

# Lecture 28 Global Warming



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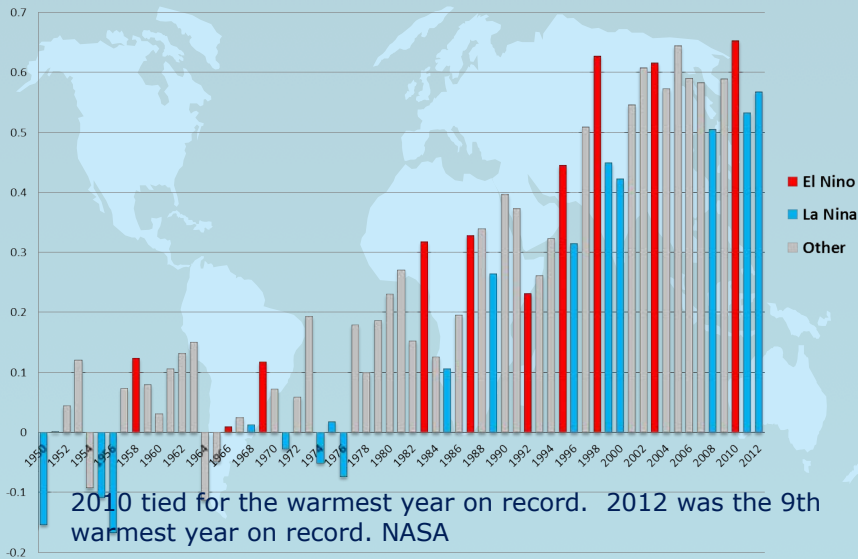
# Lecture 28 Global Warming



"2010 tied for the warmest year on record" NASA. 2012 was the 9th warmest year on record.

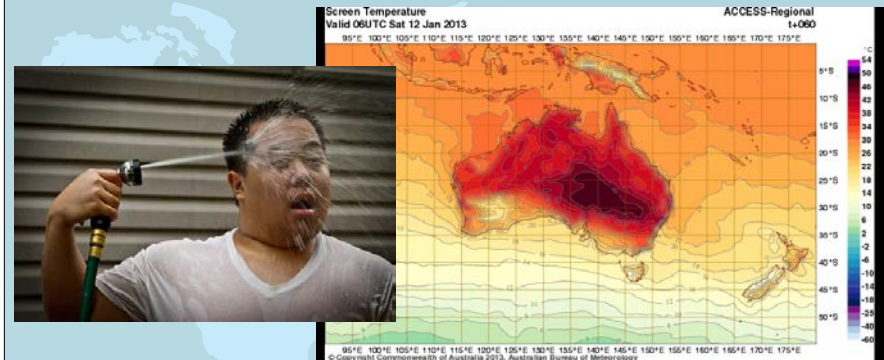
2

## Annual Global Temperature Anomalies 1950 - 2012



3

## Heat Wave Down Under



A temperature map of Australia shows expected temperatures approaching 50 degrees Celsius (122 degrees Fahrenheit) in some parts of the country Jan. 12. The Bureau of Meteorology added recently two new colors -- pink and deep purple -- to the top of its temperature spectrum, anticipating new highs. (Bureau of Meteorology)

4

## Previous Lecture: Climate Change



The climate of the Earth as a whole is controlled by the balance between incoming and outgoing radiation.

Climate can be defined as the accumulation of daily and seasonal weather events over a long period of time.

5

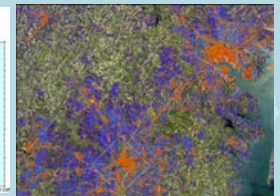
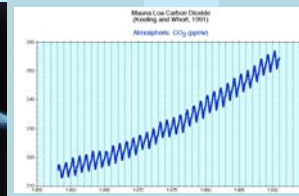
## Climate Forcing = Changes to the Earth's Radiation Balance

### External Forcing

- Astronomical
- Solar Output
- Orbital Changes
- Interplanetary dust
- Collision with comet/asteroid

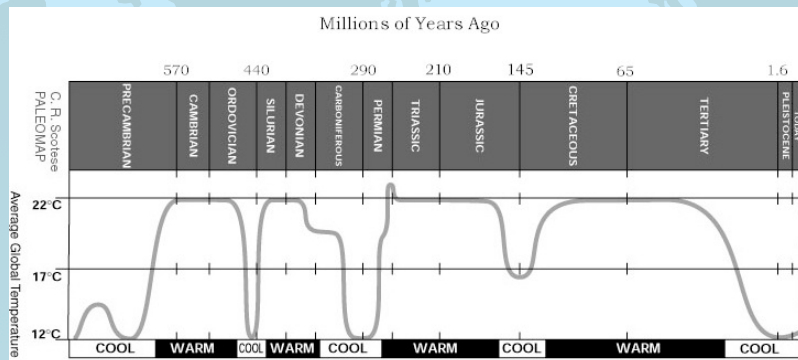
### Internal Forcing

- Atmospheric composition
- Surface Characteristics
- Ocean Currents
- Volcanic Activity
- Continental Drift



6

## Last ~Billion Years of Past Climate Were Warmer and Wetter than Today

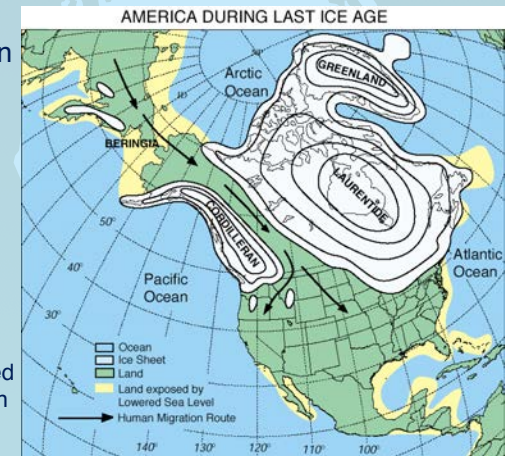


Throughout most of earth's history the temperature was warmer and wetter than today. Warm periods of hundreds of millions of years (think dinosaurs) interrupted by glacial periods.

7

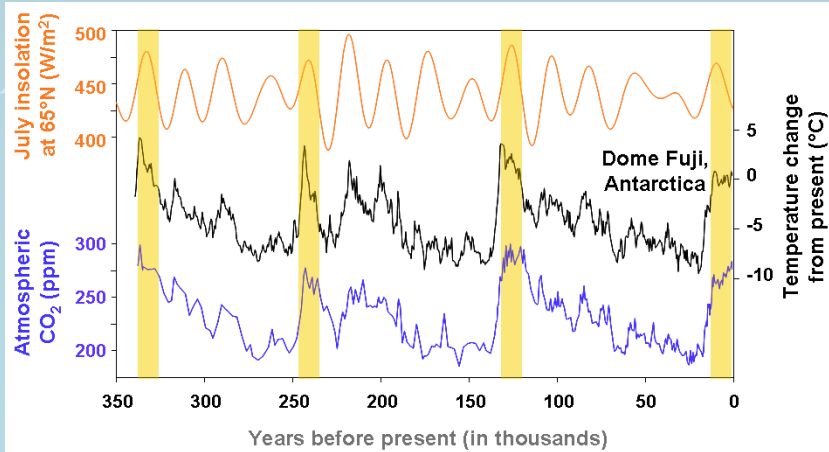
## Last ~Million Years of Past Climate Were Colder and Drier than Today

- The most recent series of Ice Ages began ~ 2 million years ago. Temperature variations linked to orbital changes.
- Recent N. American glaciers at maximum ~18,000 years ago
  - Sea level 125 m lower
  - Bering land bridge allowed Asia/N. America migration



8

## Orbital Changes and Future Climate

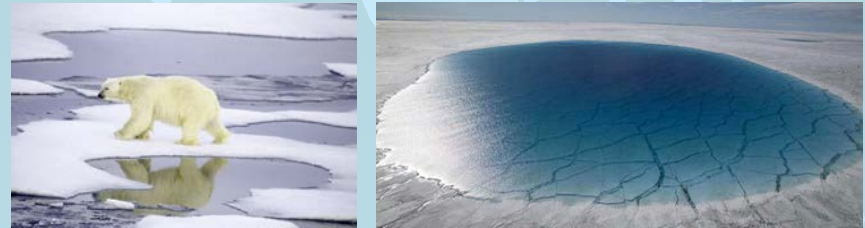


The amount of solar radiation (insolation) in the Northern Hemisphere at 65° N seems to be related to occurrence of past ice ages.

9

## Climate Feed-Back Mechanisms

- Positive-feedback mechanisms produce results that are the opposite of the initial change and tend to reinforce it.
- For example, warmer surface temperatures cause ice to melt, reducing the albedo and making more solar radiation available to warm the planet.



10

## Lecture 28 Global Warming



The climate of the Earth as a whole is controlled by the balance between incoming and outgoing radiation.

11

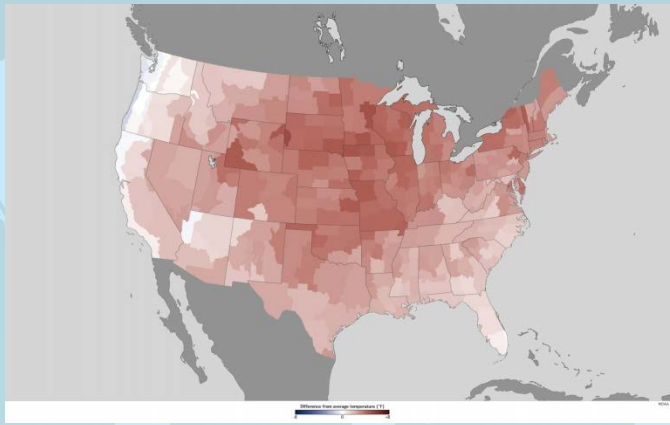
## Outline

1. What is the evidence for global warming? Just the facts.
2. What are the impacts of global warming?
3. Human factor: can the increases in carbon dioxide in the atmosphere be linked to burning of fossil fuels?
4. How reliable are climate models?
5. Should we take action regarding global warming? If so, what actions can we take?



