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FLATE
Hillsborough Community College - Brandon
10414 E Columbus Dr., Tampa, FL 33619
(813) 259-6575
www.fl-ate.org; www.madeinflorida.org; www.fesc.org

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Introduction to Alternative and Renewable Energy

EST1830

FESC Florida Energy Systems Consortium

FLATE FLORIDA ADVANCED TECHNOLOGICAL EDUCATION CENTER

A National Science Foundation Regional Center For Advanced Technological Education

1. Introductory Section

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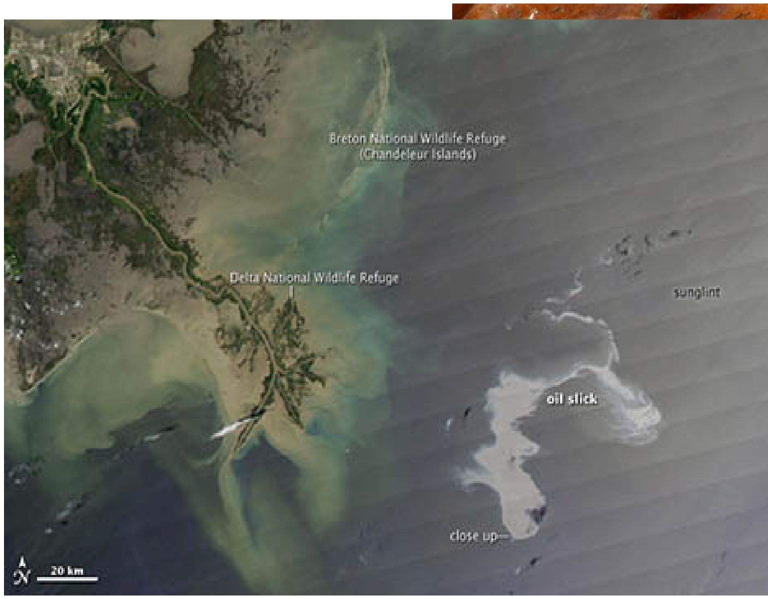
- 1.2.2B Albedo
- 1.2.2C Greenhouse Effect

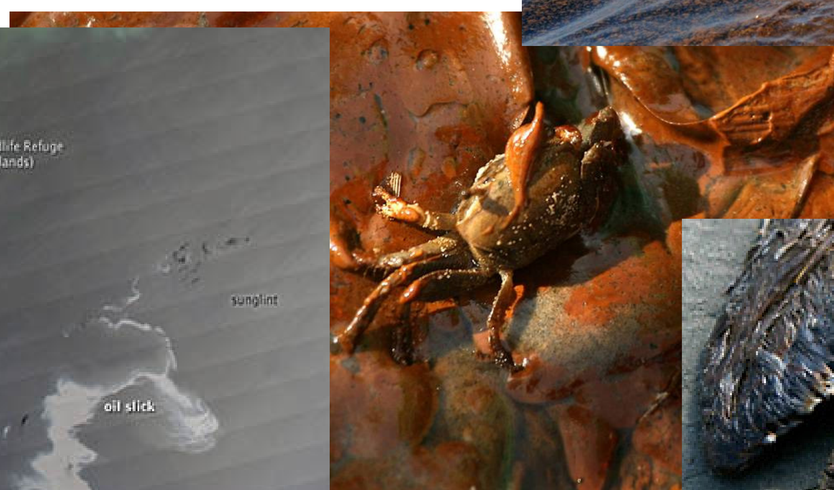
1.2.3 Greenhouse Gases

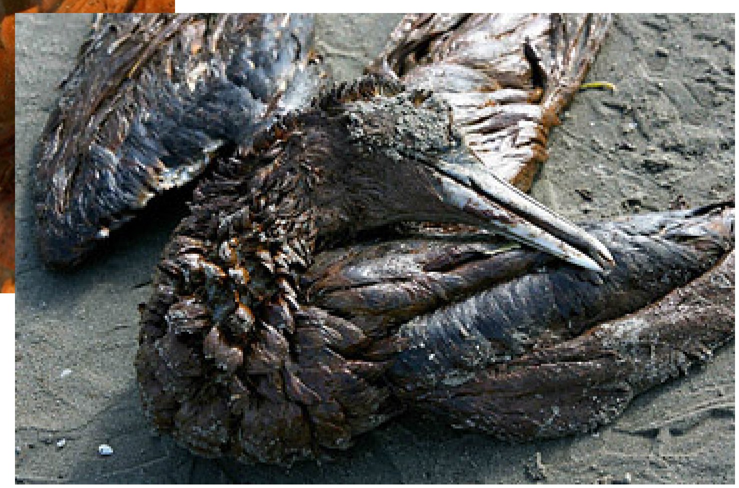
1.2.4 Radiative Forcing

1.2.1 Fossil Fuel Perturbations

Oil Spills







Source: http://www.msnbc.msn.com/id/37330890/ns/gulf_oil_spill/

1.2.2 Climate Change Variables

1.2.2A Solar Irradiance

1.2.2B Albedo

1.2.2C Greenhouse Effect

Climate Change

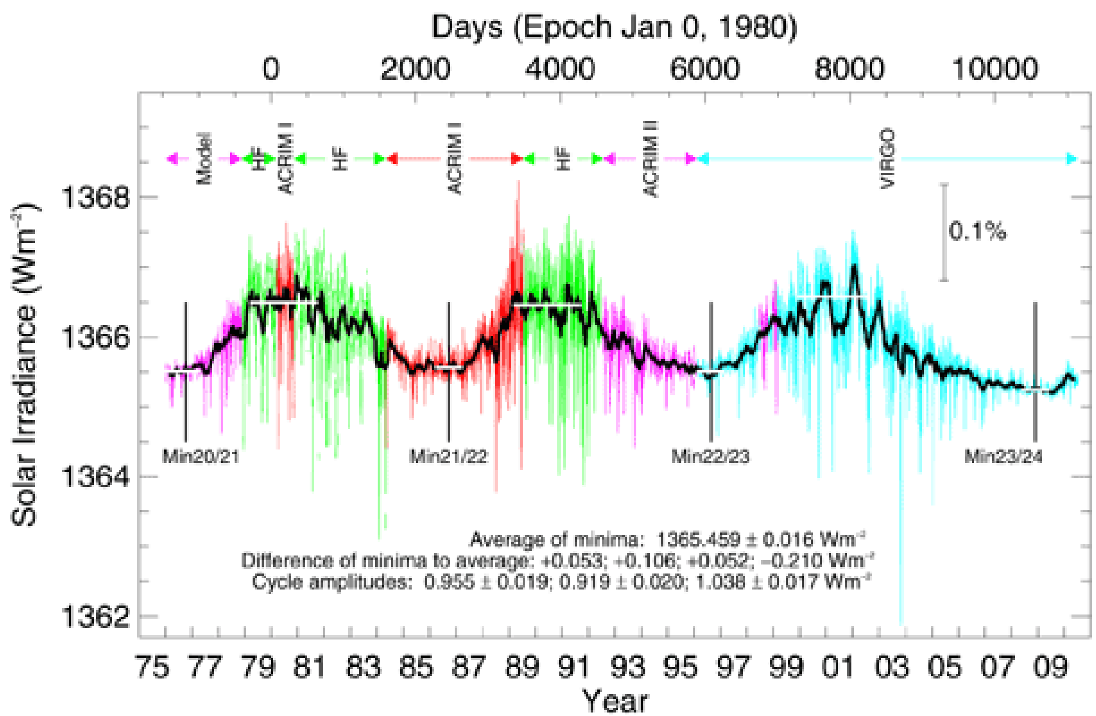
- Climate is described in terms of the mean and variability of temperature, precipitation and wind over a period of time, the classical period ranging 30 years.
- Three fundamental ways to change the radiation balance of the Earth (i.e: heating/cooling effects)
    1. By changing the incoming solar radiation.
    2. By changing the fraction of solar radiation that is reflected (albedo- changes in cloud cover, atmospheric particles or vegetation).
    3. By altering longwave radiation from Earth back towards space.

http://www.ipcc-wg1.unibe.ch/publications/wg1-ar4/wg1-ar4.html

1.2.2A Solar Irradiance

Incoming Solar Radiation

3.1.1 Solar Irradiance Cycle



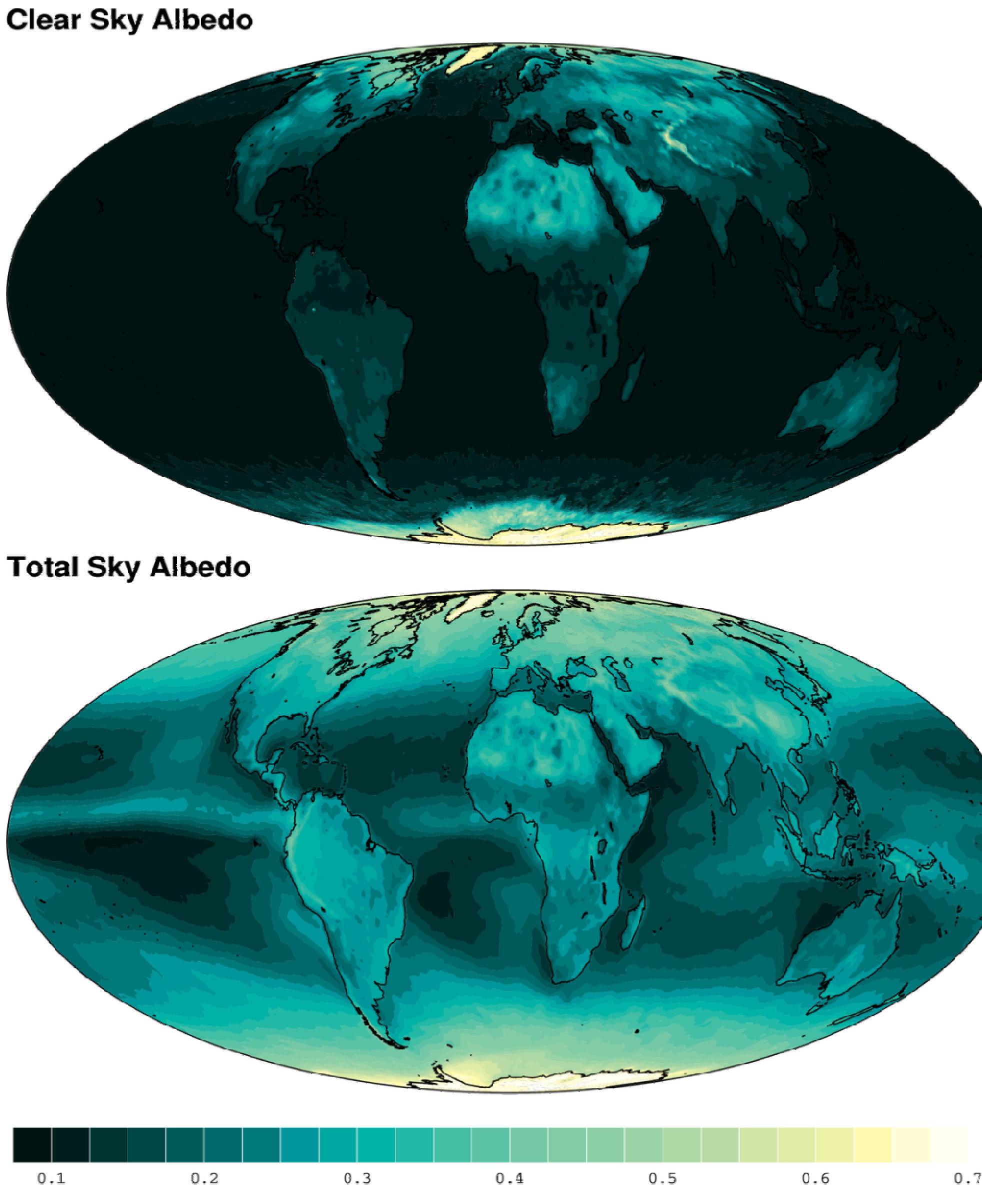
Sun has an 11-year cycle driven by dark sunspots and bright faculae.

