GREEN HOUSE EFFECT

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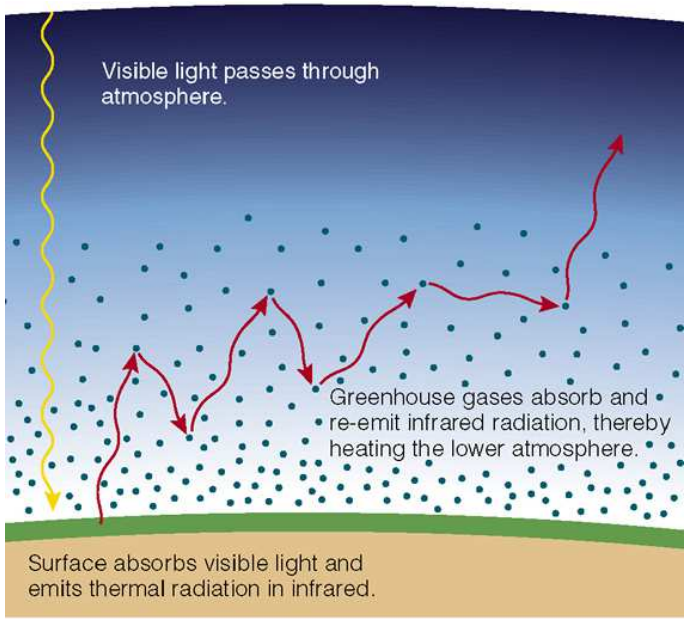
CLIMATE CHANGE: ANTHROPOGENIC

- Greenhouse effect – keeps Earth's surface habitable
  - Incoming heat energy is of shorter wavelengths
  - Longer wavelengths emitted by earth surface – some trapped, some escape, net warming effect

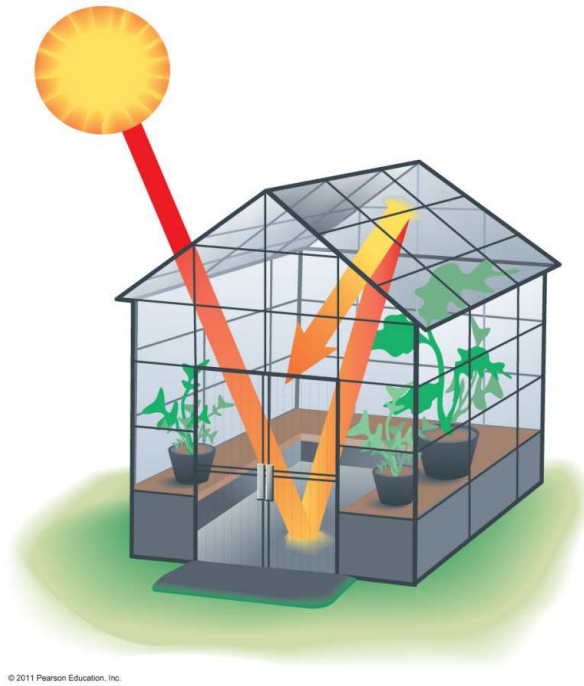


The Earth's surface thus receives energy from two sources: the sun & the atmosphere

- As a result the Earth's surface is ~33°C warmer than it would be without an atmosphere

Greenhouse gases are transparent to shortwave but absorb longwave radiation

- Thus the atmosphere stores energy



Atmospheric composition

Nitrogen	N_2	78.084%
Oxygen	O_2	20.948%
Argon	Ar	0.934%
• Carbon Dioxide	CO_2	0.036% (360 ppmv)
• Methane	CH_4	1.7 ppmv
Hydrogen	H_2	0.55 ppmv
• Nitrous Oxide	N_2O	0.31 ppmv
• Ozone	O_3	10-500 ppbv (troposphere) 0.5-10 ppmv (stratosphere)
• Water	H_2O	100 pptv – 4%

Greenhouse Gases

A greenhouse gas is one that absorbs terrestrial (LW) radiation, i.e. emitted from the Earth's surface/atmosphere

Greenhouse Gases

- Carbon dioxide; CO_2
- Water; H_2O
- CFC's
- Nitrous Oxide; N_2O
- Methane; CH_4

NOT Greenhouse Gases

- Nitrogen; N_2
- Oxygen; O_2
- Argon; Ar

➢ Greenhouse Gases

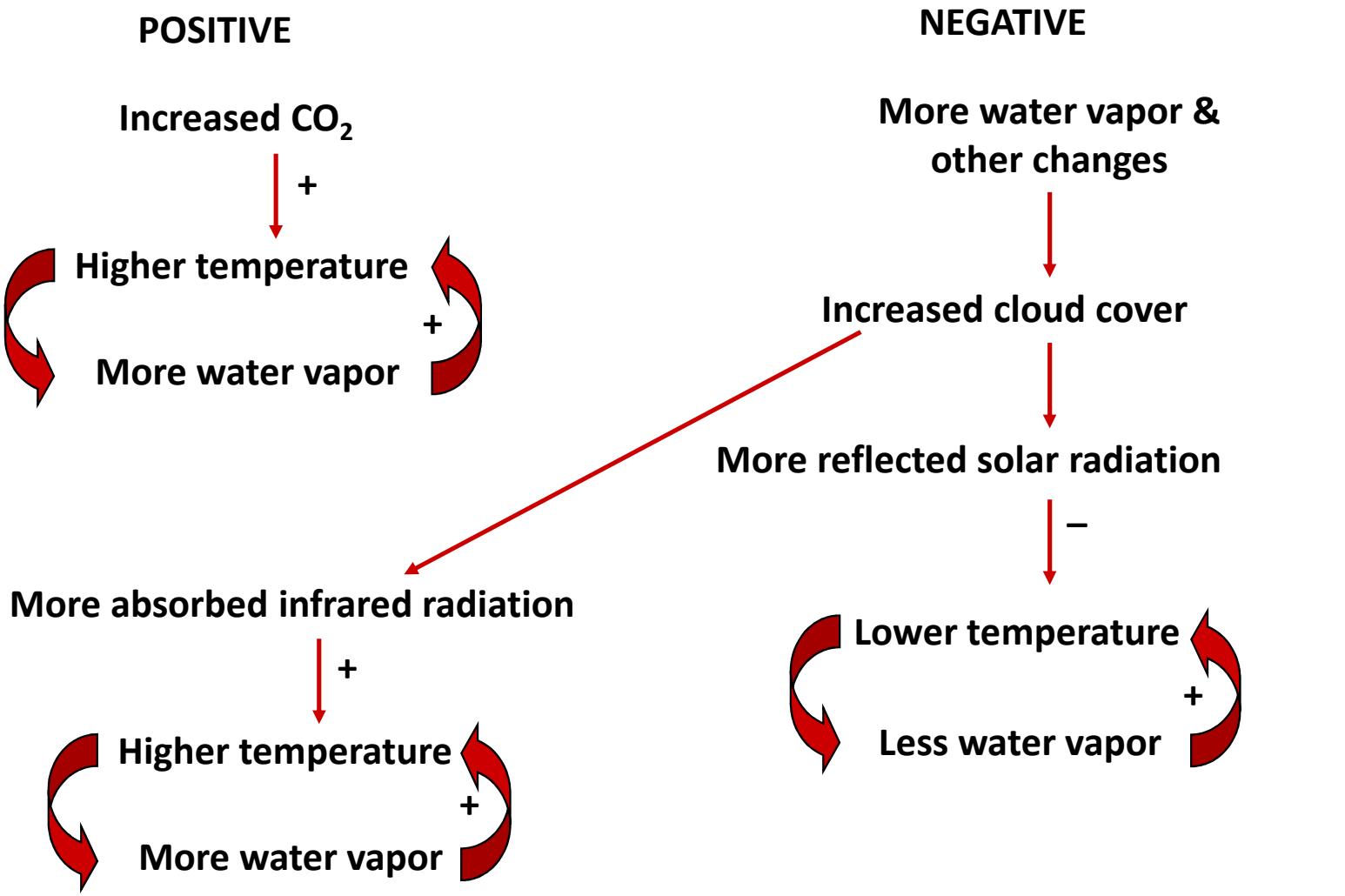
- **Carbon Dioxide (CO_2)**
  - Source: Fossil fuel burning, deforestation
  - Anthropogenic increase: **30%**
  - Average atmospheric residence time: **500 years**
- **Methane (CH_4)**
  - Source: Rice cultivation, cattle & sheep ranching, decay from landfills, mining
  - Anthropogenic increase: **145%**
  - Average atmospheric residence time: **7-10 years**
- **Nitrous oxide (N_2O)**
  - Source: Industry and agriculture (fertilizers)
  - Anthropogenic increase: **15%**
  - Average atmospheric residence time: **140-190 years**

GHG EFFECT AND GLOBAL WARMING

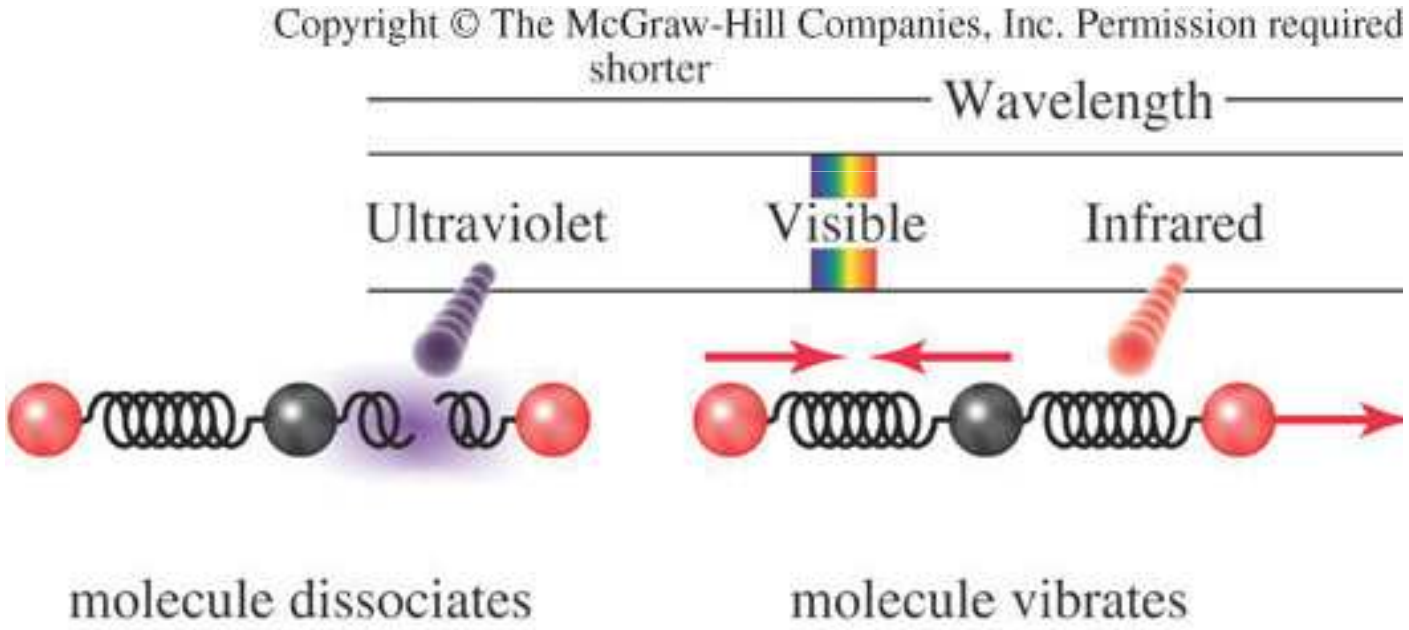
- The ***"greenhouse effect"*** & ***global warming*** are **not** the same thing.
  - Global warming refers to a rise in the temperature of the surface of the earth

