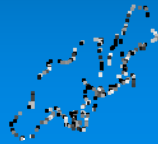


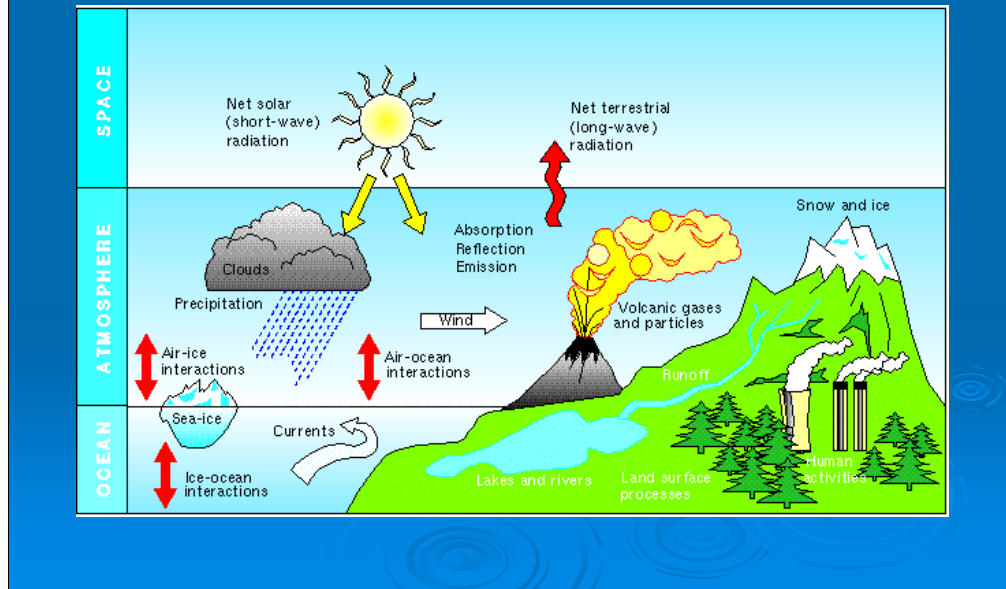
# An Introductory Overview of Climate Change

Art DeGaetano  
Associate Professor  
Dept. of Earth & Atmos. Sciences  
Cornell University

Director, Northeast Regional  
Climate Center



# The Earth's Climate System



The Earth's climate system is composed of a number of interacting components. The main driver is the sun whose energy is by far the main source of heat for earth. The sun does not heat the earth's atmosphere directly but rather its energy passes through the atmosphere and heats the surface of Earth. The surface then heats the atmosphere from below.

Clouds play two roles in the system. 1) reflecting sunlight back to space. This reflected energy is unavailable to heat the earth 2) blocking the loss of heat from earth to outer space. If the Earth did not lose heat to space, it would continue to heat up as energy is supplied from the sun. To maintain a fairly constant temperature the Earth must lose as much heat to space as it gains from the sun. Clouds prevent some of this heat from escaping and thus in some cases warm the Earth. From experience a cloudy night tends to be warmer than a clear night, but a cloudy day tends to be cooler than a clear day.

Volcanic eruptions tend to cool the climate since their emissions block sunlight in the short term. Over geological time periods volcanoes can act to warm the climate since they release carbon dioxide and other greenhouse gases.

Ice is a good reflector of solar energy. As was the case with clouds this reflected energy is not available to warm the Earth.

Vegetation plays several roles. It acts as a sink for atmospheric carbon dioxide. Evapotranspiration from plants adds water vapor to the atmosphere. The process of evapotranspiration acts to cool vegetative surfaces

Oceans provide a mechanism for transporting heat from the tropics to the poles. Due to the high heat capacity of water, oceans typically moderate coastal climates (cooler summers but warmer winters). Natural fluctuations in ocean circulation such as El Nino can influence global weather patterns

# What natural forces affect the climate system?

- Natural fluctuations in the sun's intensity
- The complex motion of the earth around the sun
  - Believed to be the trigger for Ice Ages
- Volcanic eruptions
  - Cool the climate by reflecting sunlight
- Shorter-term cycles like El Nino
- Interactions between components of the climate system
  - These are called feedbacks

The amount of energy emitted by the sun is not constant. Changes in its intensity are typically small (a few tenths of a percent), but can influence temperatures on earth if they occur over an extended period of time. A recent period of relatively cool global temperatures known as the Little Ice Age (1200-1850) is believed to have resulted in part due to a decrease in solar intensity. The distance between the Earth and the Sun, the tilt of the Earth on its axis, and the orientation of the Earth's axis all vary in regular cycles of 100,000 (Earth-Sun distance) to 23,000 (axis tilt) years. These changes influence the amount of energy that the Earth receives from the sun. Ice ages are believed to occur on 100,000 year cycles due to these orbital changes.

Violent volcanic eruptions like Mt. Pinatubo in 1991 (but not Mt. St. Helens) inject sulphur dioxide into the upper atmosphere. This compound is highly reflective to sunlight. Thus its presence in the upper atmosphere prevents the sun's energy from reaching the Earth. Once in the upper atmosphere these compounds can exist for several years following the eruption. The oceans and atmosphere work together to influence climate. Natural oscillations in ocean currents, the location of the warmest or coldest ocean temperatures, etc. can influence atmospheric circulation patterns. El Nino is an example. In this case the pool of warm water that usually resides in the western tropical Pacific Ocean migrates east. This changes the atmospheric circulation pattern in the tropics which influence global weather patterns.

All of the components of the climate system interact. Take, for example, the ice age example above. The growth of ice sheets is triggered by a reduction in the amount of energy reaching the Earth from the sun. As the ice sheets grow forest and soil covered surfaces are replaced by ice. While soil absorbs (and therefore is warmed by) solar energy, most of this energy is reflected by ice and is unavailable to warm the surface. Therefore the growth of the ice sheets contributes to further cooling of the planet. This is known as a positive feedback, since the cooling due to the orbital changes is enhanced by the ice sheet. The same positive feedback results from global warming, as the extent of the ice sheets diminishes, more soil and potentially forest is exposed. These surfaces absorb more heat than the ice covered areas and hence the warming is enhanced.