12

## US Heat

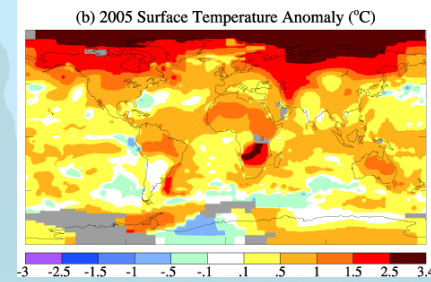
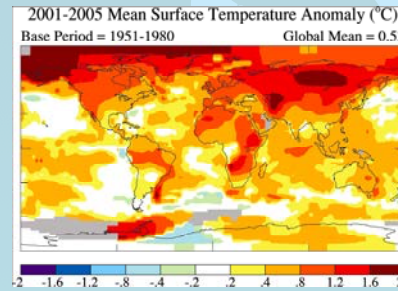
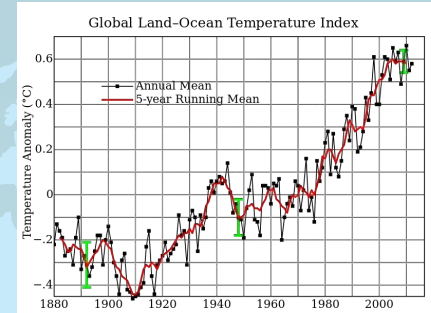


The National Oceanic and Atmospheric Administration reported Jan. 8 that 2012 average national temperature of 55.3 degrees Fahrenheit was the highest recorded temperature since recording began in 1895. (NOAA.org)

13

## 1. Evidence for Warming

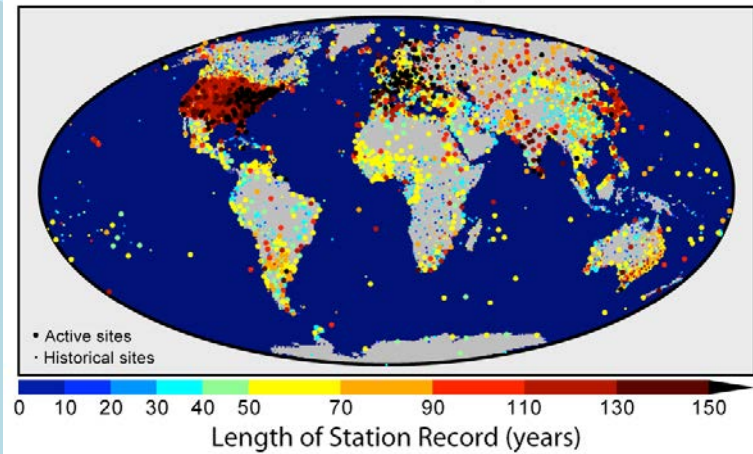
What do the data show?



14

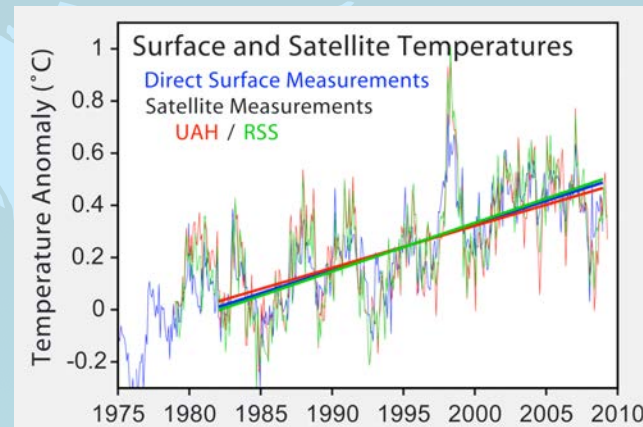
## Thermometer Record

### Global Climate Network Temperature Stations



15

## Comparison of Surface and Satellite Measurements

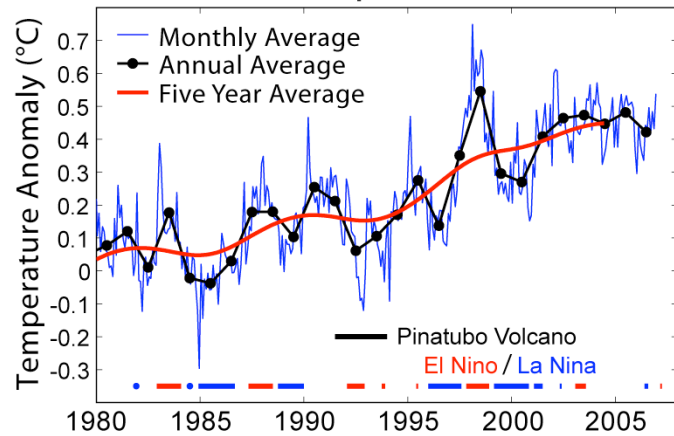


This figure compares the global average surface temperature record to the microwave sounder (MSU) satellite data of lower atmospheric temperatures. Within measurement error, all of these records paint a similar picture of temperature change and global warming.

16

## Year-to-Year Variations

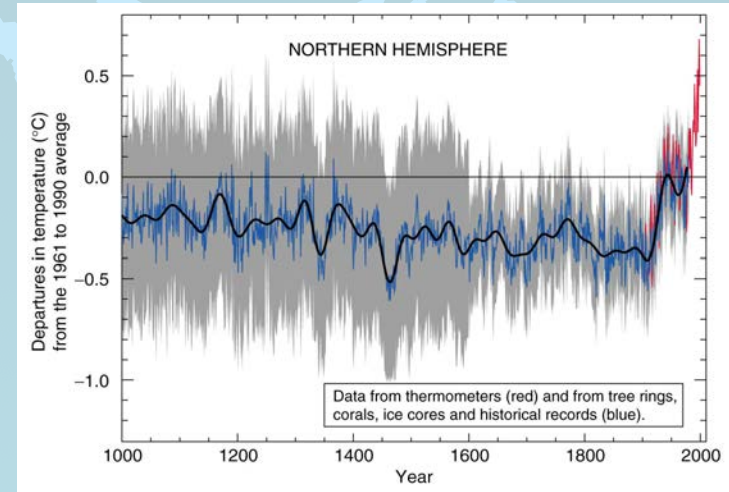
### Surface Temperature Record



Year-to-year variations in global temperature can be explained by the release or uptake of energy by the oceans and the depression of global temperatures as a result of the impact of volcanic ash.

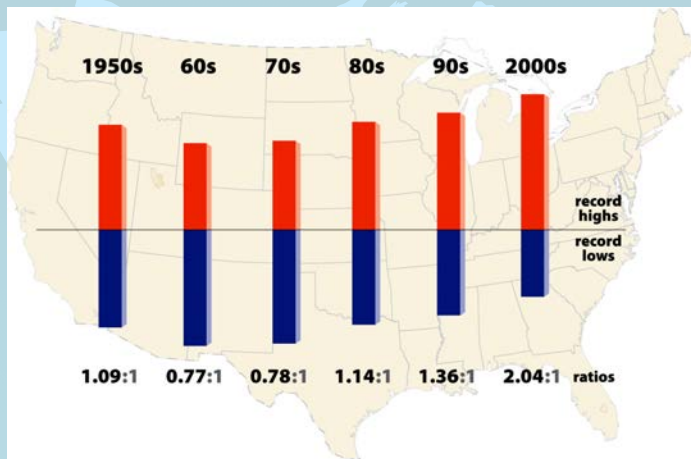
17

## Thousand Year Record



18

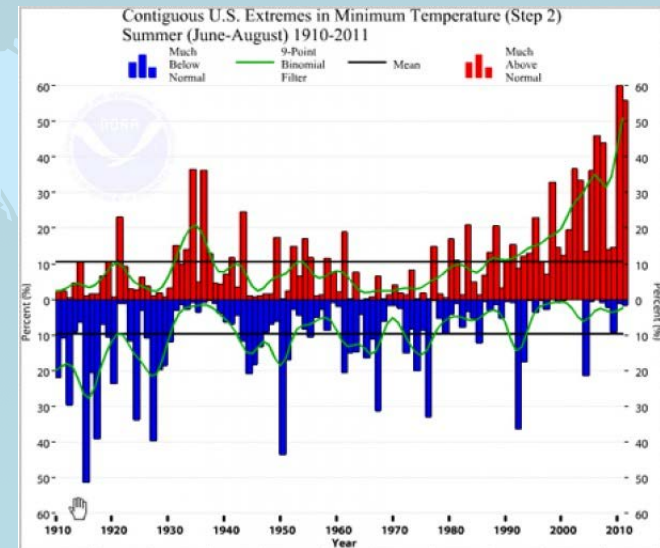
## What About the Record Cold Last Winter?



- Record High Temperatures Far Outpace Record Lows Across US in recent decades.

19

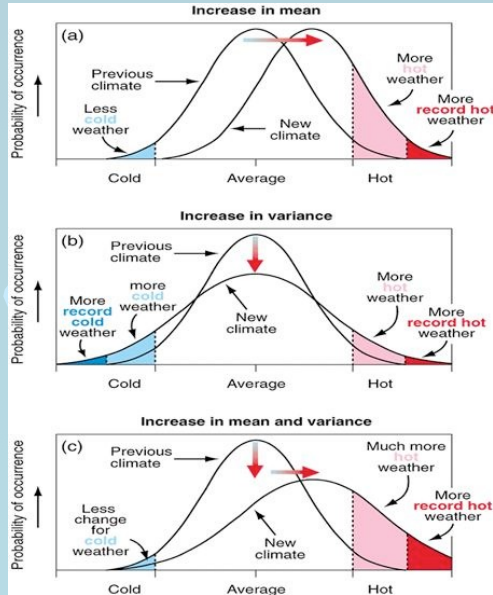
## What About the Record Cold Last Winter?