- An increase in the ***concentration of greenhouse gases*** leads to an increase in the the ***magnitude of the greenhouse effect***. (Called enhanced greenhouse effect)
  - This results in global warming

ATMOSPHERIC FEEDBACK

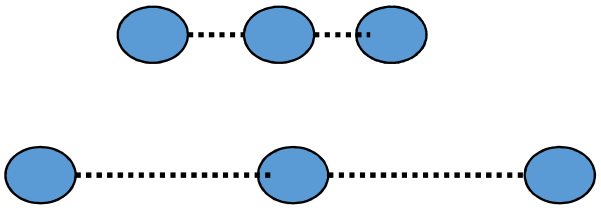


Different Types of Electromagnetic Radiation Do Different "Things" to Molecule

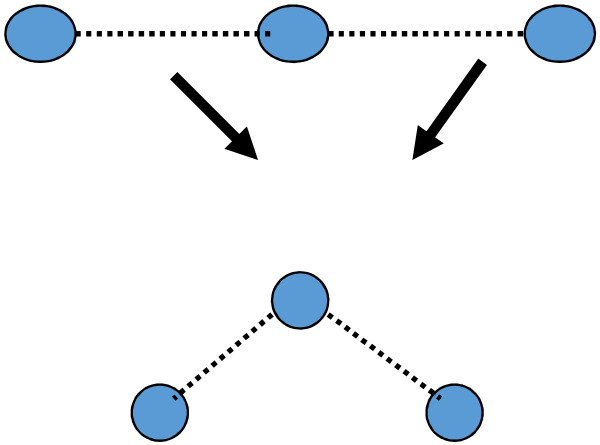


Vibrations of Molecules

- Bond Stretching

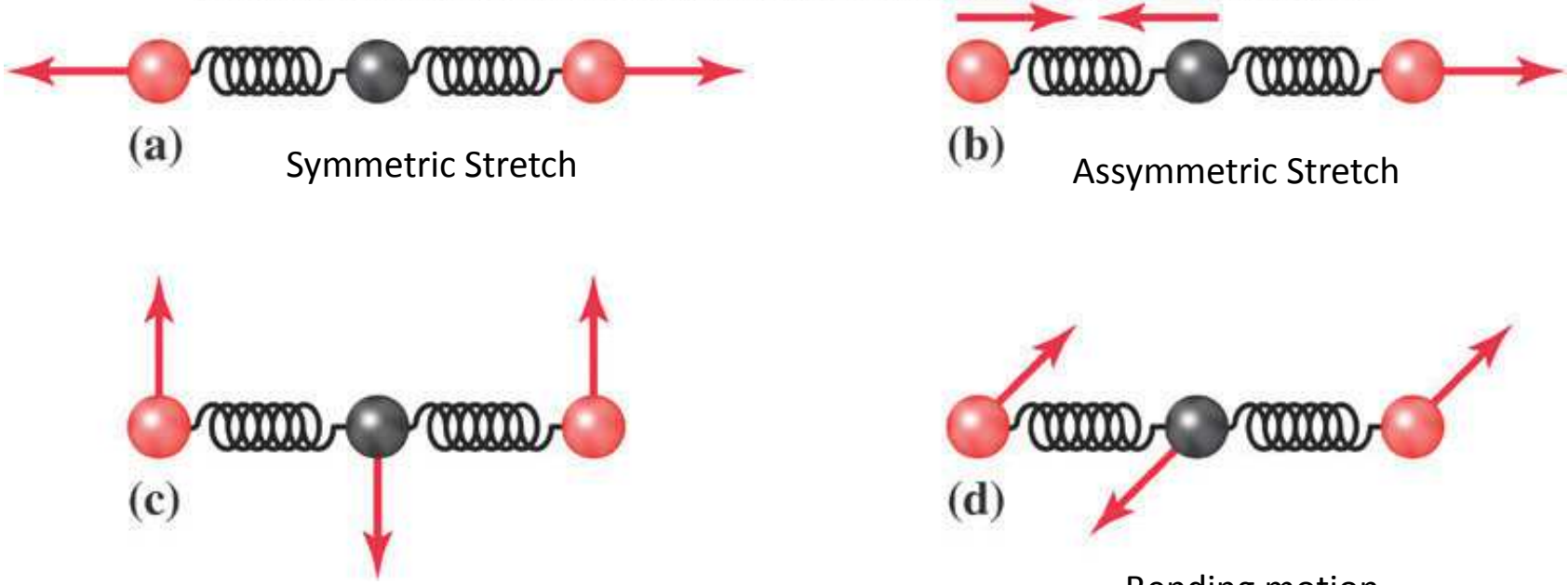


- Molecule Bending



It takes less energy to bend a molecule than stretch a bond.

Vibrations of CO_2 Molecule



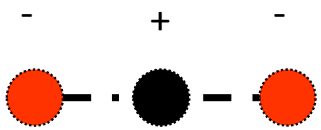
Symmetric Stretch

Assymmetric Stretch

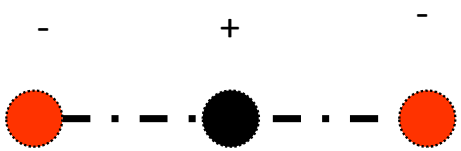
Bending motion

Bending motion

For a bending or stretching motion to absorb IR radiation; it must change the dipole moment of the molecule



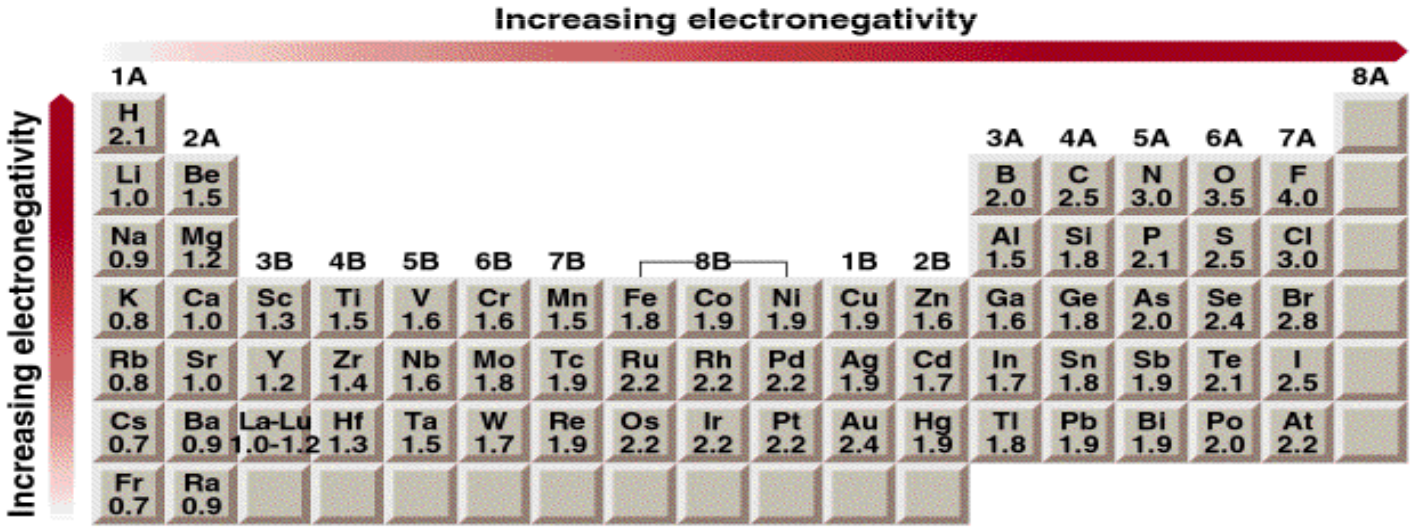
Symmetric Stretch;
IR Inactive



Antisymmetric Stretch;
IR Active

Electronegativity- Measure of an atom's attraction for the electrons it shares in a covalent bond.

Electronegativities of Common Elements



GHG requirements:

- Minimum of 2 atoms needed for stretching bonds
  - Two atoms must be different in order for vibration to change the dipole moment of molecule
- Minimum of 3 atoms needed to bend a molecule

Why Ar not a GHG?

1. Argon is in atomic form. Thus, there is no bond to another atom. So it can't absorb IR to stretch a bond it doesn't have.
2. Argon can't absorb IR to bend a molecule since a minimum of 3 atoms is needed and it has only 1 atom.

