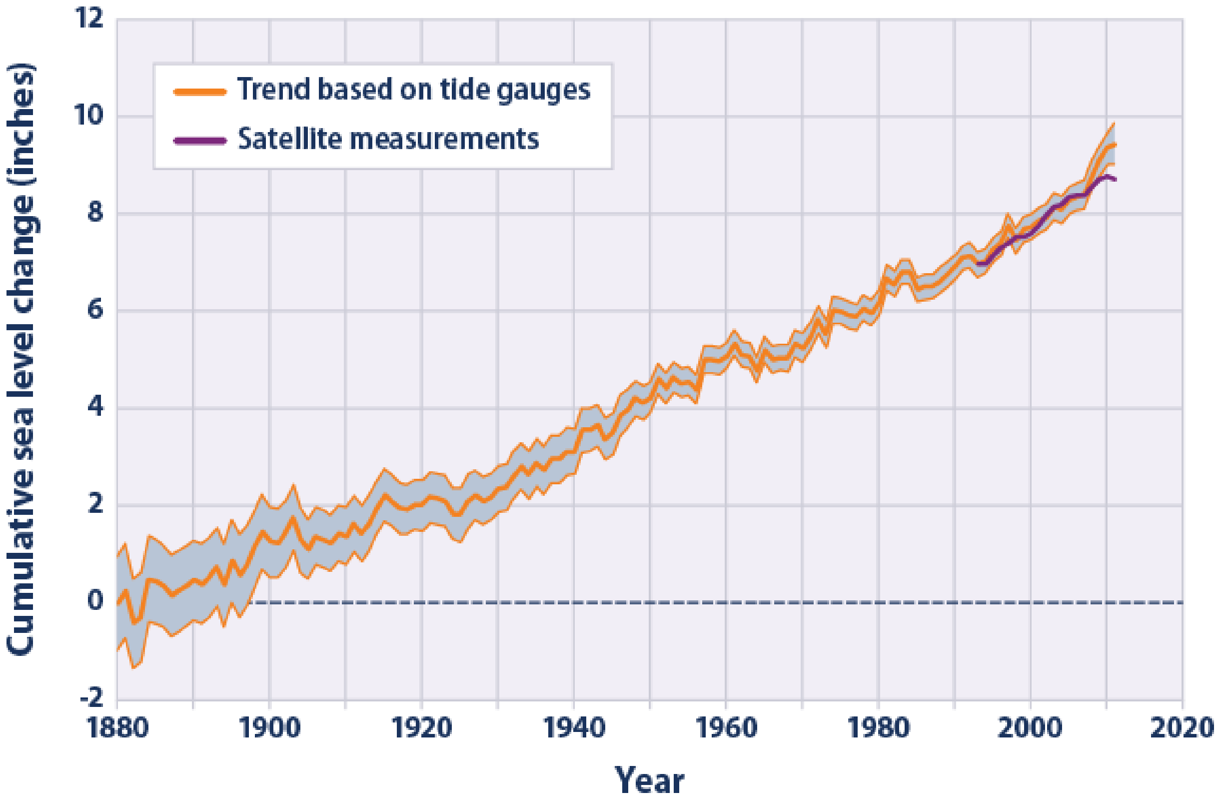


Data source: NSIDC (National Snow and Ice Data Center). 2012. Archived monthly sea ice data and images. Accessed October 2012. http://nsidc.org/data/seaice_index/archives/index.html

September 2012 had the lowest arctic sea ice extent on record, 49 percent below the 1979-2000 average for that month.

(Sea ice extent is defined as the area of ocean where at least 15 percent of the surface is frozen. September is typically the month when the sea ice extent reaches its annual minimum after melting during the spring and summer).

Trends in Global Average Sea Level



Data sources:
- CSIRO (Commonwealth Scientific and Industrial Research Organisation). 2012 update to data originally published in: Church, J.A., and N.J. White. 2011. Sea-level rise from the late 19th to the early 21st century. Surv. Geophys. 32:585–602.
- NOAA (National Oceanic and Atmospheric Administration). 2012. Laboratory for Satellite Altimetry: Sea level rise. Accessed May 2012. http://ibis.grdl.noaa.gov/SAT/SeaLevelRise/LSA_SLR_timeseries_global.php.

When averaged over all the world's oceans, absolute sea level increased at an average rate of 0.07 inches per year from 1880 to 2011.

From 1993 to 2011, average sea level rose at a rate of 0.11 to 0.13 inches per year.

(The figure shows annual absolute sea level change averaged over the entire Earth's ocean surface. The long-term trend is based on tide gauge data that have been adjusted to show absolute global trends through calibration with recent satellite data).

Key Milestones in the Science of Climate Change

1859: Tyndall discovers that some gases block infrared radiation (the Greenhouse Effect) and suggests that changes in atmospheric concentrations of the gases could bring climate change.

1896: Arrhenius publishes the first calculation of global warming from human emissions of CO_2.

1938: Callendar analyzes temperature data and argues that global warming is underway due to CO_2 emissions.

1960: Keeling accurately measures CO_2 in the Earth's atmosphere and detects an annual rise.

1965: Boulder, Colo. conference on “Causes of Climate Change”: Lorenz and others point out the chaotic nature of the climate system and the possibility of sudden shifts.

1970: Aerosols from human activity are shown to be increasing swiftly. Bryson claims they counteract global warming and may bring serious cooling.

1979: Based on improved climate modeling, the National Academy of Sciences concludes that if CO_2 in the atmosphere continues to increase significant climate change will very likely occur.

1985: Villach Conference declares consensus among experts that some global warming seems inevitable, and calls on governments to consider international agreements to restrict emissions.

1987: Intergovernmental Panel on Climate Change (IPCC) is established.

1990: First IPCC report concludes world has been warming and future warming seems likely.