20

# Extreme Weather Events

Schematic showing the effect on extreme temperatures when the mean temperature increases, for a normal temperature distribution



21

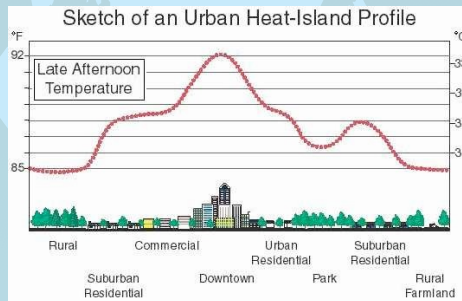
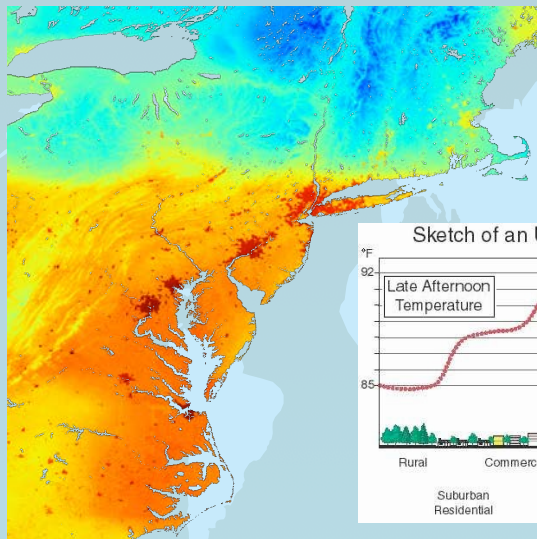
# Urban Heat Island Bias?



Cities are warmer than surrounding countryside. This bias is dealt with in the data analysis.

22

# Urban Heat Island Bias?

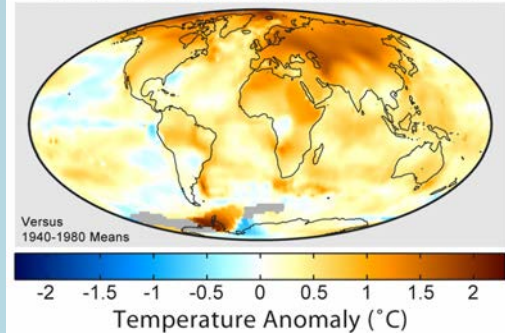


It is well known that cities are warmer than surrounding countryside. This bias is dealt with in the data analysis.

23

# Global Warming is Not Uniform

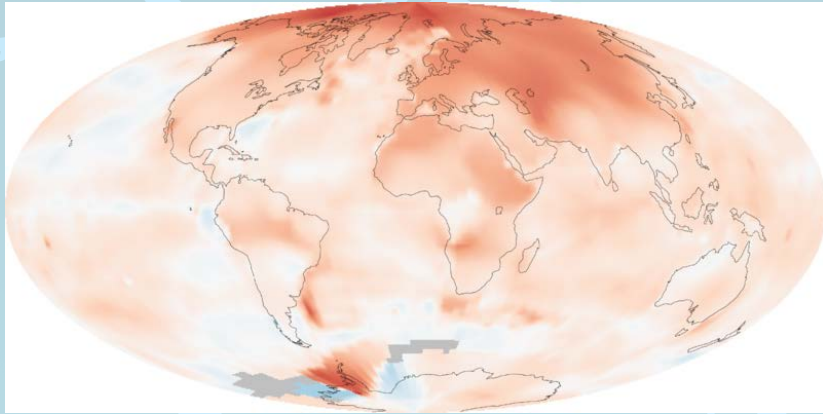
1999-2008 Mean Temperatures



Polar regions have warmed significantly more than equatorial regions of the Earth.

24

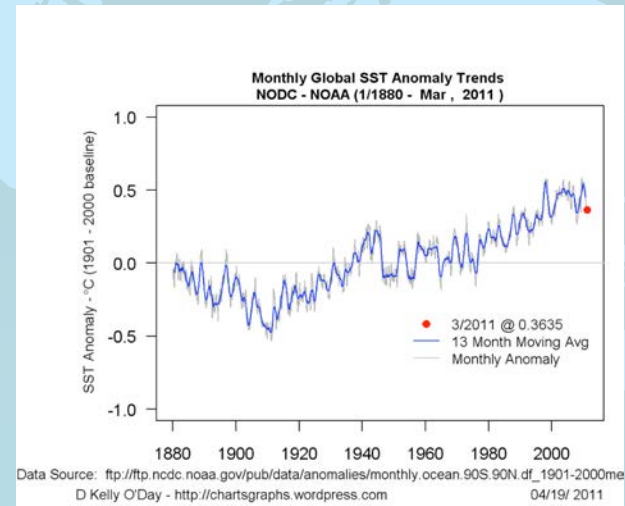
## Global Warming is Not Uniform



Polar regions have warmed significantly more than equatorial regions of the Earth. Decade (2000-2009) compared to average temperatures recorded between 1951 and 1980.

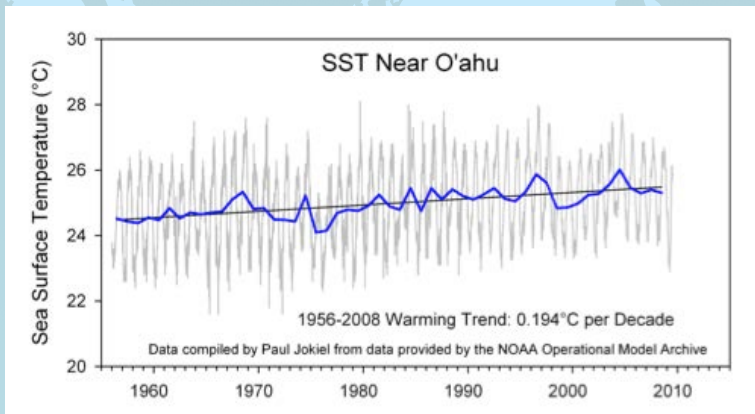
25

## Sea-Surface Temperature Trend



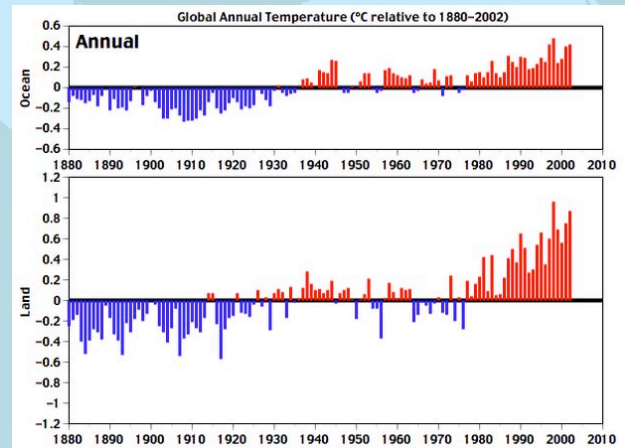
26

## Sea-Surface Temperature Trend



27

## Global Ocean and Atmosphere Temperature Trends Compared



28

## 2. Main Climate Change Impacts

- Higher temperatures - especially on land and at higher latitudes (Changes at regional level)
- Reduction in arctic sea ice and mountain glaciers
- Hydrological cycle more intense (droughts and storms intensify)
- Increased risk of wild fires
- Sea level rise



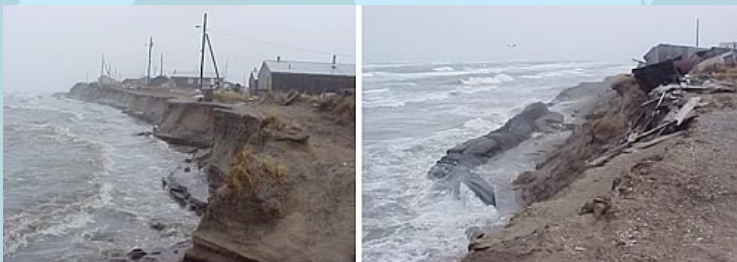
29

## Permafrost is Melting



30

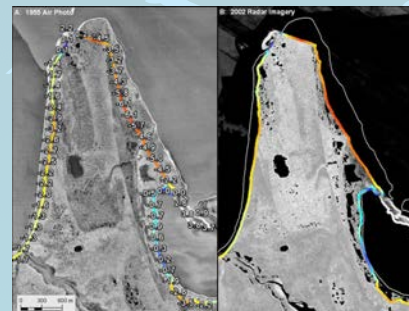
## Permafrost is Melting



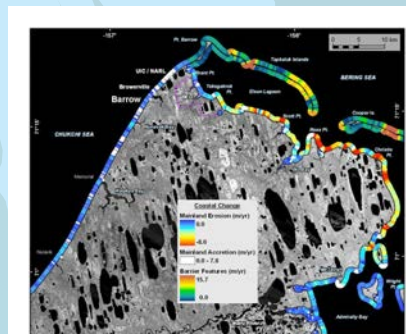
Coastal Erosion has accelerated and AK villages need to be moved as a result of the melting of permafrost and coastal erosion by storm waves, in areas protected by sea ice in the past.

31

## Coastal Erosion



Coastal Erosion has accelerated as permafrost melts.

