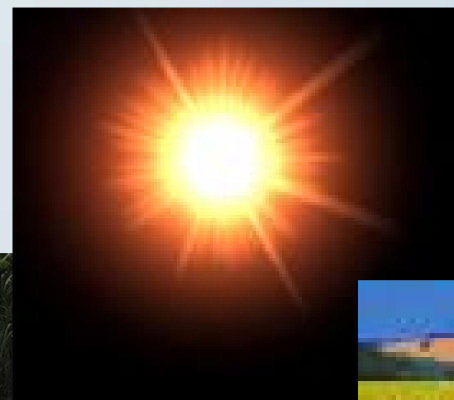
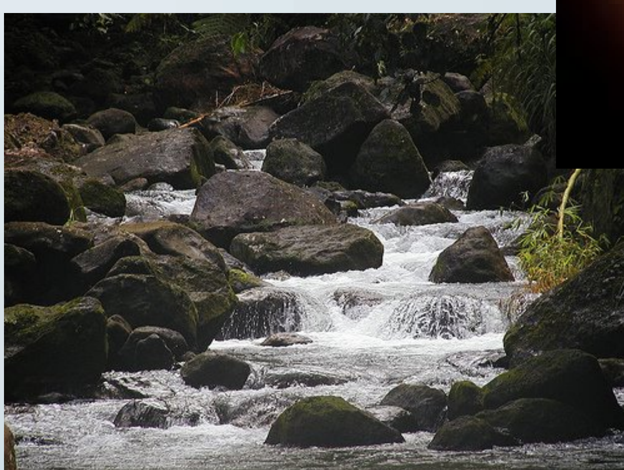
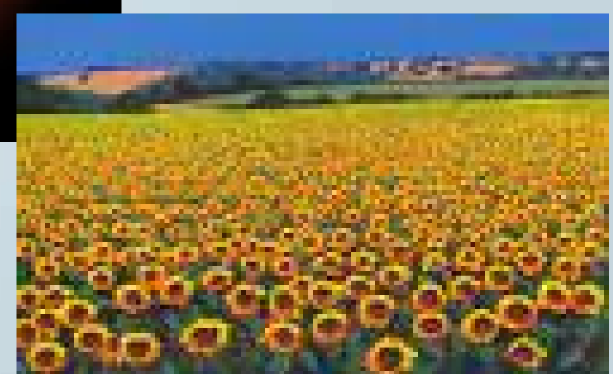
An Introduction to Climate Change

IPOL 8512







What determines Earth's temperature?

- Earth's temperature depends on the balance between energy entering and leaving.
  - When incoming energy from the sun is absorbed by the Earth system, Earth warms.
  - When the sun's energy is reflected back into space, Earth avoids warming.
  - When energy is released back into space, Earth cools.

What could change the Earth's energy balance and change the Earth's temperature?

- Changes in solar input
  - Sun's output
  - Earth's position and orientation
  - Cosmic dust
- Changes in transparency of atmosphere to incoming shortwave energy
  - Clouds
  - Dust, ash, soot
  - O_3
- Changes in transparency of atmosphere to outgoing long wave radiant energy
  - Clouds
  - Greenhouse gases (H_2O, CO_2, CH_4, N_2O, O_3)

What could change the Earth's energy balance and change the Earth's temperature?

- Changes in reflectivity & evapotranspiration at the surface
  - Changes in extent of forests, grasslands, deserts
  - Changes in extent and condition of water
  - Changes in extent and condition of snow and ice
- Changes in heat added at the surface by human activities and geothermal sources

Climate Change

- Earth's average temperature has risen by about 0.8 °C (1.4 °F) over the past century, with about 2/3 of this since 1980.
- Projected to rise another 1 to 6 °C (2 to 11.5 °F) over the next hundred years.
- Small changes in the average temperature lead to large and potentially dangerous shifts in climate and weather. For example,
  - Changes in rainfall, resulting in more floods, droughts, or intense rain, as well as more frequent and severe heat waves.
  - Oceans are warming and becoming more acidic, ice caps are melting, and sea levels are rising.

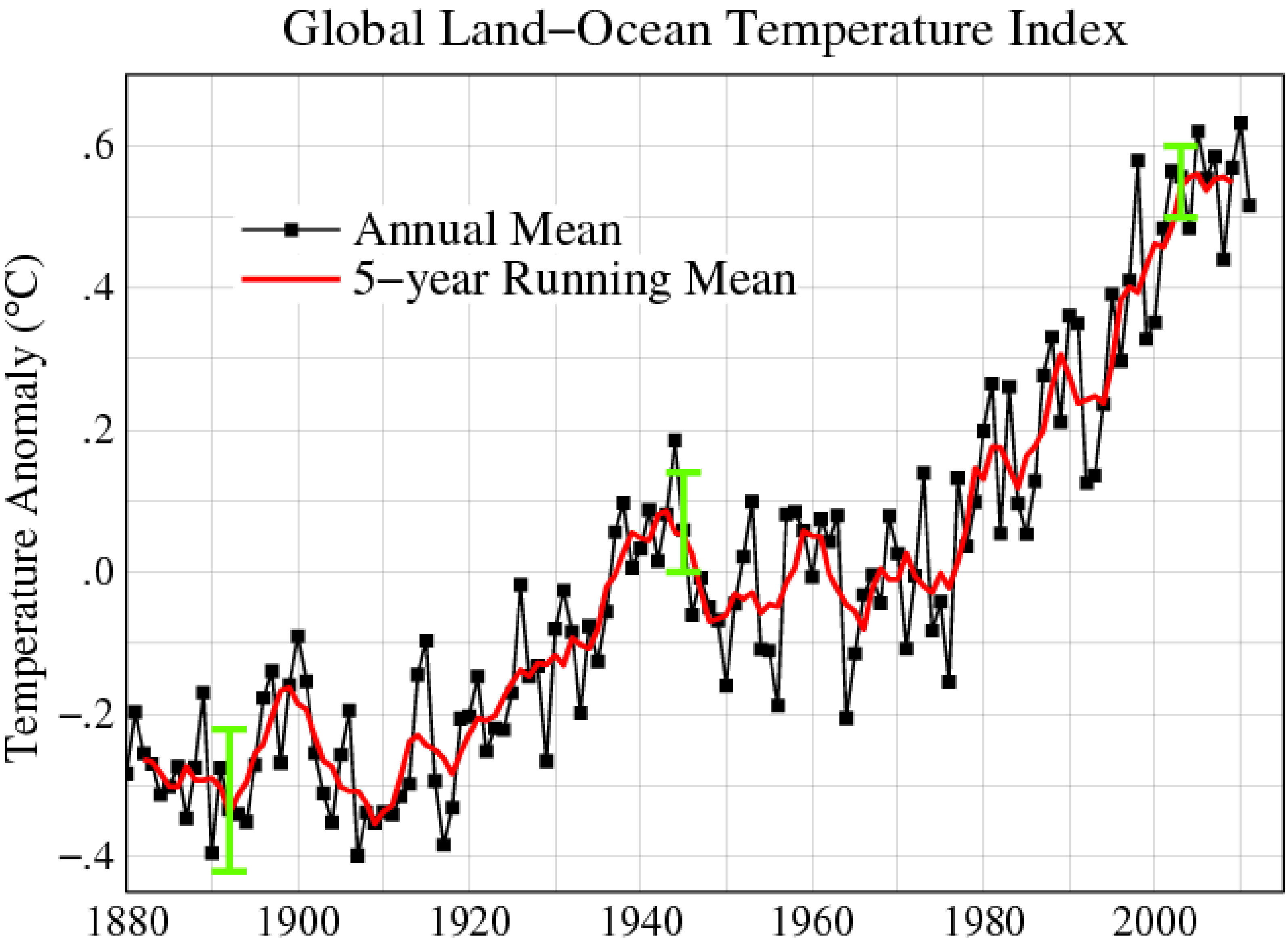
http://www.epa.gov/climatechange/basics/
http://www.explainingclimatechange.ca/

Climate vs. Weather

- **Weather** = the conditions of the atmosphere over a short period of time and typically for a local area.
  - Familiar examples of weather characteristics include the daily temperature, humidity, or the amount of precipitation produced by a storm.
  - Weather also includes severe weather conditions such as hurricanes, tornadoes, and blizzards.
  - Because of the dynamic nature of the atmosphere, it is not possible to predict weather conditions in a specific location months or years in advance.
- **Climate** = the behavior of the atmosphere over a longer period of time and usually for a large area.
  - Climate is typically defined based on 30-year averages of weather.
  - Climate represents our expectations for the weather.
  - Scientists can compare recent and long-term observations of the climate to detect the influence of greenhouse gases on climate conditions.

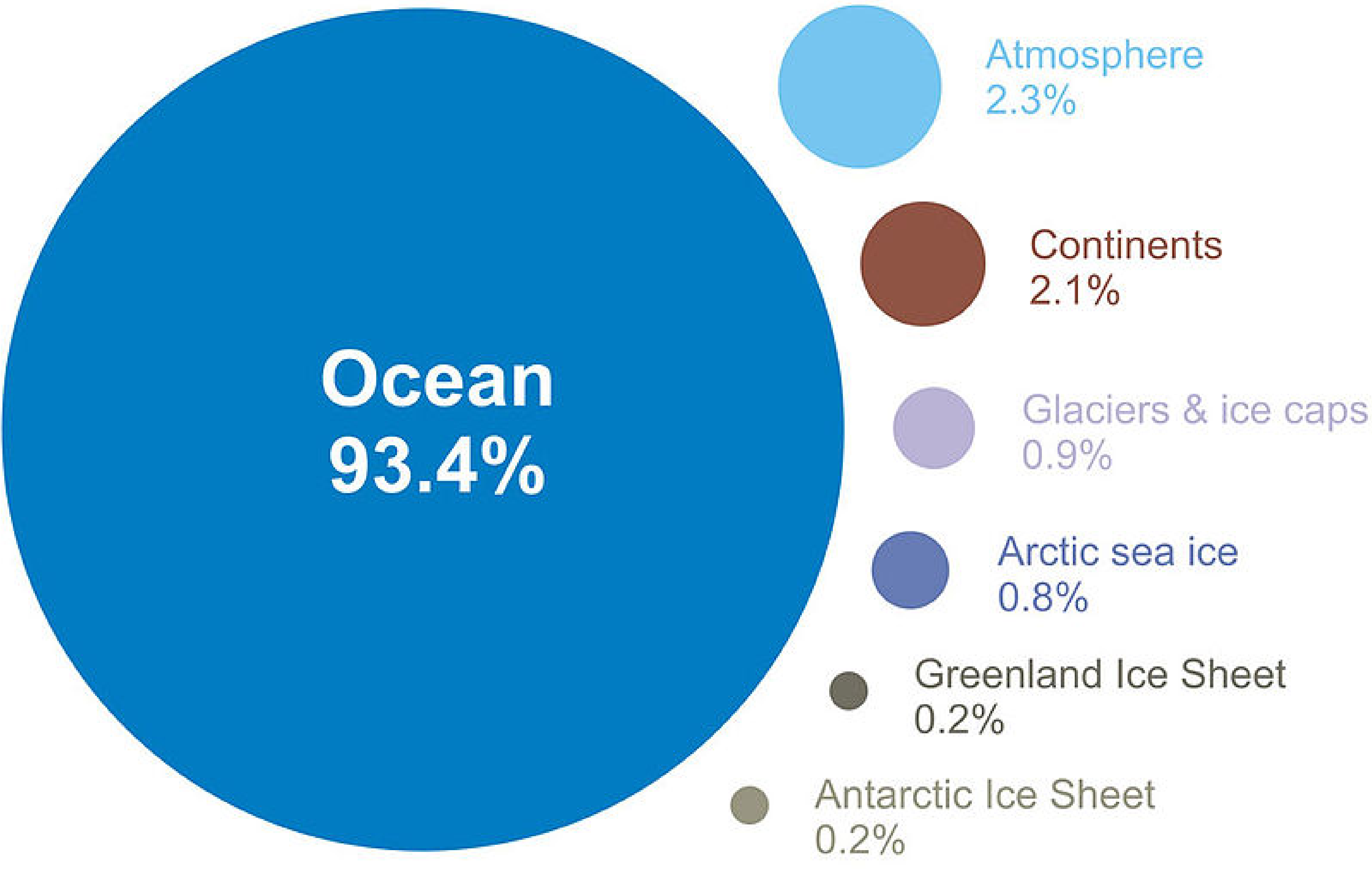
http://www.epa.gov/climatechange/science/