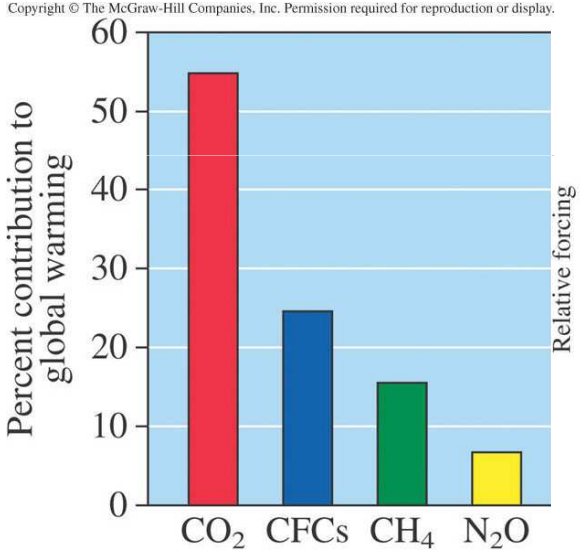
Increasing the GWP of a Greenhouse Gas

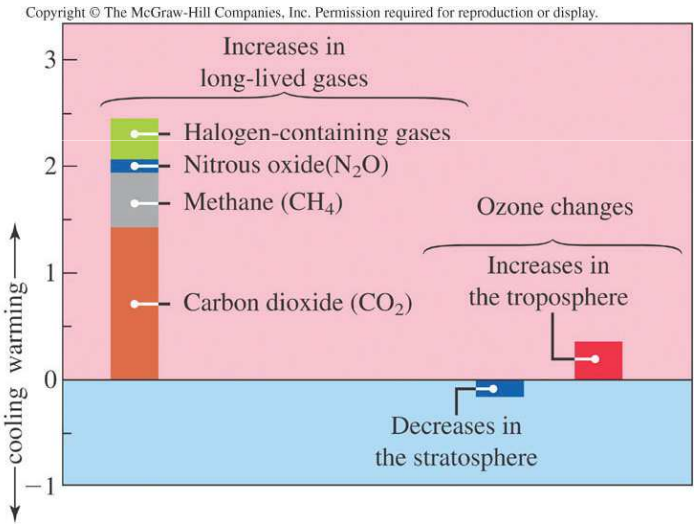
When a different greenhouse gas absorbs in the window region of the IR spectrum; it will have a higher GWP

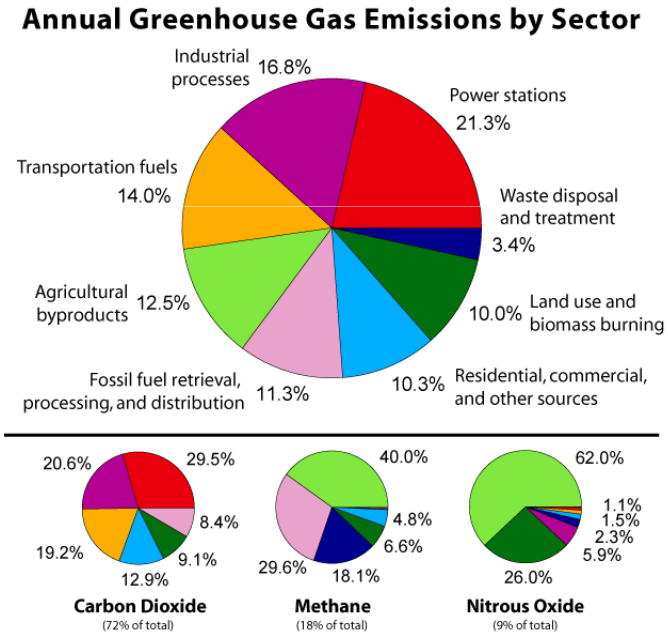
The HIGHER the tropospheric abundance; higher GWP

The LONGER the lifetime of the molecule; higher GWP

Human Contribution of Different Greenhouse Gases to Global Warming







HARBINGERS: Events that foreshadow the types of impacts likely to become more frequent and widespread with continued warming.

- Spreading disease
- Earlier spring arrival
- Plant and animal range shifts and population changes
- Coral reef bleaching
- Downpours, heavy snowfalls, and flooding
- Droughts and fires

Ways an Individual Can Help Reduce Global Warming?

- Reduce use of fossil fuels; car pool, use mass transit, walk, bike
- Use energy efficient appliances and light bulbs
- Plant trees (Cool house with shade trees)
- Use solar energy to heat household as much as possible

GHG EFFECT: SUMMARY

1. Radiation from the Sun drives our climate
2. Our distance from the Sun, and the reflectivity of the Earth determines how much radiation is absorbed
3. Earth's atmosphere traps outgoing radiation (the Greenhouse Effect), warming the surface by about 34°C
4. On Venus, a runaway Greenhouse Effect warms its surface by over 400°C; Mars thin atmosphere warms its surface by about 10°C (CO2 = 95—96 %)
5. So there is good evidence from the other planets that the atmospheric composition is important in determining the surface temperature
6. Global Warming is often called 'The Greenhouse Effect' – really it is the *Enhanced* Greenhouse Effect – the addition of more Greenhouse Gases (mainly from burning fossil fuels) to the atmosphere enhances the existing effect.
7. Humans have also changed the Earth's albedo – mainly by adding aerosols to the atmosphere – these tend to cool climate, offsetting the GHG warming

2.2 MASS OF THE ATMOSPHERE

The global mean pressure at the surface of the Earth is P_S = 984 hPa, slightly less than the mean sea-level pressure because of the elevation of land. We deduce the total mass of the atmosphere m_a:

$$m_a = \frac{4\pi R^2 P_S}{g} = 5.2x10^{18} kg \qquad (2.2)$$

where R = 6400 km is the radius of the Earth. The total number of moles of air in the atmosphere is $N_a = m_a/M_a = 1.8x10^{20}$ moles.

Exercise 1-1 Calculate the number densities of air and CO_2 at sea level for P = 1013 hPa, $T = 0^{o}$C.

Answer: Apply *(1.6)* to obtain the number density of air n_a. Use International System (SI) units at all times in numerical calculations to ensure consistency:

$$n_a = \frac{A_v P}{RT} = \frac{(6.023\text{x}10^{23}) \cdot (1.013\text{x}10^{5})}{8.31 \cdot 273} = 2.69\text{x}10^{25} \text{ molecules m}^{-3}$$

After you obtain the result for n_a in SI units, you can convert it to the more commonly used unit of molecules cm ^{3}: $n_a = 2.69\text{x}10^{19}$ molecules cm ^{3}. The air density at sea level does not vary much around the world; the sea-level pressure varies by at most 5%, and the temperature rarely departs by more than 15% from 273 K, so that n_a remains within 25% of the value calculated here.

The number density of CO_2 is derived from the mixing ratio C_{CO2} = 365 ppmv:

$$n_{CO2} - C_{CO_2} n_a - 365\text{x}10^{-6}\text{x}2.69\text{x}10^{25} - 9.8\text{x}10^{21} \text{ molecules m}^{-3}$$

Exercise 2-1. Atmospheric CO_2 concentrations have increased from 280 ppmv in preindustrial times to 365 ppmv today. What is the corresponding increase in the mass of atmospheric carbon? Assume CO_2 to be well mixed in the atmosphere.

Answer. We need to relate the mixing ratio of CO_2 to the corresponding mass of carbon in the atmosphere. We use the definition of the mixing ratio from equation *(1.3)*,

$$C_{CO2} = \frac{n_{CO2}}{n_a} = \frac{N_C}{N_a} = \frac{M_a}{M_C} \cdot \frac{m_C}{m_a}$$

where N_C and N_a are the total number of moles of carbon (as CO_2) and air in the atmosphere, and m_C and m_a are the corresponding total atmospheric masses. The second equality reflects the assumption that the CO_2 mixing ratio is uniform throughout the atmosphere, and the third equality reflects the relationship $N = m/M$. The change Δm_C in the mass of carbon in the atmosphere since preindustrial times can then be related to the change ΔC_{CO2} in the mixing ratio of CO_2. Again, always use SI units when doing numerical calculations (this is your last reminder!):

$$\Delta m_C = m_a \frac{M_C}{M_a} \cdot \Delta C_{CO2} = 5.2\text{x}10^{18} \cdot \frac{12\text{x}10^{-3}}{29\text{x}10^{-3}} \cdot (365\text{x}10^{-6} - 280\text{x}10^{-6})$$

$$= 1.8\text{x}10^{14}\ \text{kg} = 180\ \text{billion tons!}$$

QUESTIONS

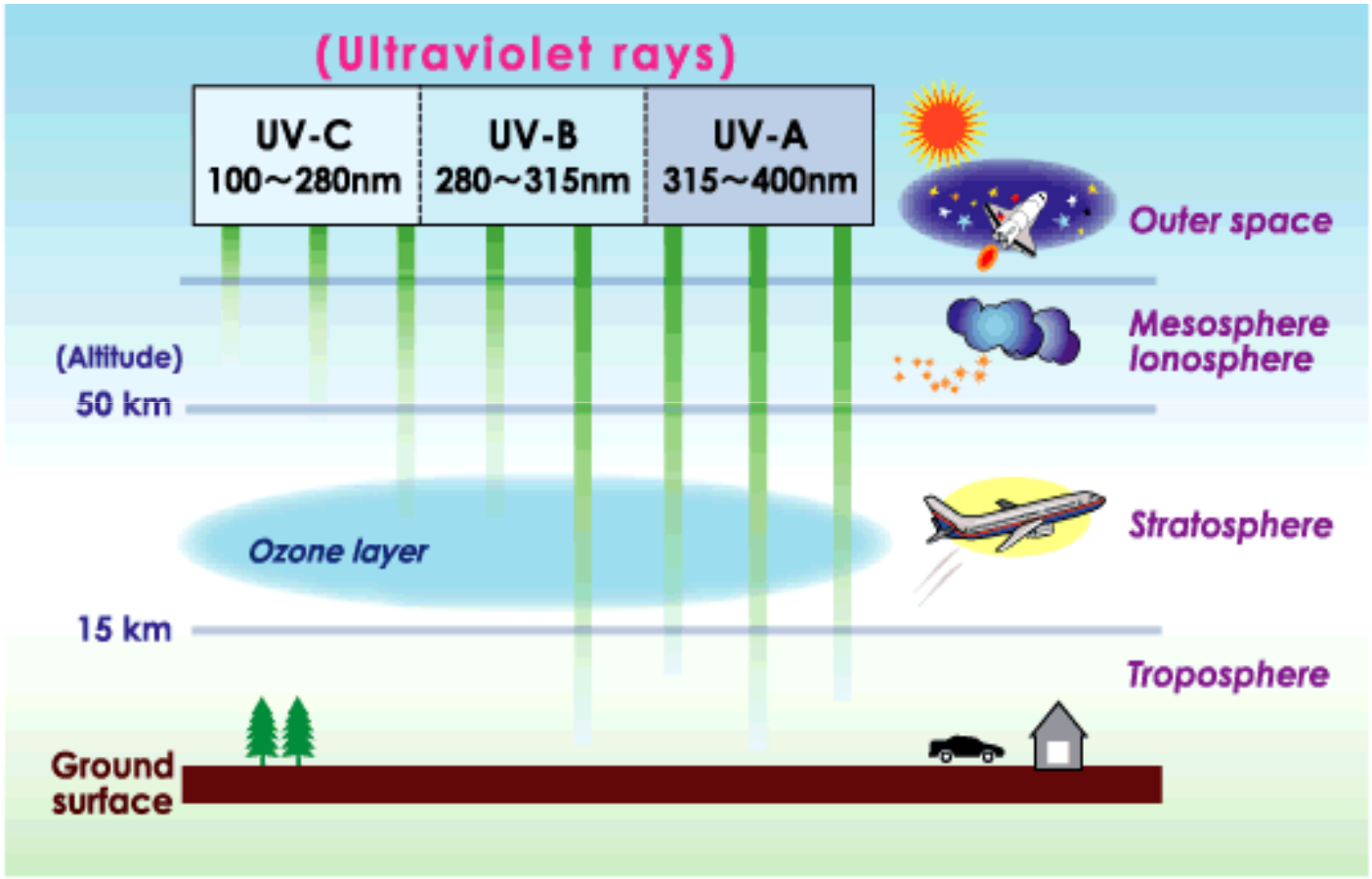
- What would be the surface temperature if there is no GHG effect?
- What is a GHG gas and what is GH effect?
- Why Ar is not a GHG, but CO2 is?
- How can we reduce GHG or Global Warming?