# Human Factors Affecting the Climate System

- Increases in greenhouse gases
  - For instance Carbon Dioxide and Methane
- Deforestation
- Other land use changes
  - Urbanization

We will see that greenhouse gases trap some of the heat that the Earth must lose to space. The greenhouse gases are similar to a blanket on a bed. You stay warm under a blanket because it prevents some of your body heat from being lost to the bedroom. Adding another blanket keeps you warmer. Adding more greenhouse gases to the atmosphere, warms the Earth.

Deforestation influences the climate in two ways. 1) trees are sinks for atmospheric carbon dioxide. They remove CO<sub>2</sub> from the air and store it as vegetative matter. Fewer trees mean less CO<sub>2</sub> is pulled from the atmosphere. If the trees are subsequently burned the CO<sub>2</sub> is added back to the atmosphere.

2) Removal of the trees changes the character of the land surface, this changes the amount of solar energy that is absorbed by the surface, evaporation, etc.

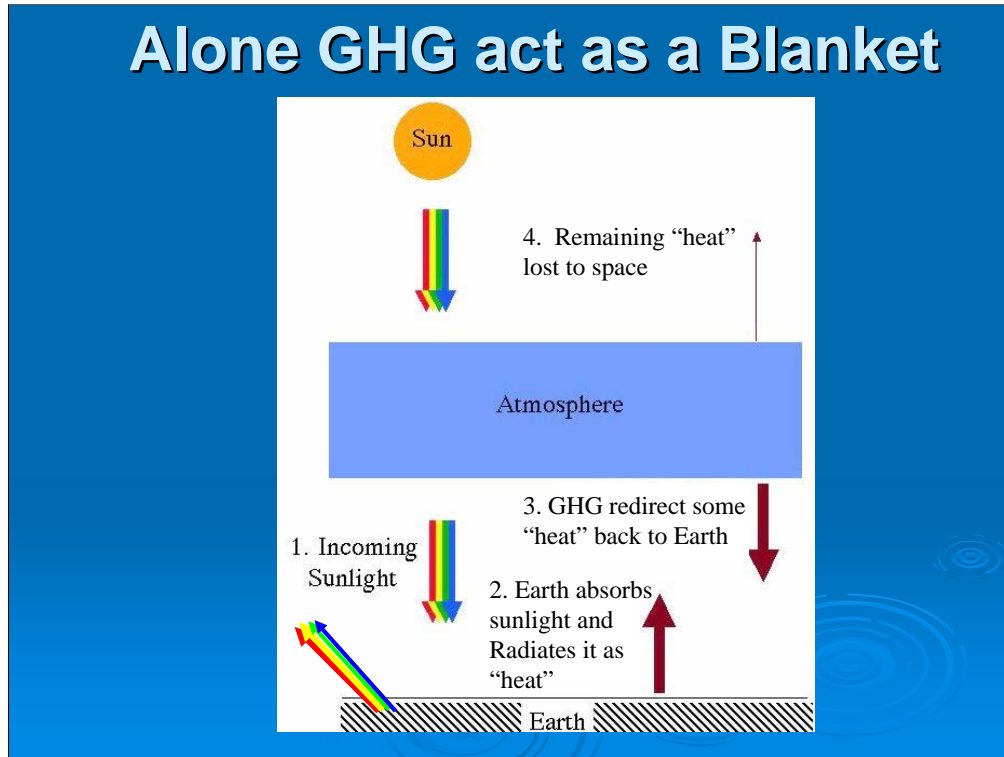
Urbanization is similar to deforestation. Urban areas tend to absorb and hold more heat than vegetated surfaces. Thus cities are typically warmer than rural environments. Likewise evapotranspiration is reduced (or eliminated) in cities. Since the process of evapotranspiration results in cooling, the lack of evaporating surfaces further warms urban environments.

## What Are Greenhouse Gases

- Gases that allow heat from the sun to pass through, but absorb heat emitted by Earth
- Natural part of the atmosphere
  - Without them -20°C vs 15°C (-4°F vs. 59°F)
- Water vapor is a strong greenhouse gas
- Carbon dioxide occurs naturally in the atmosphere.
- Human activity increases Carbon dioxide, Methane, Nitrous Oxides, HFCs

Carbon dioxide and water vapor are both greenhouse gases and are both natural components of the Earth's atmosphere. Prior to industrialization the Earth's atmosphere contained about 280 parts per million (280 CO<sub>2</sub> molecules for every 1,000,000 molecules in the atmosphere). This carbon dioxide was maintained in the atmosphere via volcanic and biological activity. Although small in concentration, the presence of this carbon dioxide is critical to life on Earth. Without it the average surface temperature of the globe would have been more than 60°F cooler than it is today.

# Alone GHG act as a Blanket

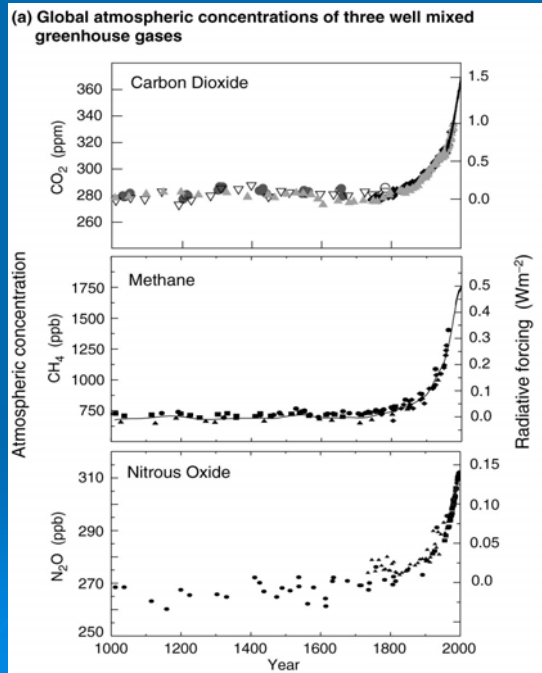


The sun's energy is primarily from the visible portion of the spectrum. This energy is able to pass through the atmosphere without being absorbed. When it encounters the Earth's surface a portion of it is reflected (about 30%). The remainder is absorbed by the earth's surface and as a result the surface is warmed.