Temperature Variation from 1880-present

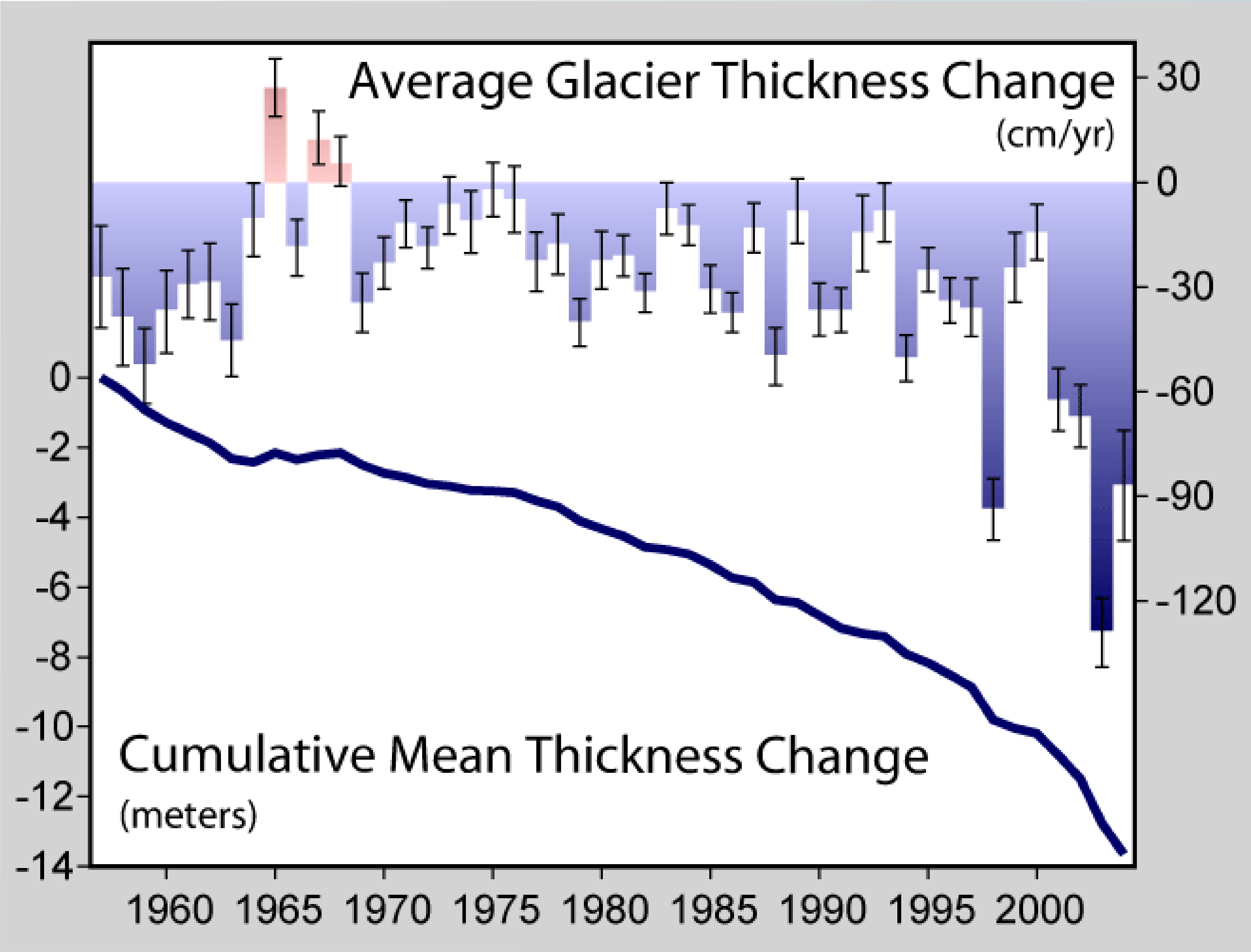


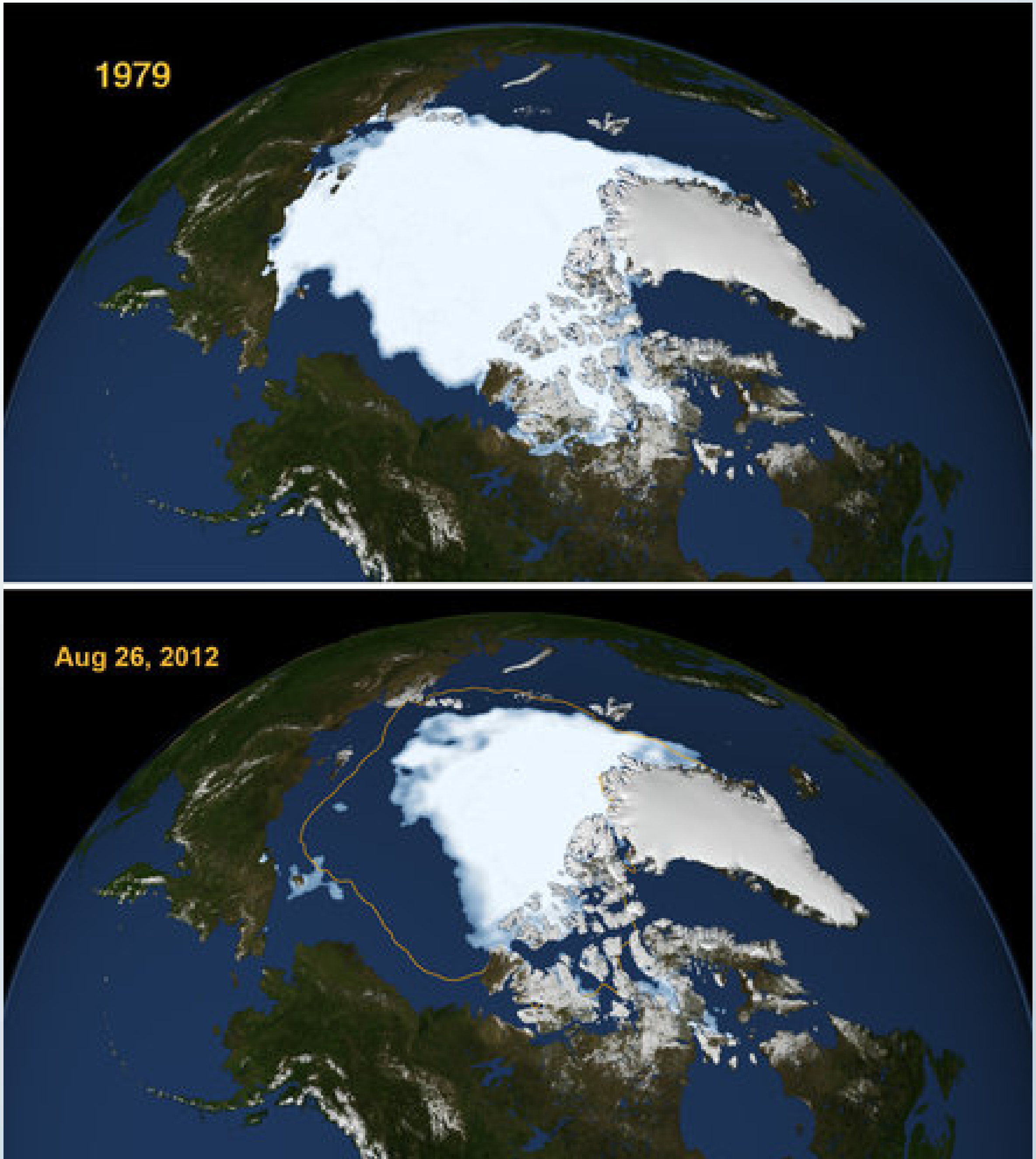
http://www.explainingclimatechange.ca/Climate%20Change/swf/videos/historical%20_temp.swf

Where is global warming going?



Effect on Glaciers



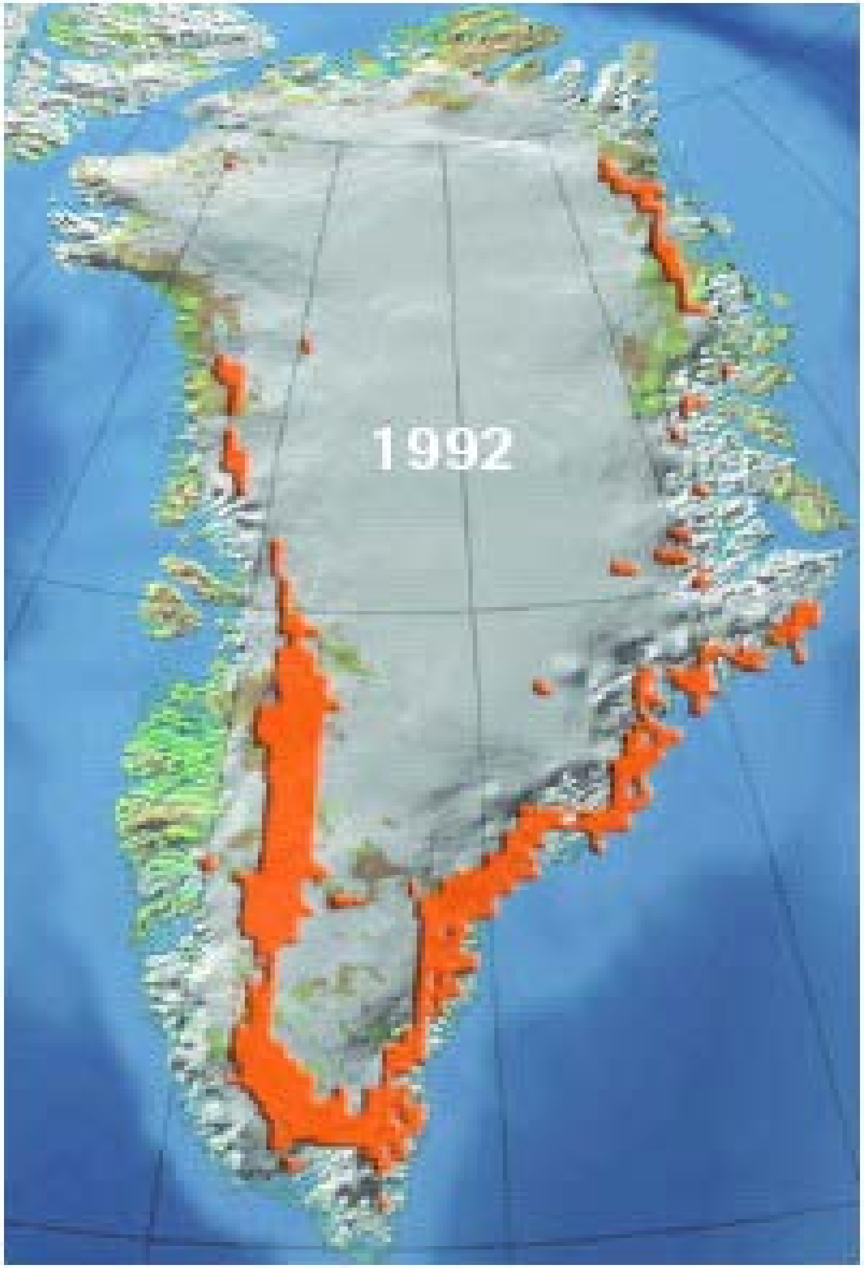


NASA photograph

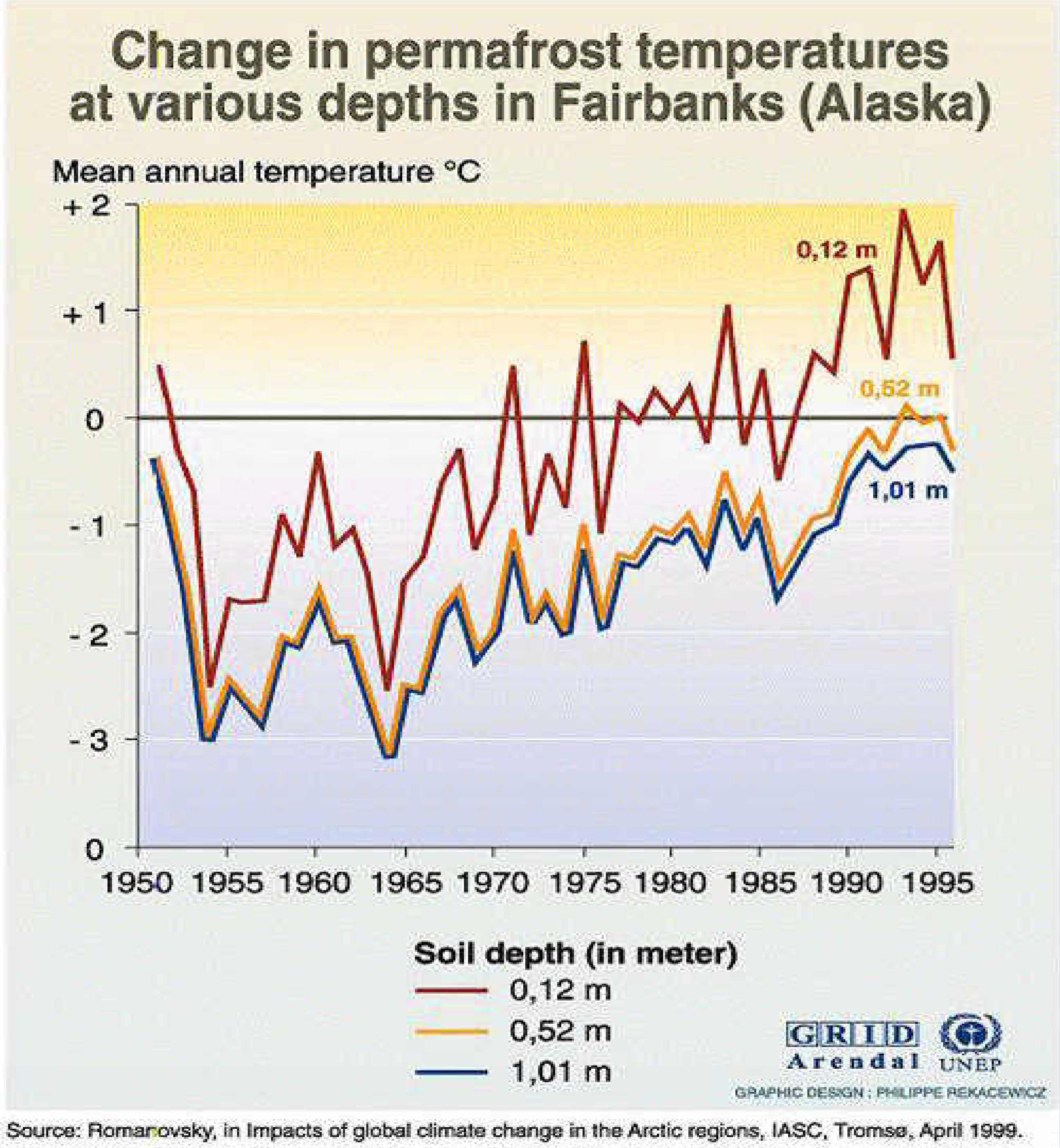
Shrinking Polar Ice

Extent of Arctic summer ice in 1979 (top satellite image) and in August 2012 (lower satellite image).