“The Ozone Treaty is] the first truly global treaty that offers protection to every single human being.”

~ Mostofa K. Tolba, Director of the UNEP

OZONE DEPLETION

OZONE DEPLETION



UV ozone generation and destruction: equilibrium

- $O_2 + h\upsilon_{185} \rightarrow 2O^{\cdot}$
- $O^{\cdot} + O_2 + M \rightarrow O_3 + M$
- $O_3 + h\upsilon_{254} \rightarrow O_2 + O^{\cdot}$

Equilibrium between production and destruction

The catalyzed cycle

1. $h\upsilon + O_2 \rightarrow 2O\cdot$
2. $O\cdot + O_2 \rightarrow O_3$
3. $O_3 + X \rightarrow O_2 + OX$
4. $OX + O\cdot \rightarrow O_2 + X$

X could be Cl from a CFC

Winter reactions /POLAR REGIONS

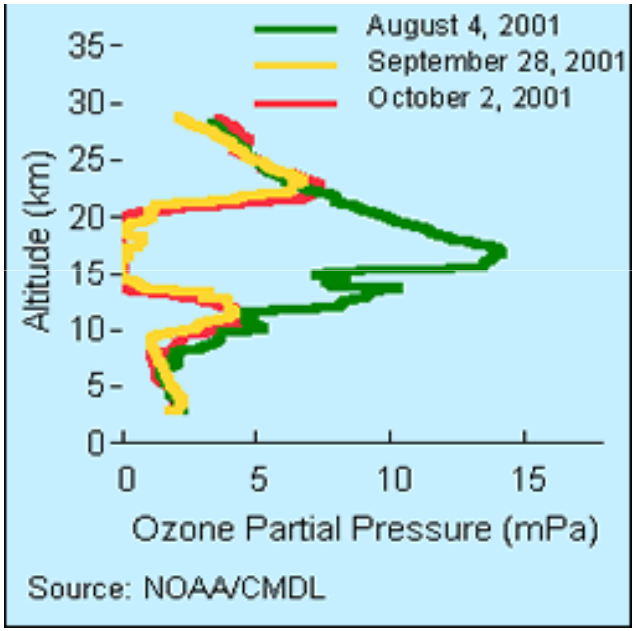
- Polar vortex: -90 ^{o}C ➔ Ice clouds

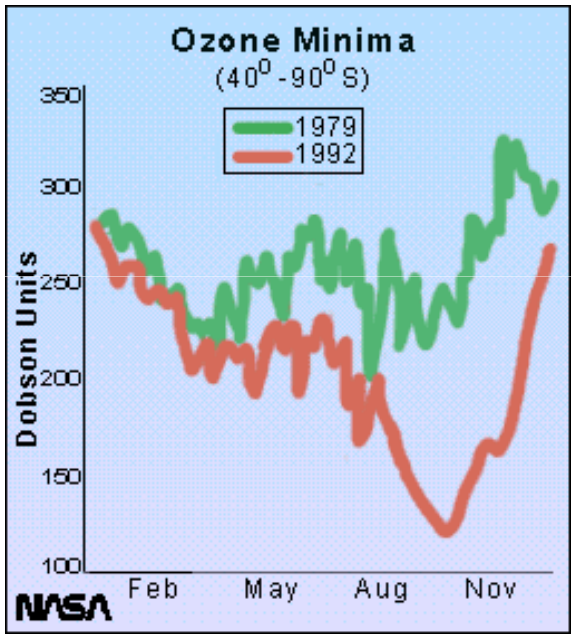
- $ClONO_2 + H_2O \rightarrow HOCl + HNO_3$
- $HOCl + HCl \Leftrightarrow Cl_2 + H_2O$

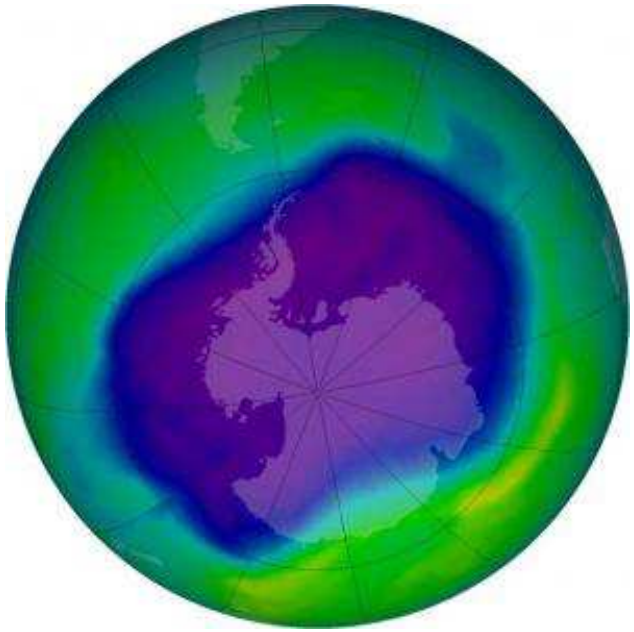
Spring reactions

- $Cl_2 + h\upsilon \rightarrow 2\ Cl$ *in early spring*
- $Cl + O_3 \rightarrow ClO + O_3$ *destructive loop*
- $HNO_3 + Cl \rightarrow ClONO_2$ *in photocatalysis*

OZONE DEPLETION







The Nobel Prize in Chemistry 1995

Paul J. Crutzen

The Netherlands

Max-Planck-Institute
for Chemistry Mainz, Germany

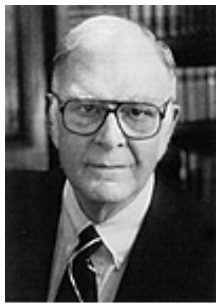
1933 -

Mario J. Molina

USA

MIT, USA
Cambridge, MA

1943 -



F. Sherwood Rowland

USA

Department of Chemistry,
University of California
Irvine, CA, USA

1927 -

"for their work in atmospheric chemistry, particularly concerning the formation and decomposition of ozone"

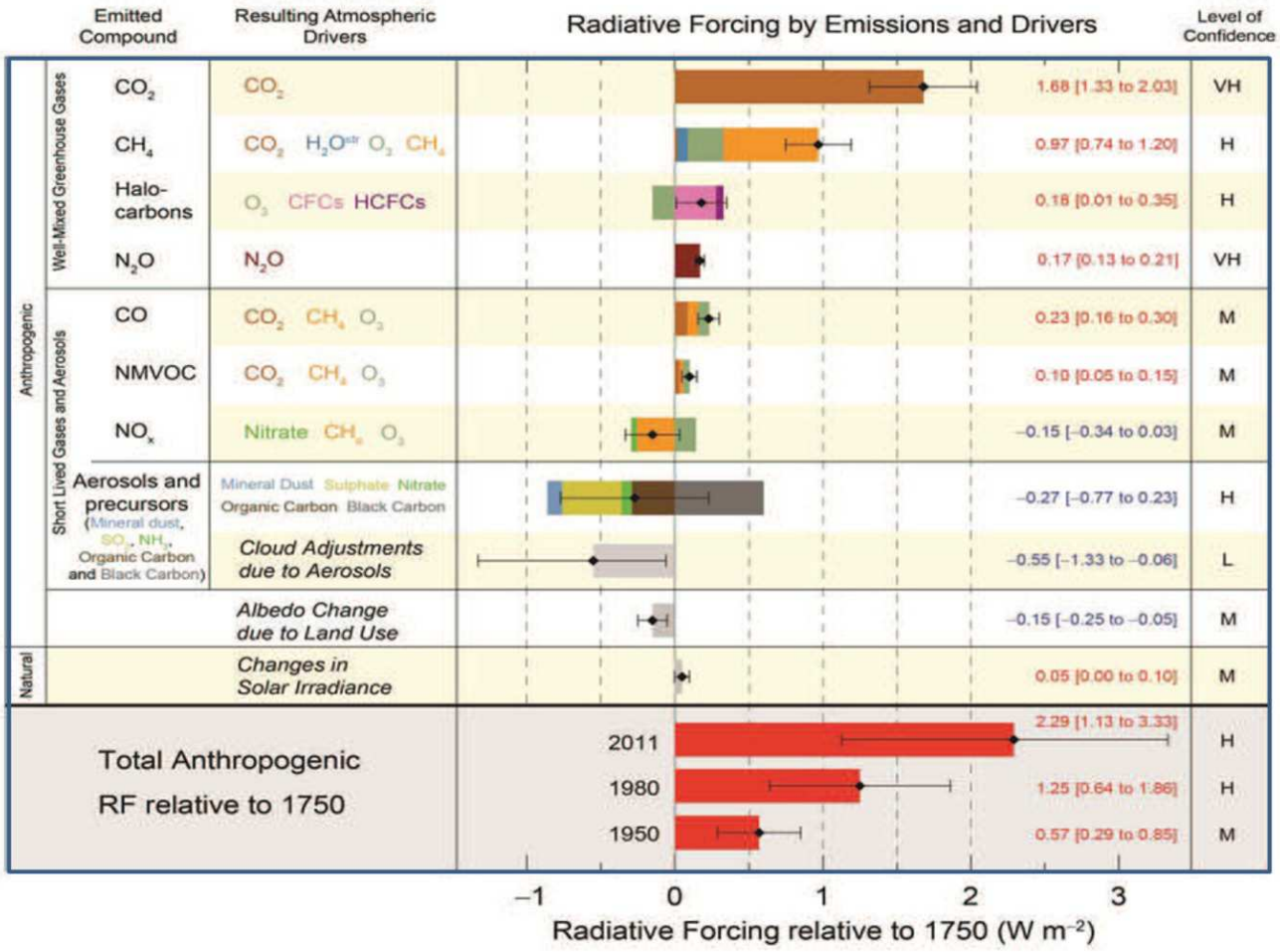
QUESTIONS

- What is ozone and what is ozone layer?
- What is the significance stratospheric ozone?
- Why stratospheric ozone is good, tropospheric ozone is bad?
- What is stratospheric ozone depletion and What is ozone hole?