If you think of the sun's energy as water and the earth's surface as a bucket, it is clear that as energy (water) is continually added through the years, the bucket will eventually overflow. In order to keep the level of water in the bucket constant, water has to be removed at a rate equal to that at which it is supplied. If the earth was not allowed to lose the energy supplied by the sun, its temperature would continue to rise. The earth loses energy by reradiating it to space. The energy from the Earth is primarily in the infrared portion of the spectrum. This energy can be absorbed by greenhouse gases in the atmosphere, which in turn redirect energy back to the Earth. This is why the Earth is 60°F warmer than it would be if there were no natural greenhouse gases. Since the concentration of natural greenhouse gases is small, not all of the energy emitted by the earth is absorbed. A portion is lost to space. This loss provided the mechanism for removing water from the bucket, or keeping the Earth at a constant temperature.

When the concentration of greenhouse gases is increased (AND EVERYTHING ELSE IN THE CLIMATE SYSTEM LIKE THE AMOUNT OF CLOUDS IS HELD CONSTANT) less of the earth's energy escapes to space as the increased GHG concentration absorbs more of it. Thus more energy is redirected back to earth and the temperature must rise.

# GHG Trends 1000-2000



These graphs show long term trends in the three primary anthropogenic greenhouse gases (Carbon dioxide, methane and nitrous oxide). In all but the most recent part of the record the data are obtained from analyzing air samples trapped in ice cores. Direct measurements have been made since the mid 1950s and fit nicely with the ice core record. For each gas, concentration was very constant from 1000-1800. From 1800-1900 a linear increase in concentration is noted for each gas. After 1900 the concentrations all increase exponentially.

## What causes these increases

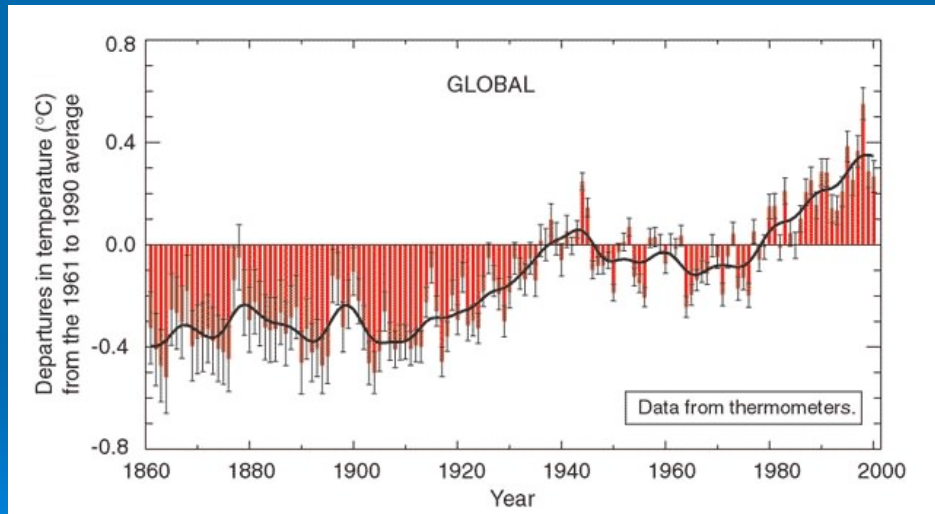
- Fossil fuel burning release about 6 billion tons of carbon each year to the atmosphere
- Methane from agriculture, livestock, landfills and industry have increased by 133%
- Nitrous oxide from agriculture and industry has increased by 15%
- Change in land use and land cover release 1 billion tons of carbon plus other gases

The increase in CO<sub>2</sub> concentration is primarily from fossil fuel burning (about 75%) Deforestation contributes to about 24% of the increase with cement production responsible for the remaining 1%

Methane is a natural component of the Earth's atmosphere. It is produced by the decay of organic matter particularly in wetlands, the oceans and termites. About 75% of the increase in methane concentrations results from anthropogenic agriculture (livestock, particularly cows, rice paddies). Fossil fuel burning contributes another 25%. Smaller contributions come from landfills and domestic sewage systems

Nitrous Oxide also occurs naturally in the ocean and as a result of microbial activity in the soil. The anthropogenic increases are primarily the result of enhanced loss from agricultural soils due to fertilizer applications. Industrial sources, feedlots and biomass burning also contribute to the increase.

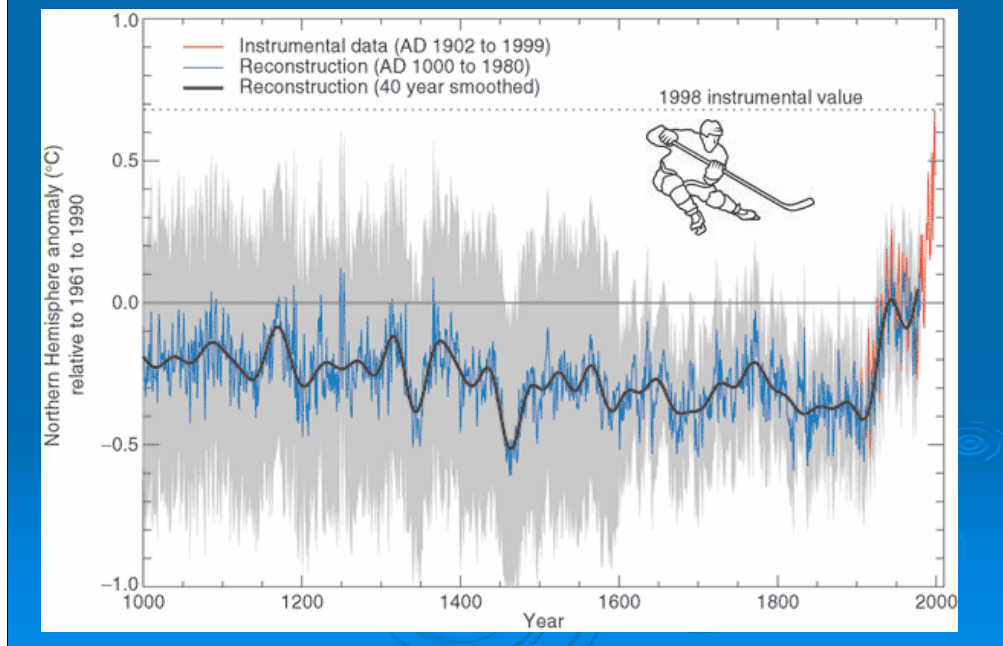
# Global Temperature 1860-2000



Direct thermometer measurements of the Earth's land surface temperature have been available since the mid 1800s. Data from about 3000 thermometers are averaged to arrive at a global value. Until the satellite era, ocean surface temperatures were made along shipping routes. A common method for making these observations was to collect a water sample with a bucket, which was then hoisted to deck and the water temperature measured with a thermometer,

Over the last 150 years the earth's temperature was fairly constant from 1860 to 1910. Between 1910 and 1940 the average temperature warmed by about  $0.5^{\circ}\text{C}$  ( $0.9^{\circ}\text{F}$ ). Temperatures leveled off (or declined slightly) between 1940 and 1975. Since 1975 global temperatures have risen about  $0.5^{\circ}\text{C}$  ( $0.9^{\circ}\text{F}$ ).