Current Solar Constant: **1366 W/m²**

1.2.2B Albedo

Reflected Solar Radiation

Surface Albedo



Albedo- fraction of solar energy reflected back to space. Earth's is approximately 30%.

•**Clear sky** albedo is the fraction of the incoming solar radiation that is reflected back into space by regions of the Earth on cloud-free days.

•**Total sky** albedo include cloudy days.

•Can generate these graphs at:

http://daac.gsfc.nasa.gov/giovanni/

CERES-Aqua 2003-2004 data

Snow albedo:	0.7 to 0.9
Ocean albedo:	<0.1

Source: *http://en.wikipedia.org/wiki/Albedo*

1.2.2C Greenhouse Effect

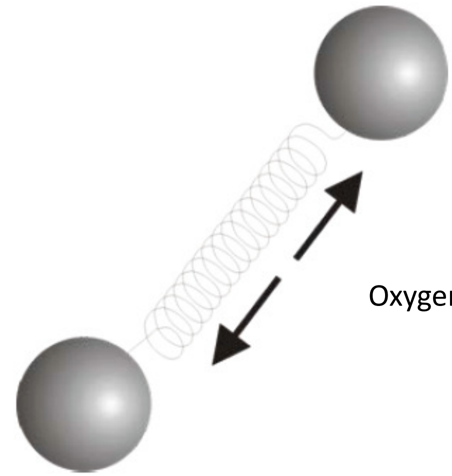
Alteration of long wave radiation from Earth back to space

- Oxygen (O_2) and Nitrogen (N_2) comprise about 97% of the atmosphere and are transparent to solar and infrared radiation.
- **If** there were no other atmospheric gases then:

$$T = 255\text{K} = 0^{o}F\ (-18^{o}C)$$

$$\sigma T_s^4 = \frac{1}{4}(1-a)S_0$$

σ= Stefan-Boltzmann constant
a= Planetary albedo
S_0 = Solar Constant
T= Temperature

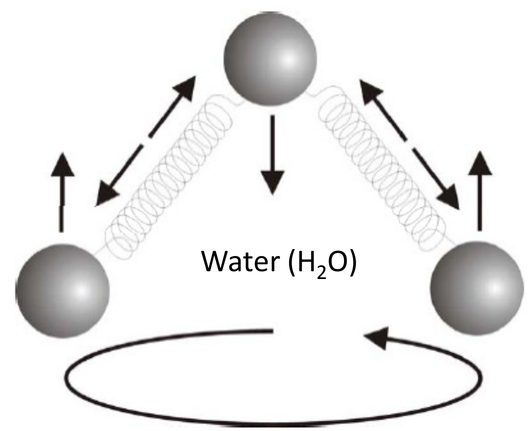


Oxygen (O_2)

Nitrogen (N_2)

BUT!

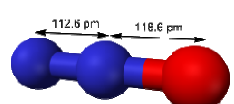
- Some trace gases interact strongly with radiation: Water vapor , Carbon Dioxide, Methane plus Nitrous Oxide. (These are the major contributors to greenhouse gases.)
- **Clouds interact strongly with radiation**
  - Mostly water vapor
  - Question: at what wavelength range does the water molecule absorb energy? Hint: think of a household item.



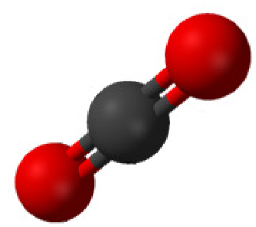
Water (H_2O)

So instead $T \approx 60^{o}F$ (or $14^{o}C$)

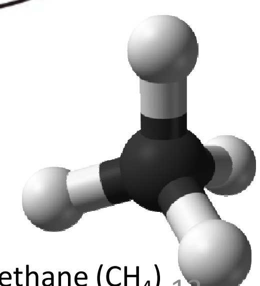
=255K + 33K (GHG)



Nitrous Oxide (N_2O)



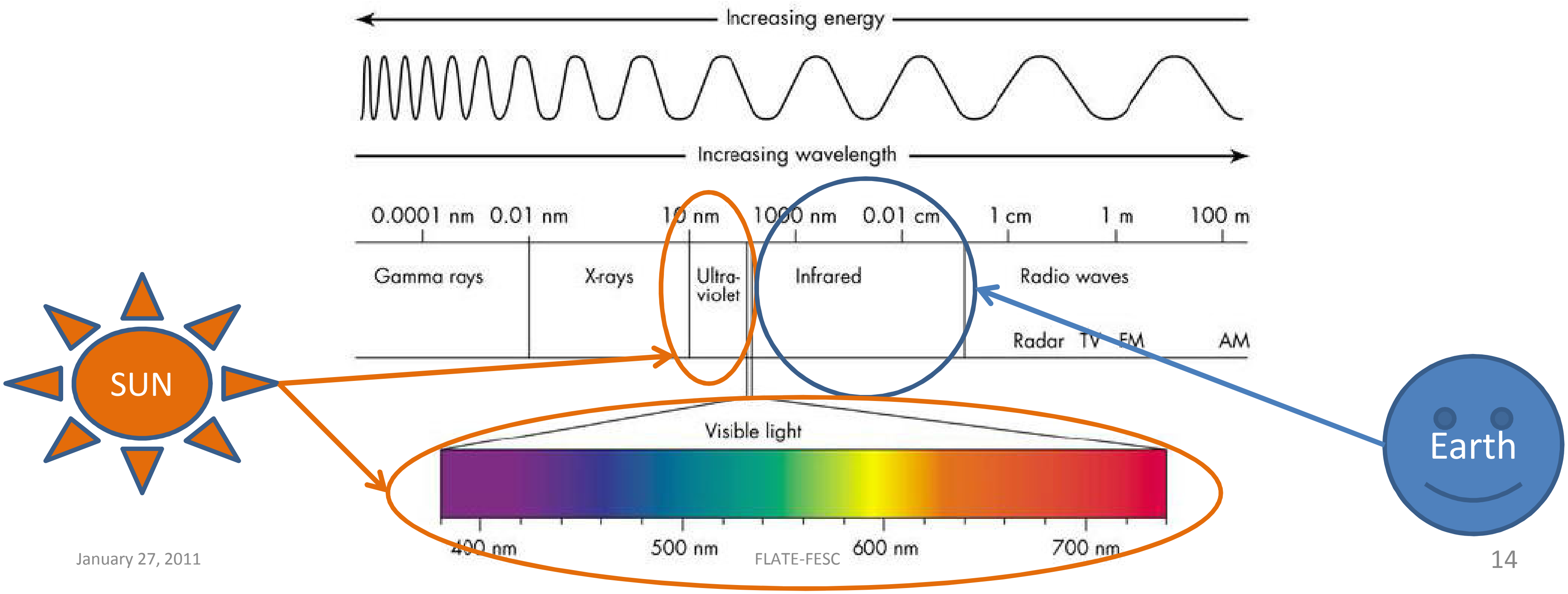
Carbon Dioxide (CO_2)



Methane (CH_4)

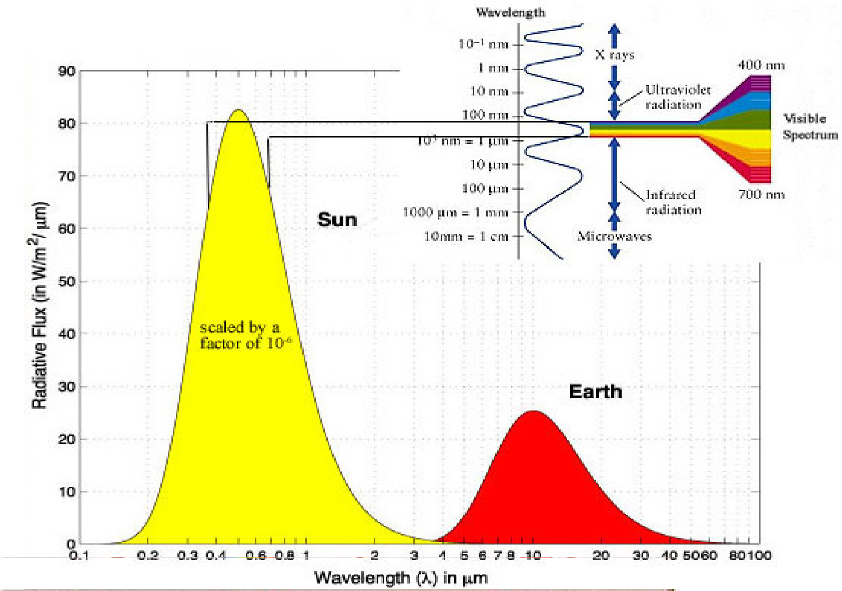
Greenhouse effect

- Sun radiates energy at the short wavelength scale (visible and ultraviolet…these have high energy).
- About 1/3 of solar energy that reaches the top of earth's atmosphere is reflected back to space.
- Remaining 2/3 is absorbed by the surface and atmosphere.
- To balance the absorbed incoming energy, the earth radiates about the same absorbed energy out to space…..but is in the longer wavelength scale (infrared…lower energy).

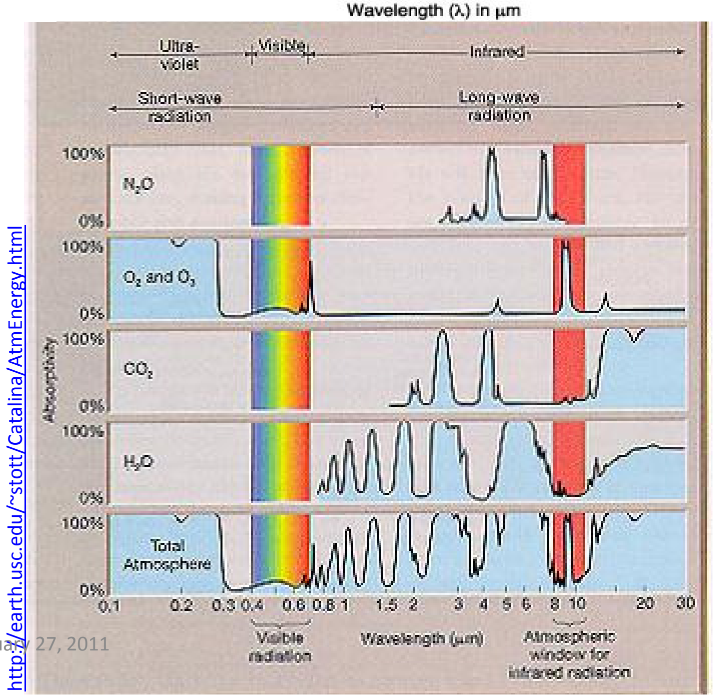


Energy Balance: Sun/Earth

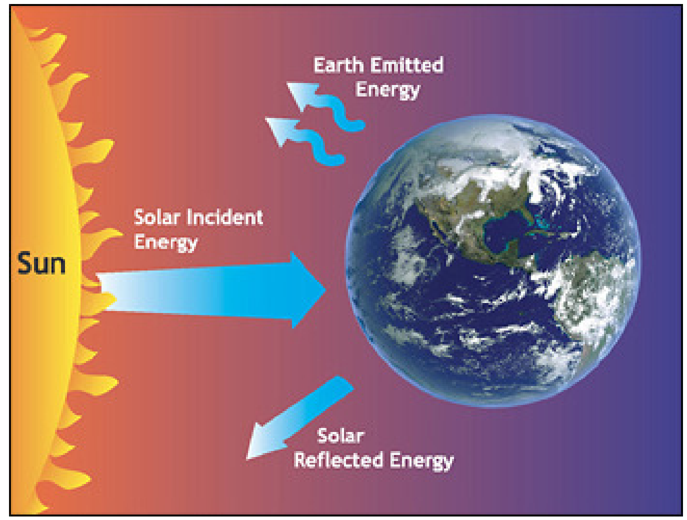
http://www.learner.org/courses/envsci/visual/visual.php?shortname=electromagnetic_spectrum



http://earth.usc.edu/~stott/Catalina/AtmEnergy.html



Earth's outgoing radiation falls in the infrared spectrum.