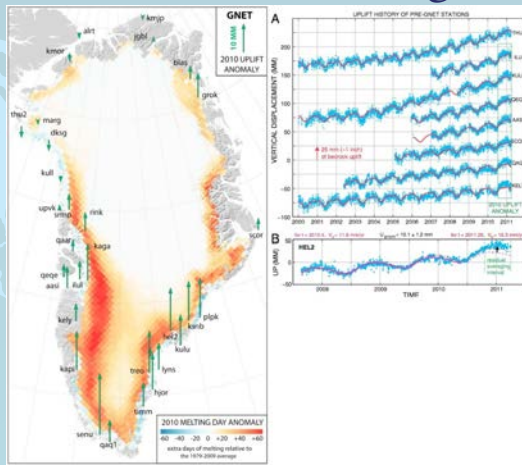


32





## Greenland Melting

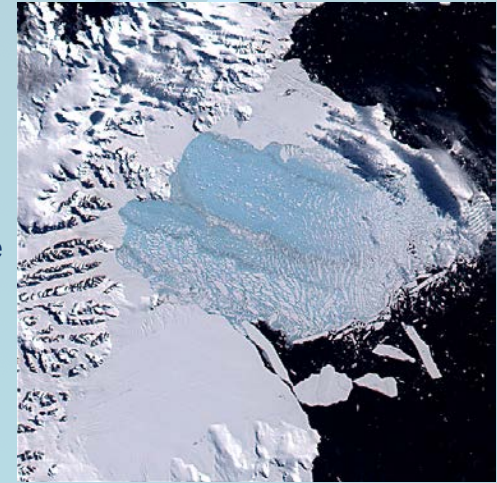


As Greenland warms, water from melting glaciers flows to the sea, reducing the weight of ice and allowing underlying bedrock to rise. On the map at left, red represents the number of greater-than-usual melting days experienced in 2010. At right, GPS readings from stations around Greenland's perimeter measure bedrock elevation -- falling in winter, lifting in spring, and on average rising steadily during the last decade.

37

## Evidence for Warming?

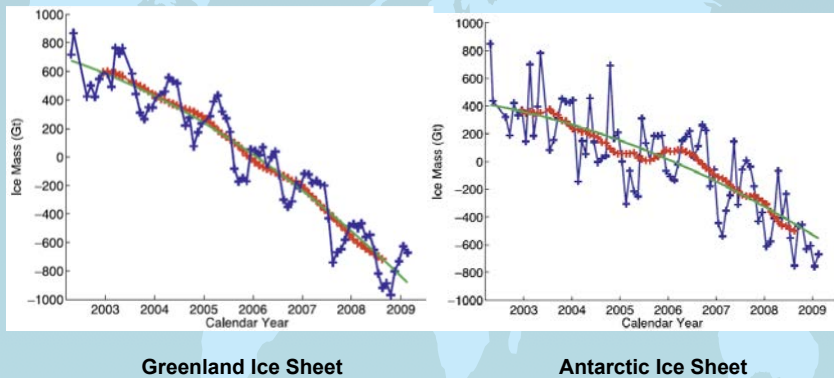
Breakup of Larsen ice shelf in the antarctic.  
Average winter temperatures on the Antarctic Peninsula have risen nearly 9°F (5°C) since 1950.



Breakup of the Larsen Ice Self

38

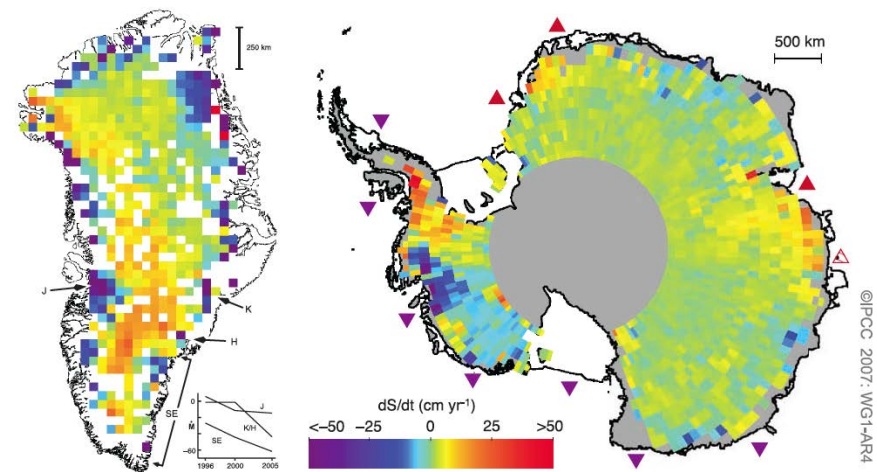
## Gravity Satellite Ice Sheet Mass Measurements



Source: Velicogna, I. *Geophys. Res. Lett.*, **36**, L19503, doi:10.1029/2009GL040222, 2009.

39

## RATES OF OBSERVED SURFACE ELEVATION CHANGE



©IPCC 2007: WG1-AR4

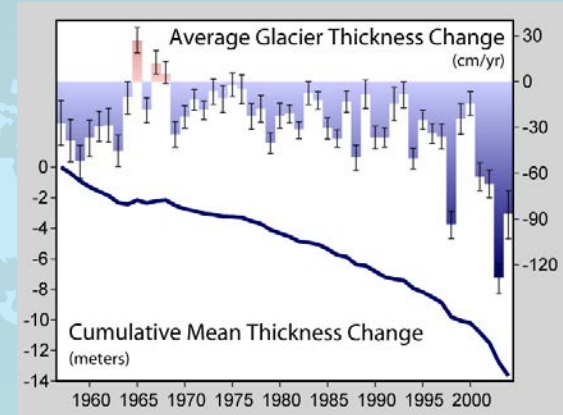
40

## Alpine Glaciers are in Retreat



Tourists in the canton of Valais, Switzerland, stand at the site where the Rhone Glacier ended in the mid-1800s. The glacier has since retreated up the valley as Alpine temperatures have risen. It can be seen in this photo peeking over a cliff in the distance

41



This figure shows the average rate of thickness change in mountain glaciers around the world. The glaciological mass balance, is found by measuring the annual snow accumulation and subtracting surface ablation driven by melting, sublimation, or wind erosion. These measurements do not account for thinning associated with iceberg calving, flow related thinning, or subglacial erosion. All values are corrected for variations in snow and firn density and expressed in meters of water equivalent (Dyurgerov 2002).

42

## Goodbye Glacier

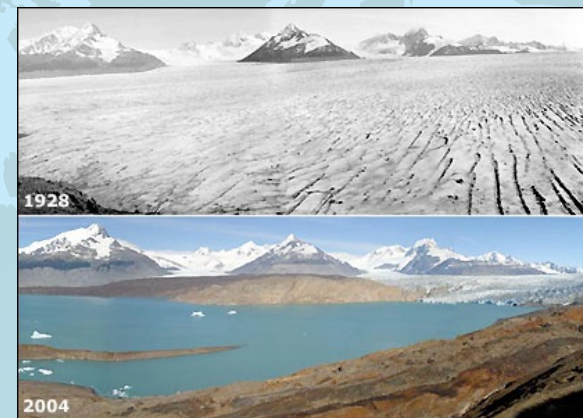


Miur Glacier, AK  
1941 vs 2004



43

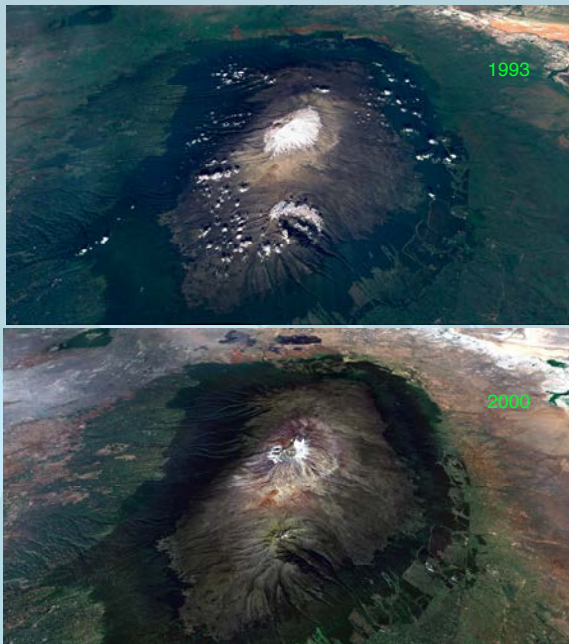
## Alpine Glaciers are in Retreat



Upsala Glacier in Patagonia, Argentina

44

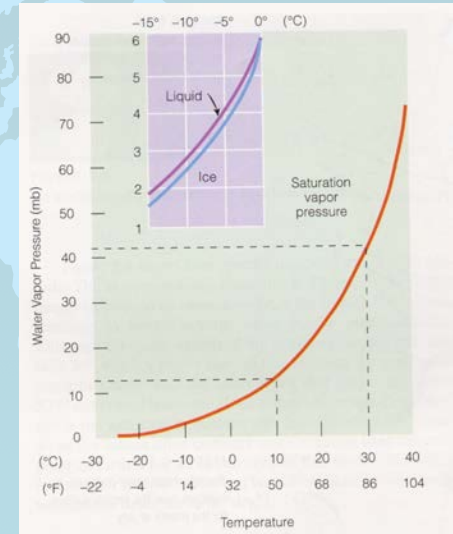
## Kilimanjaro Snow Melt



45

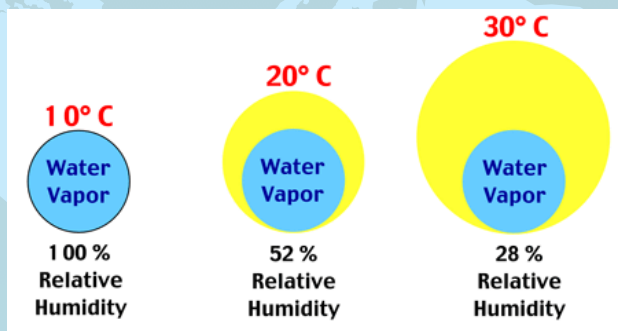
## More Intense Hydrological Cycle

There is a non-linear increase in the amount of water vapor in the air at saturation as the temperature increases. Thus, given a source of vapor from the ocean, the amount of water available in the air to rain out increases rapidly with warmer ocean temperatures.