GLOBAL ATMOSPHERIC CHANGE

CLIMATE CHANGE

"Radiative forcing is a measure of the influence, a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism. In this report radiative forcing values are for changes relative to preindustrial conditions defined at 1750 and are expressed in Watts per square meter (W/m^2)." (IPCC, 2007)



IPCC, 2013

GLOBAL CHANGE

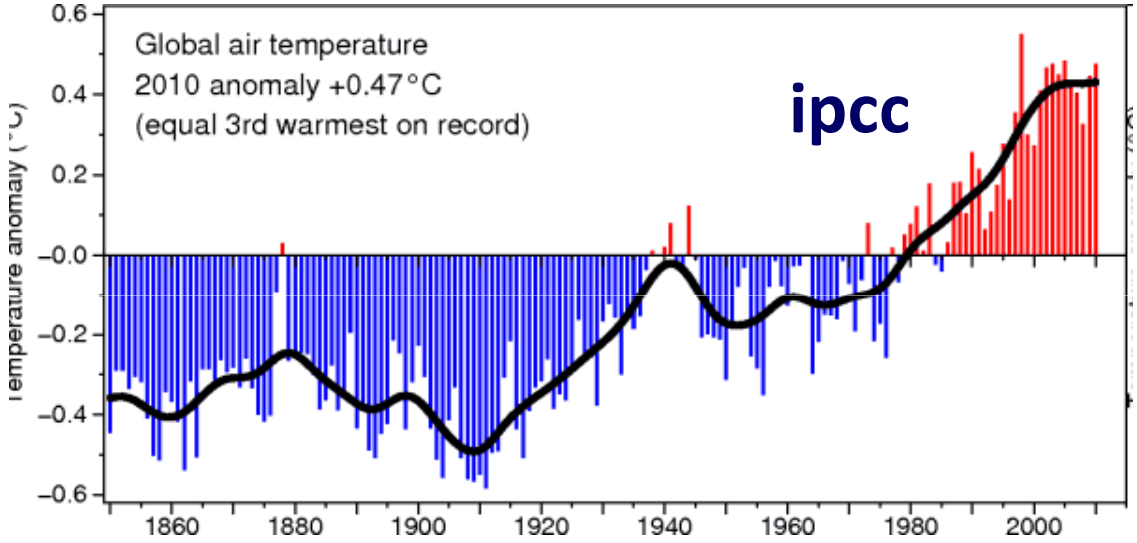
CLIMATE CHANGE EVIDENCE

- **Surface warming has increased**, with 11 of the past 12 years being the warmest since 1850. Balloon and satellite data confirm same trend in the atmosphere.
- **Water vapor content has increased.**
- **Ocean temperatures have increased** to depths of at least 3 km.
- **Mountain glaciers and snow cover have declined** in both hemispheres
- **New data show it is very likely that Greenland** and Antarctic ice sheet losses have led to sea level rises.
- Rates of **sea level rise have increased** from about 2 mm /year (1961 – 2003) to about 3 mm/ year (1993 – 2003).
- **Arctic temperatures have increased** at twice the global average rate and permafrost temperatures have increased by about 3°C.