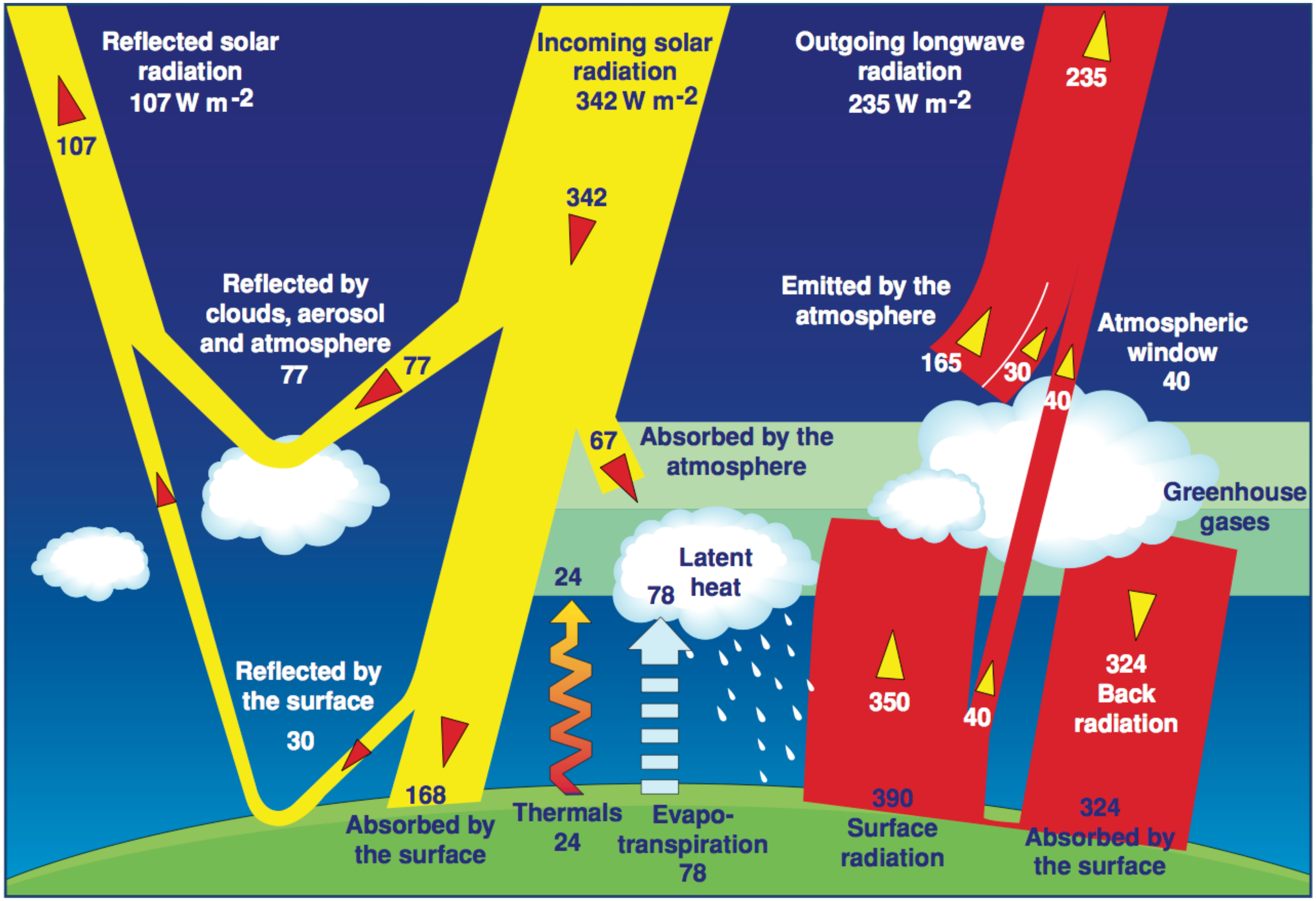


http://earthobservatory.nasa.gov/Features/CALIPSO/CALIPSO2.php

Gases affecting Earth's outgoing radiation in order of impact

1. Water Vapor
2. Carbon Dioxide
3. Methane
4. Nitrous oxide

Earth’s Energy Balance



http://ceres.larc.nasa.gov/ceres_brochure.php?page=2

CERES: Clouds and Earth's Radiant Energy System

- CERES is an instrument that provides very high quality measurements of the Earth's Radiation Budget, including both longwave (Earth emitted) and shortwave (Earth reflected) radiation.

- There are four functional CERES instruments currently in Earth orbit.

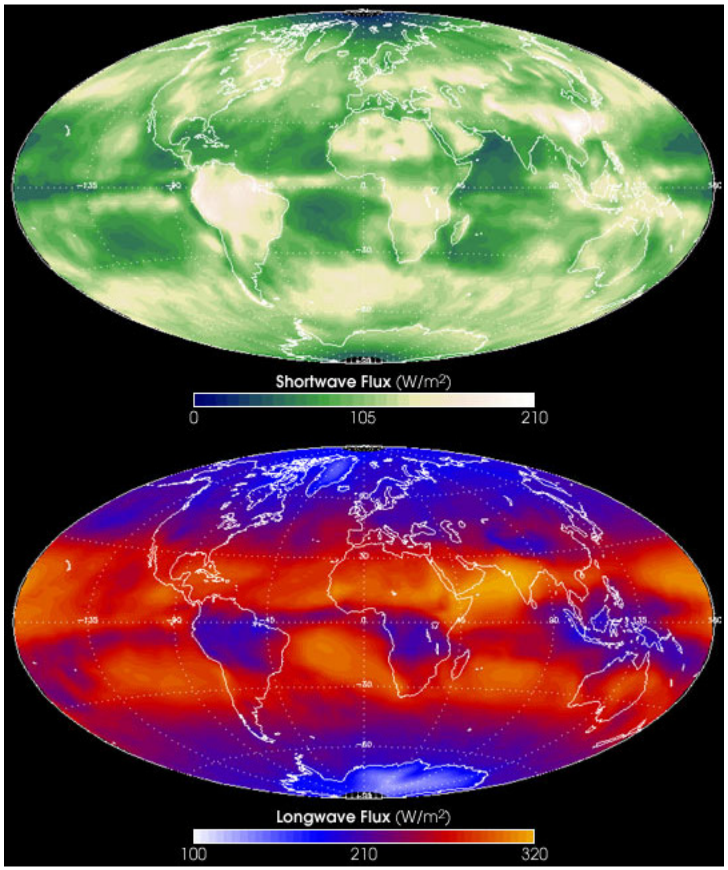
    - Two CERES instruments are on Terra, launched in December 1999.

    - An additional two are on Aqua, launched in May 2002.

http://ceres.larc.nasa.gov/

CERES: Clouds and Earth's Radiant Energy System

CERES can measure the radiant energy reflected and emitted back into space accurately enough to tell scientists which aspects of the Earth's climate system are changing.



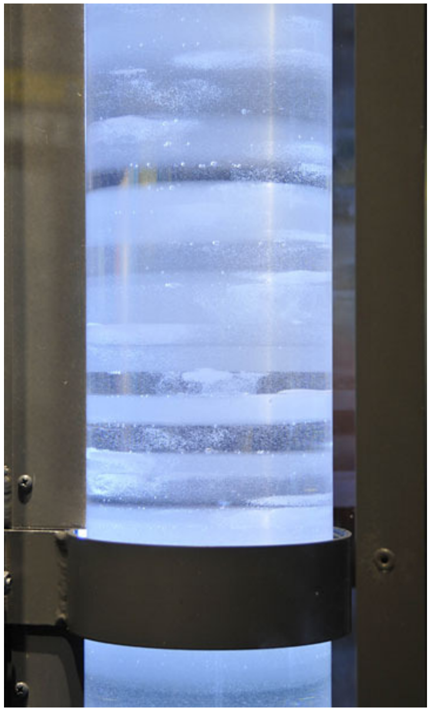
http://veimages.gsfc.nasa.gov/187/ceres_monthly_200003.jpg

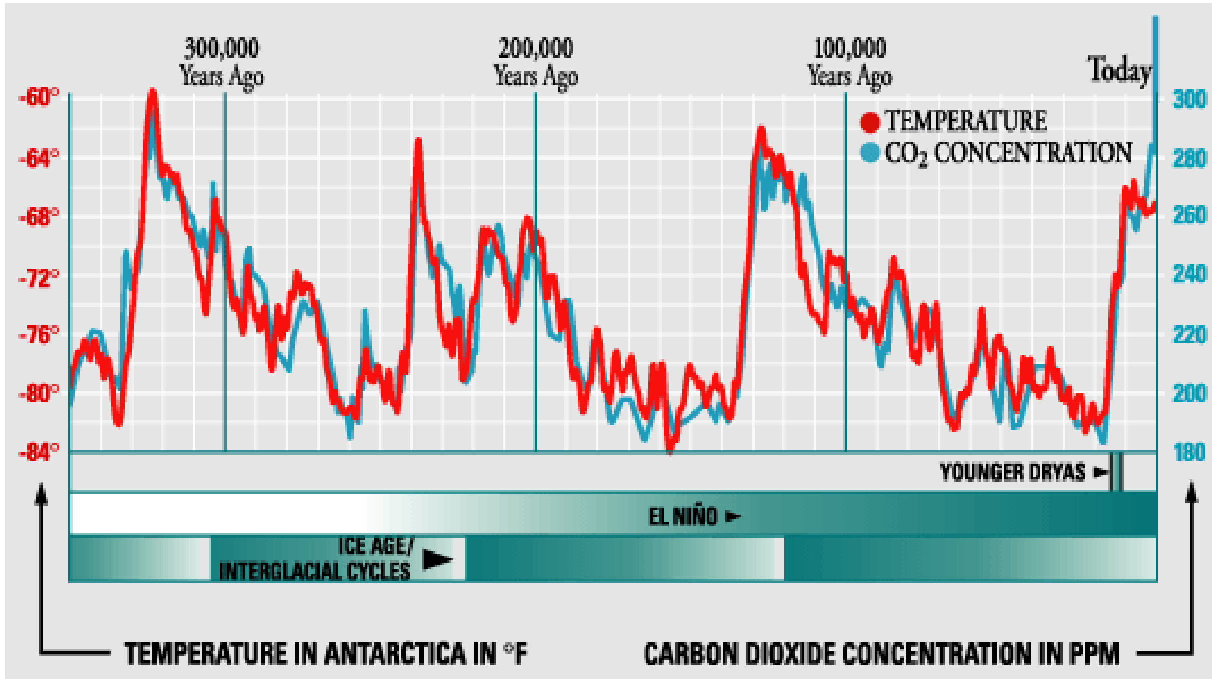
- These measurements were acquired by CERES sensors during March 2000.
- The top image shows shortwave radiation (sunlight) that is reflected back into space by our planet, averaged over the entire month.
- The bottom image shows longwave radiation (heat) that is emitted by the Earth back into space.