46

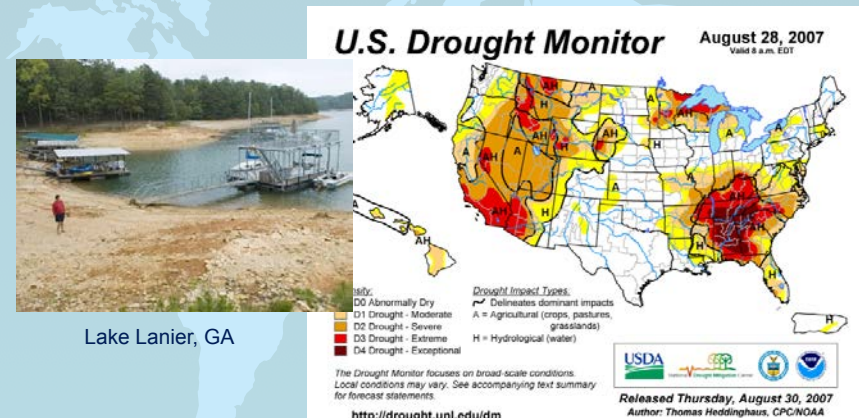
## More Intense Hydrological Cycle



If the amount of water in the air is limited as it is over inland areas, but the temperature increases, then the relative humidity drops. Lower relative humidity means drier conditions are experienced, e.g., droughts.

47

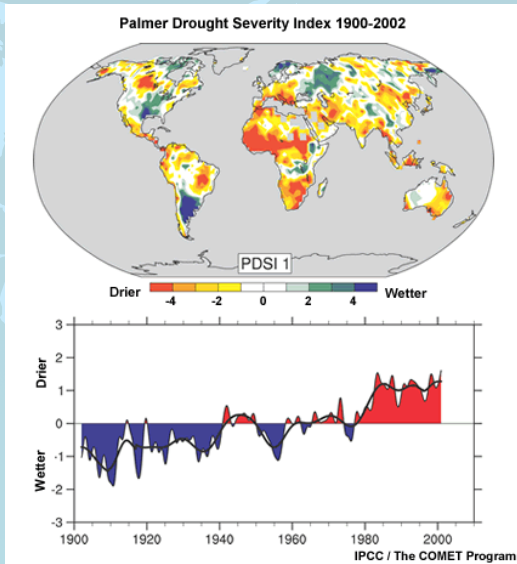
## More Intense Hydrological Cycle



Severe drought in SE US is consistent with predictions of more droughts over continents.

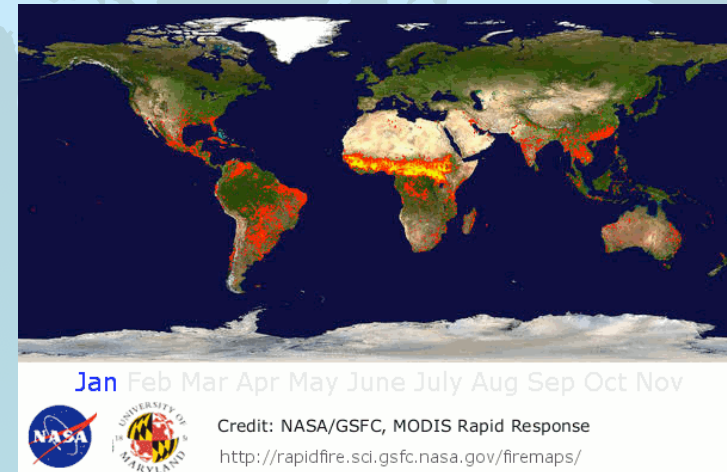
48

## Increase in Droughts



49

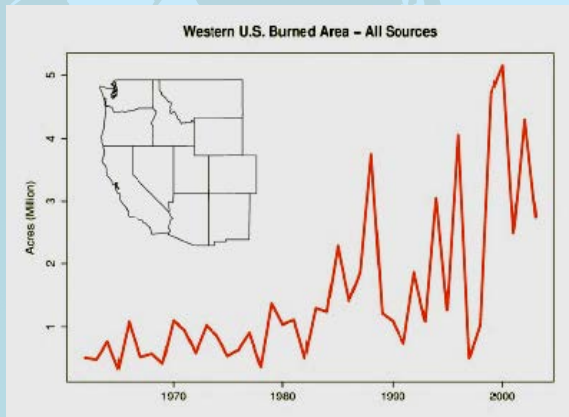
## Global Wildfires



50

## Wildfires Are Increasing World-Wide

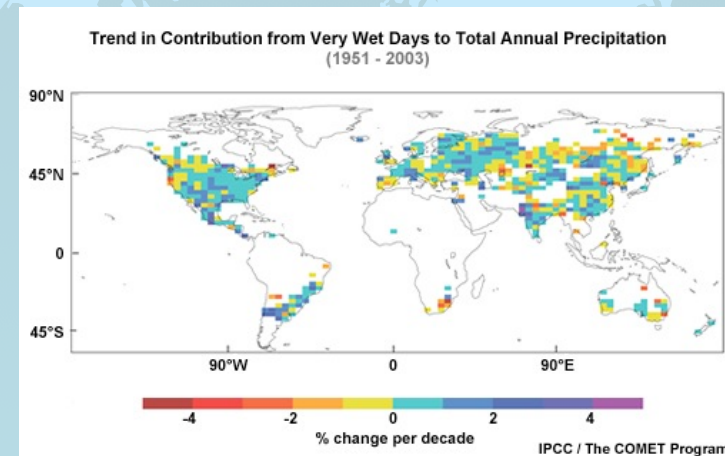
Wildfires in Western US have increased 4-fold in 30 years.



Source: Westerling et al. 2006

51

## Increasing Heavy Rainfall Events

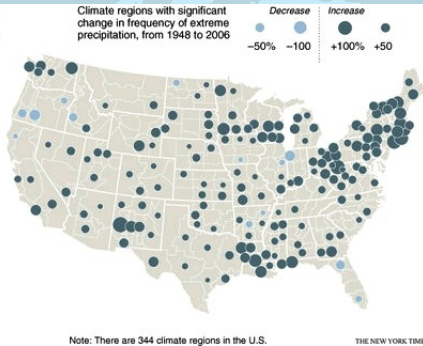


52

## More Intense Hydrological Cycle

### Where Storms Are Worsening

The number of severe rainstorms and heavy snow has grown significantly in the last 60 years, with some of the largest increases in New England and New York, according to a new report by Environment America, an advocacy group. The trends are consistent with scientists' predictions that global warming is likely to increase the intensity of storms.



If warm air is saturated, it contributes fuel (latent heat) to make storms more intense. Extreme events are days when it rains more than 2 inches.

53

## Tornado in London?



On December 7, 2006 a tornado ripped through parts of London injuring 6 and damaging houses.

54

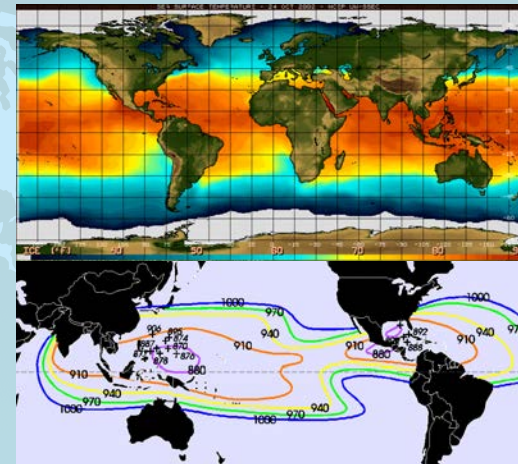
## Warmer Oceans

- result in sea level rise, coral bleaching and the death of coral reefs
- support higher humidities, more heavy rains and more powerful hurricanes



55

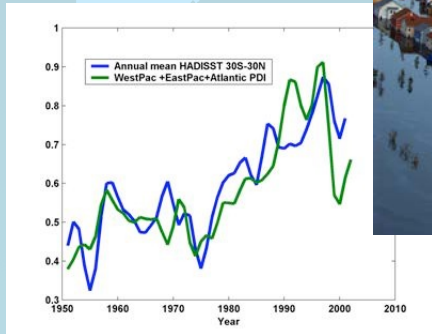
## Hurricane Energy Source



Observed sea surface temperature and predicted and observed minimum central pressure at sea level in tropical cyclones.

56

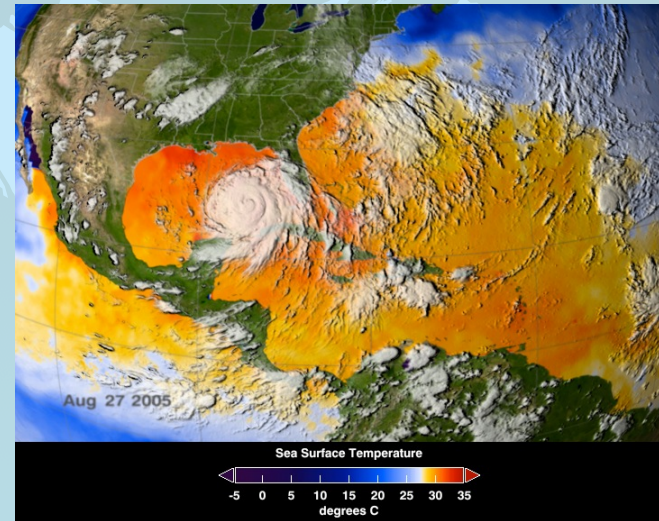
## Warmer Oceans: Stronger Tropical Storms



Annual mean sea surface temperature and hurricane intensity index (strength times duration).