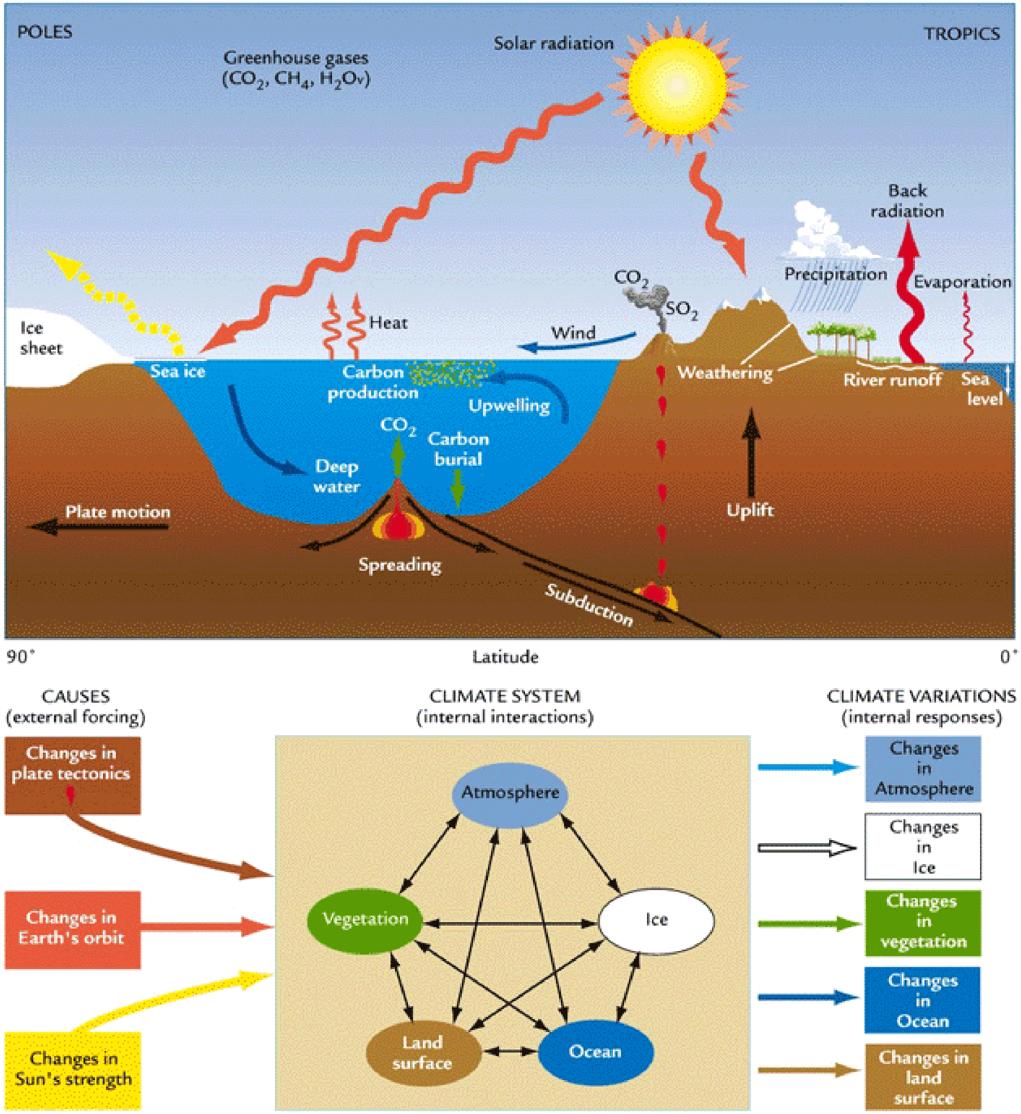
1995: Second IPCC report detects "signature" of human-caused greenhouse effect warming, declares that serious warming is likely in the coming century.

2001: Third IPCC report states that global warming, unprecedented since the end of the last ice age, is "very likely”, with possible severe surprises. Effective end of debate among all but a few scientists.

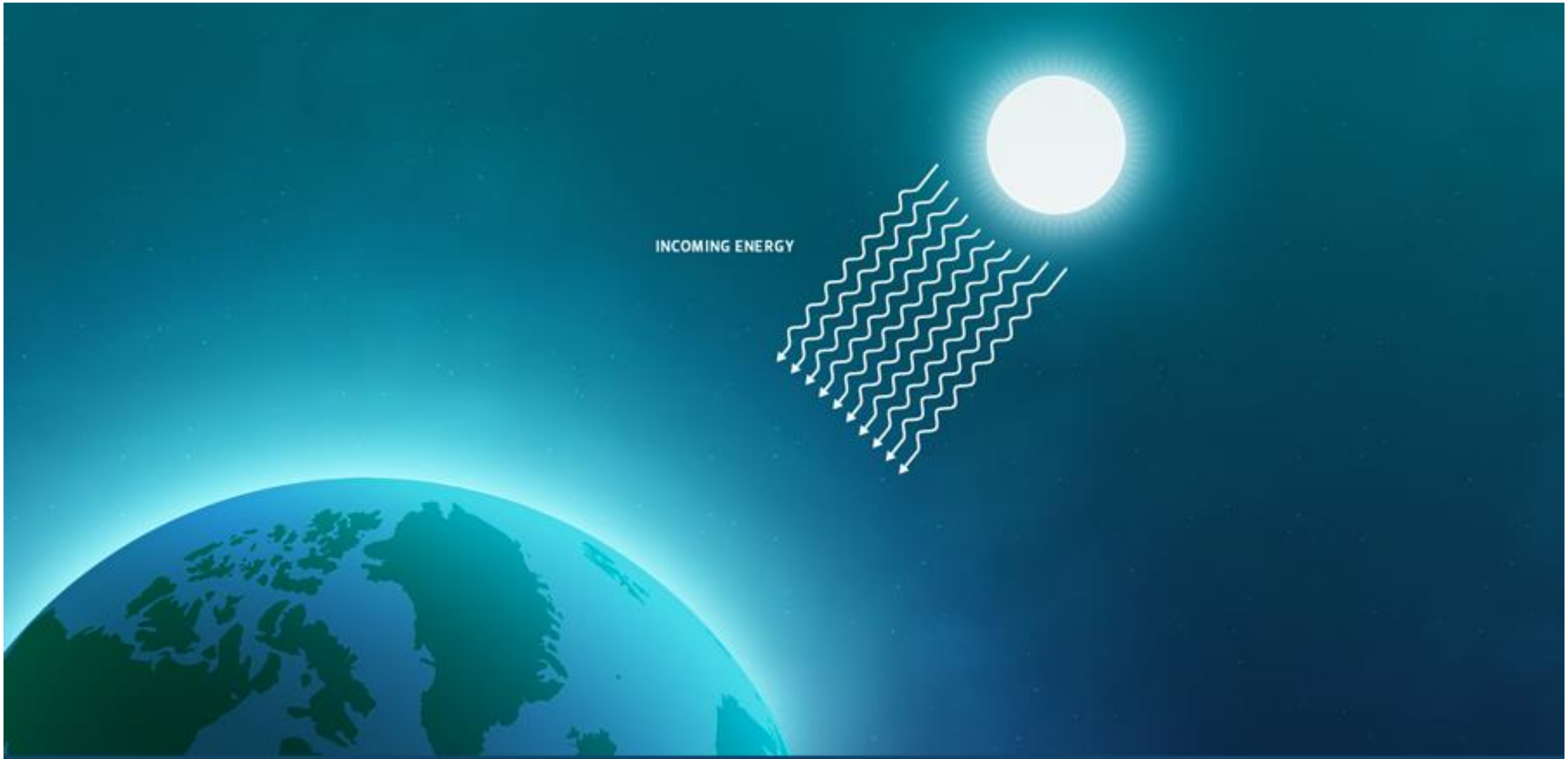
2007: Fourth IPCC report warns that serious effects of warming have become evident and that the cost of reducing emissions would be far less than the damage they will cause.