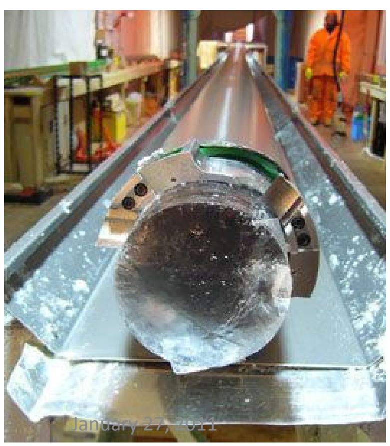
1.2.3 Greenhouse Gases

Carbon Dioxide, Methane, Nitrous Oxide

Carbon Dioxide (CO2)



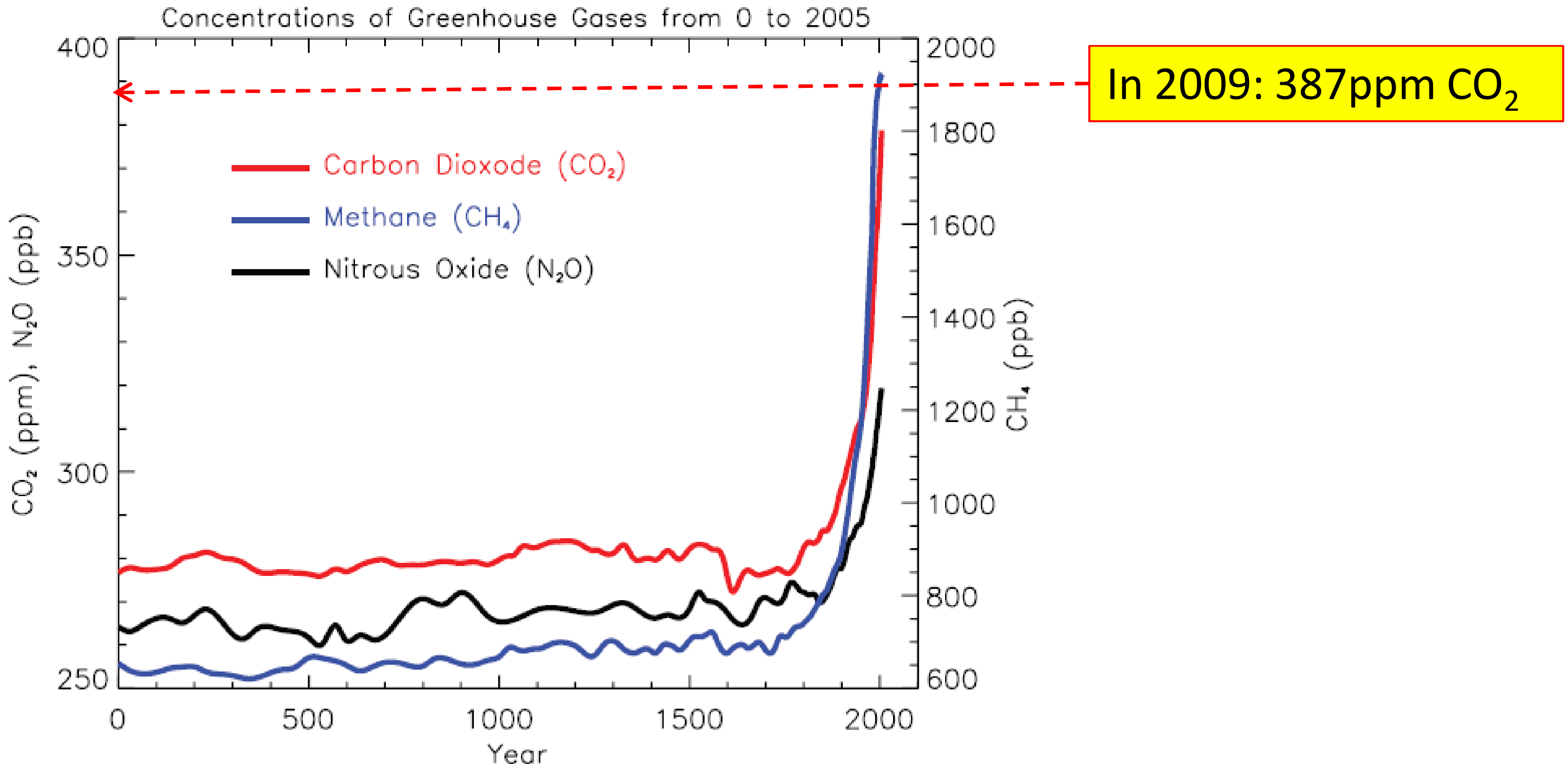




As recorded in ice cores from Vostok, Antarctica, the temperature near the South Pole has varied by more than 20 degrees Fahrenheit during the last 350,000 years. There have been peaks of warmth approximately every 100,000 years. The temperature and the carbon dioxide concentrations at the south pole parallel each other. The rise and fall of temperatures gives rise to the ice age/interglacial cycle.

http://www.koshland-science-museum.org/exhibitgcc/historical02.jsp

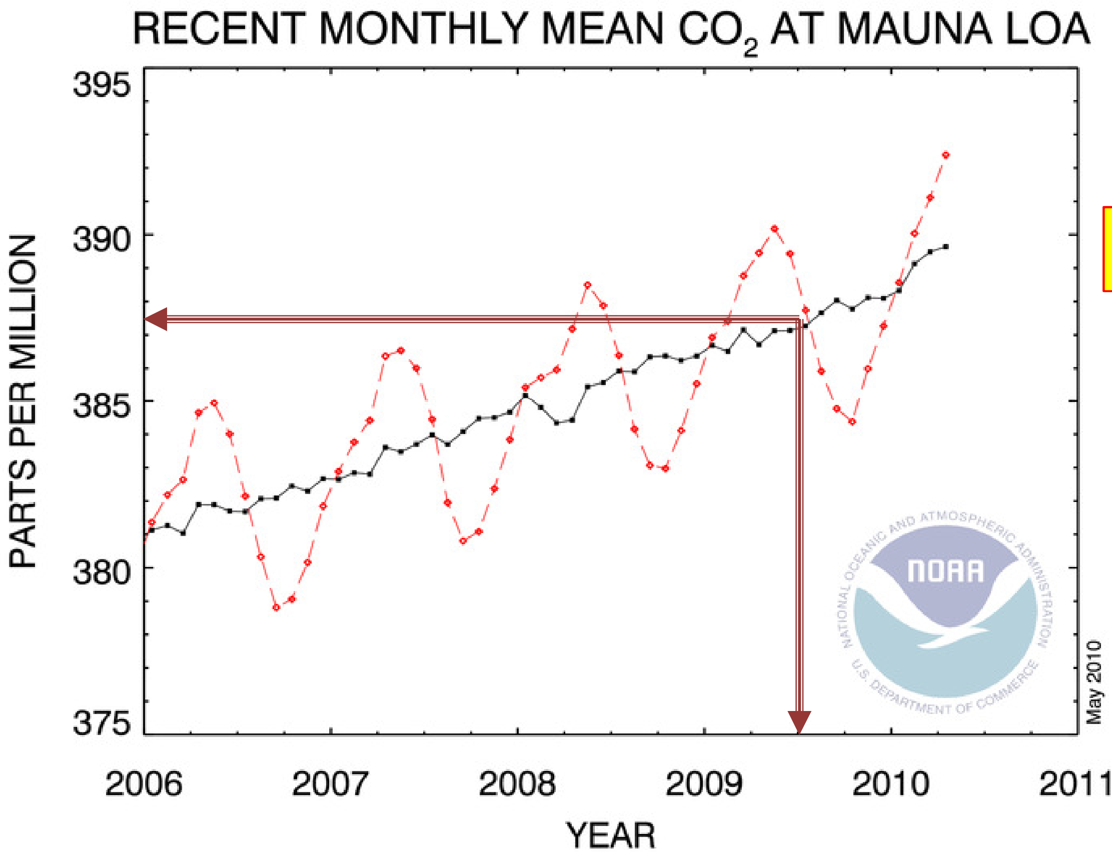
CO2, Methane, Nitrous Oxide



FAQ 2.1, Figure 1. *Atmospheric concentrations of important long-lived greenhouse gases over the last 2,000 years. Increases since about 1750 are attributed to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion air molecules, respectively, in an atmospheric sample. (Data combined and simplified from Chapters 6 and 2 of this report.)*

http://www.ipcc-wg1.unibe.ch/publications/wg1-ar4/wg1-ar4.html

Recent CO_2 Measurements

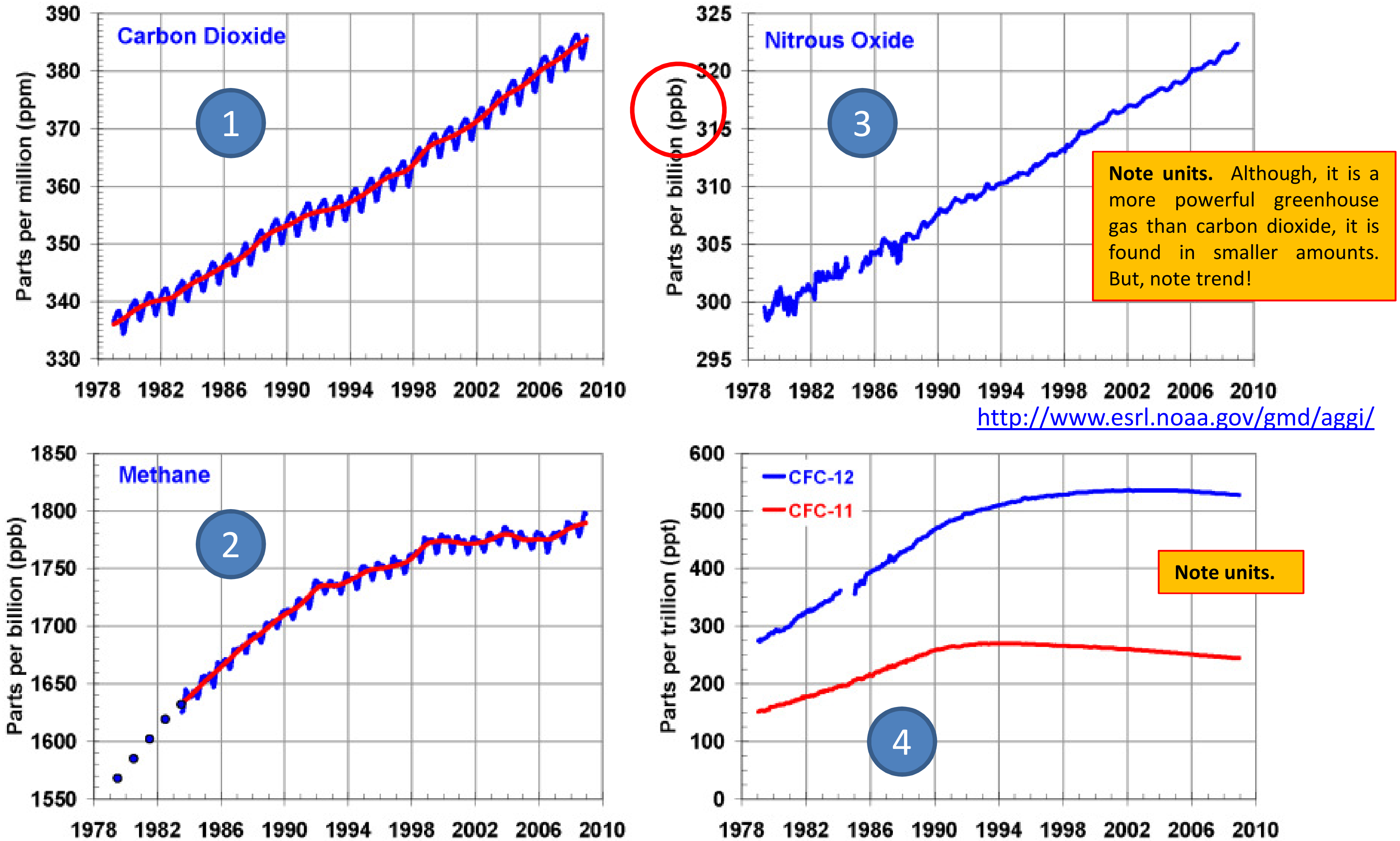


In 2009: 387ppm CO_2

Why is there seasonal variation?