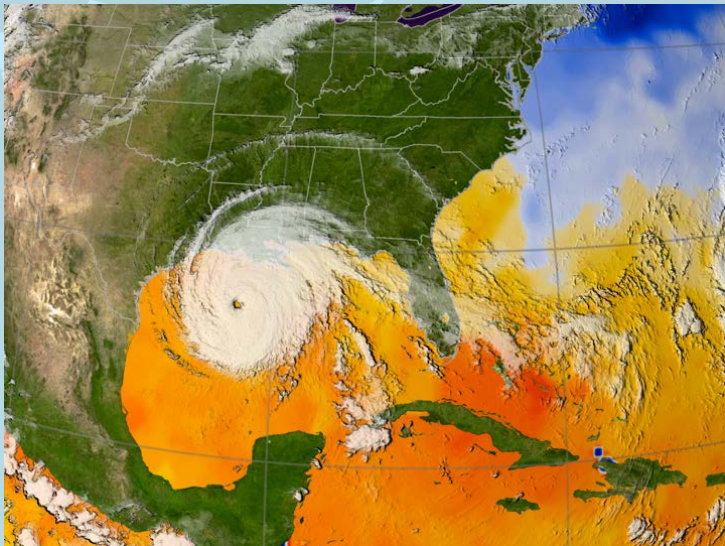
57

## Hurricane Katrina and SST



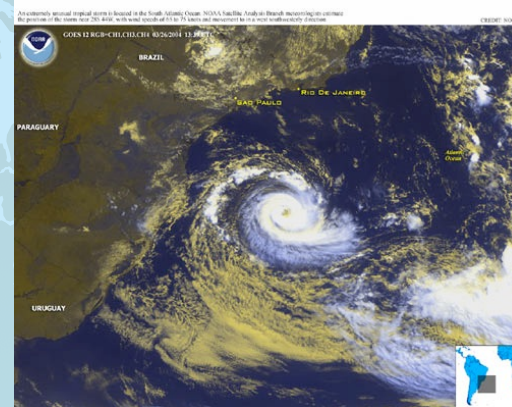
58

## Hurricane Rita and SST



59

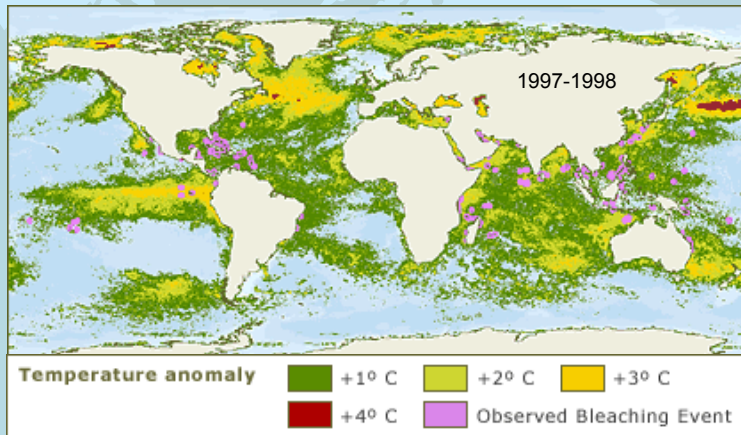
## Warmer Oceans and Tropical Storms



Warmer oceans support more powerful hurricanes. Photo above is of the first hurricane ever to strike Brazil.

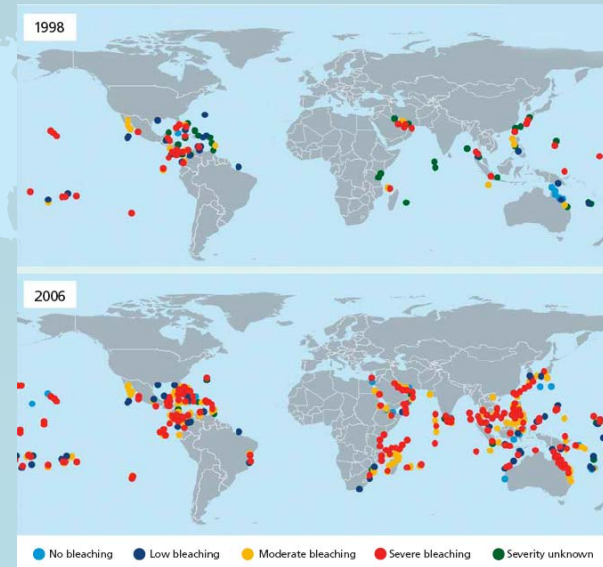
60

## Warmer Oceans and Coral Bleaching



61

## Warmer Oceans and Coral Bleaching



62

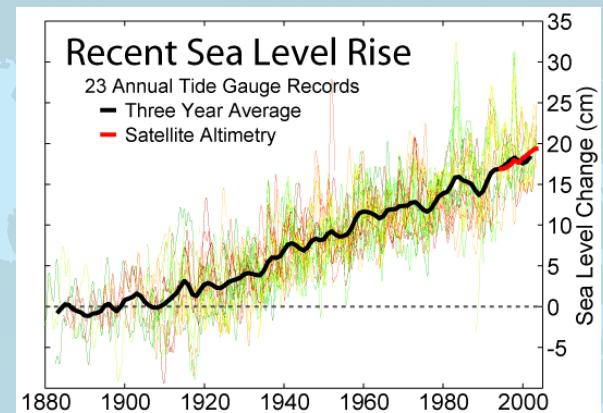
## Sea-Level Rise



Observations of global sea level rise are difficult to make because of the vertical motion of the land in many parts of the world, and the small signal in the data.

63

## Sea-Level Rise

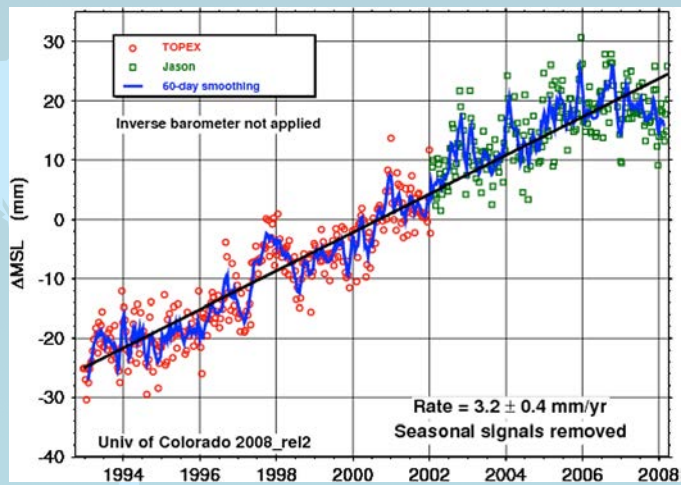


- Global average sea level rose ~0.2 m during 20<sup>th</sup> century
- Warmer temperatures cause sea level rise because of
  - Thermal expansion
  - Melting of continental and Greenland glacier ice

64



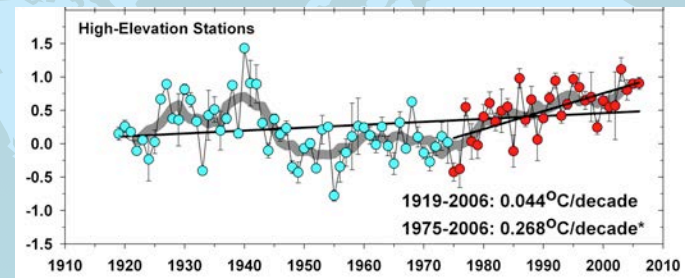
## Sea-Level Rise



Satellite altimetry record indicates ~3 mm per year of sea level rise over the past decade.

65

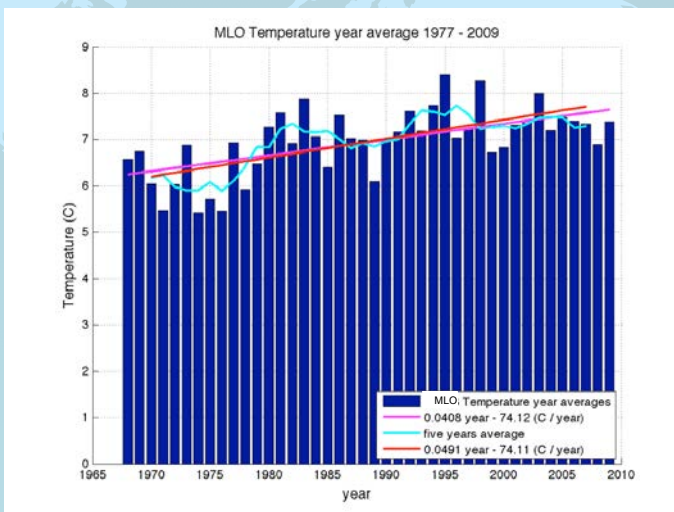
## Climate Change in Hawaii



Average surface temperature trends in Hawaii. Time series calculated from monthly station data after removing the calendar month means and averaging into calendar years. Smoothed curve is the annual data filtered with a 7-yr running mean. Linear trends computed for two periods, 1919–2006 and 1975–2006. (bottom) Time series plot from observing stations located at the higher elevations (> 800 meters). (Giambelluca et al. 2008).