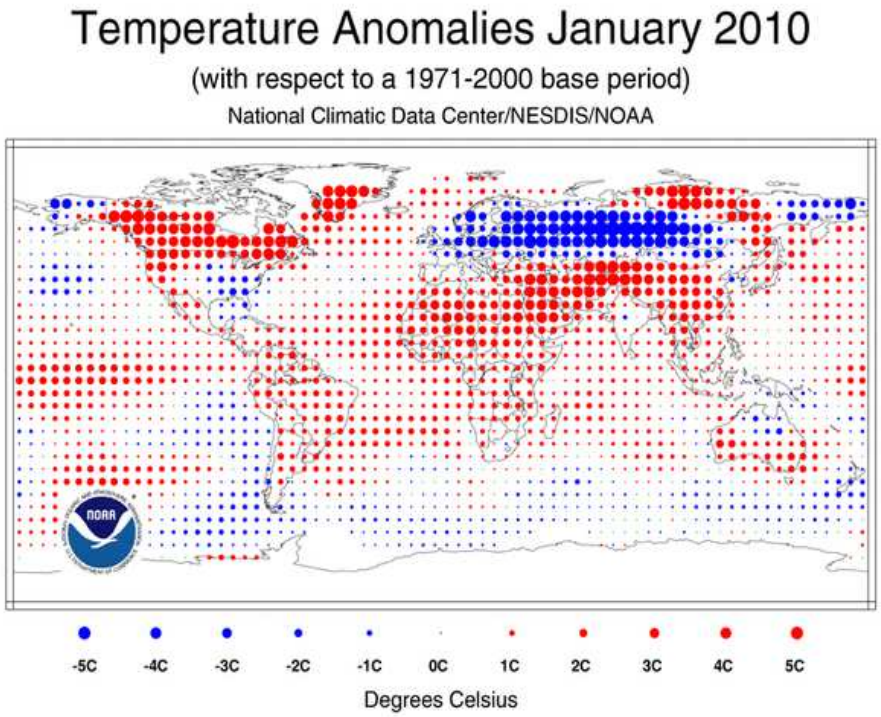
CHNAGES OBSERVED FOR

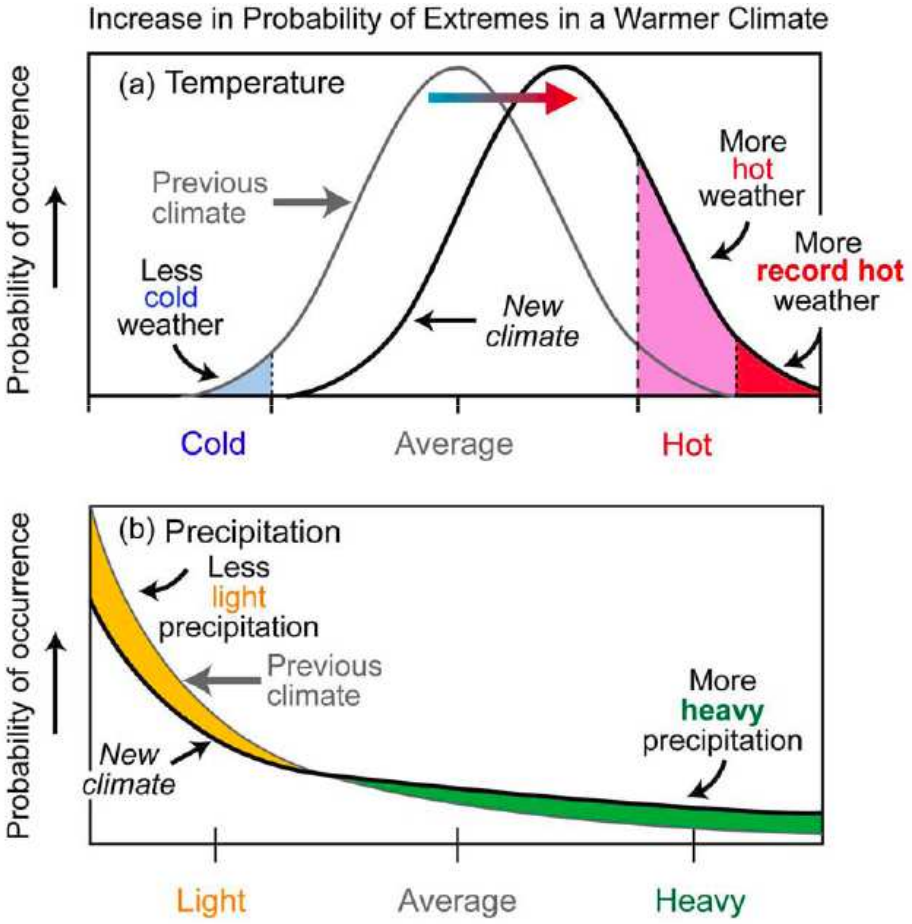
TEMPERATURE, PRECIPITATION, GLACIERS, GHGs, SEA LEVEL, AND ENSO

CLIMATE CHANGE EVIDENCE: TEMPERATURE



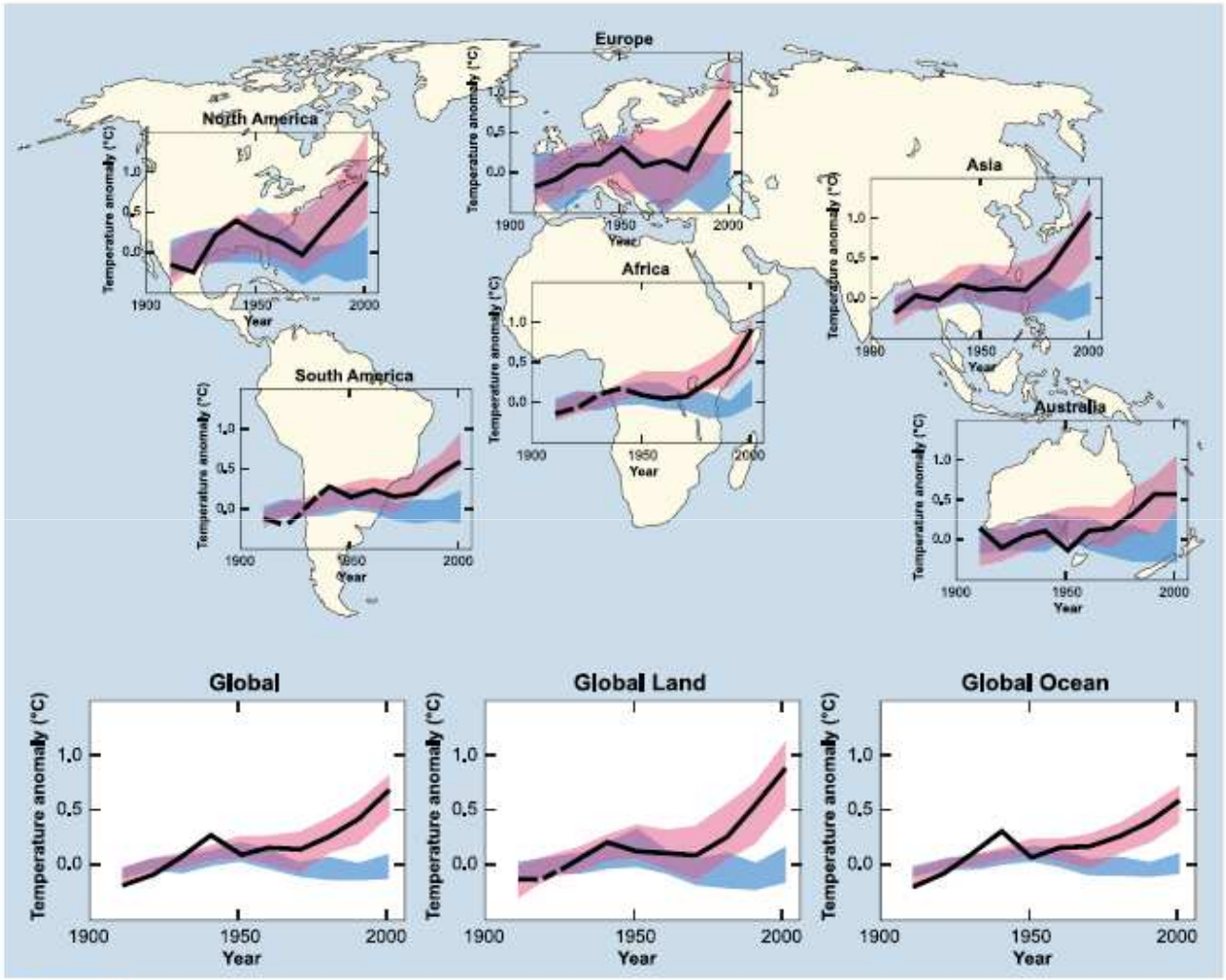
CLIMATE CHANGE EVIDENCE: TEMPERATURE





The Land and Oceans Have Warmed

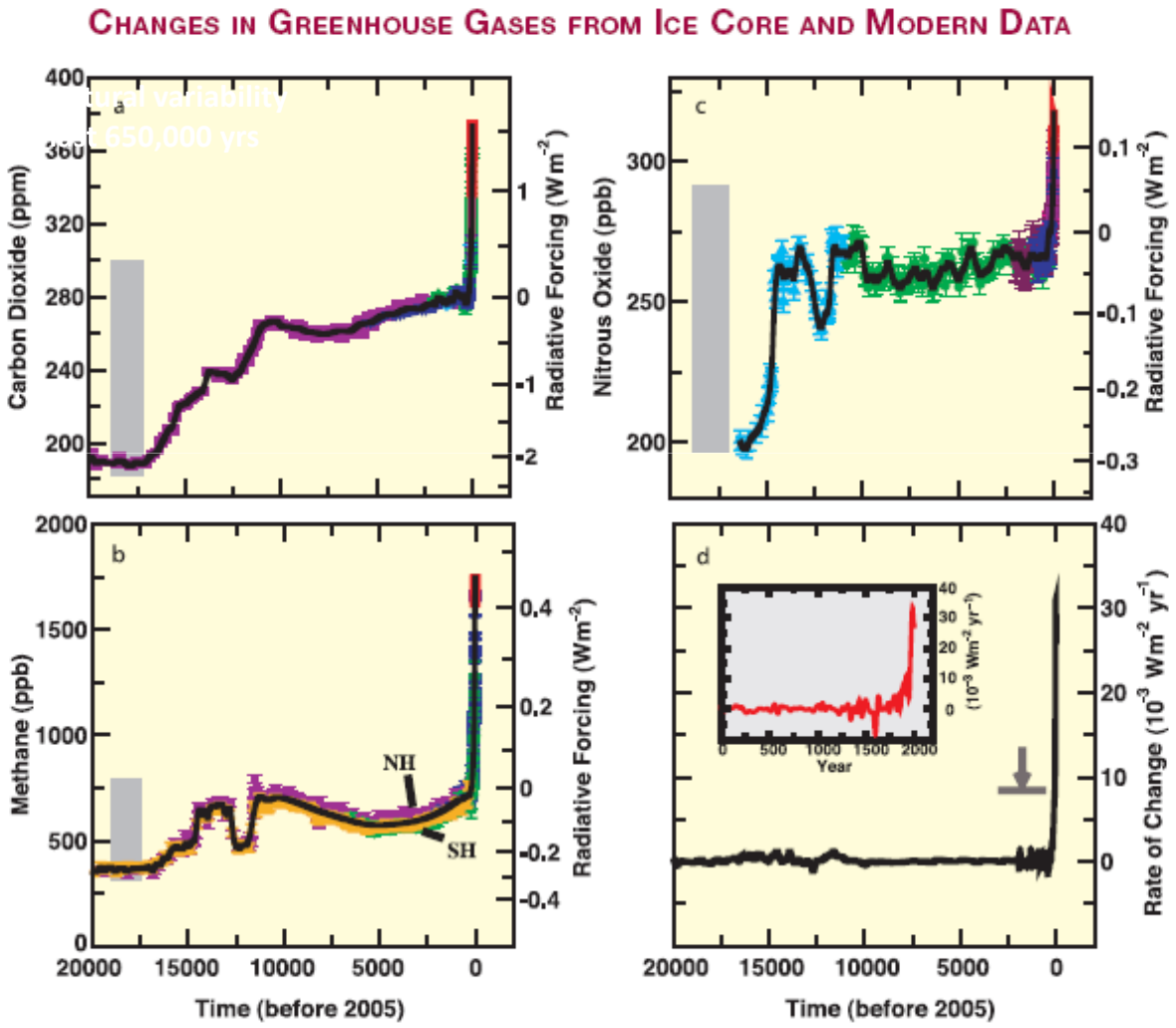
Global and Continental Temperature Change



TEMPERATURE CHANGE ATTRIBUTION

- It is *extremely unlikely* that global warming patterns can be explained without external forcing.
- It is *very likely* that anthropogenic greenhouse gases have contributed to most of the warming.
- Without atmospheric aerosols it is *likely* that temperature rise would have been greater.

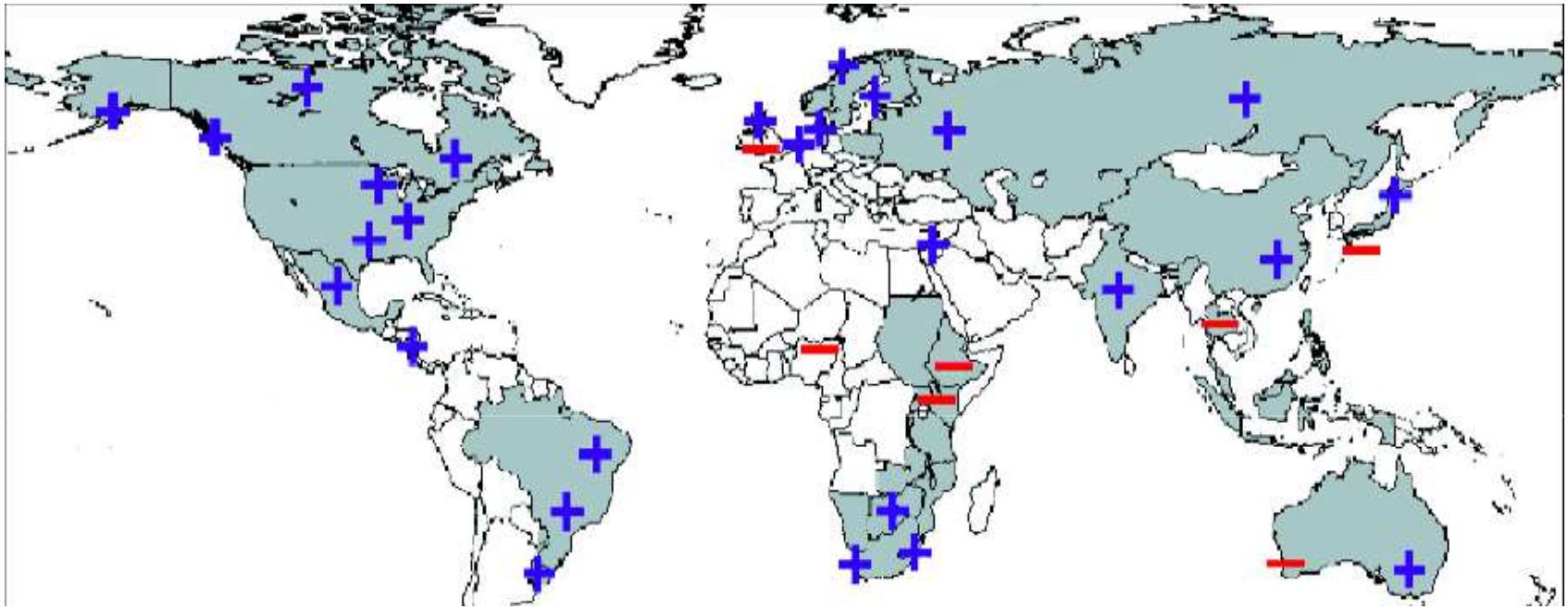
CLIMATE CHANGE EVIDENCE: ATTRIBUTION; GHGs



Rate of change of combined forcing

IPCC(2007)

CLIMATE CHANGE EVIDENCE: PRECIPITATION PATTERNS

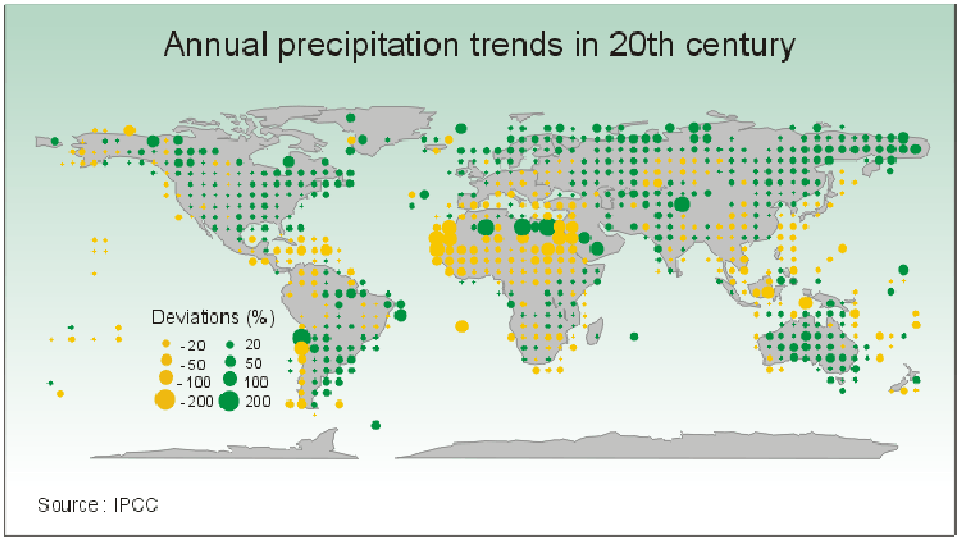


The frequency of heavy precipitation events has increased over most land areas - consistent with warming and increases of atmospheric water vapor while more intense and longer droughts have been observed since the 1970s, particularly in the tropics and subtropics.