http://www.esrl.noaa.gov/gmd/ccgg/trends/

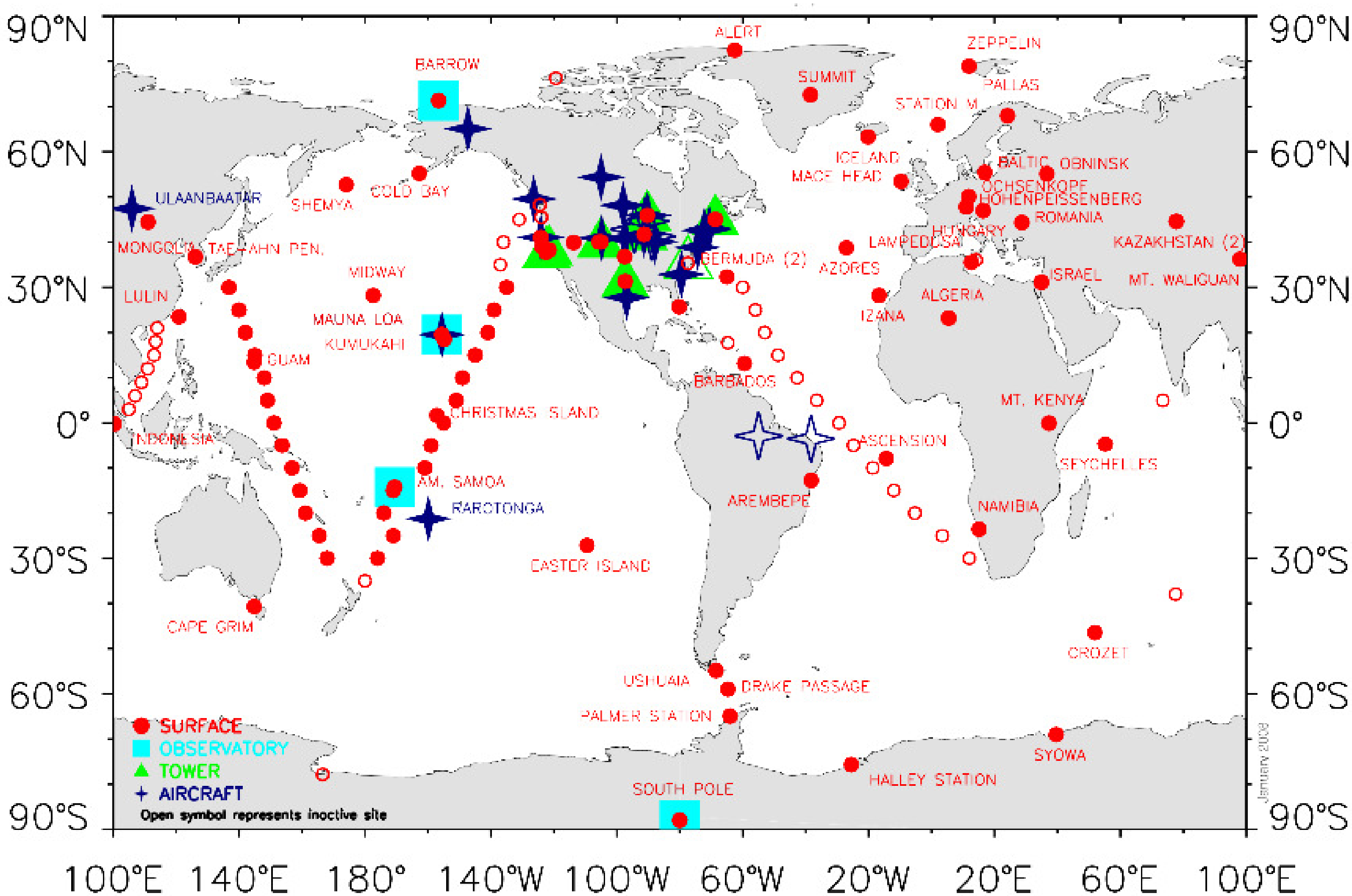
Annual Greenhouse Gas Index



http://www.esrl.noaa.gov/gmd/aggi/

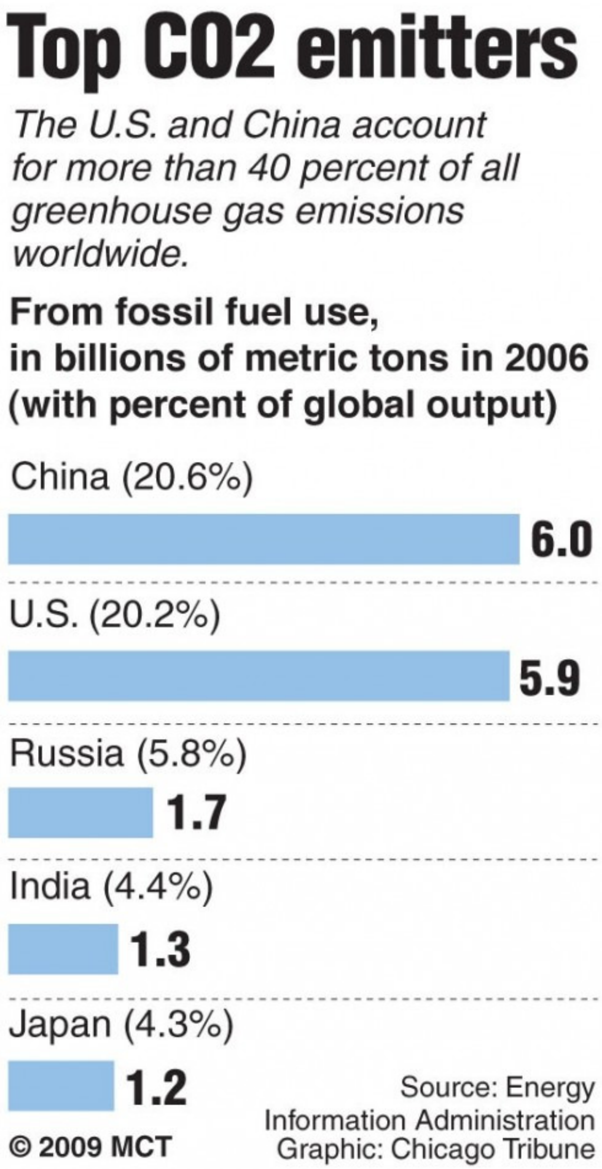
Global averages of the concentrations of the major, well-mixed, long-lived greenhouse gases - carbon dioxide, methane, nitrous oxide, CFC-12 and CFC-11 from the NOAA global flask sampling network since the beginning of 1979. These gases account for about 96% of the direct radiative forcing by long-lived greenhouse gases since 1750. The remaining 4% is contributed by an assortment of 15 minor halogenated gases . Methane data prior to 1983 are annual averages from *Etheridge et al. (1998)*, adjusted to the NOAA calibration scale *[Dlugokencky et al., 2005]*.

NOAA Sampling Locations Worldwide

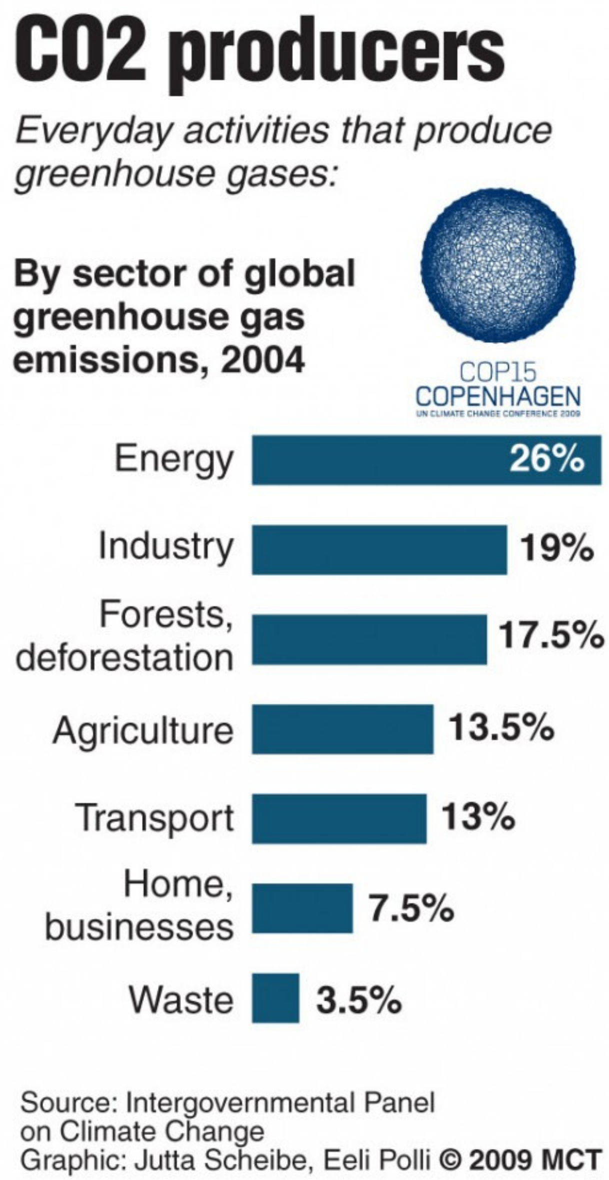


NOAA Earth System Research Laboratory global cooperative air sampling network used to determine the AGGI.

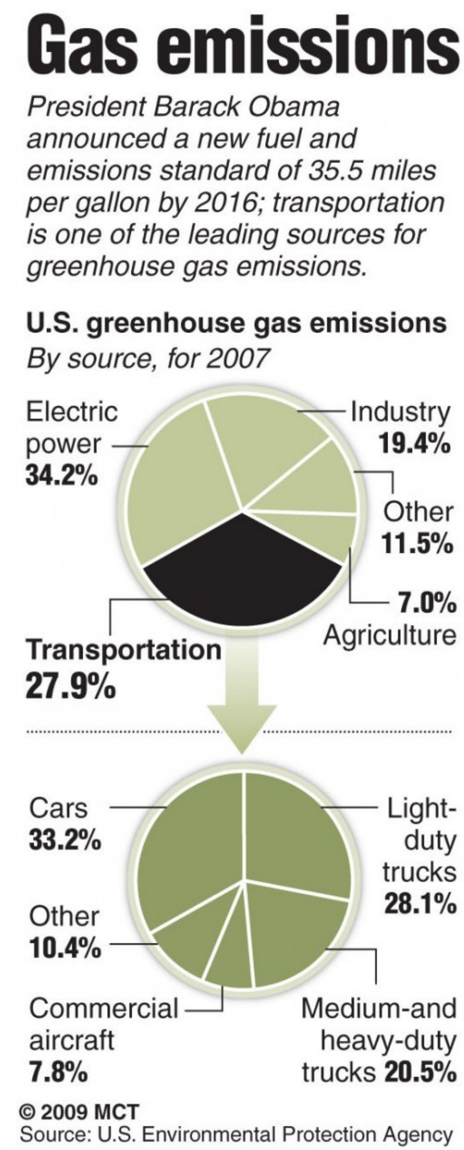
http://www.esrl.noaa.gov/gmd/aggi/



Top CO2 emitters
The U.S. and China account for more than 40 percent of all greenhouse gas emissions worldwide.
From fossil fuel use, in billions of metric tons in 2006 (with percent of global output)
China (20.6%)
6.0
U.S. (20.2%)
5.9
Russia (5.8%)
1.7
India (4.4%)
1.3
Japan (4.3%)
1.2
Source: Energy Information Administration
Graphic: Chicago Tribune
© 2009 MCT



CO2 producers
Everyday activities that produce greenhouse gases:
By sector of global greenhouse gas emissions, 2004
COP15 COPENHAGEN
UN CLIMATE CHANGE CONFERENCE 2009
Energy
26%
Industry
19%
Forests, deforestation
17.5%
Agriculture
13.5%
Transport
13%
Home, businesses
7.5%
Waste
3.5%
Source: Intergovernmental Panel on Climate Change
Graphic: Jutta Scheibe, Eeli Polli © 2009 MCT



Gas emissions
President Barack Obama announced a new fuel and emissions standard of 35.5 miles per gallon by 2016; transportation is one of the leading sources for greenhouse gas emissions.
U.S. greenhouse gas emissions
By source, for 2007
Electric power 34.2%
Industry 19.4%
Other 11.5%
7.0% Agriculture
Transportation 27.9%
Cars 33.2%
Light-duty trucks 28.1%
Other 10.4%
Commercial aircraft 7.8%
Medium-and heavy-duty trucks 20.5%
© 2009 MCT
Source: U.S. Environmental Protection Agency

Aim for 350ppm CO_2 ?