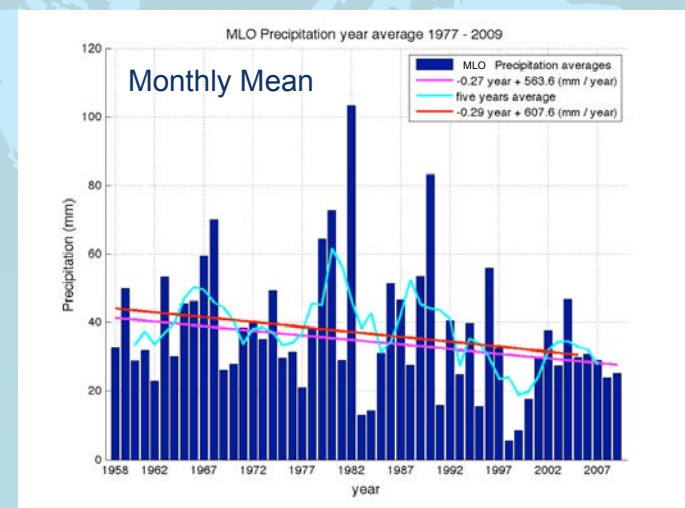
66

## Mauna Loa Temperature Trend



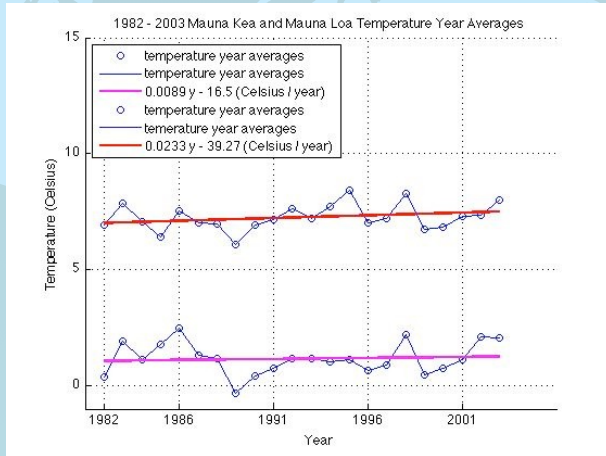
67

## Mauna Loa Rainfall Trend



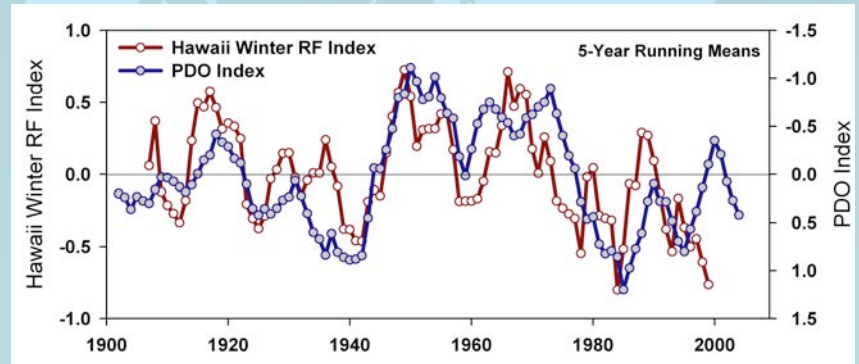
68

## MLO and MK Temperature Trends



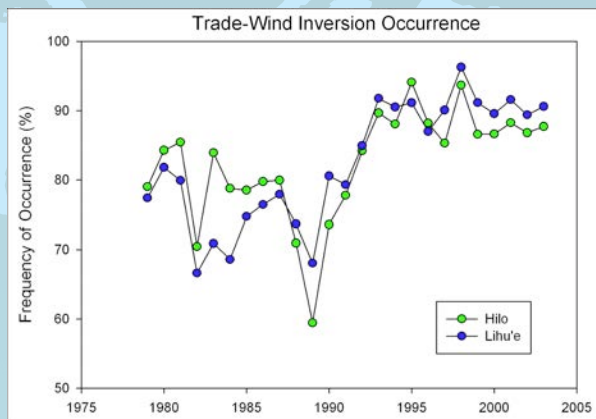
69

## Rainfall Correlation with North Pacific SST



70

## Recent Data Analysis

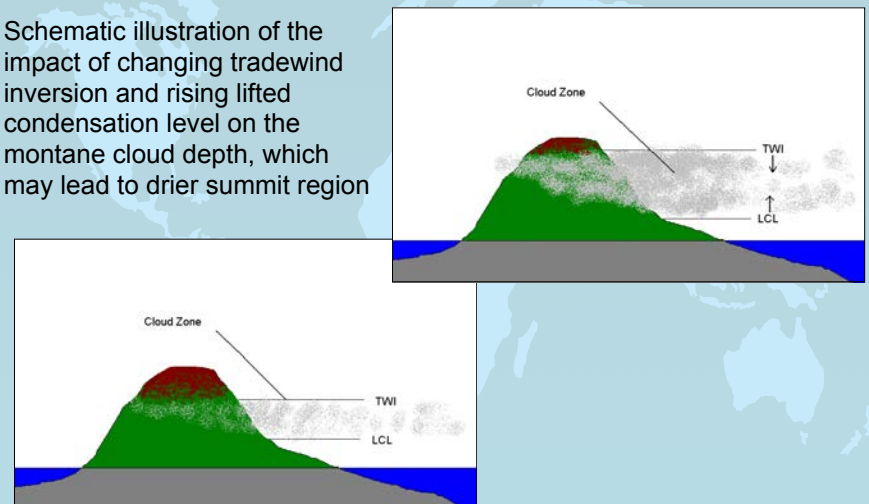


Frequency of trade wind inversion occurrence from 1975 to 2003 based on analysis of radiosonde data.

71

## Climate Change in Hawaii

Schematic illustration of the impact of changing tradewind inversion and rising lifted condensation level on the montane cloud depth, which may lead to drier summit region



72

## Summary: Evidence for Recent Warming

- The global average surface temperature increased by 0.6 °C since 1970.
  - the bulk of the warming has occurred at higher latitudes.
- Hydrological cycle is more intense
  - Heavy rain events increasing - more latent-heat energy for storms
  - Droughts and heat waves more common
  - Increased in number and size of wild fires
- Decrease in sea ice thickness and extent in last 40 years
- Widespread melting of permafrost.
- Widespread retreat of mountain glaciers seen in non-polar regions.
  - Snow cover extent decreased ~20% in last 40 years
- Sea surface temperature rise
  - increasing incidence of coral bleaching
- A gradual rise in sea level shows recent signs of acceleration.

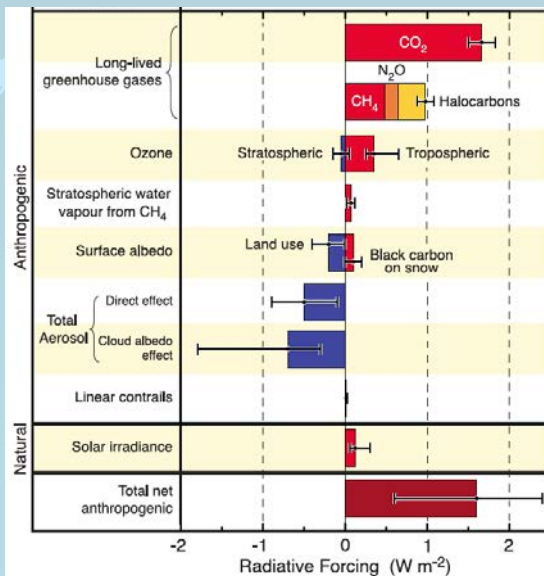
73

## What is causing the warming?



74

## Forcing of Climate Change – 1750 to Now



Carbon dioxide is causing the bulk of the forcing, and it lives a long time in our atmosphere (some of it lives for more than 1000 years). Every year of emission means a commitment to climate change for more than 30 generations.

Changes in sunlight are relatively small by contrast.

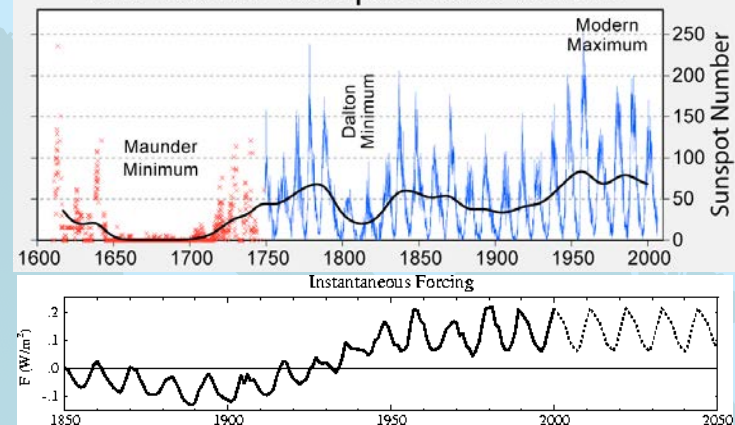


1-watt light bulbs

75

## Solar Forcing

### 400 Years of Sunspot Observations

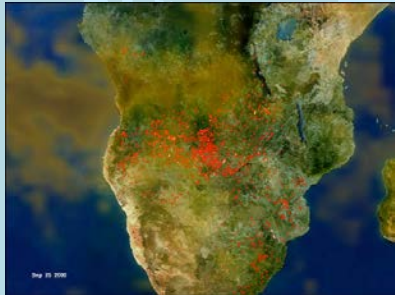


- Output of the sun is modulated by sunspot cycle.
- But, changes are too small to explain warming

76

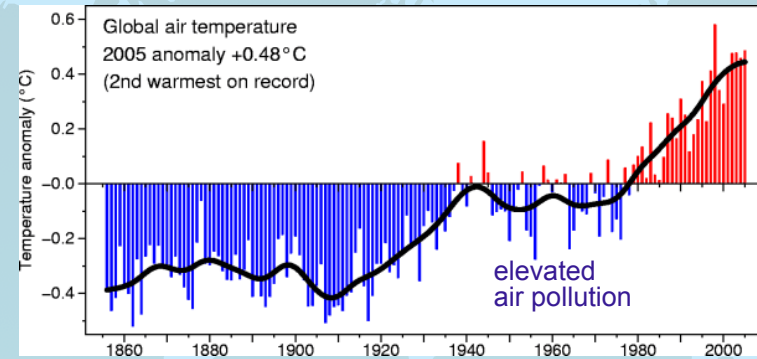
## Aerosol Forcing Leads to Cooling

Aerosol loading tends to cool the troposphere & warm stratosphere by raising the albedo.