Extent of ice melt in Greenland, 1992 and 2002



Arctic Climate Impact Assessment 2004

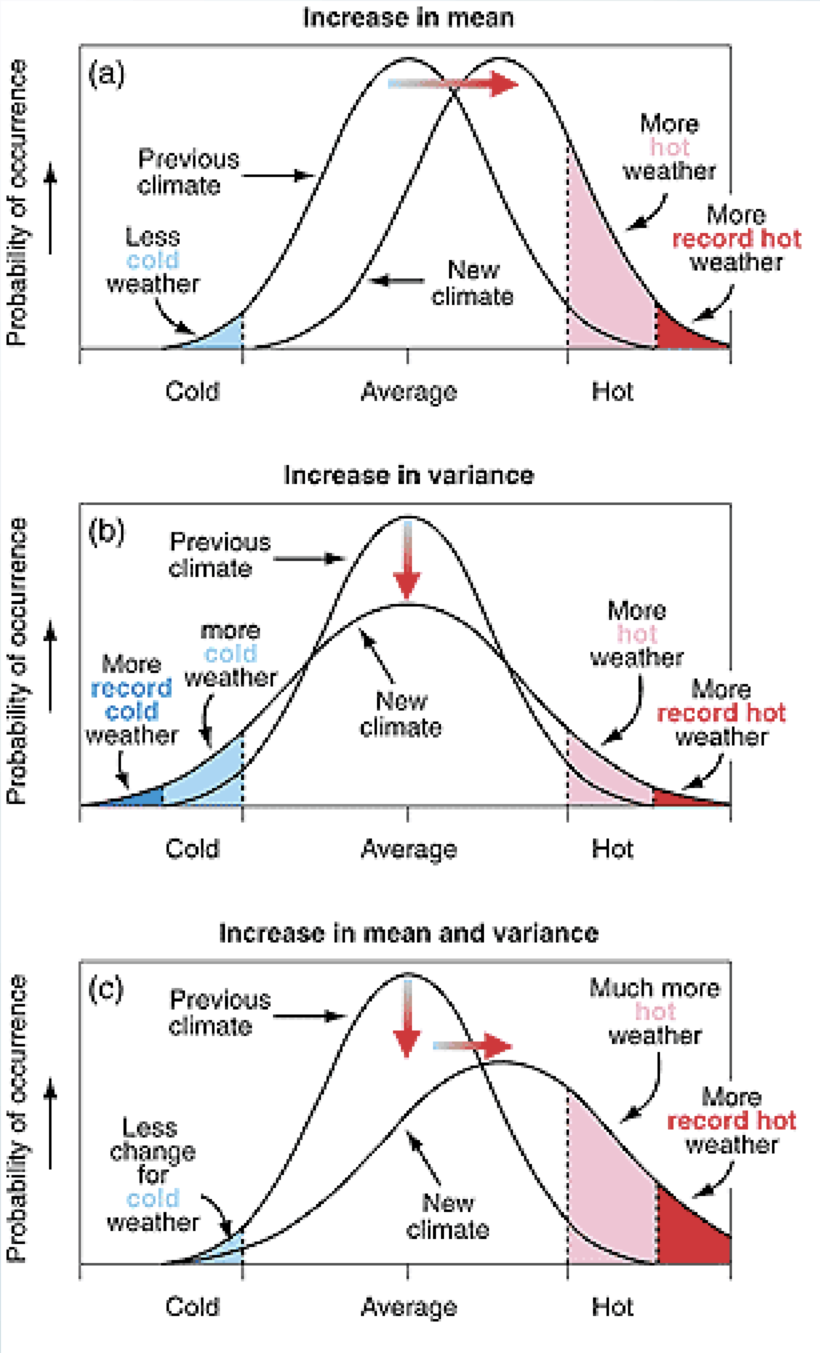


When permafrost temperature rises above the freezing point, and the permafrost melts, power lines, pipelines, and buildings built over the permafrost can topple, sag, and crack.

Why care about climate?

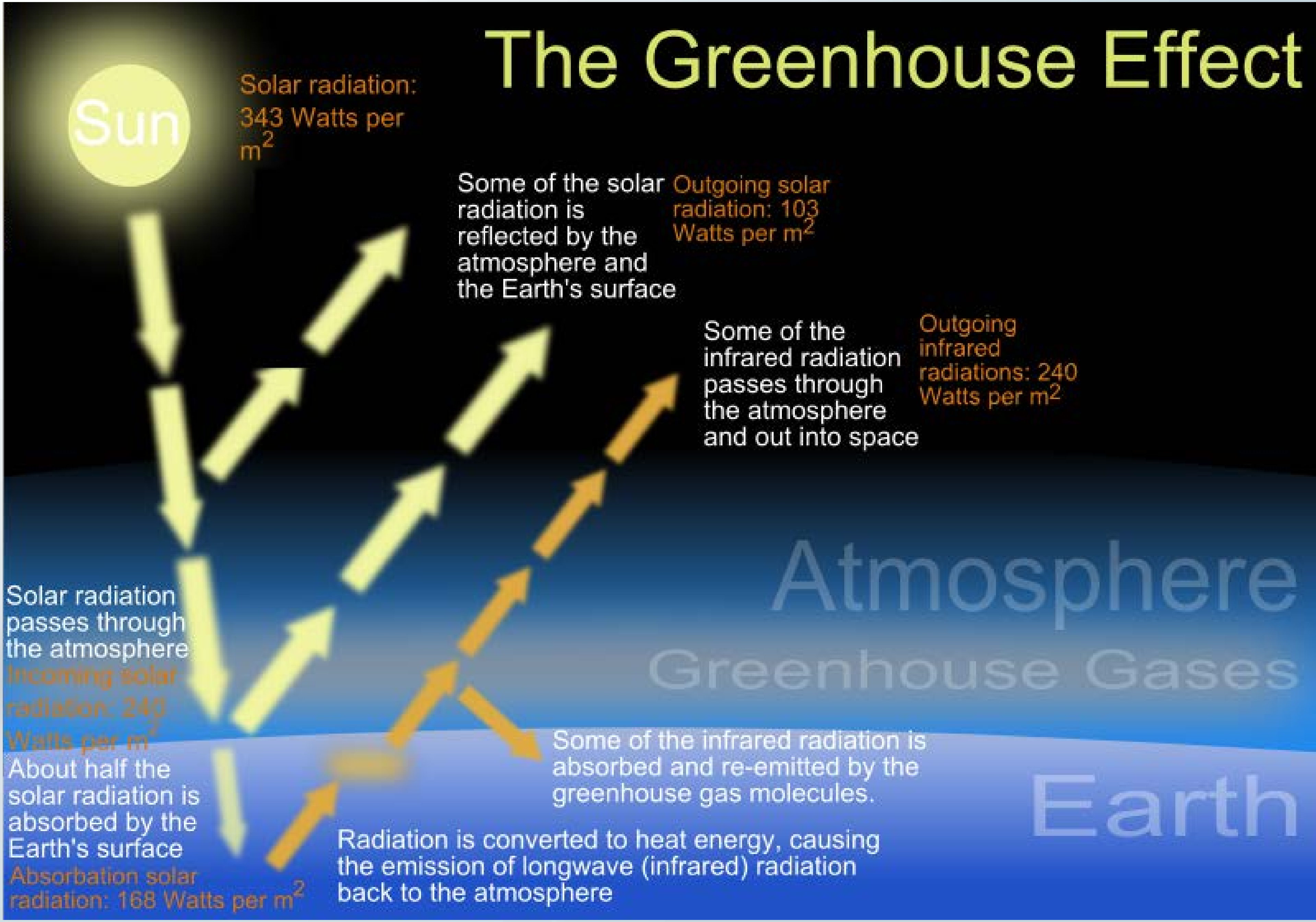
Climate governs:

- Distribution & abundance of species
- Productivity of farms, forests, & fisheries
- Geography of disease
- Livability of cities in summer
- Damages from storms, floods, wildfires
- Property losses from sea-level rise
- Expenditures on engineered environments



"Climate change" means a change in the means and extremes (variances about the mean) that define the climate, either globally or in a particular climate zone.

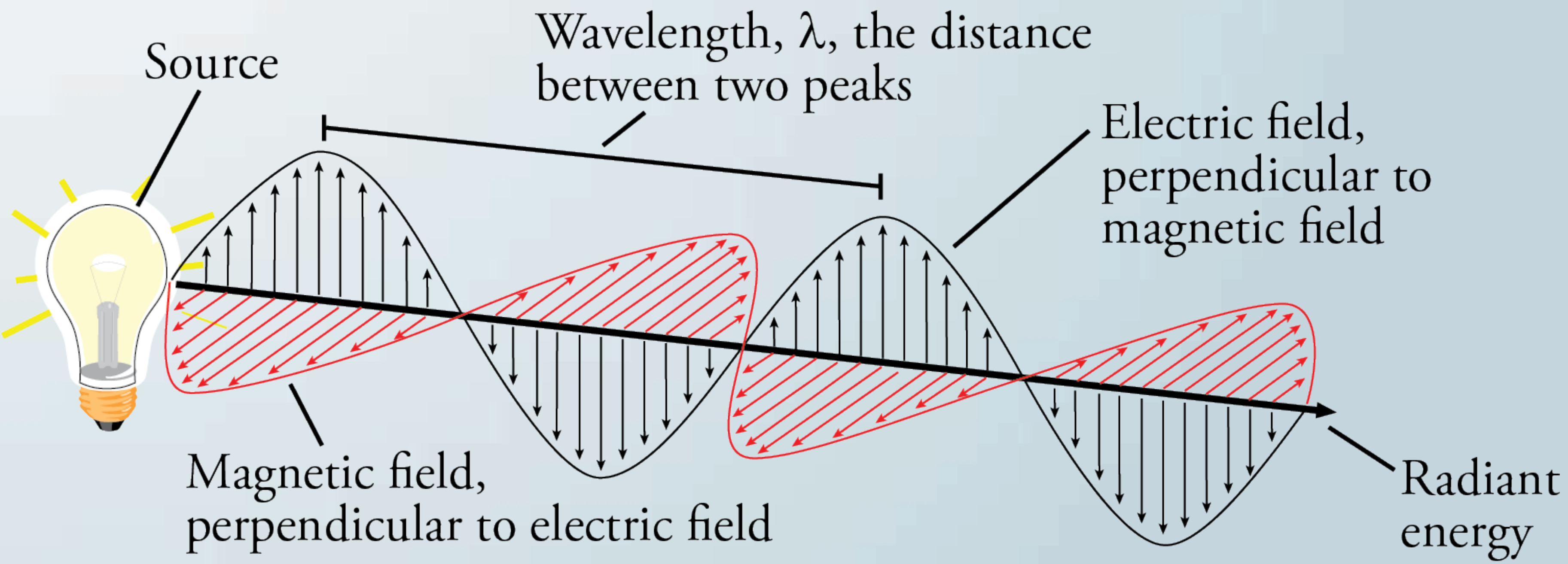
A key example is a change in average surface temperature. Another is occurrence of more extreme events - heat waves, droughts, hurricanes, etc.