2014: Fifth IPCC report due to be finalized.

The Climate System



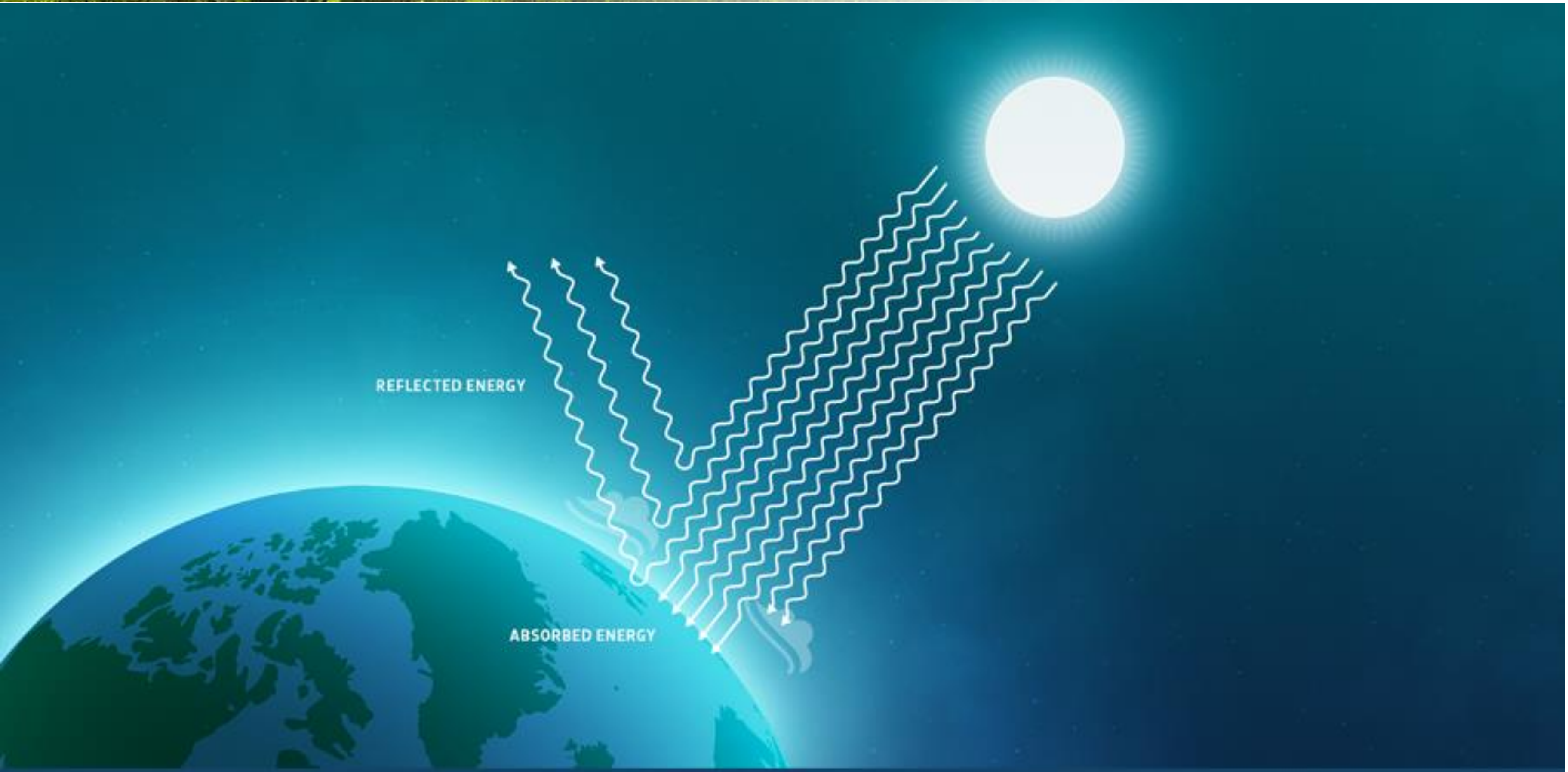
Global Energy Balance
Part 1: Sunlight



The Sun’s energy is transmitted to Earth in high-energy short wavelengths of light that penetrate the Earth's atmosphere.

(Figure adapted from www.epa.gov/climatechange/science/, April 30, 2013.)

Global Energy Balance
Part 2: Refection and Absorption



About 30% of the Sun's energy is reflected (albedo) directly back into space by clouds, aerosols, and the surface of the Earth (e.g., ice sheets, snow, deserts). The rest of the Sun's energy is absorbed into the Earth's climate system.

(Figure adapted from www.epa.gov/climatechange/science/, April 30, 2013.)

Global Energy Budget
Part 3: Re-radiation

The warmed Earth emits energy in the form of radiation with longer wavelengths (infrared) than the incoming solar energy.

(Figure adapted from www.epa.gov/climatechange/science/, April 30, 2013.)