77

## Evidence for Warming



The cooler period in the middle of last century coincides with elevated aerosol (particles) loading by industry and transportation. The clean-air act in 1970 reduced particulate loading.

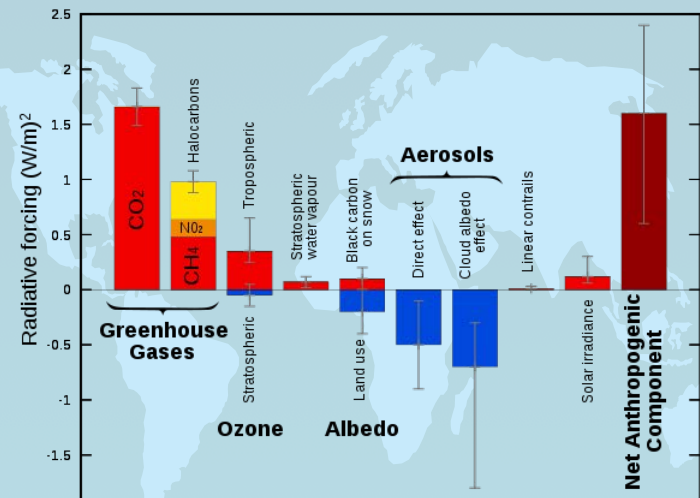
78

## Contrails



79

## Radiative Forcing Components



Global average radiative forcing estimates and ranges in 2005 for anthropogenic greenhouse gases and other important agents and mechanisms.

80



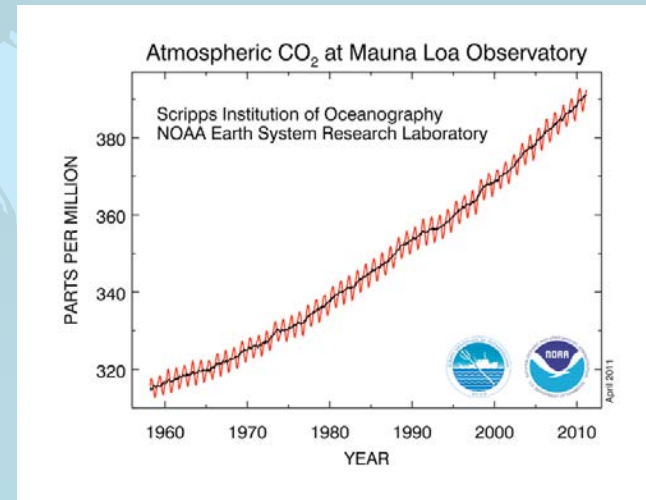
## Anthropogenic Climate Change will Persist for a Long Time

Gas	CO <sub>2</sub>	CH <sub>4</sub>	N <sub>2</sub> O	CFC's
Atmospheric lifetime	50-200 yr	12	120	50-300

Water vapor has a residence time in the atmosphere of only a few weeks. Therefore, it is a slave (positive feedback) to the other longer lived greenhouse gases.

85

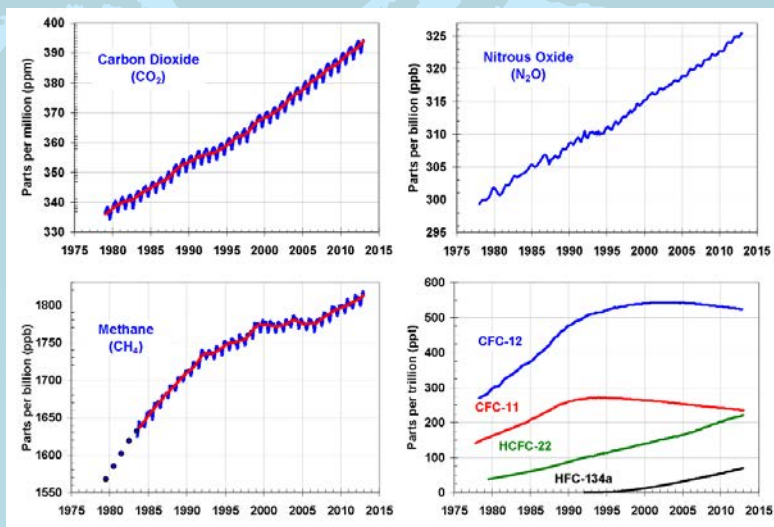
## CO<sub>2</sub> Gas Concentrations



Famous carbon dioxide data from Mauna Loa, Hawaii.

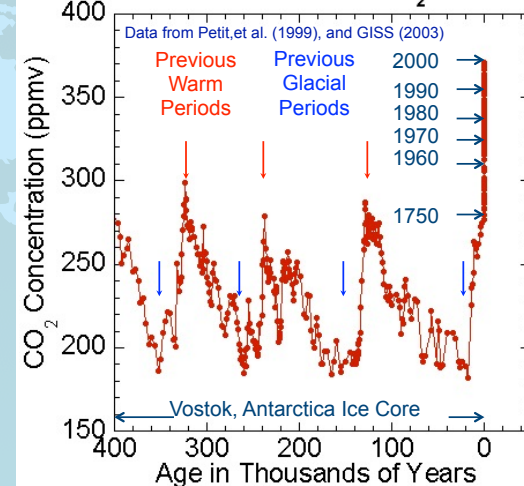
86

## Major Greenhouse Gas Trends



87

## Vostok plus Modern CO<sub>2</sub> Record



88

## What is causing the CO<sub>2</sub> to increase in the Atmosphere?

A: Fossil Fuel Burning: Coal, Oil and Natural Gas.

How do we know that?

- Circumstantial Evidence of timing of increase with rise of fossil fuel use.
- Smoking gun evidence of isotopic studies: ratio of C<sub>14</sub> to C<sub>12</sub>.

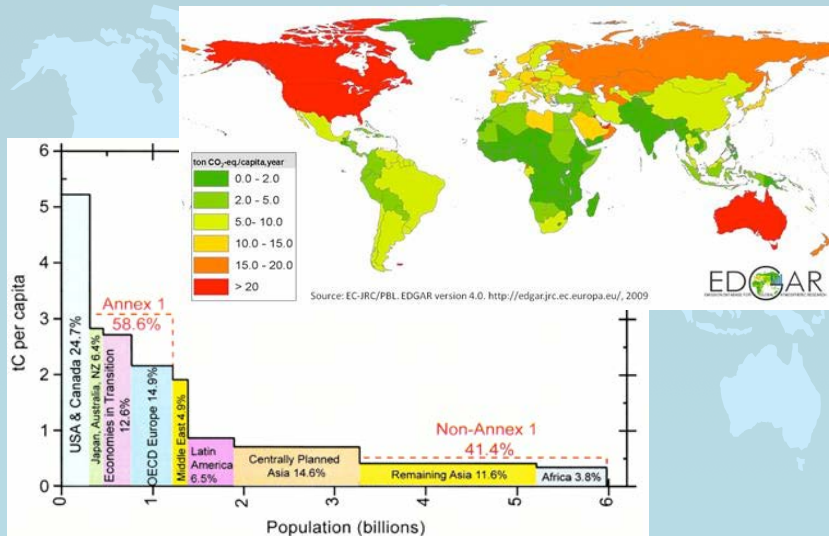
89

## The Carbon Isotope Evidence

- The Carbon 14 isotope is produced in the atmosphere by cosmic rays.
- C<sub>14</sub> is incorporated into CO<sub>2</sub> and taken up in plants during photosynthesis
- Dead plant matter is used to make Fossil Fuels
- C<sub>14</sub> is radioactive and decays with a half life of ~5,700 years
- Since the plant matter in fossil carbon fuels is millions of years old, it contains no C<sub>14</sub>.
- C<sub>14</sub> is decreasing with time in the atmosphere at the right rate to be explained by fossil fuel burning.
- This is strong evidence that the new carbon in the atmosphere in the form of CO<sub>2</sub> is coming from fossil fuel burning.

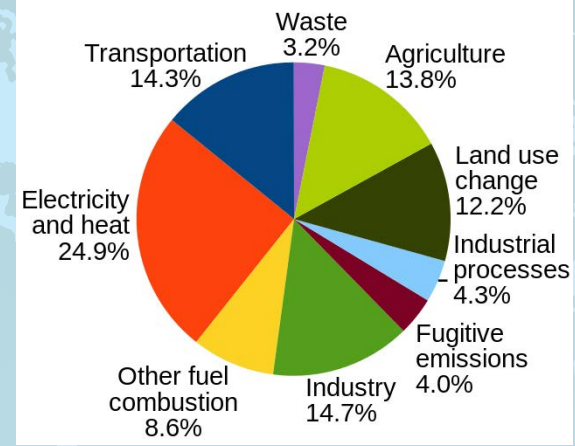
90

## Greenhouse Gas Emitters



91

## Annual world greenhouse gas emissions, in 2005, by sector



This pie chart shows annual world greenhouse gas emissions, in 2005, by sector. Emissions are measured as a percentage of total world carbon dioxide equivalent emissions

92

## Preponderance of the Evidence

The preponderance of the evidence supports the observation that our planet's climate is becoming increasingly warmer. The Supreme Court decided in 2007 that this legal threshold has been met. They ruled that rising carbon dioxide concentrations in the atmosphere pose a sufficient threat to society that the EPA must regulate CO<sub>2</sub> emissions.

93

Questions?

94