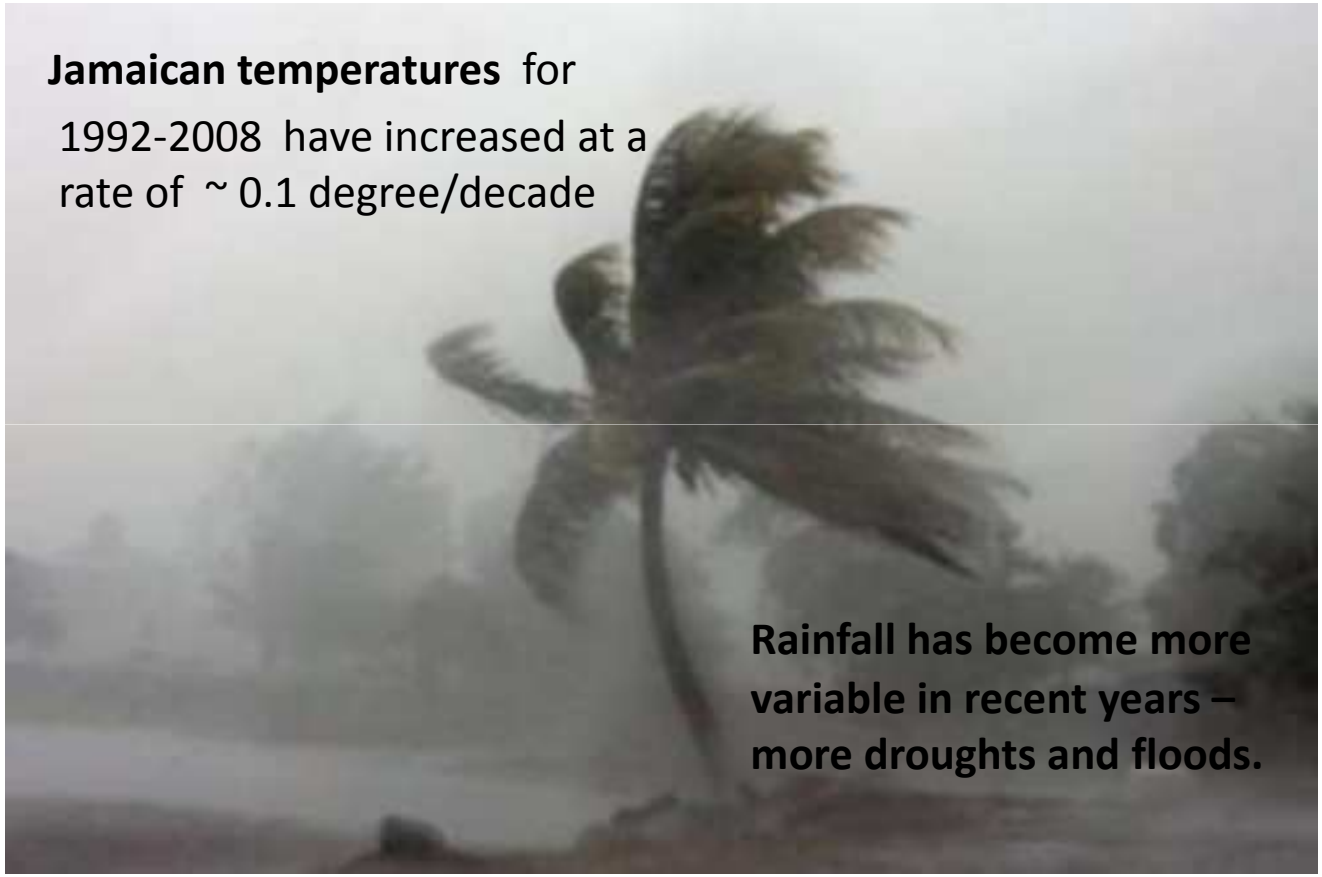
CLIMATE CHANGE EVIDENCE: PRECIPITATION PATTERNS

- **PRECIPITATION PATTERN CHNAGES**

- The world has seen changes in **amount, intensity, frequency and type** of precipitation.
- **Rainfall strongly characterized by year to year variations.**



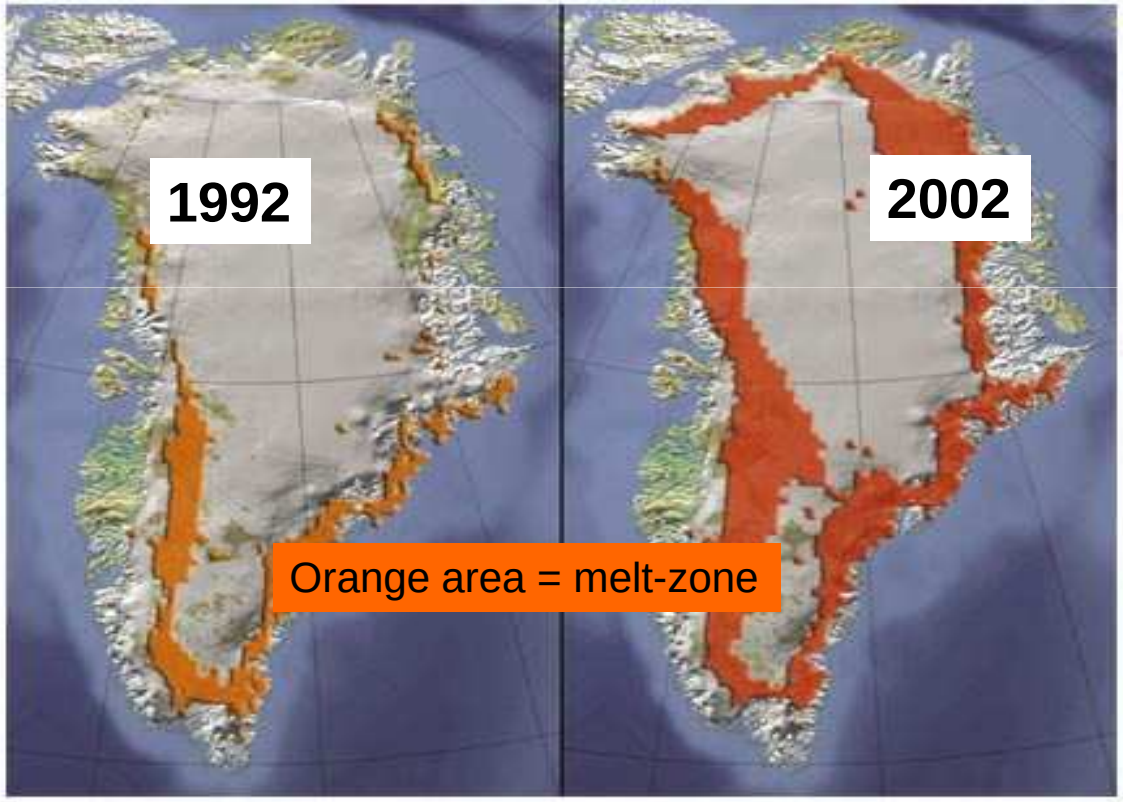
CLIMATE CHANGE EVIDENCE: PRECIPITATION PATTERNS



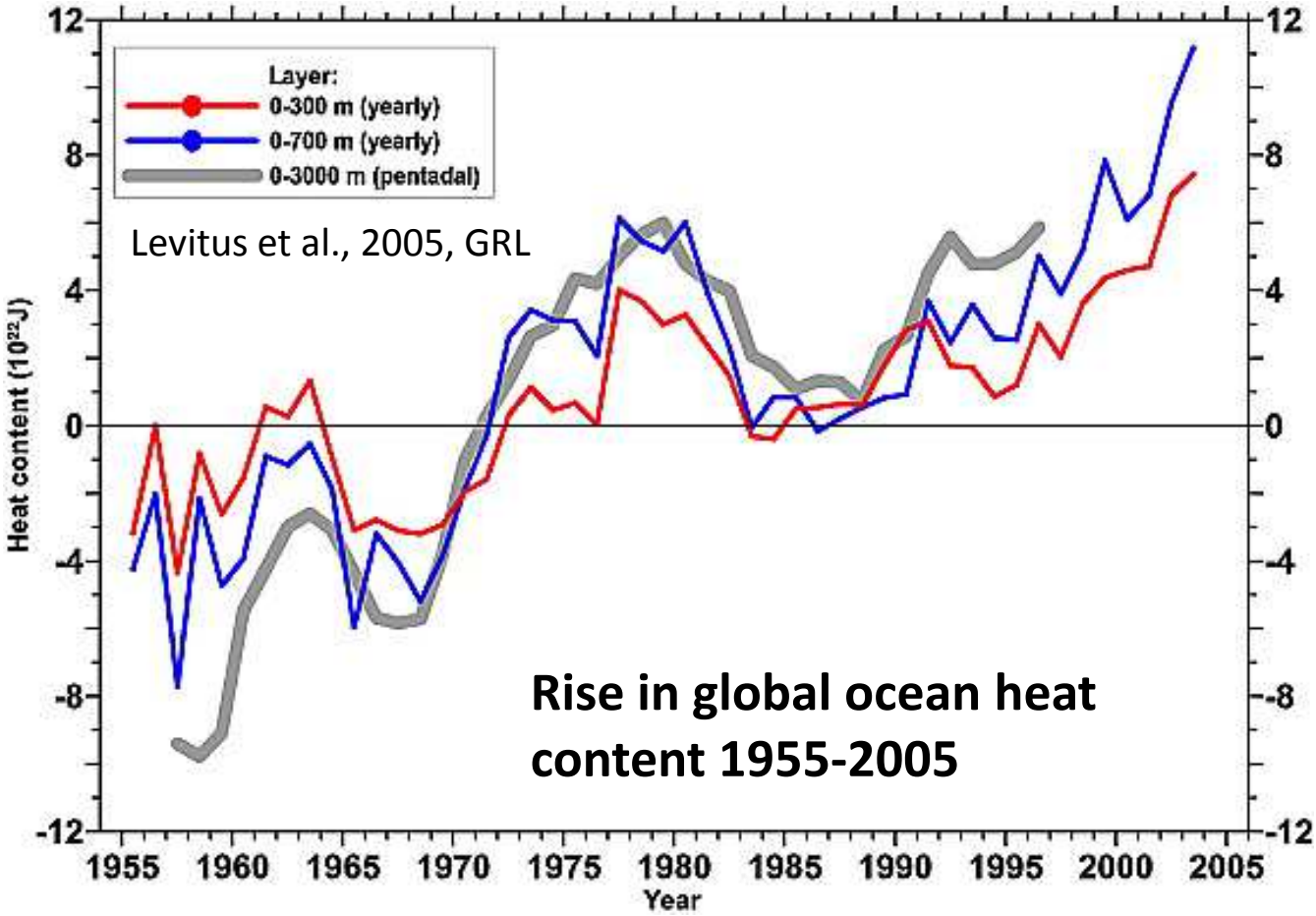
CLIMATE CHANGE EVIDENCE: GLACIAL RETREAT

Greenland Ice Sheet

(Arctic Climate Impact Assessment, 2004)