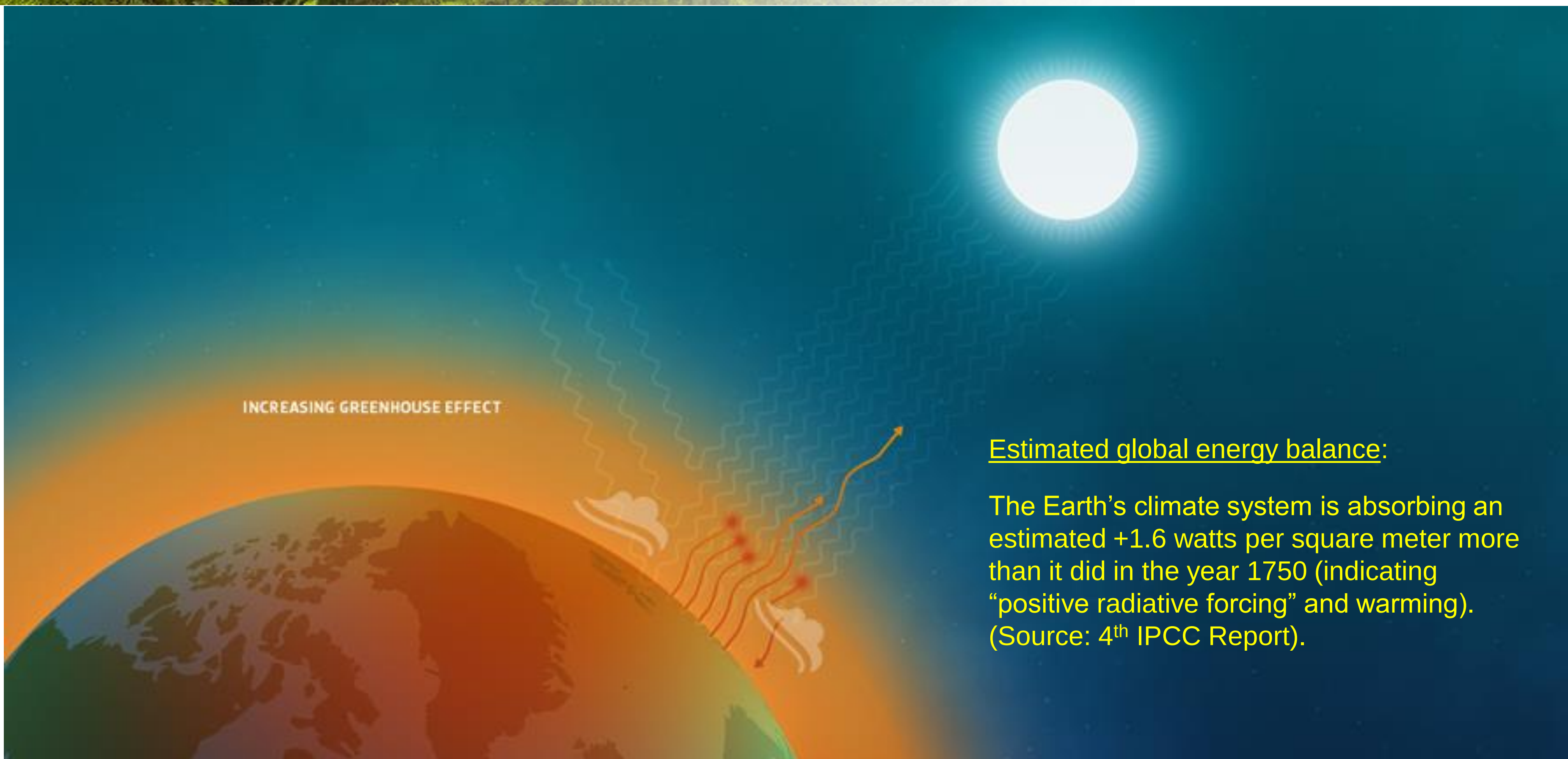
Global Energy Balance
Part 4: The "Natural" Greenhouse Effect

The Earth has an average surface temperature of 57^{o}F. Without the Greenhouse Effect, it would be 0^{o}F.

Greenhouse gases and clouds in the atmosphere absorb much of the long-wave energy emitted from the Earth's surface, preventing it from immediately escaping from the Earth's climate system. The greenhouse gases then re-emit this energy in all directions, warming the Earth's surface and lower atmosphere.

(Figure adapted from www.epa.gov/climatechange/science/, April 30, 2013.)

Global Energy Balance: The “Anthropogenic” Greenhouse Effect



Estimated global energy balance:

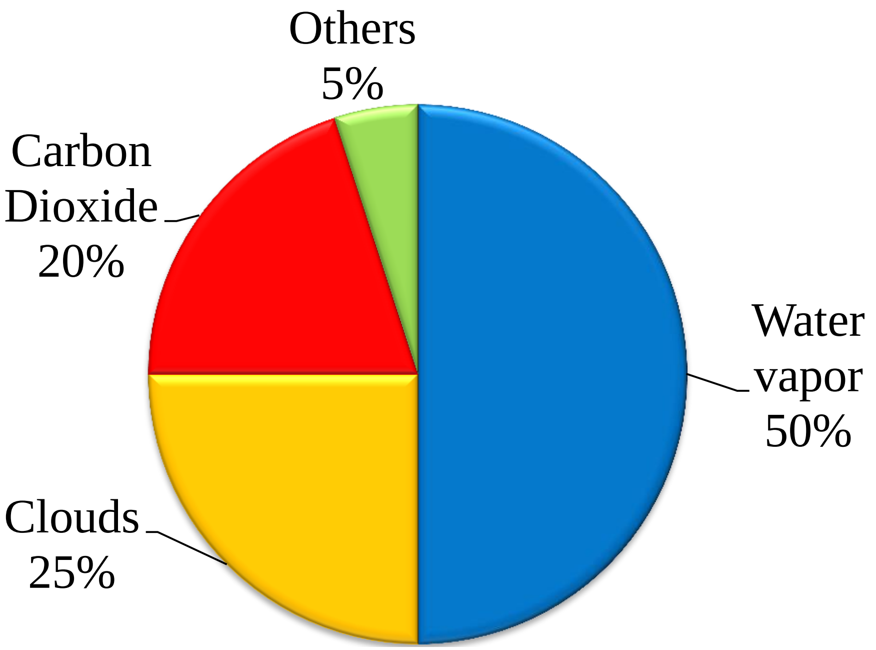
The Earth’s climate system is absorbing an estimated +1.6 watts per square meter more than it did in the year 1750 (indicating “positive radiative forcing” and warming). (Source: 4th IPCC Report).

The atmospheric concentration of greenhouse gases has increased over the past two centuries, largely due to human-generated carbon dioxide emissions from burning fossil fuels. This increase has amplified the natural greenhouse effect by trapping more of the re-radiated energy emitted by the Earth. This change causes the Earth's surface temperature to increase.

(Figure adapted from www.epa.gov/climatechange/science/, April 30, 2013.)