Target Atmospheric CO_2: Where Should Humanity Aim?

James Hansen*[,1,2], Makiko Sato[1,2], Pushker Kharecha[1,2], David Beerling[3], Robert Berner[4], Valerie Masson-Delmotte[5], Mark Pagani[4], Maureen Raymo[6], Dana L. Royer[7] and James C. Zachos[8]

[1]NASA/Goddard Institute for Space Studies, New York, NY 10025, USA
[2]Columbia University Earth Institute, New York, NY 10027, USA
[3]Dept. Animal and Plant Sciences, University of Sheffield, Sheffield S10 2TN, UK
[4]Dept. Geology and Geophysics, Yale University, New Haven, CT 06520-8109, USA
[5]Lab. Des Sciences du Climat et l'Environnement/Institut Pierre Simon Laplace, CEA-CNRS-Universite de Versailles Saint-Quentin en Yvelines, CE Saclay, 91191, Gif-sur-Yvette, France
[6]Dept. Earth Sciences, Boston University, Boston, MA 02215, USA
[7]Dept. Earth and Environmental Sciences, Wesleyan University, Middletown, CT 06459-0139, USA
[8]Earth & Planetary Sciences Dept., University of California, Santa Cruz, Santa Cruz, CA 95064, USA

Abstract: Paleoclimate data show that climate sensitivity is ~3°C for doubled CO_2, including only fast feedback processes. Equilibrium sensitivity, including slower surface albedo feedbacks, is ~6°C for doubled CO_2 for the range of climate states between glacial conditions and ice-free Antarctica. Decreasing CO_2 was the main cause of a cooling trend that began 50 million years ago, the planet being nearly ice-free until CO_2 fell to 450 ± 100 ppm; barring prompt policy changes, that critical level will be passed, in the opposite direction, within decades. If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that CO_2 will need to be reduced from its current 385 ppm to at most 350 ppm, but likely less than that. The largest uncertainty in the target arises from possible changes of non-CO_2 forcings. An initial 350 ppm CO_2 target may be achievable by phasing out coal use except where CO_2 is captured and adopting agricultural and forestry practices that sequester carbon. If the present overshoot of this target CO_2 is not brief, there is a possibility of seeding irreversible catastrophic effects.

http://arxiv.org/abs/0804.1126v3

1.2.4 Radiative Forcing

Radiative Forcing

What is Radiative Forcing?

Radiative forcing is a measure of how the energy balance of the Earth-atmosphere system is influenced when factors that affect climate, such as a greenhouse gas, are altered.

The word radiative arises because these factors change the balance between incoming solar radiation and outgoing infrared radiation within the Earth's atmosphere.

The radiative balance controls the Earth's surface temperature.

The term forcing indicates that Earth's radiative balance is being pushed away from its normal state.

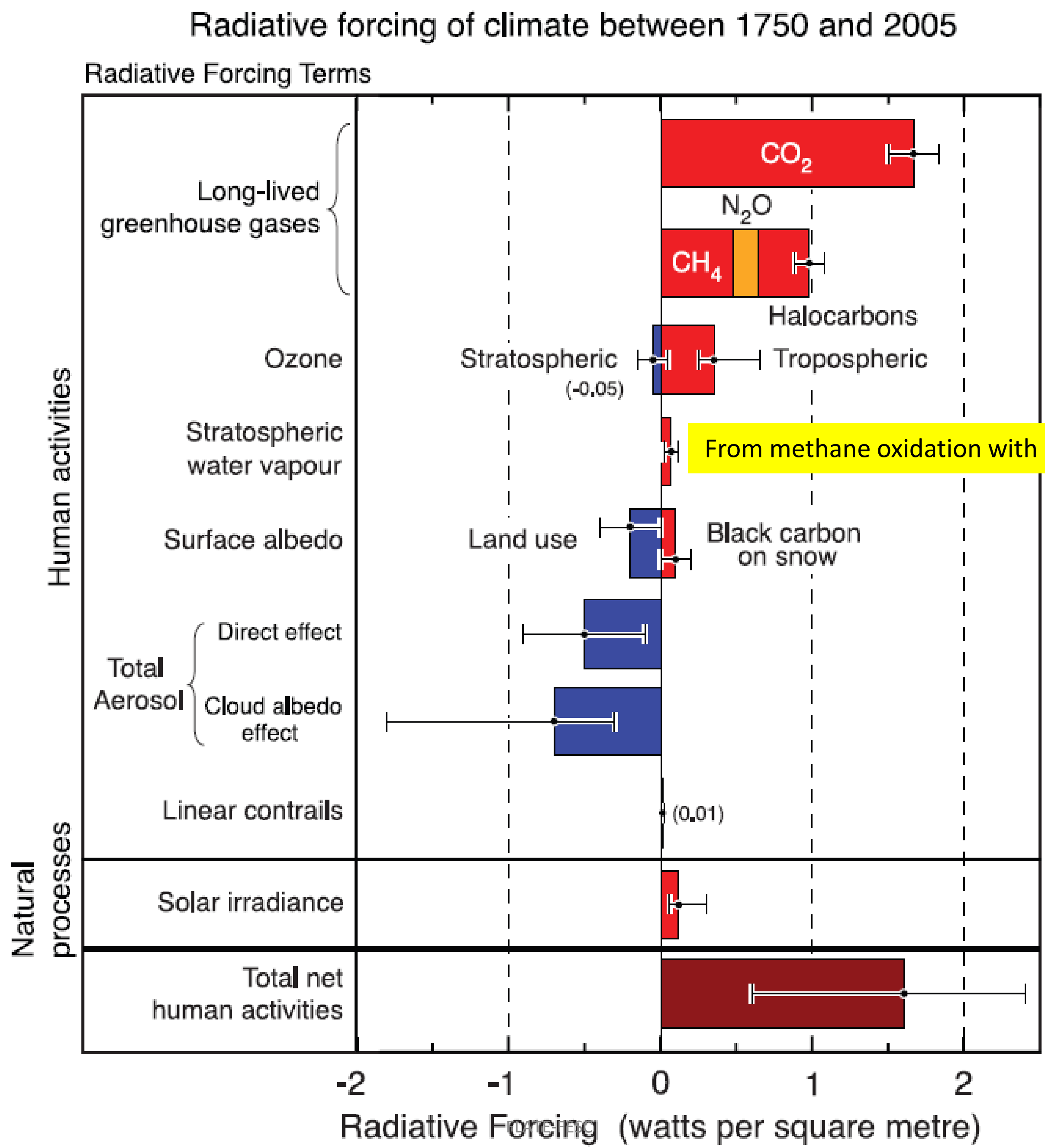
(+)

When radiative forcing from a factor is evaluated as **positive**, the energy of the Earth-atmosphere system will ultimately **increase**, leading to a **warming** of the system.

(-)

For a **negative** radiative forcing, the energy will ultimately **decrease**, leading to a **cooling** of the system.

Radiative forcing is the 'rate of energy change per unit area of the globe as measured at the top of the atmosphere', in units of 'Watts per square meter'.

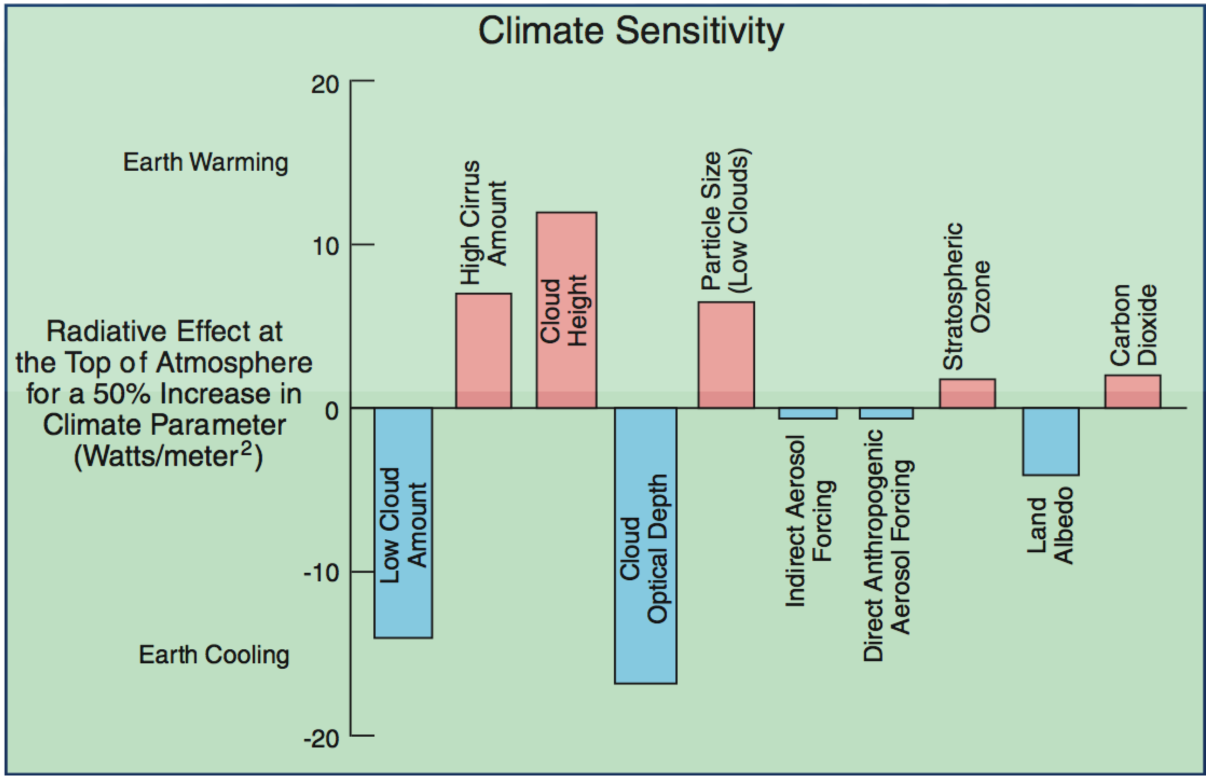


From methane oxidation with OH radicals

http://www.ipcc-wg1.unibe.ch/publications/wg1-ar4/wg1-ar4.html

Cloud Cover

The complex interaction between a changing climate system and the changing cloud conditions is called cloud-climate "feedback."