# Global Temperature 1000-2000



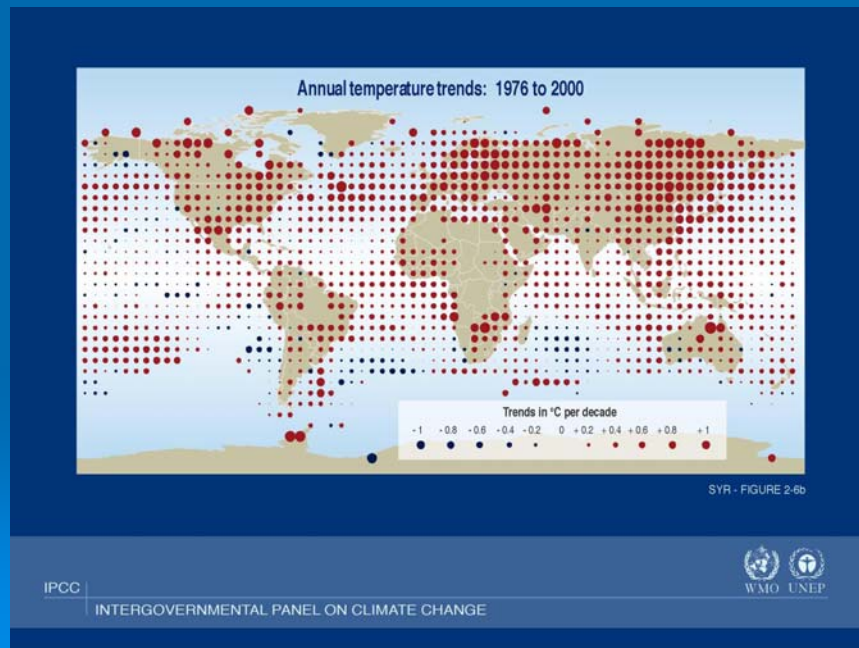
Placed in a longer term context, the temperature of the northern hemisphere during the 1990s has been warmer than any period in the last 1000 years. Recent research suggests this has been the warmest period in the last 2000 years.

To compile this graph (which is referred to as the hockey stick given the long period of fairly constant temperature, the handle, and the rapid onset of the warming trend in the 1900s, the blade), early temperatures (shown in blue) were inferred from tree rings. The widths of the annual growth rings of tree growing near the tree line provide a useful surrogate for temperature observations.

The instrumental record (analogous to the previous slide is shown by the red line). The gray band encompassing the temperature record represents the uncertainty in the measurements. This band is large for the tree-ring record, particularly in the early part of the series where the number of available tree rings is small. Uncertainty is still present in the instrumental record, due to changes in the number of available thermometers, changes in instrumentation, etc.

1998 was the warmest year in the northern hemisphere. It should be noted the warmth of the 1990 exceeds the large error bars associated with the early tree ring data.

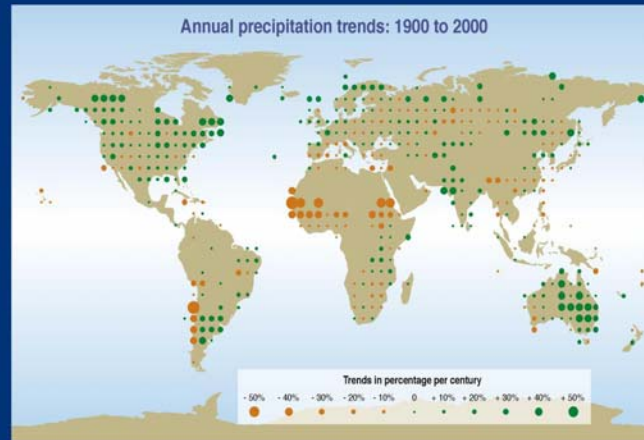
# Spatial Temperature Trends



The observed warming is not uniform globally. Northern locations have seen the largest increase in temperature since 1976. While the smallest changes occur in tropical latitudes. Presumably the large increases in polar latitudes result from a positive feedback associated with shrinking ice volume. As the atmosphere is warmed by increasing greenhouse gases, ice volume and extent declines allowing the earth's surface to absorb more solar energy at these latitude. Thus the warming is enhanced.

Areas of cooling exist, but are rare.

# Spatial Precipitation Trends



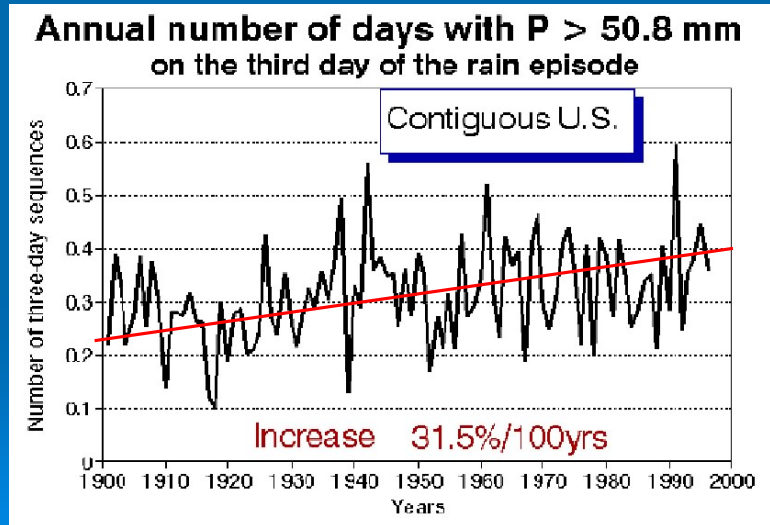
IPCC  
INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE



Global trend in precipitation are not as consistent. Over most areas increasing precipitation trends (green) are observed. But the increases are generally small (< 5%). A relatively high number of areas show decreasing precipitation trends.