Role of water vapor and clouds in the Greenhouse Effect

- Water vapor and clouds absorb and emit infrared radiation and are dominant contributors to the Greenhouse Effect.
- Long-term changes in water vapor and clouds in the atmosphere are the result of internal <u>feedback mechanisms</u> resulting from external forcings.
- Water vapor and clouds are not anthropogenic GHGs.



Relative contributions of atmospheric infrared absorbers to the present-day global greenhouse effect

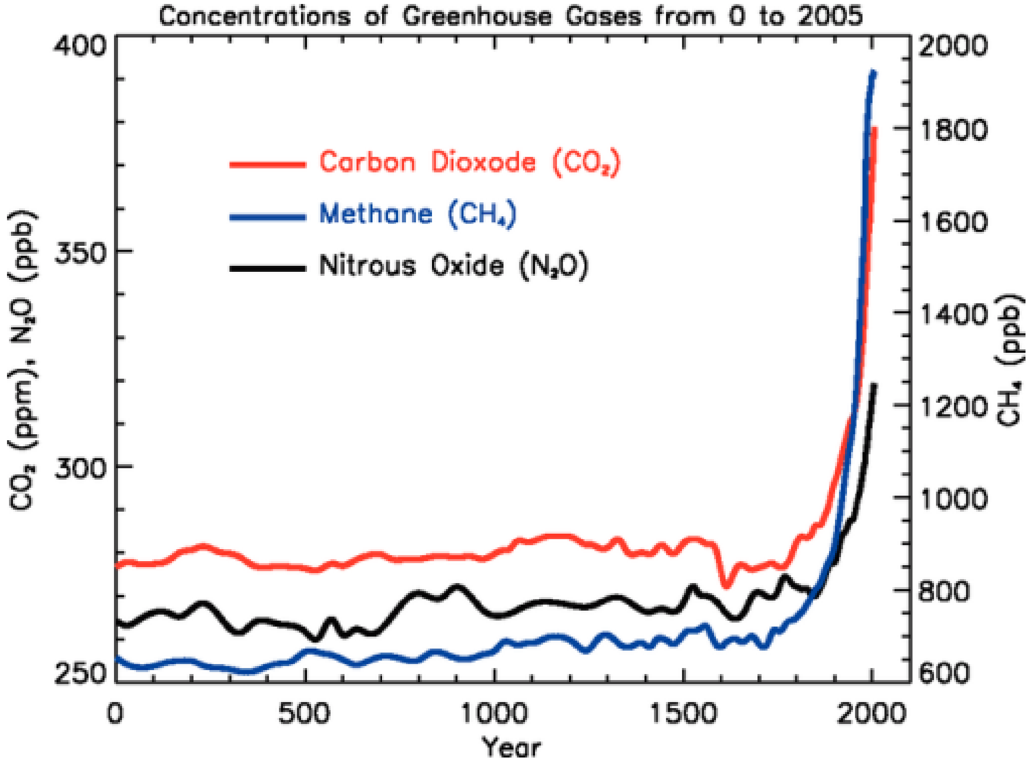
(Schmidt, et. al., *Attribution of the Present-Day Total Greenhouse Effect*, Journal of Geophysical Research, 2010).

Greenhouse Gases (GHGs)

	Chemical Formula	Natural Sources	Anthropogenic Sources	Global Average Radiative Forcing (Watts / m^2)
<u>Long-lived GHGs (Covered Under Kyoto Protocol, AB-32)</u>				
Carbon Dioxide	CO_2	Carbon cycle (oceans, soils, plants, animals, wildfires), geologic sources	Fossil fuel combustion, deforestation and land-use change, cement manufacturing	1.66
Methane	CH_4	Carbon cycle (wetlands, termites, oceans, animals), geologic sources	Agriculture, landfills, natural gas leaks	0.48
Nitrous oxide	N_2O	Nitrogen cycle (soils, oceans)	Fertilizer use, fossil fuel combustion, livestock	0.16
Fluorinated Gases	HFCs, PFCs, SF_6	None	Refrigerants, aerosol propellants, fire retardants, semiconductor mfg.	0.34
<u>Short-lived Radiative Forcing Agents</u>				
Ozone	O_3	Stratospheric: oxygen + UV light; Lower atmosphere: HC from plants, soils; NOx from soils, lightning, wildfires	Lower atmosphere – HC from incomplete fossil fuel combustion, gasoline marketing, solvent use; NOx from fuel combustion	0.30
Black Carbon	Various	Wildfires	Fossil fuel and biomass combustion	0.20

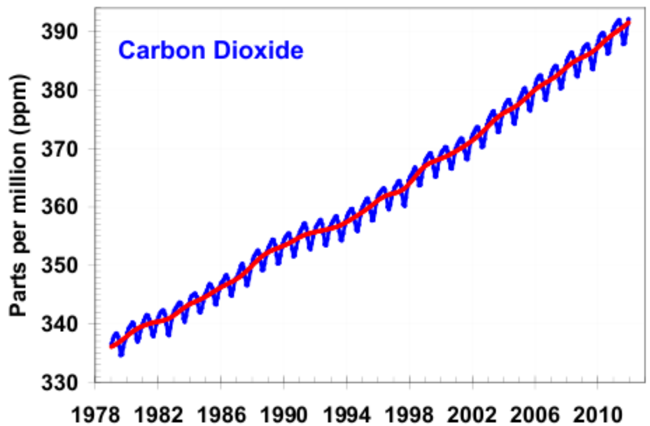
(Radiative Forcings listed are for cumulative emissions from 1750 to 2005 (4th IPCC Report – 2007)).