http://ceres.larc.nasa.gov/ceres_brochure.php?page=4

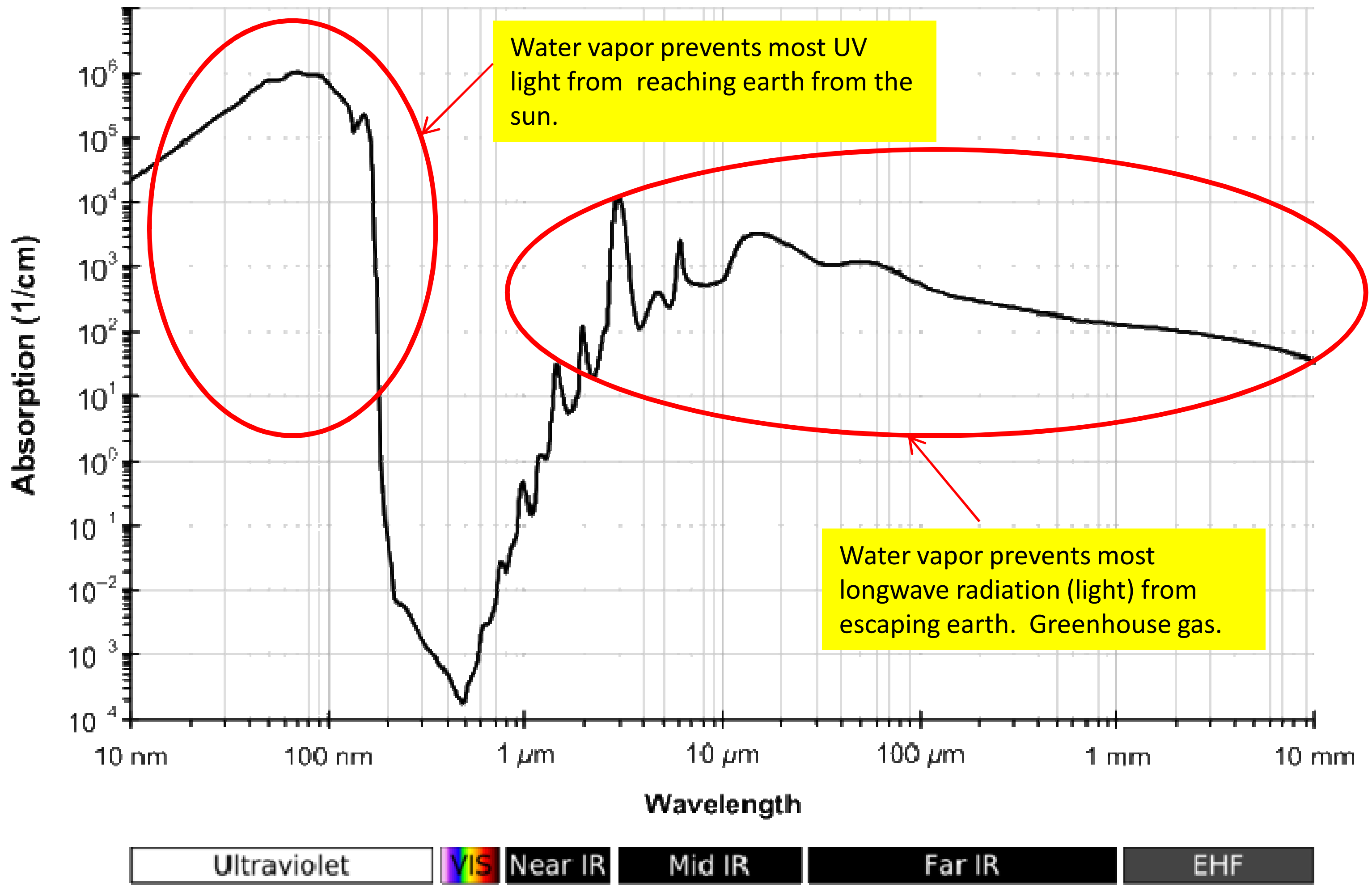
One of the major sources of uncertainty in predicting climate change lies in the impact of clouds upon the radiative energy flow through the Earth-atmosphere system. The largest uncertainty in climate prediction models is how to correctly account for the effects of clouds.

As the Earth undergoes changes in its climate, the amount of cloud cover as well as the physical properties of clouds may well change in ways that are not yet understood.

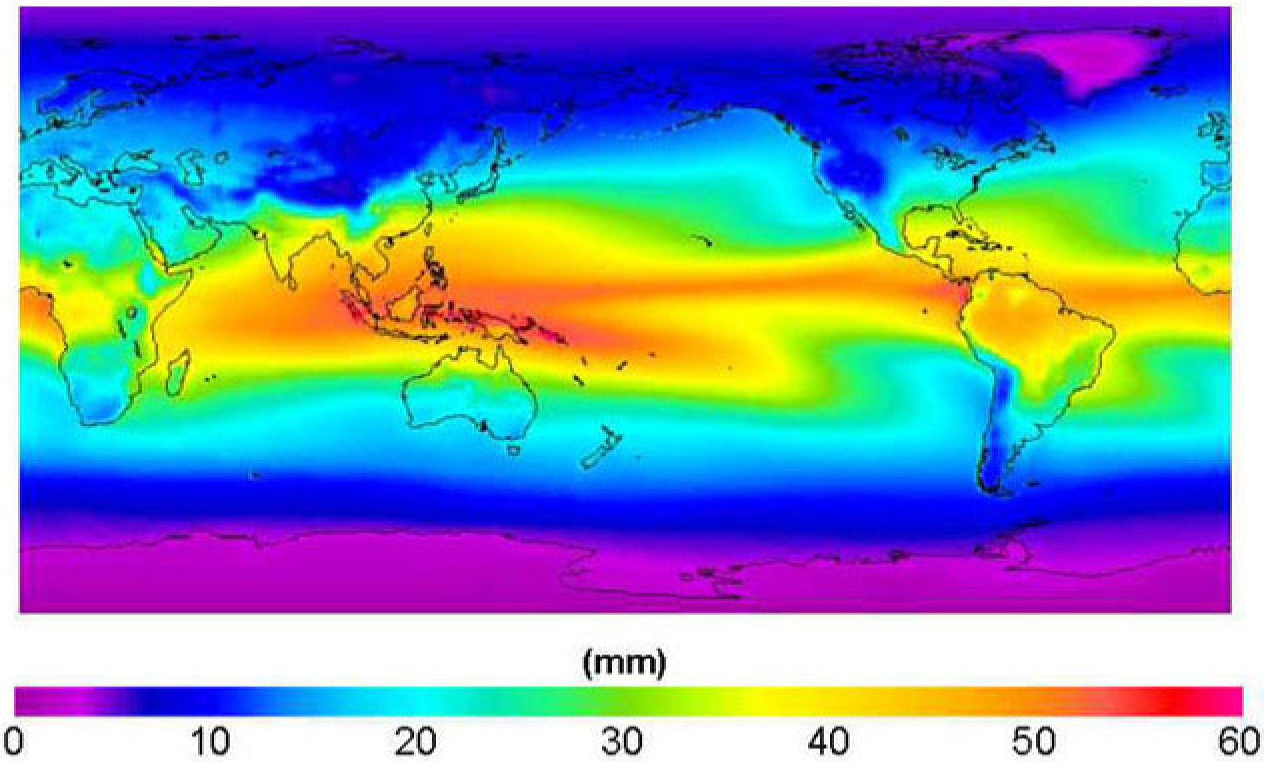
Sensitivity results above indicate that relatively small changes in global cloudiness can have a large impact on our climate system. For example, a 50% increase in carbon dioxide may warm the Earth much less than a 50% increase in the amount of high cirrus clouds.

Do clouds decrease or increase global warming? Will a warmer climate result in fewer or more clouds?

Water absorption



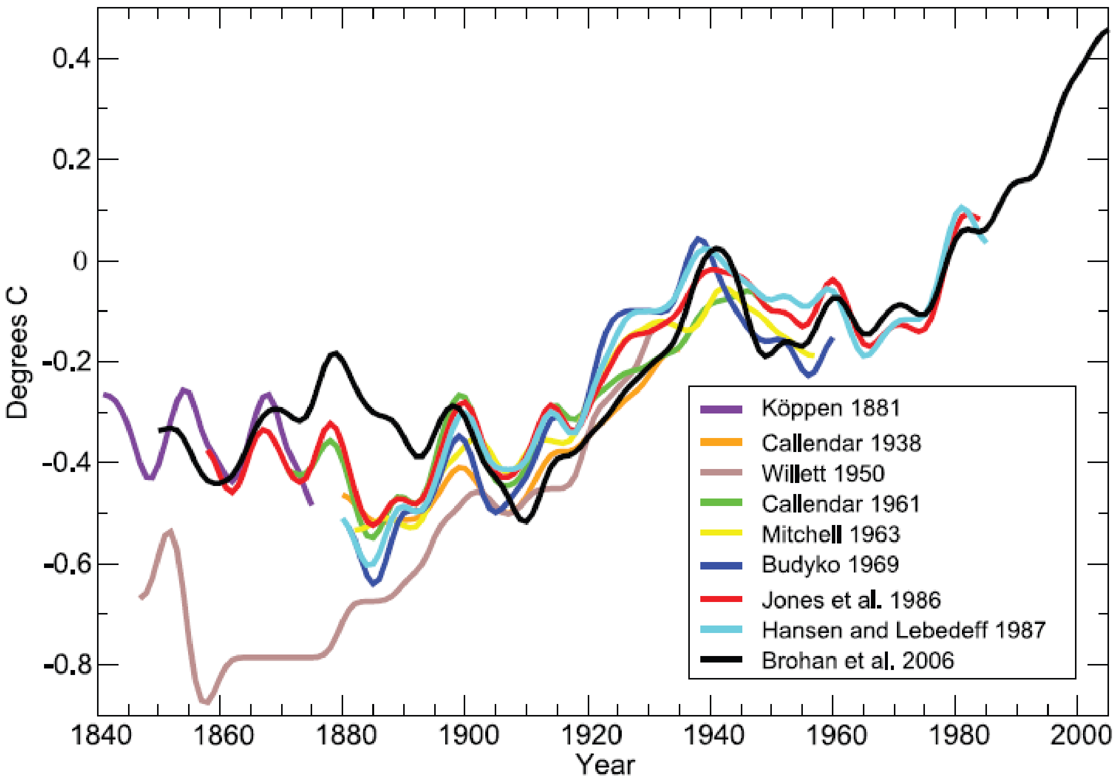
Average total precipitable water

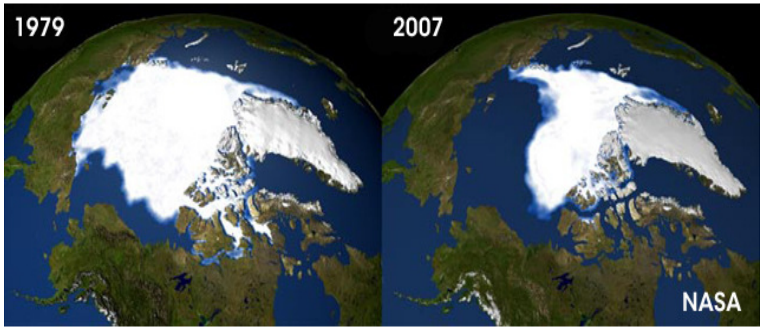


Global mean total precipitable water (mm) 1988 - 1999 from the NASA Water Vapor Project (NVAP). The dataset was processed from many satellites by Science and Technology Corp., METSAT Division and scientifically analyzed at the Cooperative Institute for Research in the Atmosphere at Colorado State University.