The Greenhouse Effect
Sun
Solar radiation: 343 Watts per m2
Some of the solar radiation is reflected by the atmosphere and the Earth's surface
Outgoing solar radiation: 103 Watts per m2
Some of the infrared radiation passes through the atmosphere and out into space
Outgoing infrared radiations: 240 Watts per m2
Atmosphere
Greenhouse Gases
Solar radiation passes through the atmosphere
Incoming solar radiation: 240 Watts per m2
About half the solar radiation is absorbed by the Earth's surface
Absorbation solar radiation: 168 Watts per m2
Some of the infrared radiation is absorbed and re-emitted by the greenhouse gas molecules.
Earth
Radiation is converted to heat energy, causing the emission of longwave (infrared) radiation back to the atmosphere

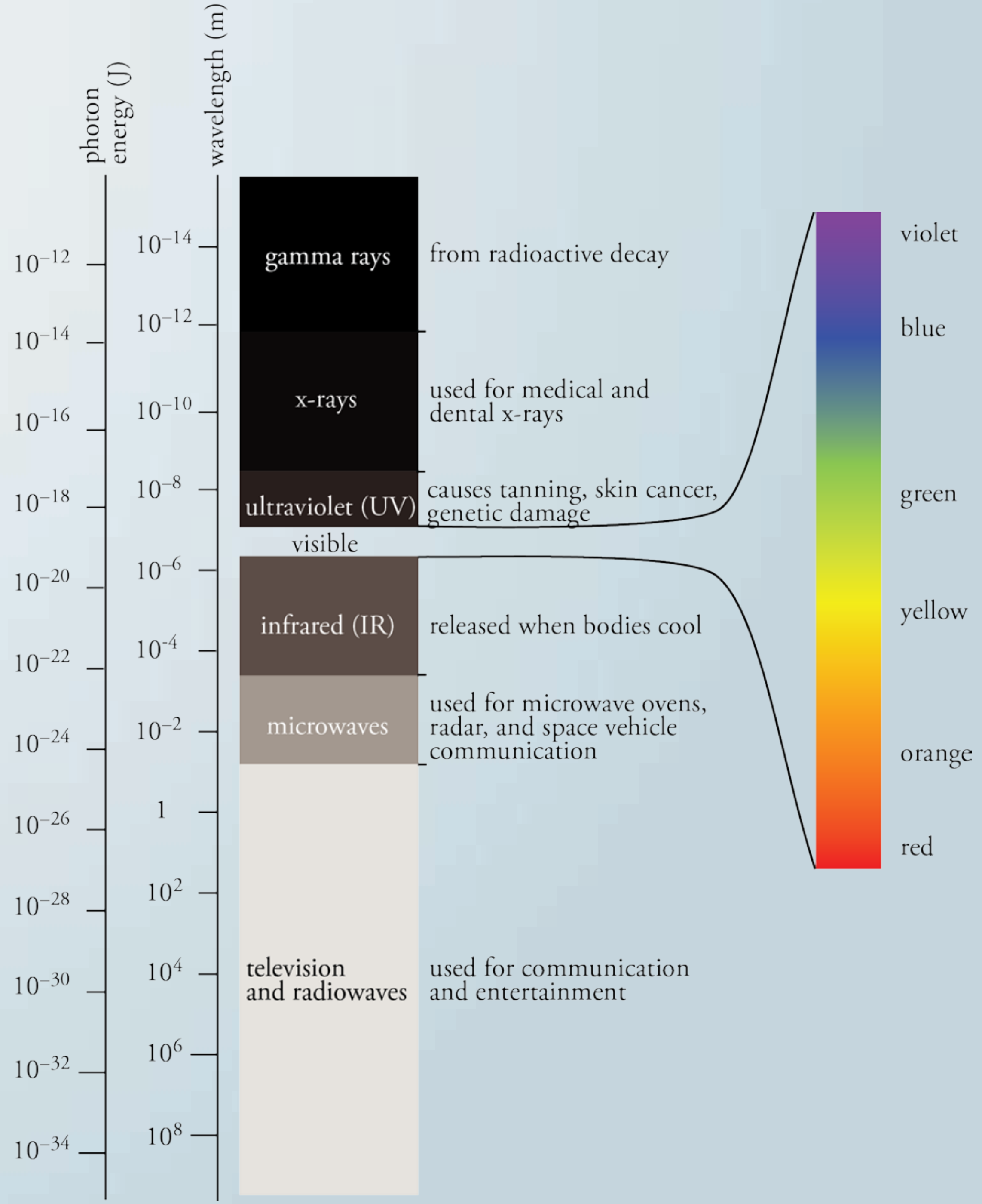
Radiant Energy

- **Radiant Energy** is electromagnetic energy that behaves like a stream of particles.
- It has a dual Nature
  - Particle
    - photons = tiny packets of radiant energy
    - 10^{17} photons/second from a flashlight bulb
  - Wave
    - oscillating electric and magnetic fields
    - describes effect on space, not true nature of radiant energy

A Light Wave's Electric and Magnetic Fields



Radiant Energy Spectrum



Greenhouse gases

- **Greenhouse gas =** Any gas that absorbs infrared radiation in the atmosphere. Each gas absorbs radiation at specific wavelengths as function of its structure.
- Without them, Earth's surface would be on average about 33 °C (59 °F) colder than at present.
- *Important greenhouse gases:*
  - **Water vapor (H_2O)**
  - **Carbon dioxide (CO_2)**
  - **Methane (CH_4)**
  - **Nitrous oxide (N_2O)**
  - Chlorofluorcarbons (CFCs)
  - Halogenated fluorocarbons (HCFCs)
  - Ozone (O_3)
  - Hydrofluorocarbons (HFCs).

Individual Emissions

http://www.epa.gov/climatechange/ghgemissions/individual.html

Vibration Modes of Greenhouse Gas Molecules

- As the Earth cools, it emits infrared (IR) photons.
- When a greenhouse gas molecule absorbs an IR photon, the molecule gets excited to a higher vibrational energy.
- When the molecule returns to a more stable vibrational energy, it emits an IR photon in a random direction.
- Some of the remitted photons return to Earth.

http://www2.ess.ucla.edu/~schauble/MoleculeHTML/CO2_html/CO2_page.html

http://www2.ess.ucla.edu/~schauble/MoleculeHTML/H2O_html/H2O_page.html

http://www2.ess.ucla.edu/~schauble/MoleculeHTML/N2O_html/N2O_page.html

http://www2.ess.ucla.edu/~schauble/MoleculeHTML/CH4_html/CH4_page.html

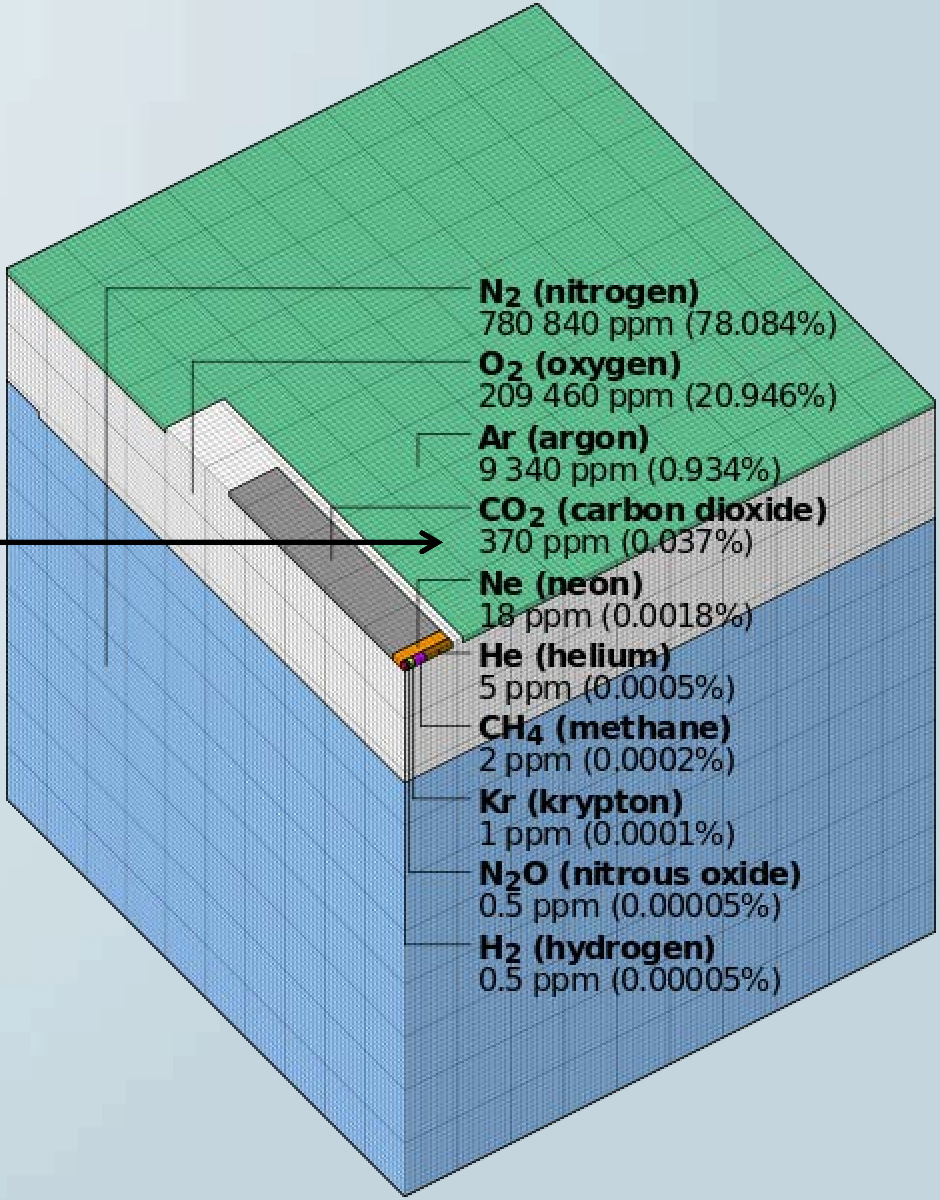
http://www2.ess.ucla.edu/~schauble/MoleculeHTML/CHClF2_html/CHClF2_page.html

http://www.explainingclimatechange.ca/Climate%20Change/swf/irwindows/IRwindows2.swf

Composition of Air

Average composition of dry atmosphere (mole fractions)

Gas	**from NASA**
Nitrogen, N_2	78.084%
Oxygen, O_2	20.946%
Argon, Ar	0.934%
Minor constituents (mole fractions in ppm)	
Carbon dioxide, CO_2	About 395 and rising
Neon, Ne	18.18
Helium, He	5.24
Methane, CH_4	1.7
Krypton, Kr	1.14
Hydrogen, H_2	0.55
Water vapor	Highly variable; typically makes up about 1%



Radiative Forcing

- **Radiative forcing** = anything that changes the radiation balance at earth's surface
- Measured in W/m^2
- A change in radiative forcing leads to a change in surface temperature
- Both natural and anthropogenic
  – adding greenhouse gases
  – adding aerosols
  – changing albedo (land use, black carbon)
  – change in solar radiation