# Daily Rainfall > 2 inches

Does 40 inches come in 100 events of 0.4 inches or 10 4" storms?



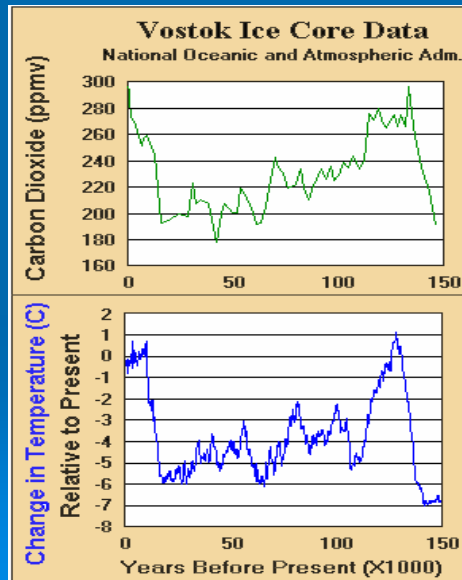
Groisman et al BAMS 2001

Although average precipitation across the globe has not changed dramatically a change in the character of precipitation has been observed in many parts of the world. What is happening is the portion of rain coming in heavy events has shown a marked increase.

Suppose a location receives 40 inches of rain per year. This 40 inches could come from 100 storms each producing 0.4 inches of rain. Alternatively it could be produced by 10 storms each producing 4 inches of rain. The observed trends suggest a shift from more frequent moderate rainfall events to more infrequent heavy rainfall events. In this later case since the period of time between rainfall events increases, drought may become more prevalent. But since the rain events that do occur can be quite heavy, the increased risk of flooding is also a concern. Clearly this change in the character of precipitation has implications for water resource and irrigation decisions.

The above graph shows the number of 2 inch rainfall events per year averaged across the United States. The frequency of these events has increased by over 30% through the last 100 years. Another way of looking at this is in 1900 an average station would expect 1 two-inch rain storm every 5 years. In 2000, a 2 inch rainfall would occur almost every other year.

# Does a Degree or Two Matter?



At first glance a degree or two or even 5 degrees of “global warming” does not seem like a big deal. The difference between a daily temperature of 80 degrees versus 82 degrees is hardly even noticeable. On a 20 degree winter day, an increase of 5 degrees, although welcome, is hardly a reason to break out the shorts.

What has to be considered is that this increase is global, not just in your backyard. Consider the amount of energy required for your stove to increase the temperature of a pot of water by a degree or two. You’re right, not much. Now have your stove increase the temperature of all the water in the oceans by a degree. A big difference, right?

The above graph shows that from the height of an ice age to the intervening interglacial period (like today) the average temperature of the globe changes by about 6 degrees. Since 1900 the increase in temperature has been about 10% of this ice age to interglacial range. Projections are that by 2100, increase global temperature will be about half of that associated with the ice age cycle. Also keep in mind that for ice ages this 6 degree change occurs over 100,000 years. We expect to see a 3 degree change over 200 years!

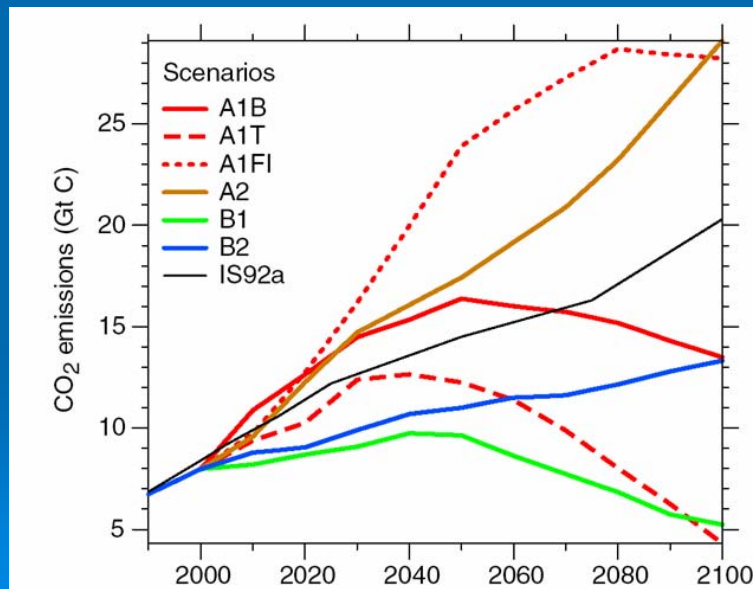
The above shows another interesting observation. Even during ice ages the earths carbon dioxide concentration and temperature change in unison. When temperatures are their coldest carbon dioxide concentration is at a minimum. Clearly there is a tie between carbon dioxide concentration and temperature.

## Looking to the Future

- What will happen to concentrations of climate altering gases such as carbon dioxide?
- What will happen to global temperature and precipitation?

While global observations show trends in climate parameters such as temperature and precipitation, projecting these trends into the future requires projections of our future CO<sub>2</sub> emissions. These emissions scenarios provide a basis for future atmospheric CO<sub>2</sub> concentrations. Determining how these new GHG concentration will influence future climate requires complex computer models of the Earth's climate system.