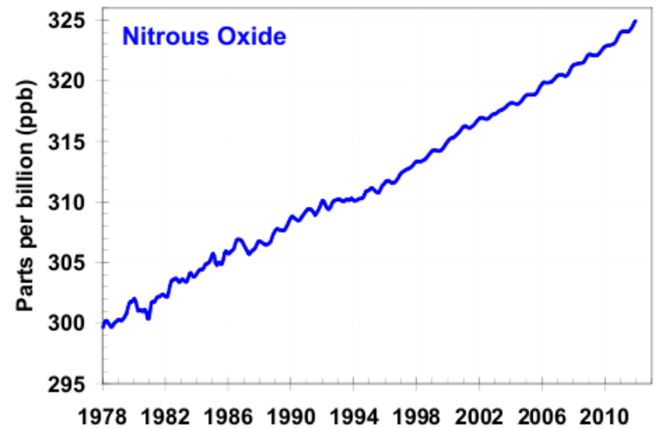
Trends in Atmospheric GHG Levels

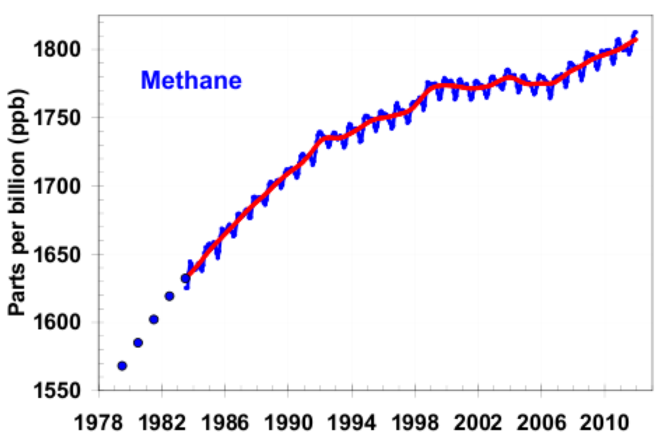


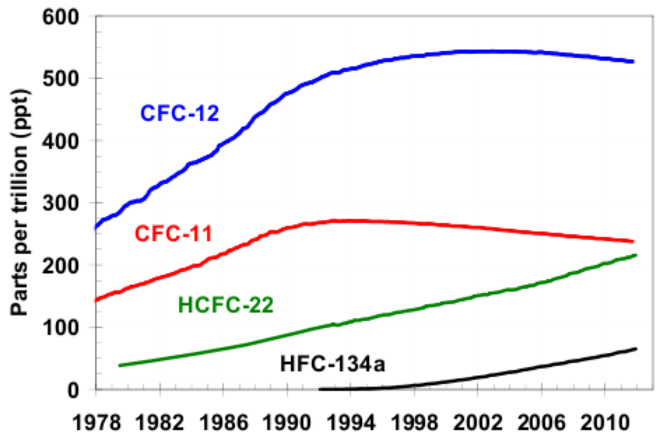
From: U.S. Global Change Research Program, *Global Climate Change Impacts in the U.S.*, 2009 Report.

Trends in Atmospheric GHG Levels



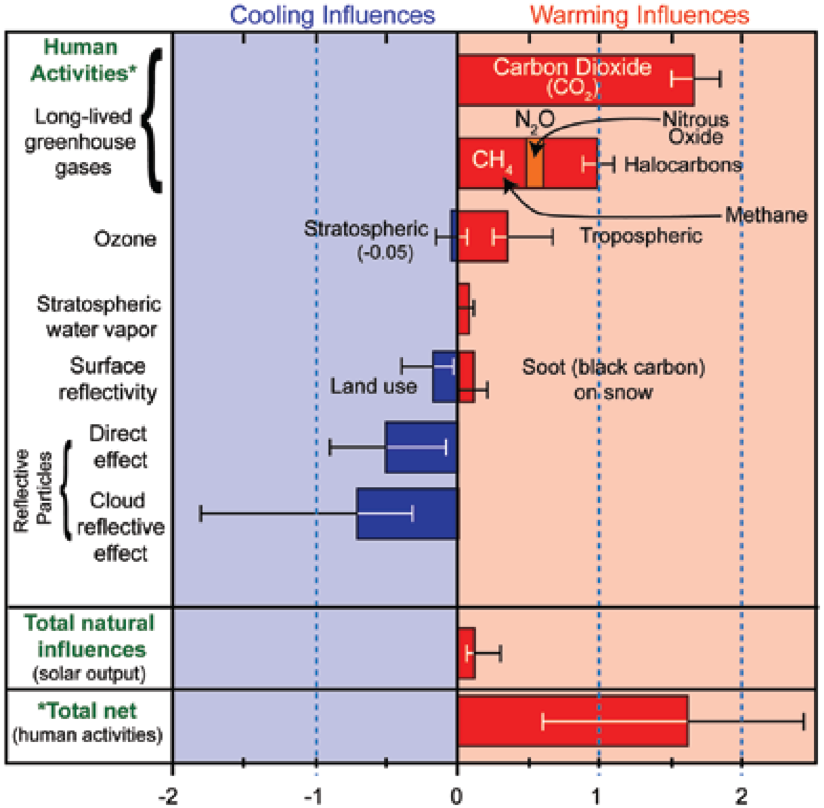






(Figures show global average air concentrations of the long-lived greenhouse gases from the National Oceanic and Atmospheric Administration (NOAA) global air sampling network).