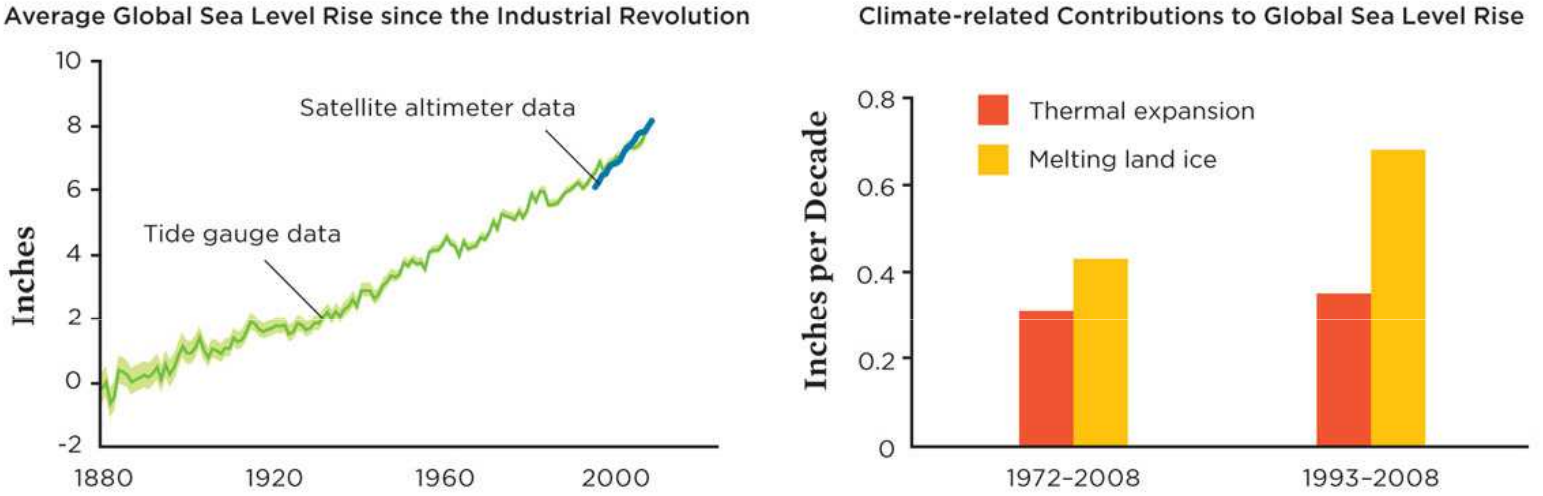


CLIMATE CHANGE EVIDENCE: SEA LEVEL RISE



CLIMATE CHANGE EVIDENCE: SEA LEVEL RISE

FIGURE 1. Global Sea Level Rise and Recent Causes



Loss of ice on land and thermal expansion of seawater—both primarily caused by global warming—have been the key drivers of an average global sea level rise of about eight inches since 1880. Tide gauges around the world have recorded the long-term rise in sea level since 1870 (green line with shaded error range). Satellite observations since 1993 (blue line) have confirmed the trend.

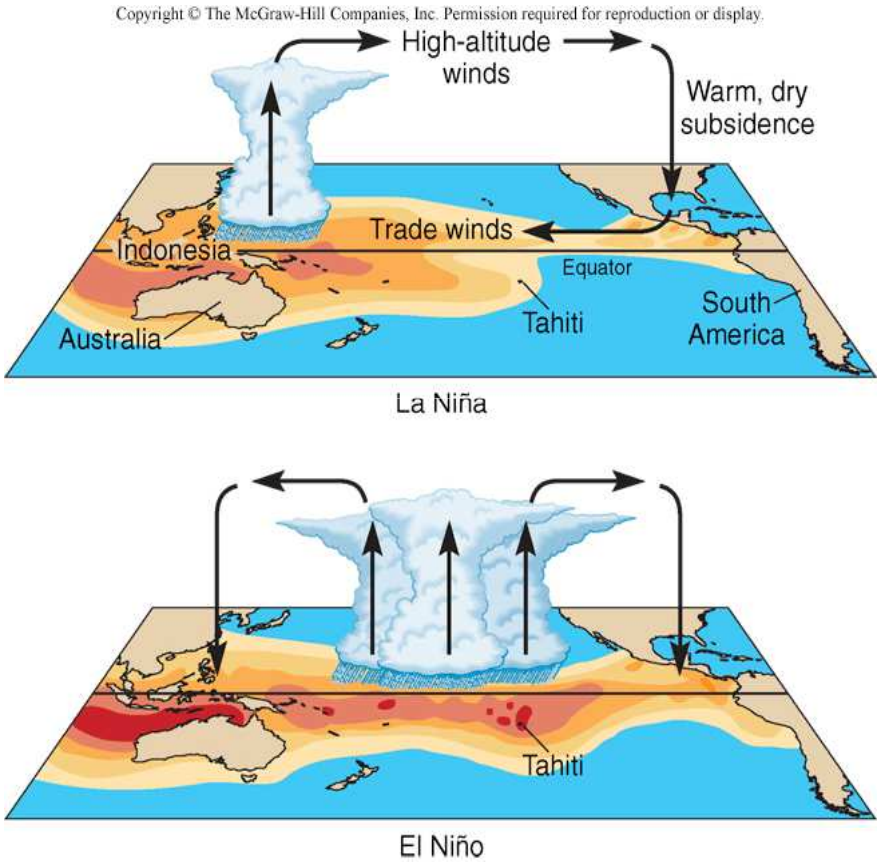
SOURCES: NRC 2012; CHURCH ET AL. 2011; CAZENAVE AND LLOVEL 2010.

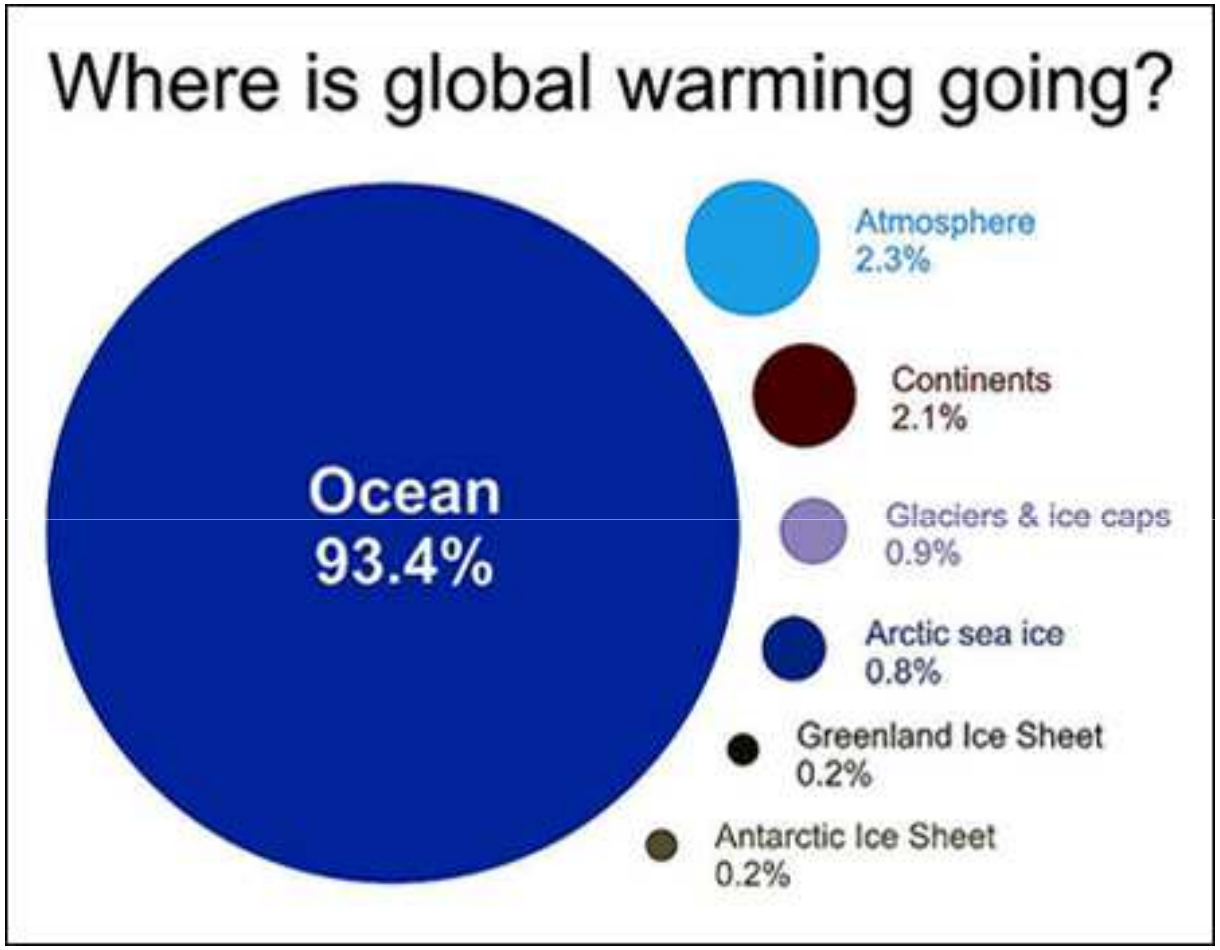
From 1972 to 2008, melting land ice—glaciers, ice caps, and ice sheets—accounted for 52 percent of sea level rise, while warmer oceans contributed 38 percent. Groundwater withdrawal and other factors, both known and unknown, contributed the remaining 10 percent. Ice loss has accelerated since the early 1990s, and has accounted for 75 percent to 80 percent of sea level rise since 2003.

SOURCES: NRC 2012; CHURCH AND WHITE 2011; CAZENAVE AND LLOVEL 2010; NICHOLLS AND CAZENAVE 2010.

CLIMATE CHANGE EVIDENCE: ENSO

- Trade winds keep warm water in W. Pacific. La Nina
- El Nino: **Shift in tropical depression**
- **Northern Jet stream split changes rainfall patterns**




Where is global warming going?
Ocean
93.4%
Atmosphere
2.3%
Continents
2.1%
Glaciers & ice caps
0.9%
Arctic sea ice
0.8%
Greenland Ice Sheet
0.2%
Antarctic Ice Sheet
0.2%

CLIMATE CHANGE: NO EVIDENCE

No SIGNIFICANT CHANGE HAS BEEN OBSERVED **for :**

- **Tornadoes**
- **Dust-storms**
- **Hail**
- **Lightning**
- **Antarctic sea ice**

GLOBAL CHANGE: SUMMARY

- Global surface temperatures have risen by about 0.6°C since 1900

- The 1990s were the warmest decade in the last millennium.
- The warming differs in different parts of the world, but over the last 25 years, almost everywhere has warmed, and very few places have cooled.

- In addition, e.g.:
  - Sea level has risen by about 20 cm,
  - Ocean heat content has increased,
  - Almost all mountain glaciers have retreated
  - Major climate anomalies (Elnino)
  - Factors acting together for air temp. increase (ENSO, PDO, AO, GW)

GLOBAL CHANGE: SUMMARY

- Not all recent increases in global temperatures are due to anthropogenic sources.
- Global temperatures and CO_2 concentrations in ice cores are strongly correlated. Coincident with this global warming, levels of CO_2 (and other GHGs) have dramatically increased.
- The relative importance of various greenhouse gases is given by their relative abundance and global warming potential.
- Controlling population growth and economic development, energy conservation, alternate energy sources, and CO_2 sequestration are key elements in mitigating climate change.

QUESTIONS

- What is global atmospheric change?
- What are the manifestations of global change?
- What are the observational evidence presented in IPCC report regarding the global change or Global warming effects?