## Possible Emission Scenarios



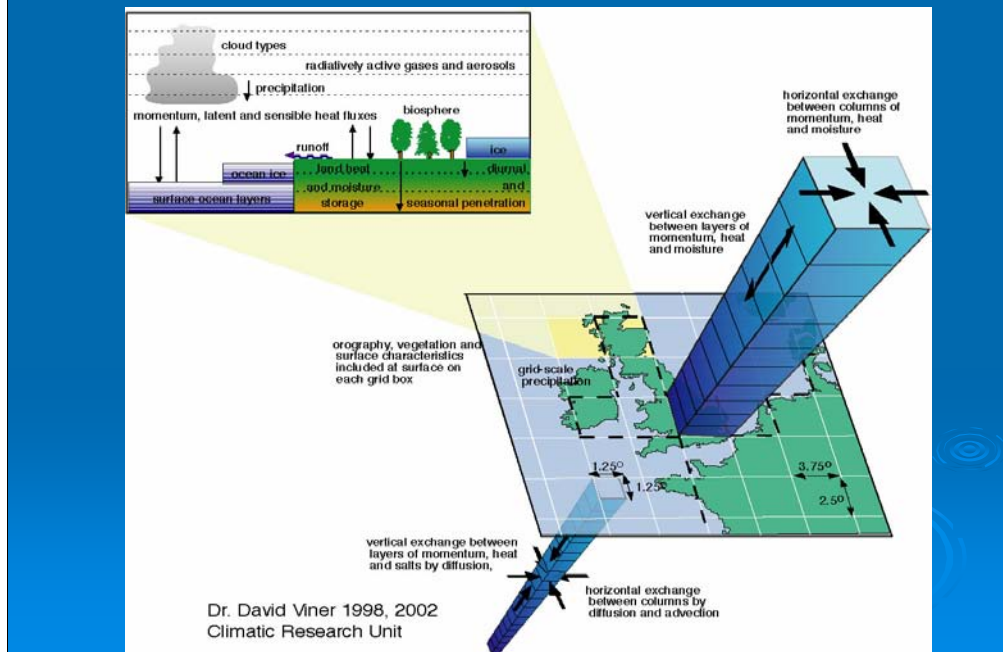
In order to project future climate conditions, scientists must predict what the world will look like politically, economically and environmentally in 100 years. Imagine trying to predict today's fossil fuel usage if you lived a little more than 100 years when air travel was unheard of and automobiles were in their infancy.

Given the uncertainty in such predictions scientists have developed a range of scenarios of future GHG emissions. These range from a fossil-fuel intense society that undergoes rapid economic growth and experiences a modest increase in population (top dashed red line in figure). In this case atmospheric CO<sub>2</sub> levels increase to also 4 times their pre-industrial values by 2100.

A business-as-usual scenario...continuing the present trend in GHG emissions leads to a similar increase in CO<sub>2</sub> levels by 2100 (gold line).

More environmentally-friendly scenarios, with reductions in fossil fuel usage also lead to increases in atmospheric CO<sub>2</sub> concentration. This results from the lifetime of CO<sub>2</sub> in the atmosphere (about 100 years). Thus today's CO emissions are not removed from the atmosphere until 2106. Even the most environmentally friendly emission scenarios lead to an increase in atmospheric CO<sub>2</sub> concentration over the next 100 years, to about double pre-industrial levels.

# Typical Climate Model



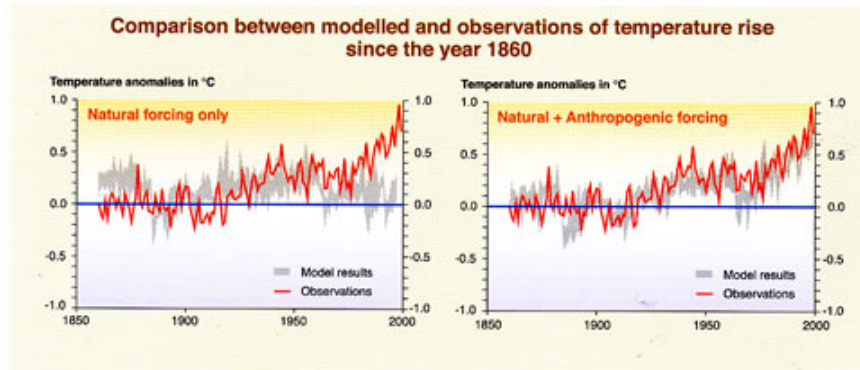
To assess how these changes in CO<sub>2</sub> concentrations influence the climate system requires a climate model. These mathematical models have evolved in complexity through time, as more and more power computers have been developed. In the models, the land and ocean surfaces are represented as grids. Typically land grids have a resolution (size) of 2.5 degrees of latitude by 2.5 degrees of longitude (about the size of New York). The grids are smaller over the ocean. Grids extend upward into the atmosphere and downward into the ocean and soil. The grids represent the smallest spatial division in the model. Thus a grid is either all land or all water. Each grid has a single elevation. Each grid has a single value for cloud cover and rainfall. So the models represents large aerial averages. They give little direct insight into climate conditions at a particular location, or in a given watershed.

A series of mathematical equations are solved using calculus techniques to assess how climate will change with time for a given increase in CO<sub>2</sub>. The atmospheric portion of the model “talks” with the ocean so these components are said to be coupled (changes in one effect the other). Another example is ice extent. As the climate warms, ice extent decreases in the model. This decrease is felt by the model atmosphere since it appears as a decrease in the amount of reflected solar energy. Thus the models are able to simulate many of the climate systems feedbacks.

Other components of the model are parameterized. For instance models of the biosphere are just beginning to be coupled with the atmospheric and oceanic models. Now grids that are forested remain forested, regardless of whether the new climate conditions support forest or not. Clouds must also be parameterized in a climate model. This is because the physics that govern cloud formation occurs a scale much smaller than the grids. Perhaps the biggest source of uncertainty in climate model projections comes from an inadequate representation of clouds in the models.