Natural and Anthropogenic Greenhouse Effect

NATURALLY MODERATED GREENHOUSE EFFECT

ANTHROPOGENIC GREENHOUSE EFFECT - ADDING GHG’S, INCREASING RADIATIVE FORCING

The Climate Change Story Line

Human Activities →

GHG Emissions and Land Use Changes →

Change in Atmospheric Concentrations →

Change in Radiative Forcing →

Change in Average Surface Temperature →

Direct & Indirect Feedbacks →

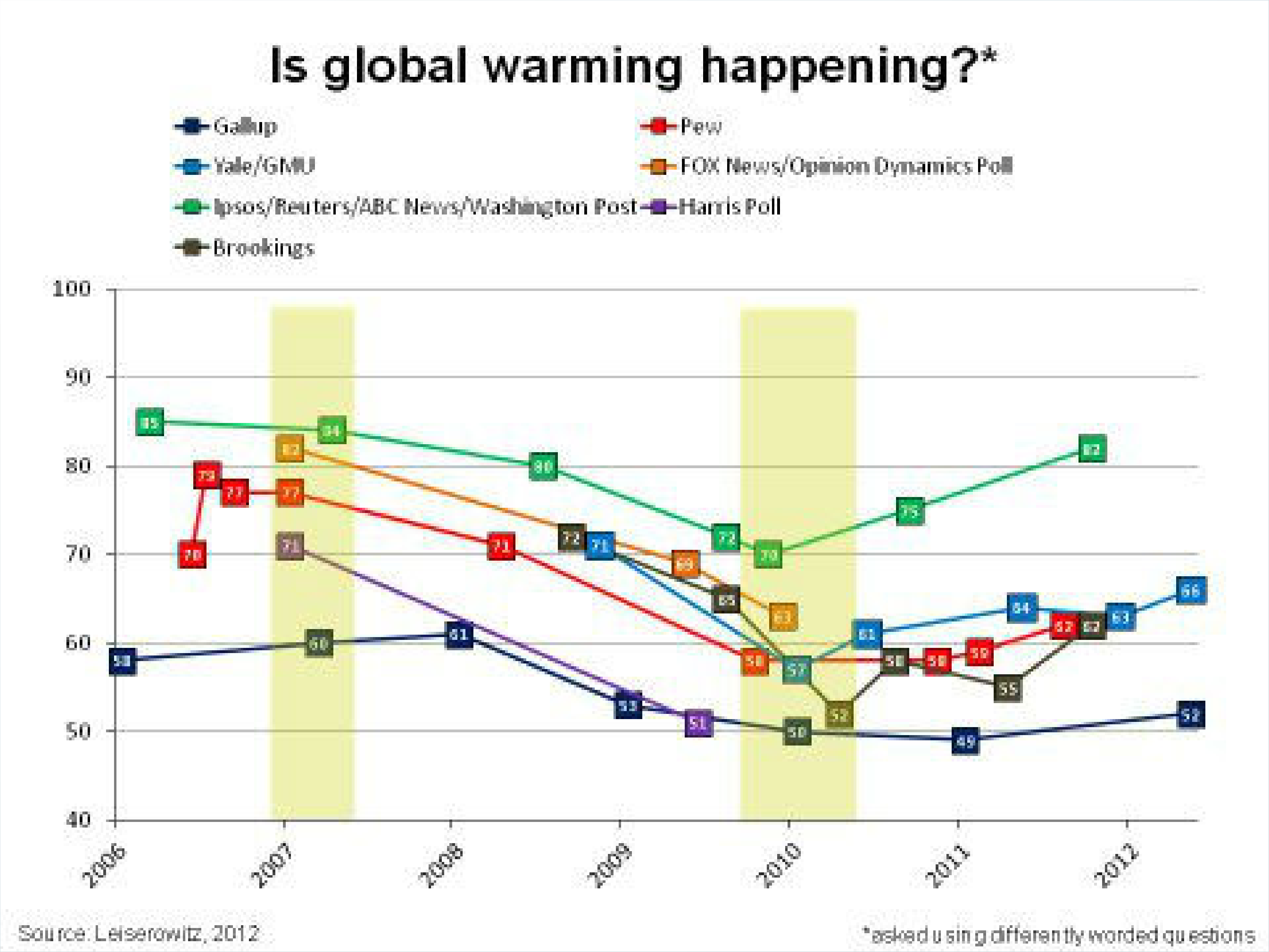
Direct & Indirect Biogeophysical Impacts →

Societal Impacts →

Policy Response?

- Change in GHG Emissions? (Mitigation)
- Adapting to Changes? (Adaptation)
- Suffering the Consequences? (Suffering)

Public Opinion of Climate Change



GHG Atmospheric Lifetimes and Global Warming Potential

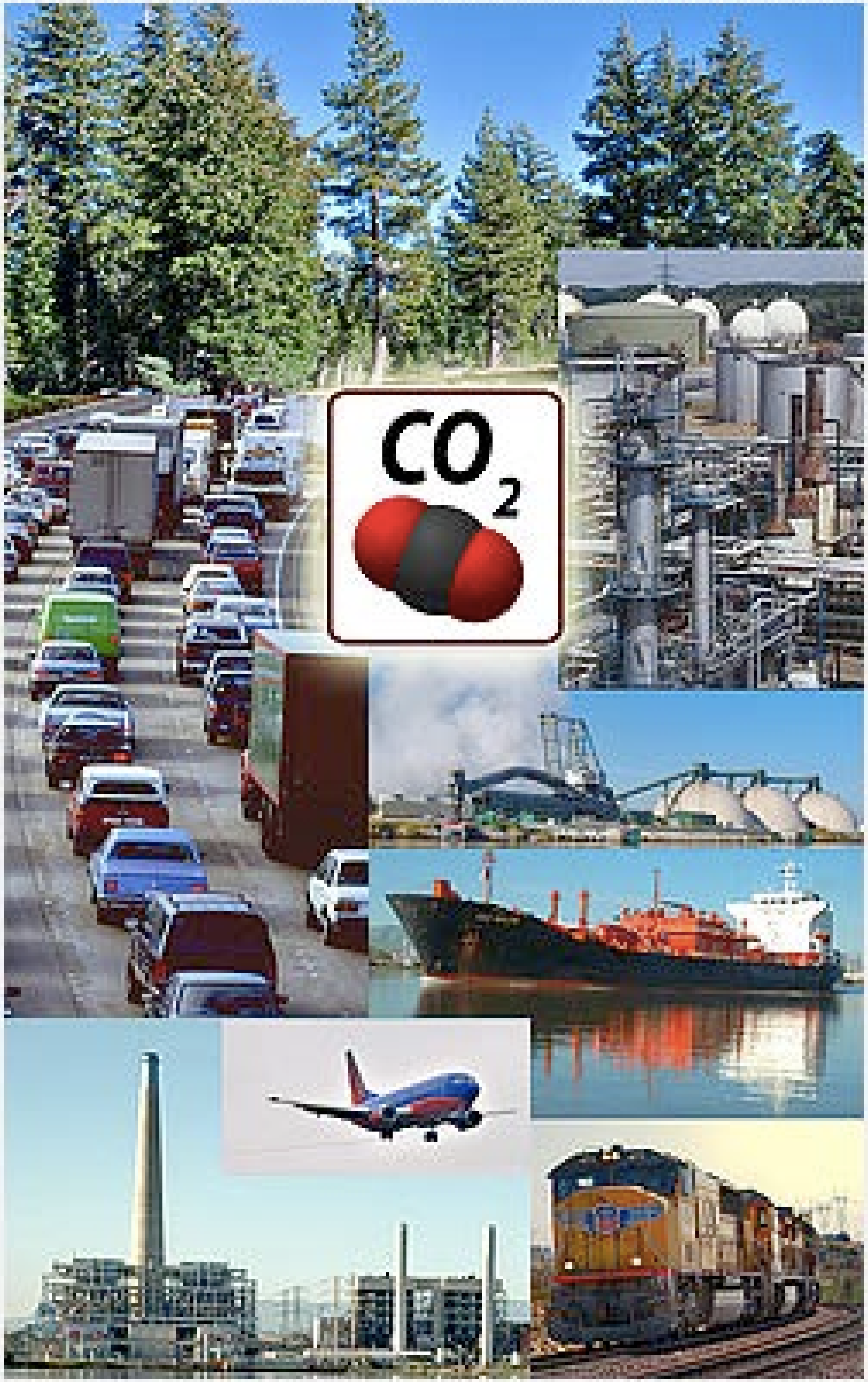
- Each GHG has its own atmospheric residence time, governed by the sinks that remove it from the atmosphere.
- The global warming potential (GWP) of each GHG is measured relative to CO_2. GWP combines the GHG's efficiency at trapping IR radiation with its residence time in the atmosphere.
- Example: Over a 100 year period, a molecule of CH_4 contributes as much radiative forcing as 25 molecules of CO_2.

Global Warming Potential (GWP) =

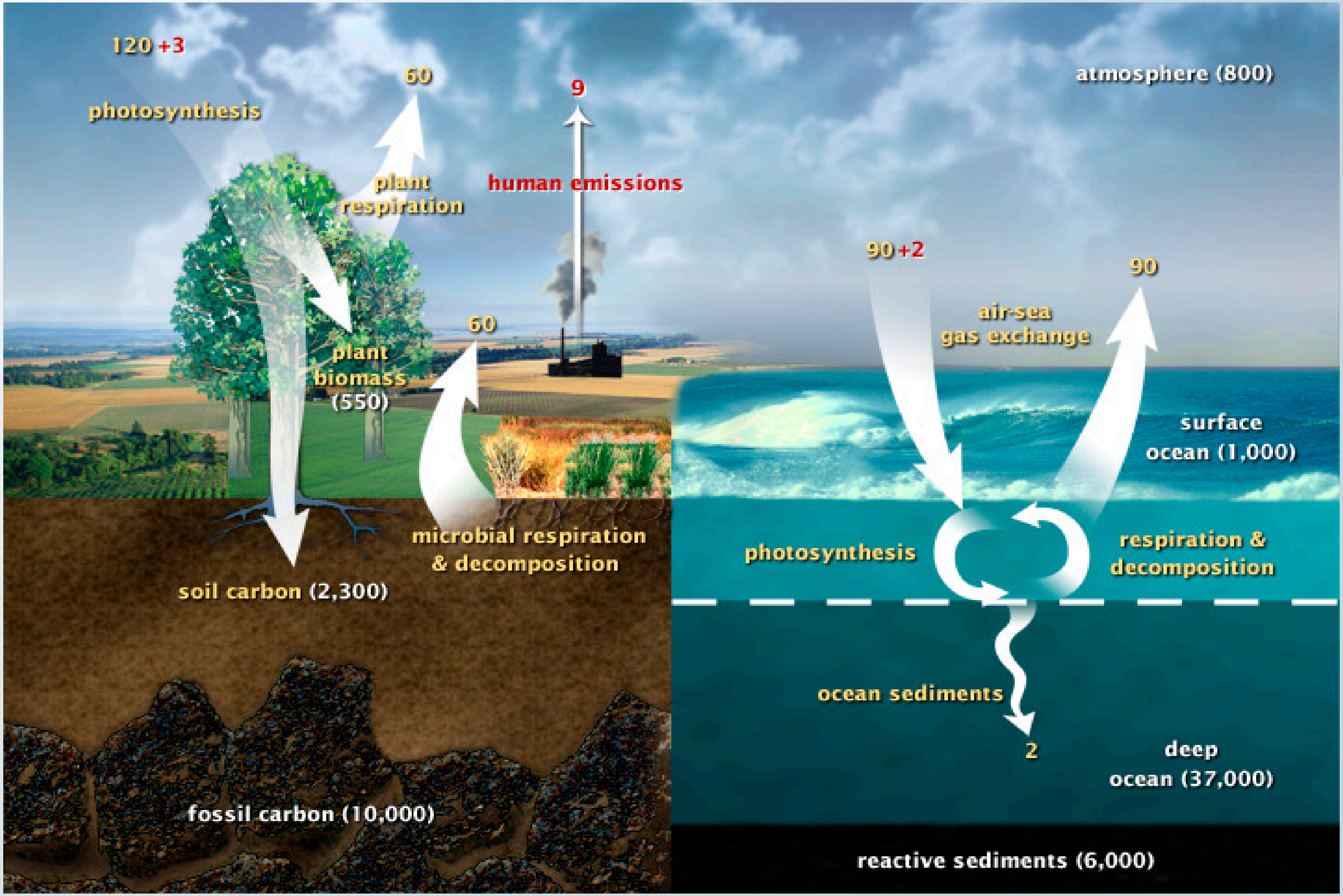
radiative impact of a GHG per molecule relative to impact of CO_2, taking into account its radiative properties and atmospheric lifetime

Atmospheric lifetime and GWP relative to CO_2 at different time horizon for various greenhouse gases.