http://www.learner.org/courses/envsci/unit/text.php?unit=2&secNum=5

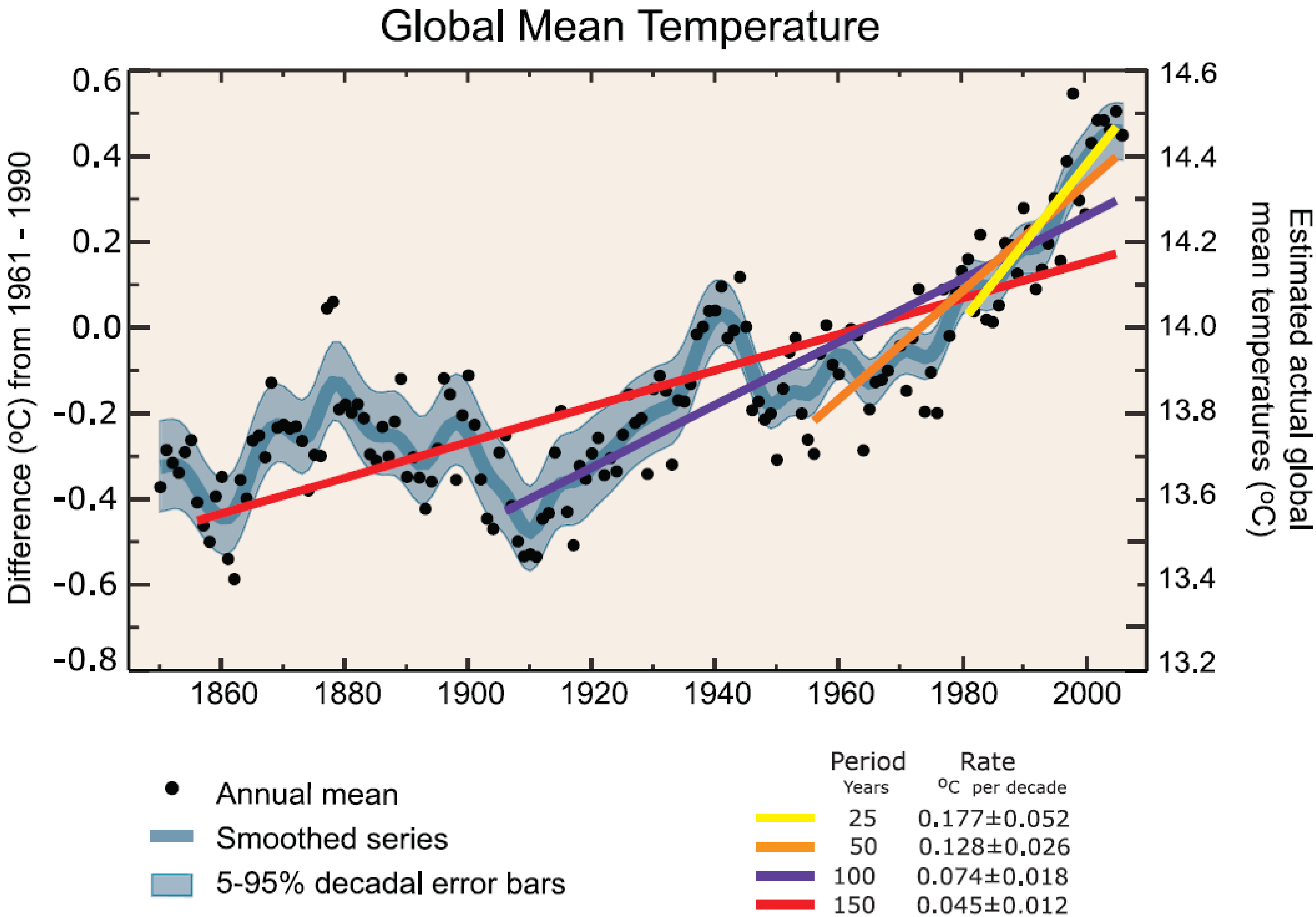
Temperature changes from mean





http://www.350.org/about/science

http://www.ipcc-wg1.unibe.ch/publications/wg1-ar4/wg1-ar4.html



http://www.ipcc-wg1.unibe.ch/publications/wg1-ar4/wg1-ar4.html

Global Carbon Cycle

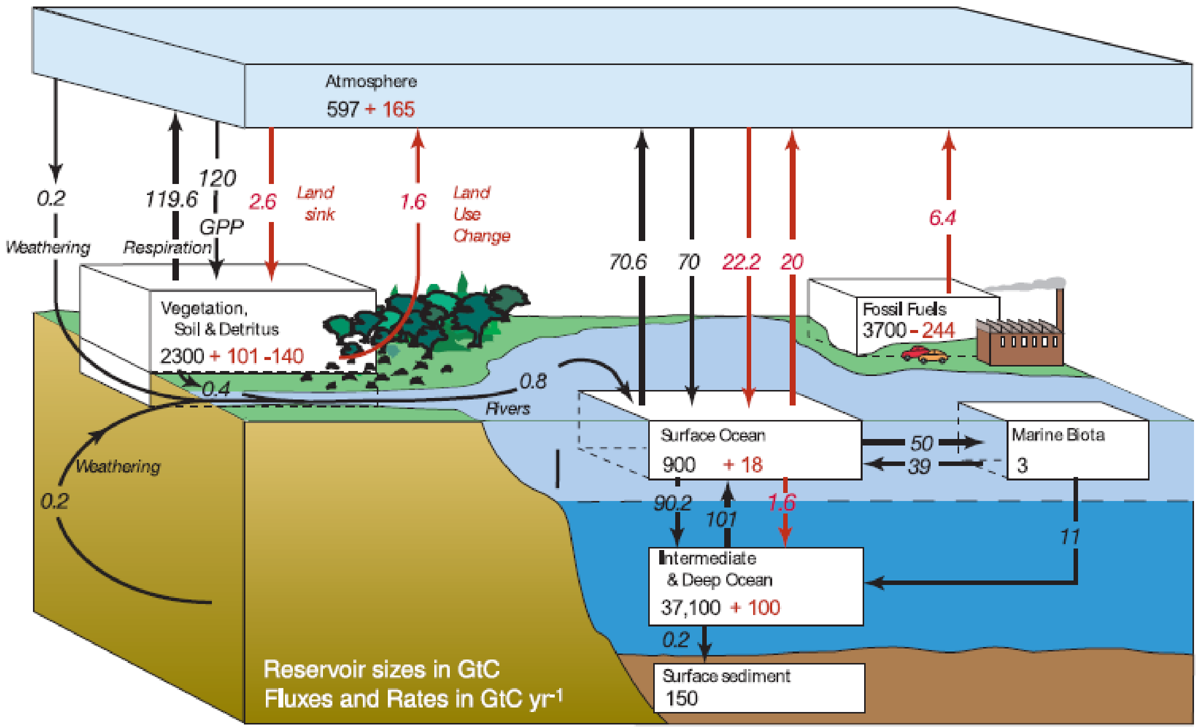
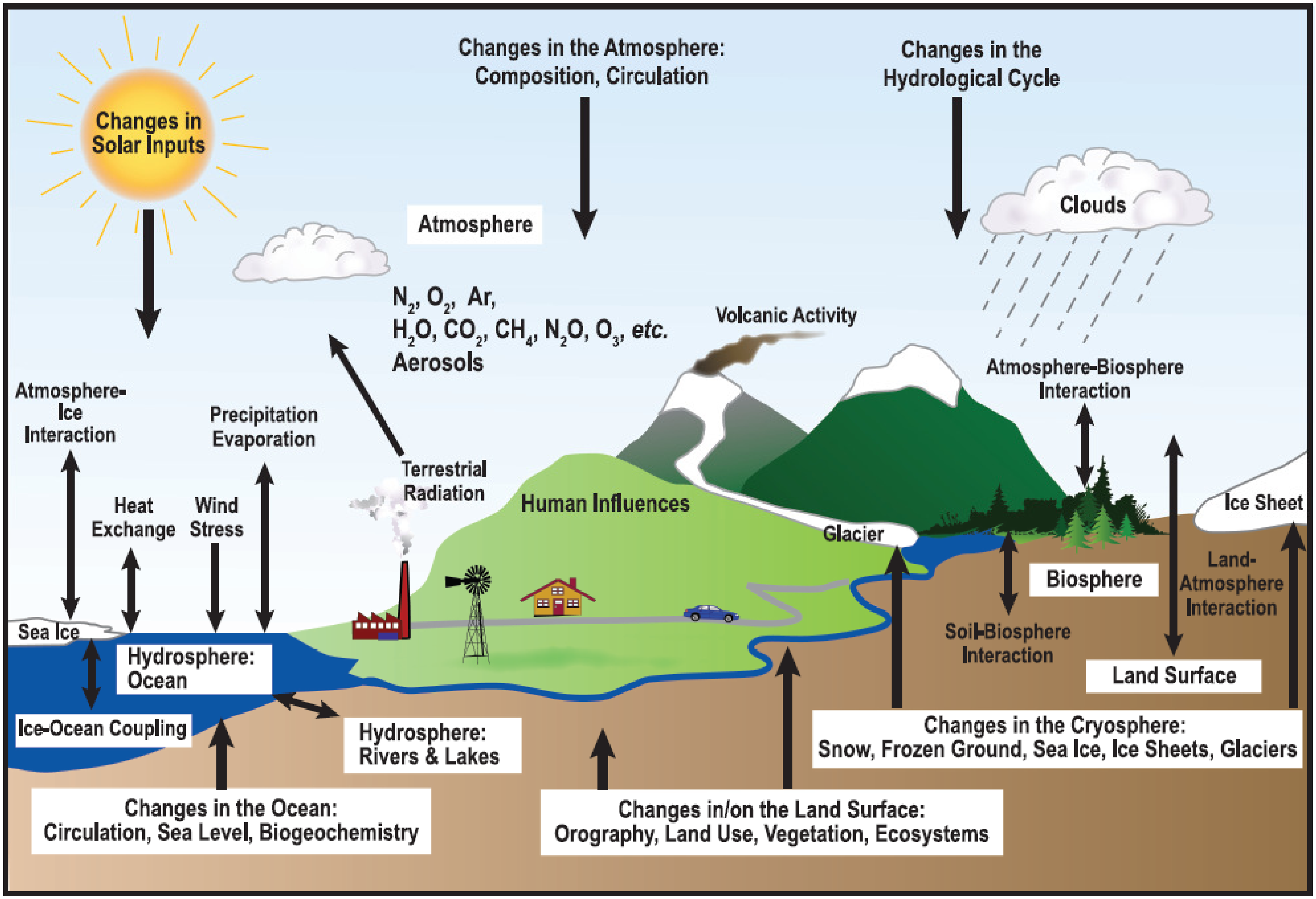


Figure 7.3. *The global carbon cycle for the 1990s, showing the main annual fluxes in GtC yr^{-1}: pre-industrial 'natural' fluxes in black and 'anthropogenic' fluxes in red (modified from Sarmiento and Gruber, 2006, with changes in pool sizes from Sabine et al., 2004a). The net terrestrial loss of –39 GtC is inferred from cumulative fossil fuel emissions minus atmospheric increase minus ocean storage. The loss of –140 GtC from the 'vegetation, soil and detritus' compartment represents the cumulative emissions from land use change (Houghton, 2003), and requires a terrestrial biosphere sink of 101 GtC (in Sabine et al., given only as ranges of –140 to –80 GtC and 61 to 141 GtC, respectively; other uncertainties given in their Table 1). Net anthropogenic exchanges with the atmosphere are from Column 5 'AR4' in Table 7.1. Gross fluxes generally have uncertainties of more than ±20% but fractional amounts have been retained to achieve overall balance when including estimates in fractions of GtC yr^{-1} for riverine transport, weathering, deep ocean burial, etc. 'GPP' is annual gross (terrestrial) primary production. Atmospheric carbon content and all cumulative fluxes since 1750 are as of end 1994.*

http://www.ipcc-wg1.unibe.ch/publications/wg1-ar4/wg1-ar4.html



http://www.ipcc-wg1.unibe.ch/publications/wg1-ar4/wg1-ar4.html

Important challenges for climate scientists are to identify all the factors that affect climate and the mechanisms by which they exert a forcing, to quantify the radiative forcing of each factor and to evaluate the total radiative forcing from the group of factors.