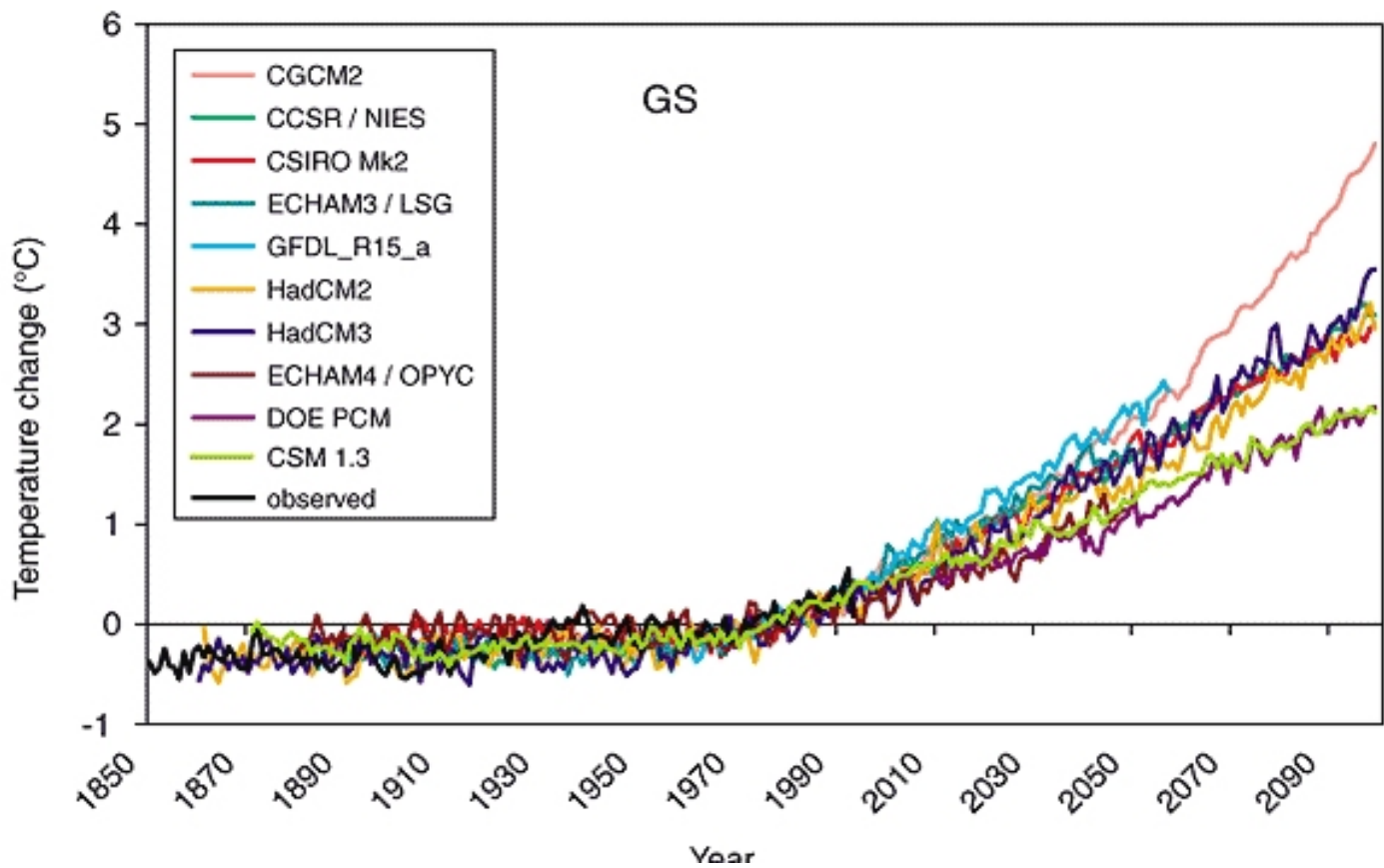
# Model Validation & Attribution

Chart 2. Global temperature changes since 1860



*These figures show average global surface temperature as measured (red line), compared to estimates from a computer simulation, respectively without (left) and with (right) the effects of human emissions included.*

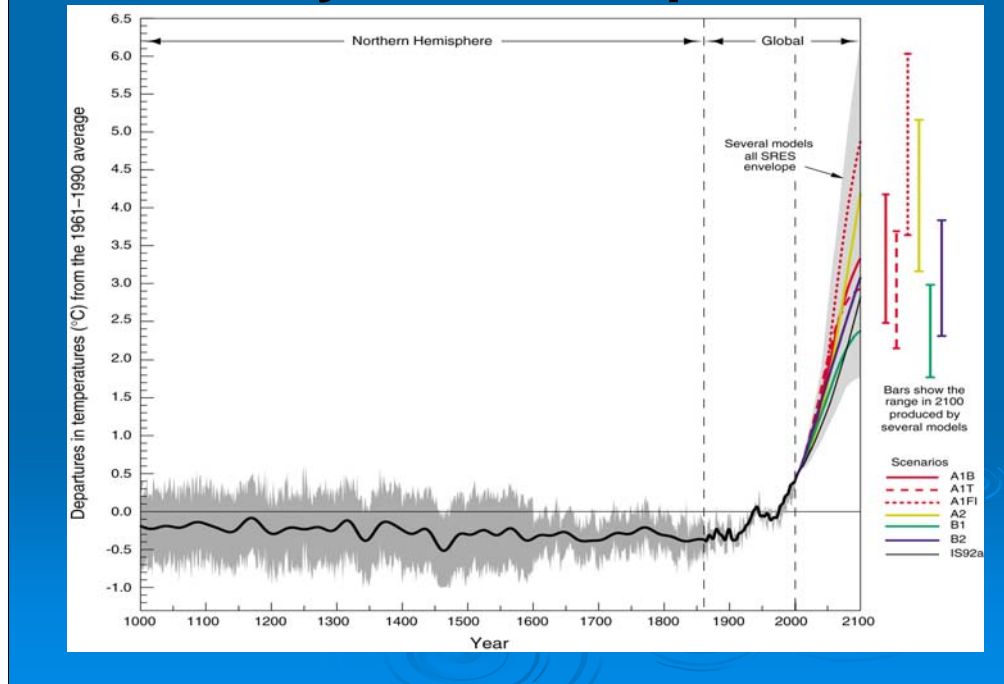
Source: Reproduced from Intergovernmental Panel on Climate Change, Third Assessment, Synthesis Report, 2001 (Figure SPM-2).



Many climate models exist. Although they all rely on the same physics, they differ in the ways in which variables like clouds are parameterized. The “art” of climate modeling is how processes that can not be well represented by the physics of the models are accounted for.

All models experience the same increase in GHG concentration. They all show a warming by 2100. The only difference being the magnitude of the warming. Here model warming estimates range from 1.5 to 5.0°C by 2100.