Gas name	Chemical formula	Lifetime (years)	Global warming potential (GWP) for given time horizon		
			20-yr	100-yr	500-yr
Carbon dioxide	CO_2	See above	1	1	1
Methane	CH_4	12	72	25	7.6
Nitrous oxide	N_2O	114	289	298	153
CFC-12	CCl_2F_2	100	11,000	10,900	5 200
HCFC-22	$CHClF_2$	12	5160	1810	549
Tetrafluoromethane	CF_4	50,000	5210	7390	11,200
Hexafluoroethane	C_2F_6	10,000	8630	12,200	18,200
Sulphur hexafluoride	SF_6	3200	16,300	22,800	32,600
Nitrogen trifluoride	NF_3	740	12,300	17,200	20,700

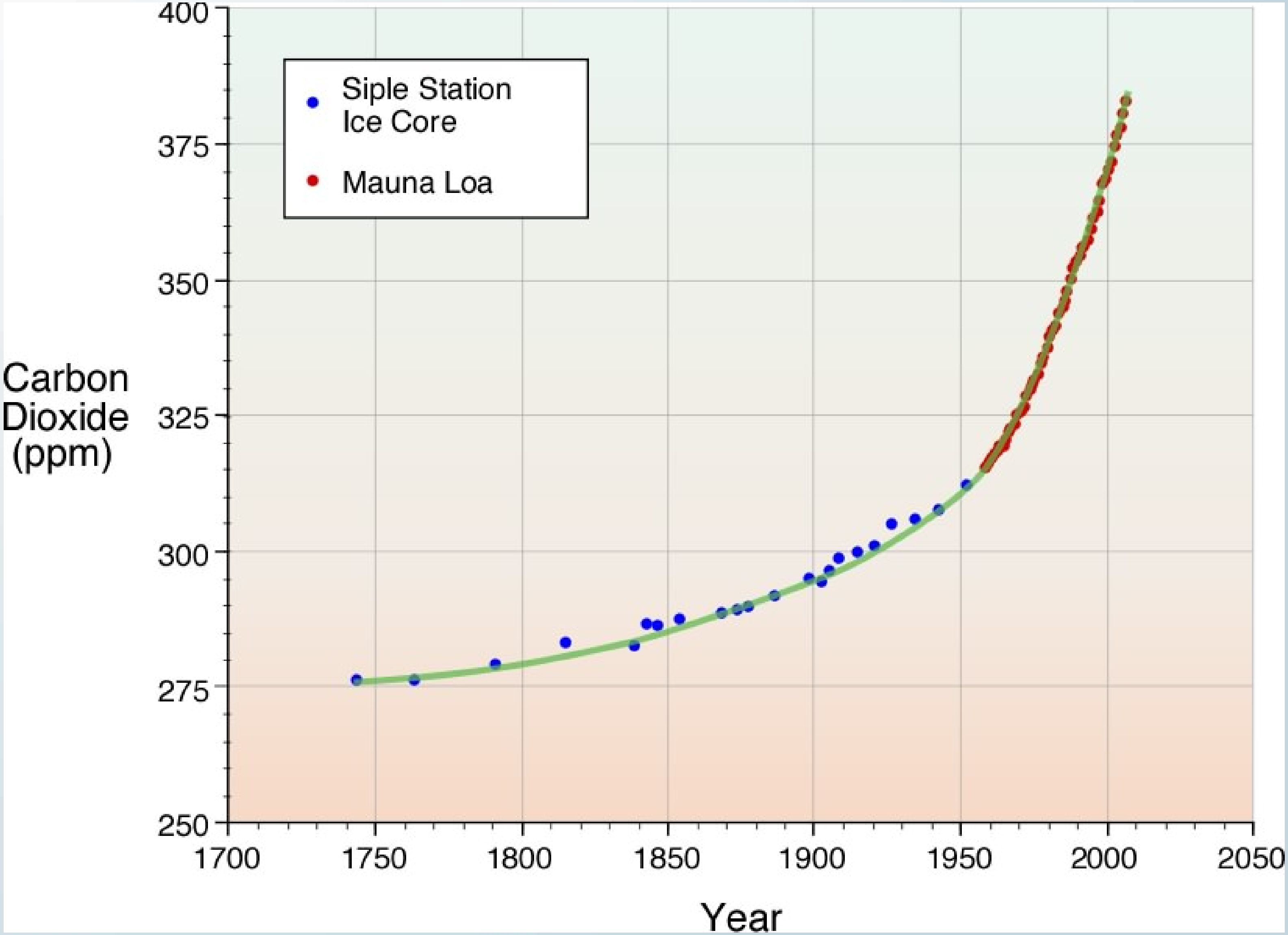

CO2

Fast Carbon Cycle



The movement of carbon between land, atmosphere, and oceans in billions of tons of carbon per year. Yellow numbers are natural fluxes, red are human contributions in Gt of carbon per year. White numbers indicate stored carbon.

CO_2 Concentrations



http://www.eoearth.org/article/Greenhouse_gas

Role of Humans in the CO_2 Increases

- About 65% of anthropogenic CO_2 to atmosphere is from combustion of fossil fuels.
- Remaining 35% from deforestation and the conversion of prairie, woodland, and forested ecosystems primarily into less productive agricultural systems.
- Natural ecosystems can store 20 to 100 times more carbon dioxide per unit area than agricultural systems.

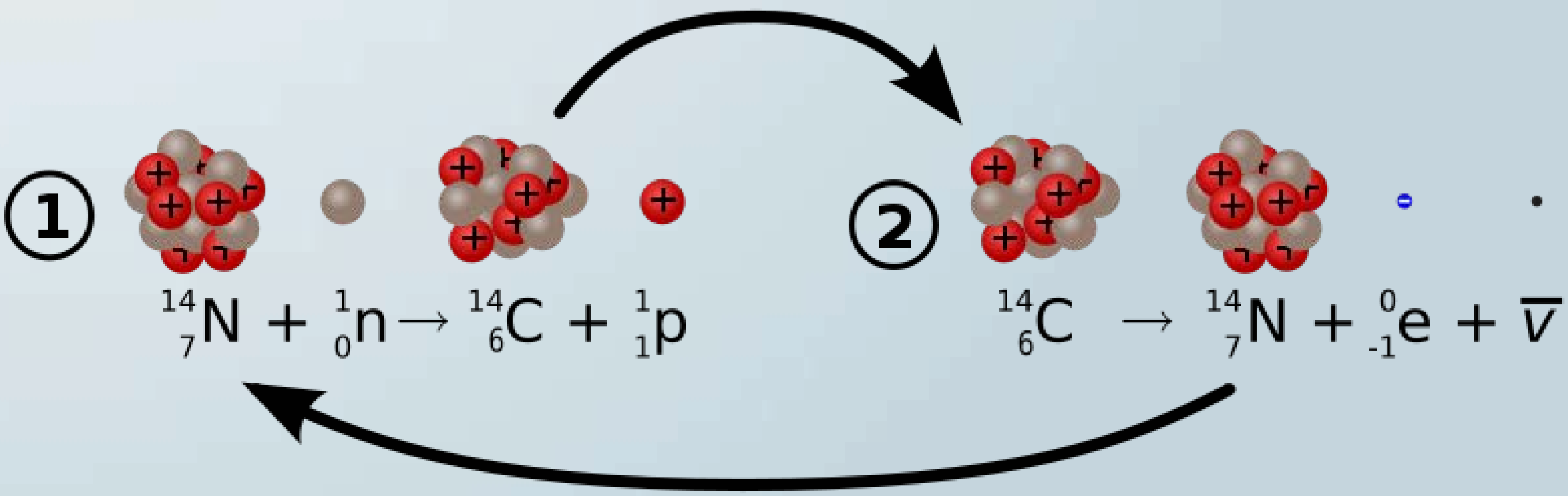
http://www.eoearth.org/article/Greenhouse_gas

Role of Humans in the CO_2 Increases

- The main human sources of CO_2 – deforestation and fossil-fuel burning – are quite well quantified. The observed CO_2 build-up in the atmosphere matches these human inputs, after subtraction of estimated rates of uptake in the oceans and northern forests.
- The ice-core data show that atmospheric CO_2 has not been above 300 ppm in the last 400,000 years (it's over 390 ppm today) and that natural fluctuations in atmospheric CO_2 over the past 10,000 years have been only ±10 ppm (compared to the 90 ppm increase since the start of the Industrial Revolution).
- Carbon-14 analysis of tree rings back to 1800 confirms the fossil-fuel contribution to the atmospheric CO_2 burden in the last 200 years.

Carbon-14

- Carbon-14 is produced in the atmosphere when neutrons are absorbed by nitrogen atoms.
- Carbon-14 then undergoes beta decay, emitting an electron and an antineutrino and forming nitrogen-14.
- Carbon-14 has a half-life of 5730 years.



Measuring CO_2 from fossil fuels by Measuring $^{14}CO_2/^{12}CO_2$ Ratio

- About one in a trillion CO_2 molecules naturally contain ^{14}C, but the carbon locked up in fossil fuels, such as coal and oil has none.
- Because the half-life of ^{14}C is 5730 years, the carbon-14 in fossil fuels decayed to ^{14}N millions of years ago

$$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$$

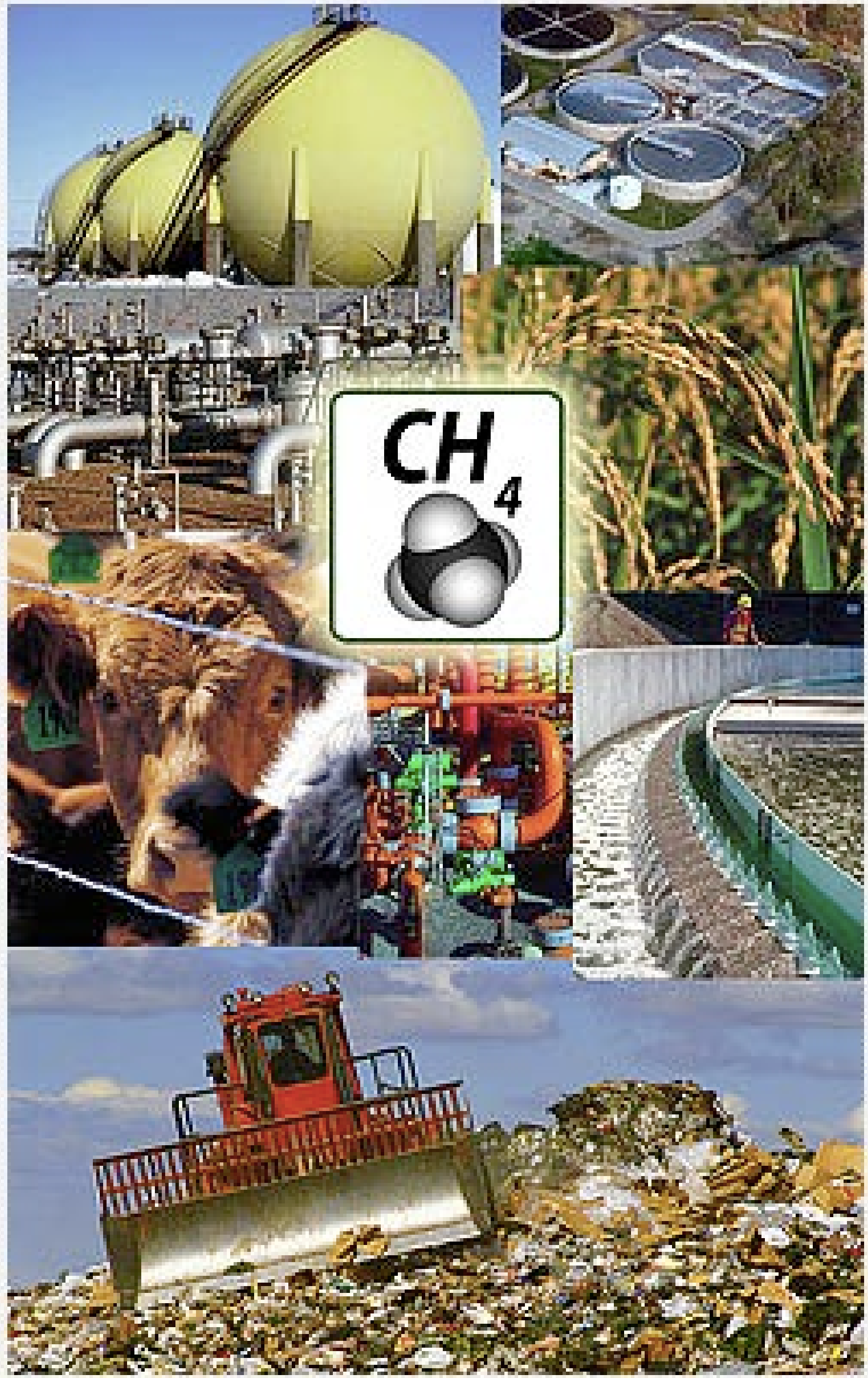
- Therefore, as the amount of CO_2 in the atmosphere from fossil fuels rises, the ratio of $^{14}CO_2/^{12}CO_2$ decreases in a measurable way.

Measuring CO_2 from fossil fuels by Measuring $^{14}CO_2/^{12}CO_2$ Ratio

- Monitoring stations in the Swiss Alps and in Antarctica found that the $^{14}CO_2/^{12}CO_2$ is now about 0.5% lower in the Northern Hemisphere than in the Southern Hemisphere.
- Reversal since preindustrial days…tree ring records show that the Southern Hemisphere had less $^{14}CO_2$ because upwelling of deep waters in the southern oceans brought radiocarbon-depleted CO_2 to the surface.

Measuring CO_2 from fossil fuels by Measuring $^{14}CO_2/^{12}CO_2$ Ratio

- Uncertainties in estimates of fossil-fuel emissions from $^{14}CO_2$ are still large, because accurate modeling depends on knowing all possible sources of both radioactive and nonradioactive CO_2.
- One confounding factor is emissions from nuclear power plants, which generate a significant amount of ^{14}C in regions where nuclear plants are concentrated, offsetting at least 20% of the reduction in $^{14}CO_2$ due to fossil fuels.