Radiative (Climate) Forcings



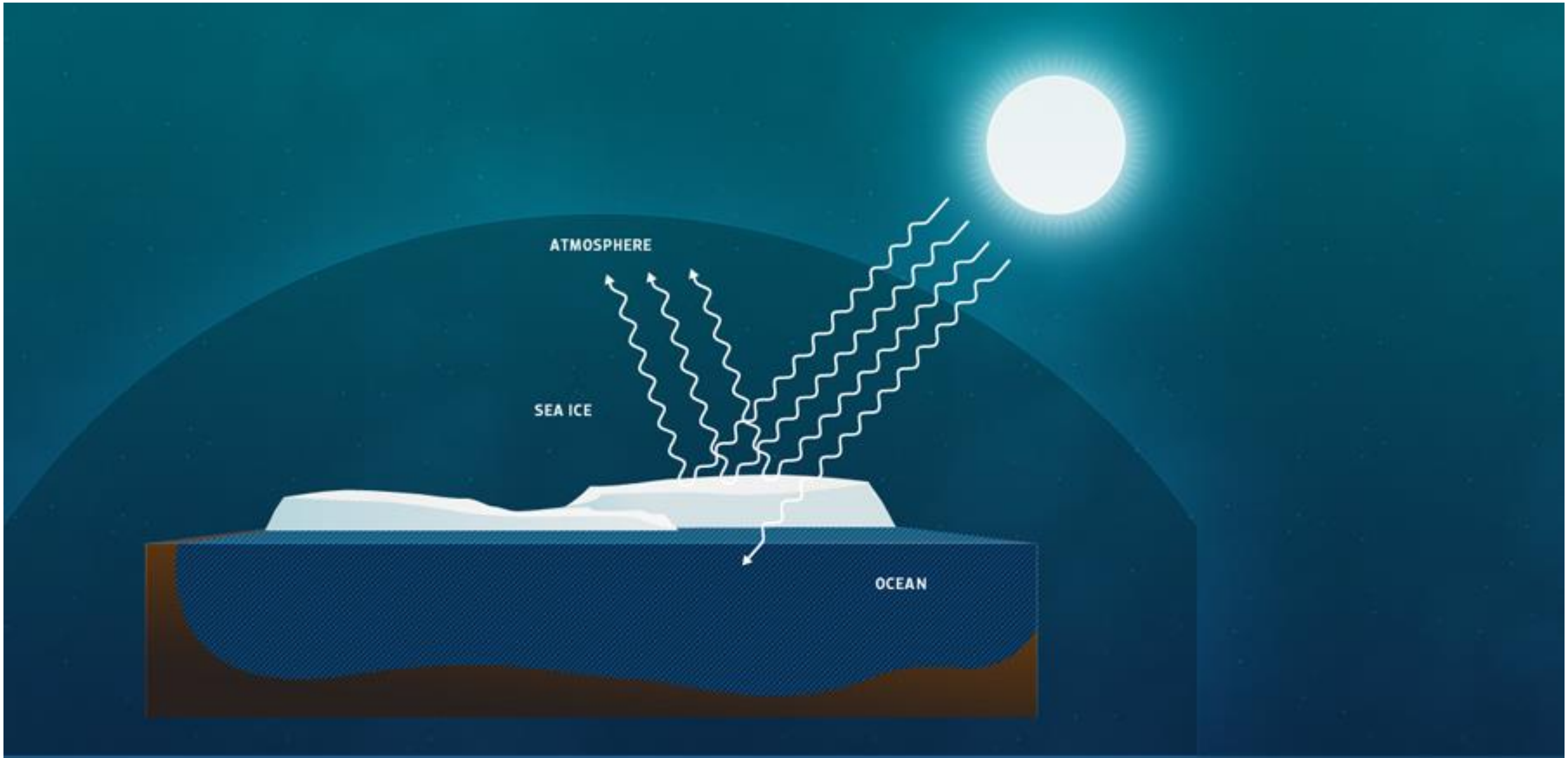
Radiative forcing is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth's climate system. The radiative forcing values in this figure are from the 4th IPCC Report (2007), and are for changes relative to preindustrial conditions in the year 1750 expressed in Watts per square meter (W / m^2). Some forcings are positive, causing globally averaged warming, and some are negative, causing cooling.

Climate Feedbacks

How much will the Earth warm in response to climate forcing? The answer depends on climate feedbacks.
A feedback is when an initial process triggers changes in a second process that in turn influences the initial process.
A positive climate feedback increases climate warming, while a negative climate feedback decreases that warming.

(Figure adapted from www.epa.gov/climatechange/science/, April 30, 2013.)

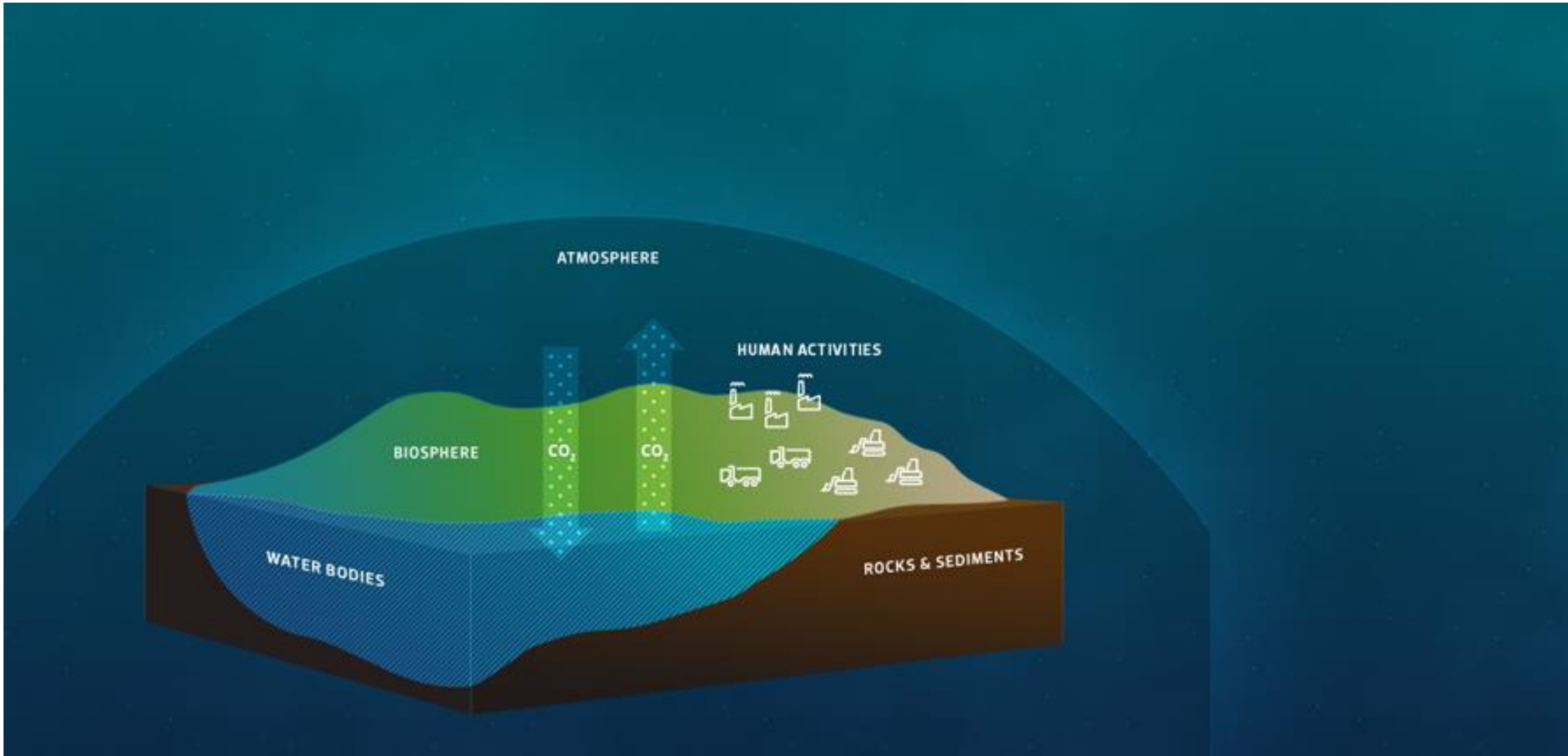
Climate Feedbacks: Ice Reflectivity



The dark ocean surface absorbs most of the Sun's energy, while sea ice reflects most of it. As the air and ocean warm, sea ice melts. As ice melts, more of the dark ocean surface is exposed. The exposed ocean surface absorbs more of the Sun's energy, leading to greater melting of sea ice. This is an example of a positive feedback.