CH4

Naturally Occurring Methane

- Naturally occurring methane is mainly produced by the process of methanogenesis, a multistep process is used by microorganisms as an energy source. The net reaction is:

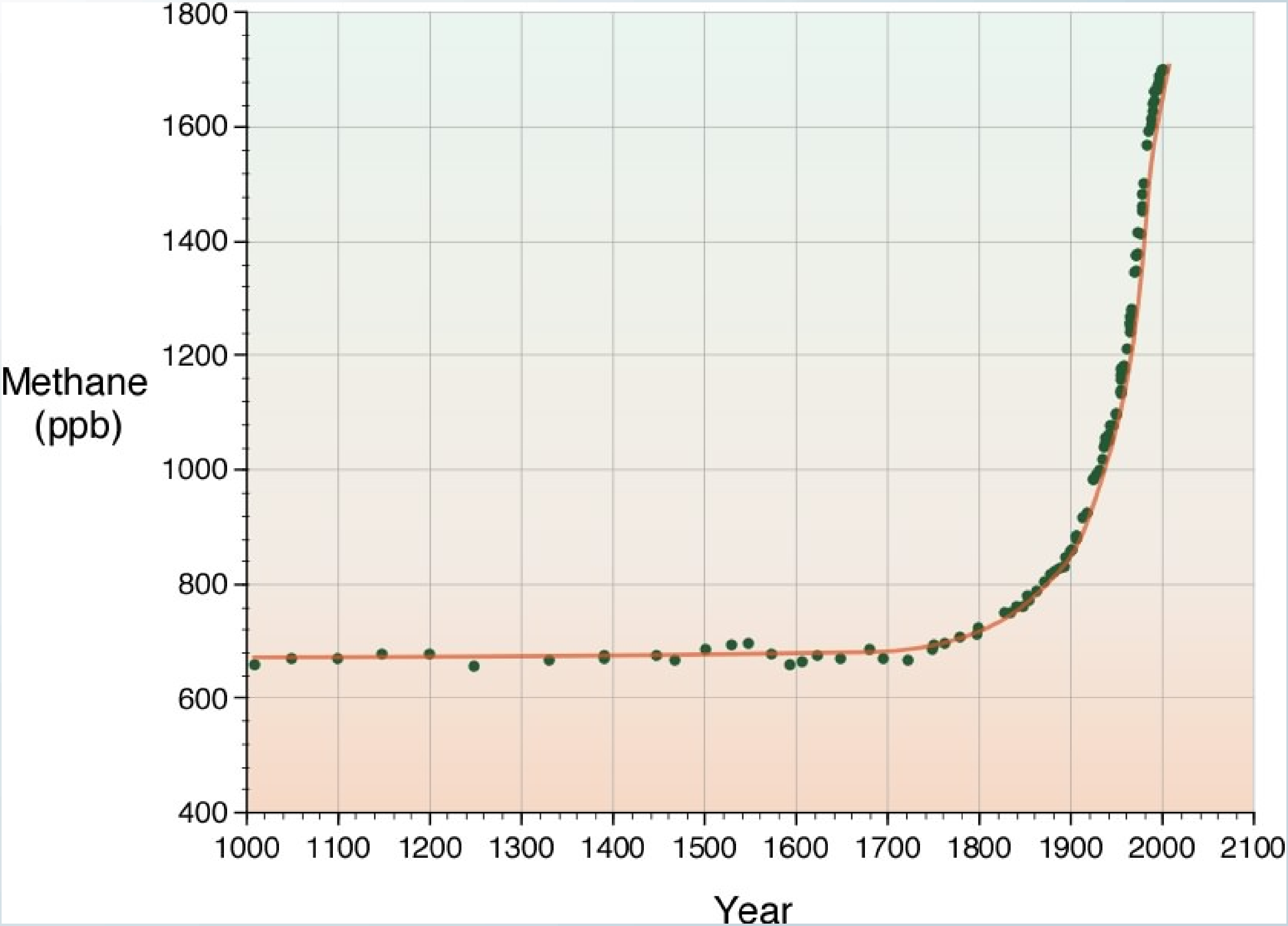
$$CO_2 + 8\,H^+ + 8\,e^- \rightarrow CH_4 + 2\,H_2O$$

- Methanogenesis is a form of anaerobic respiration used by organisms that occupy landfill, ruminants (e.g., cattle), and the guts of termites.

Atmospheric Methane Sources

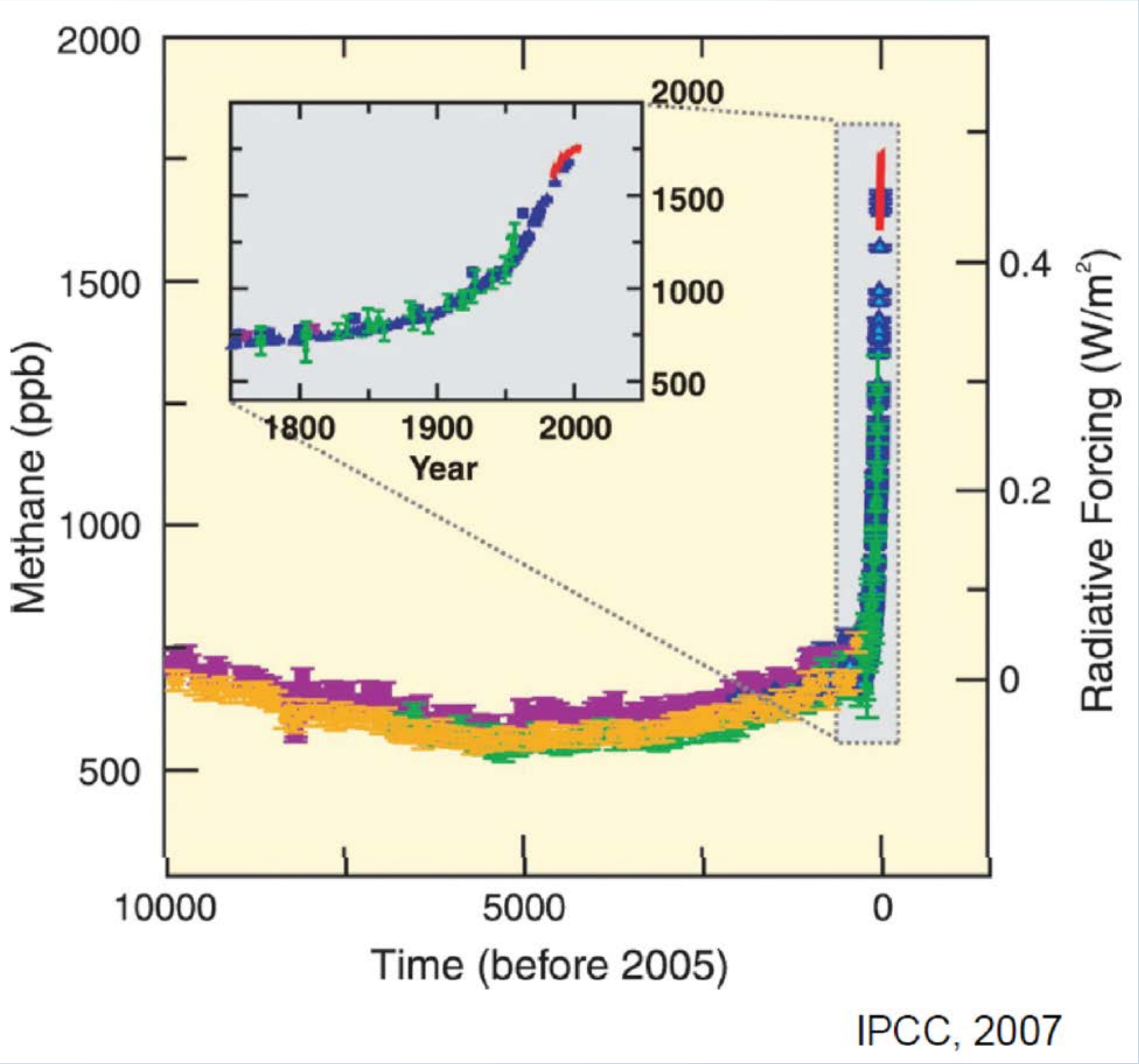
- Biogenic sources (>70% of total)
  - Wetlands
  - Rice agriculture
  - Livestock
  - Landfills
  - Biomass burning
  - Forests
  - Oceans
  - Termites
- Non-biogenic sources
  - Emissions from fossil fuel mining and burning
  - Natural gas, petroleum and coal
  - Waste treatment
  - Geological sources (methane clathrates)
  - Fossil CH_4 from natural gas seepage
  - Geothermal/volcanic CH_4

Methane Concentrations 1000-2000 AD



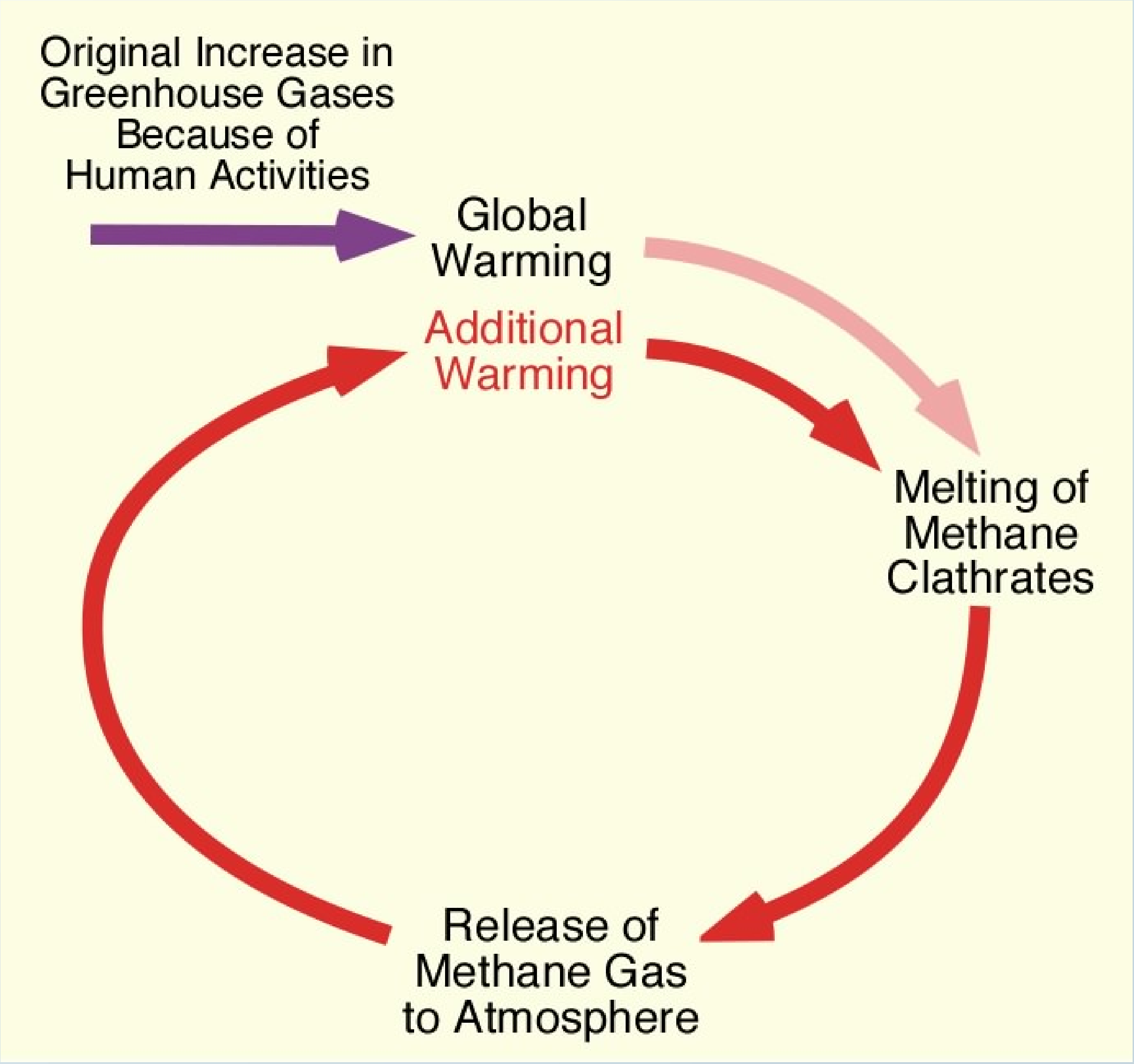
http://www.eoearth.org/article/Greenhouse_gas

Methane Concentrations and Radiative Forcing



IPCC = Intergovernmental Panel on Climate Change http://www.ipcc.ch/

Feedback Example



http://www.eoearth.org/article/Greenhouse_gas

Estimated Global Methane Balance (Tg CH_4/yr)

NATURAL SOURCES	220
• Wetlands	175
• Termites	20
• Ocean	15
• Hydrates	10
HUMAN SOURCES	380
• Energy	110
• Landfills	40
• Ruminants	115
• Waste treatment	25
• Rice agriculture	50
• Biomass burning	40
TOTAL SOURCES	**600**

NATURAL SINKS	580
• Soils	30
• Tropospheric OH	510
• Stratos. destruction	40
TOTAL SINKS	**580**

ANNUAL IMBALANCE

= SOURCES - SINKS

= 600 – 580 = **+20**

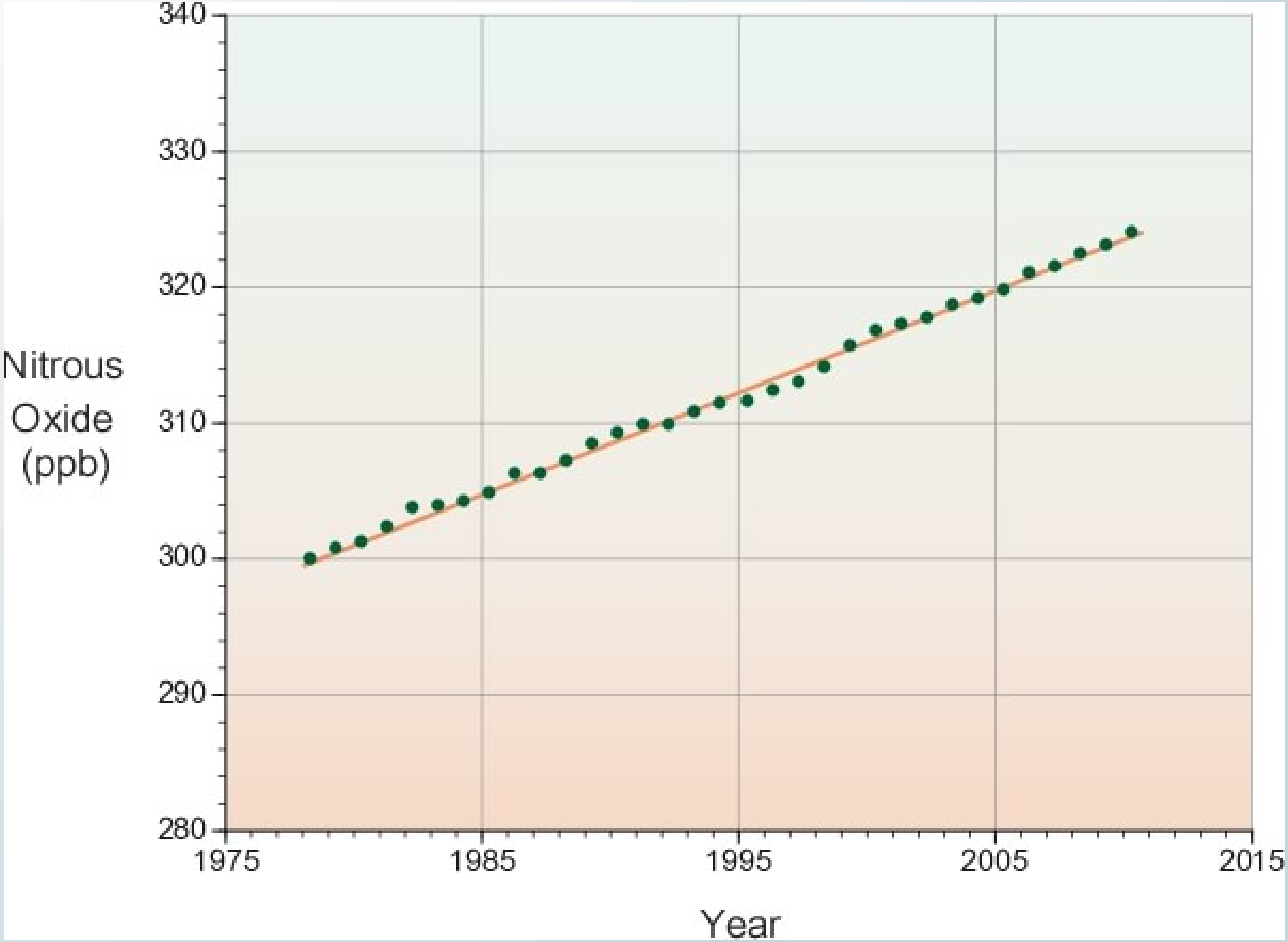

N2O

Role of Humans in the N_2O Increases

- The average concentration of nitrous oxide in the atmosphere is now increasing at a rate of 0.2 to 0.3% per year.
- Sources for the increase of nitrous oxide in the atmosphere include land-use conversion, fossil fuel combustion, biomass burning, and soil fertilization.
  - Most of the nitrous oxide added to the atmosphere each year due to human activities comes from agricultural soils, where nitrogen-rich fertilizer and manure is converted to nitrous oxide by soil bacteria. Nitrous oxide is also released into the atmosphere when fossil fuels and biomass are burned.

http://www.eoearth.org/article/Greenhouse_gas

N_2O Concentrations



http://www.eoearth.org/article/Greenhouse_gas

Global Nitrous Oxide Balance (Tg(N)/yr)

NATURAL SOURCES 9.6

- Oceans 3.0
- Atmosphere 0.6
- Tropical soils 4.0
- Temperate soils 2.0

HUMAN SOURCES 5.4

- Agriculture 3.0
- Biomass burning 0.5
- Industry/energy 1.3
- Cattle/feedlots0.6

TOTAL SOURCES **15.0**

ONLY SINK IS…

- Destruction in stratosphere 11.0

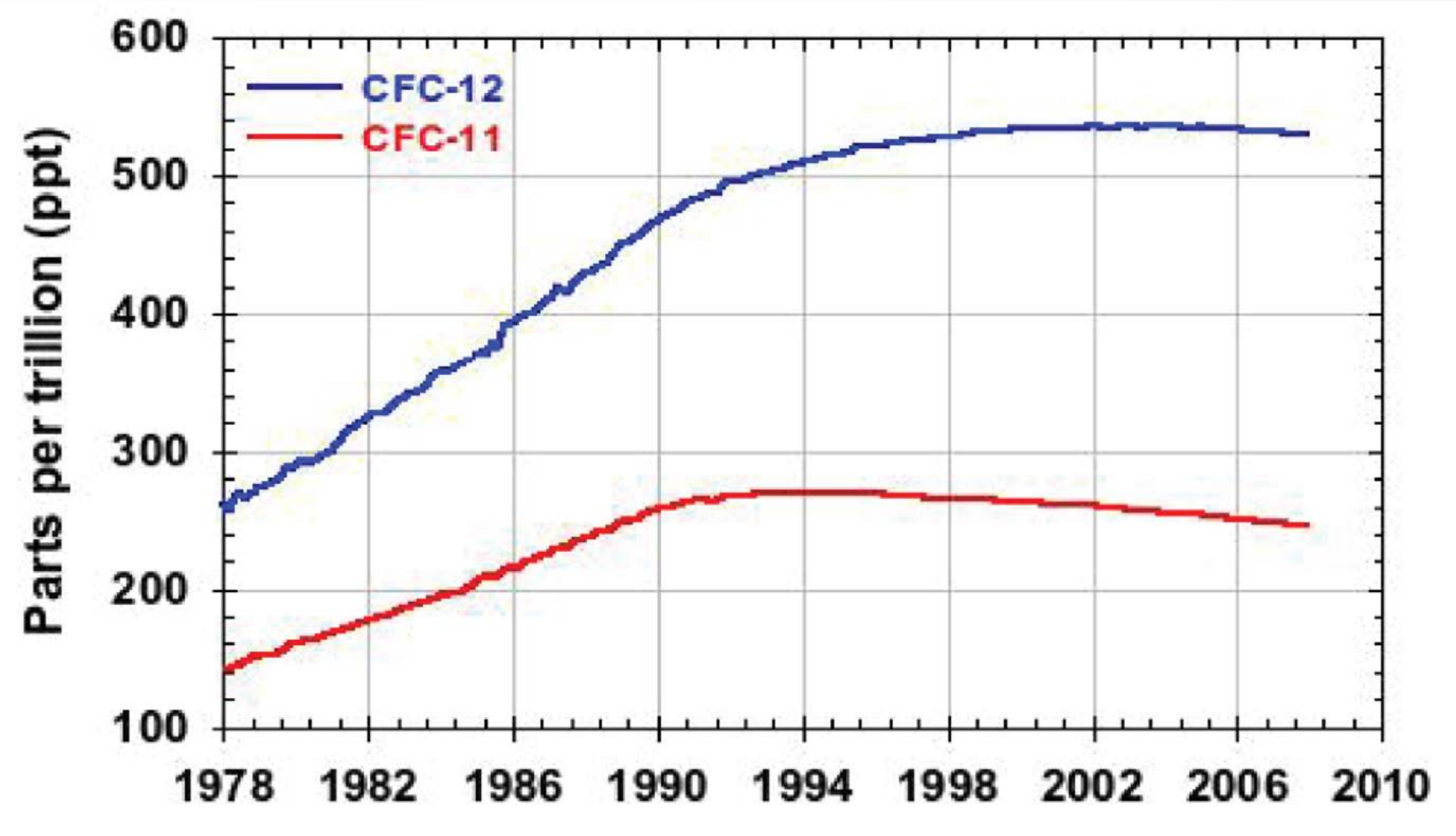
TOTAL SINK **11.0**

ANNUAL IMBALANCE

= INFLOWS – OUTFLOW

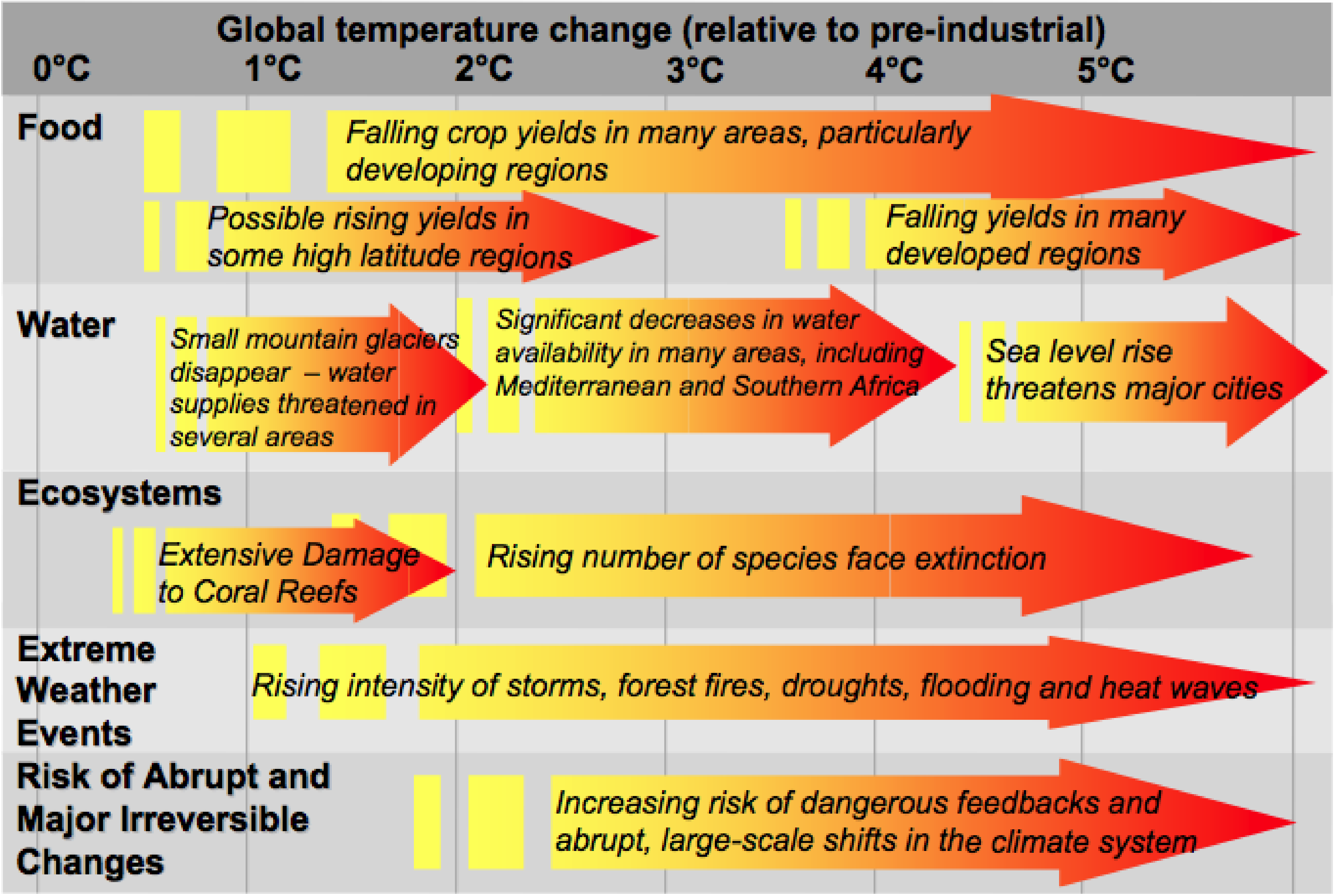
= 15.0 – 11.0 = 4.0 Tg N/y

CFC Concentrations



NOAA global flask sampling network, http://www.esrl.noaa.gov/gmd/ccgg/

Projected impacts of climate change



SOME EXAMPLES OF CLIMATE CHANGE IMPACTS

- Biodiversity
- Coral Reefs
- Disease vectors
- Extreme Weather
- Sea level rise
- Water supplies
- Wildfires