(Figure adapted from www.epa.gov/climatechange/science/, April 30, 2013.)

Climate Feedbacks: Ocean-Atmosphere Carbon Cycle



As global warming and ocean acidification continue, the world's oceans may start to absorb less CO_2 from the atmosphere. If less CO_2 is absorbed by the oceans, more CO_2 would accumulate in the atmosphere, causing greater warming. This is another example of a positive feedback.

(Figure adapted from www.epa.gov/climatechange/science/, April 30, 2013.)

Projections of Future Global Warming

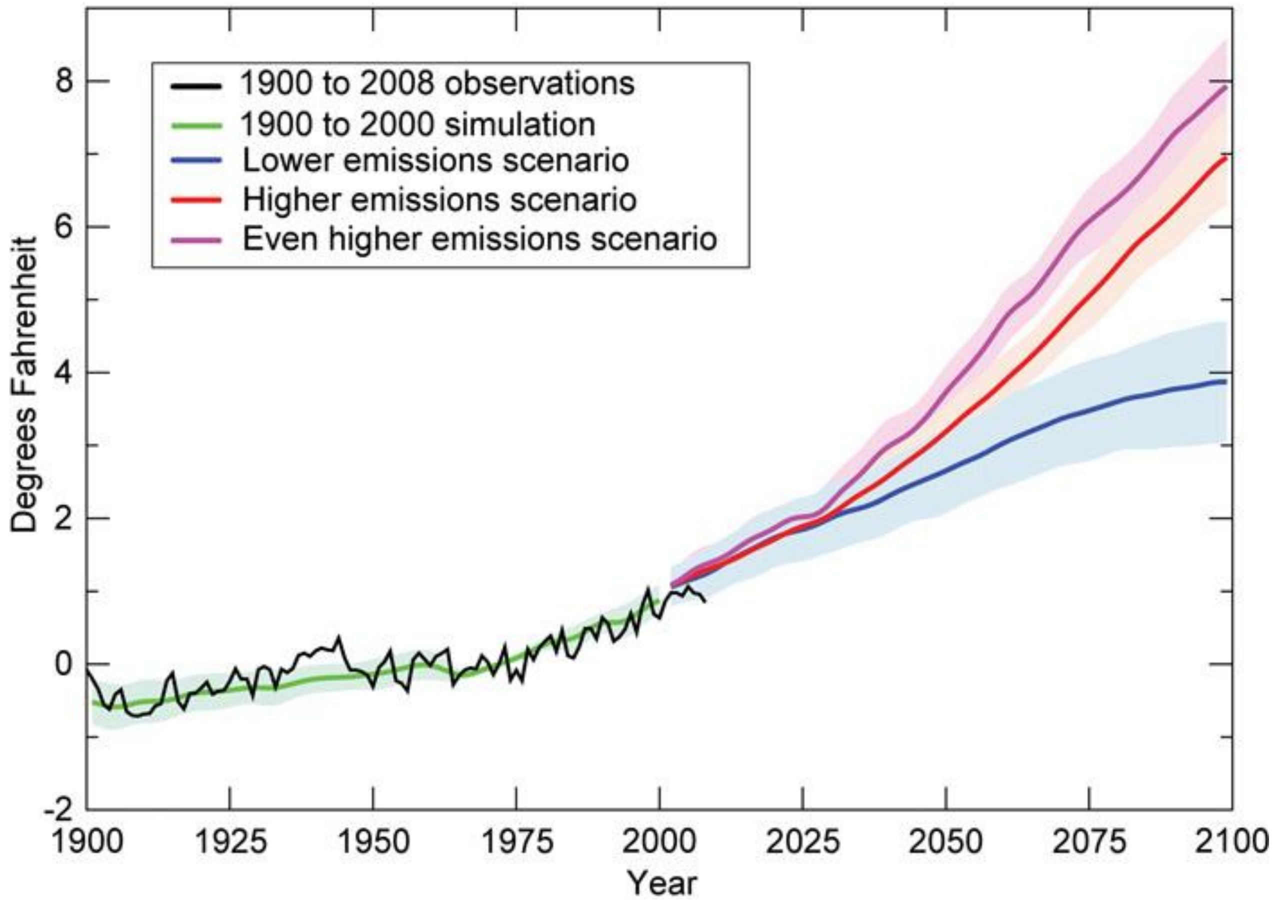


Figure shows observed and modeled projected changes in global average temperature under three IPCC “no-policy” emissions scenarios (relative to the 1960-1979 average). A wider range of model types shows outcomes from 2 to 11.5°F. (Source: U.S. Global Change Research Program, *Global Climate Change Impacts in the U.S.*, 2009 Report.)

Global Warming Potential (GWP)

- Provides a common basis for judging emissions of different GHGs
- Determined based on:
  - Radiative efficiency
  - Atmospheric lifetime
- Different GWPs for different time horizons
  - 100 year time horizon is most commonly used

GHG	Radiative Efficiency (W / m^2 per ppb)	Atmospheric Lifetime (years)	GWP for Given Time Horizon		
			20 year	100 year	500 year
Carbon Dioxide	0.000014	30 - 90	1	1	1
Methane	0.00037	12	72	25	7.6
Nitrous oxide	0.00303	114	289	298	153
HFC-23	0.19	270	12,000	14,800	12,200
HFC-125	0.23	29	6,350	3,500	1,100
PFC-14	0.10	50,000	5,210	7,390	11,200

2010 GHG Emissions by Country (Fuel Combustion)

Country (or State)	Greenhouse Gas Emissions (million metric tons per year, CO_2e)	Percent of Worldwide Emissions	Per Capita GHG Emissions (tons per year, CO_2e)
Worldwide	33,509	100.0	4.9
China	8,241	24.6	6.2
United States	5,492	16.4	17.6
India	2,070	6.2	1.7
Russia	1,689	5.0	11.8
Japan	1,138	3.4	8.9
Germany	763	2.3	9.3
California	454	1.4	13.4

(Source: International Energy Agency (IEA) (2011), *CO2 Emissions From Fuel Combustion: Highlights (2011 edition)*. California estimate is 2002 – 2004 statewide average less High GWP GHGs, *Climate Change Scoping Plan*, CARB, Dec. 2008.)