# Hockey Stick Perspective

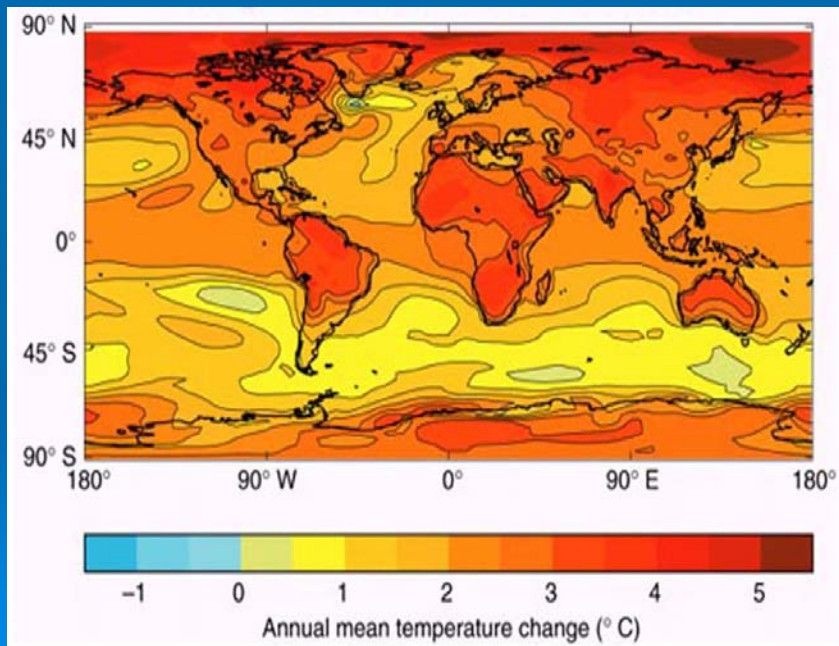


This slide puts the model projections into perspective, relative to the temperature climatology of the last 1000 years. Clearly the temperature projections far exceed the values from the climatology.

In the case of a fossil-fuel intensive economy, the global average temperature by the end of this century is projected to be 5°C warmer than was observed during the 1961-1990 period (red dashed line). The more environmentally friendly emission scenarios show about 1.5°C to 2.5°C temperature increase by 2100 (green line).

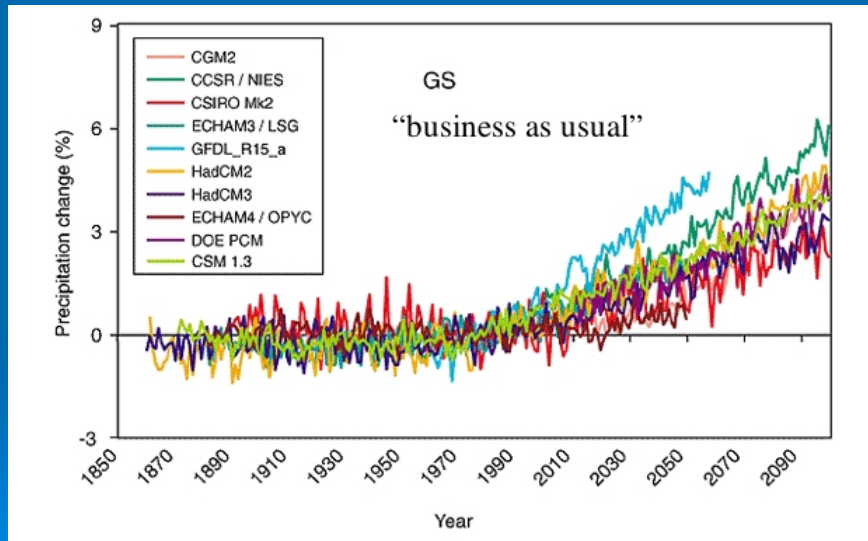
The bars along the side of the plot show uncertainty based on the range of results from several climate models. In the fossil-fuel intense case, estimates of global average temperature in 2100 range from 6.25 to 3.5°C. For the environmentally friendly scenario estimates range from 1.5 to 3.0°C.

## Geographic Temp. Change



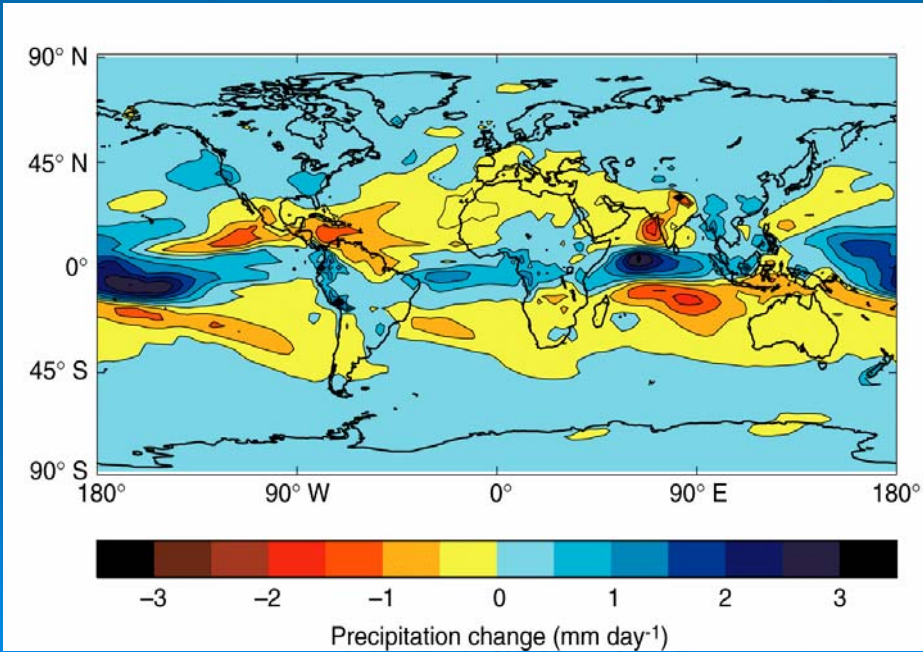
This is a climate model projection of how warming will vary geographically by 2100. Not all locations will warm by the same amount. Rather the warming is most pronounced in polar regions ( $>5^{\circ}\text{C}$ ) and least drastic in tropical and subtropical regions ( $1\text{-}2^{\circ}\text{C}$ ). Presumably the enhanced warming in polar regions is due to positive feedbacks associated with decreasing ice extent.

# Projected Average Precipitation



This is similar to the previous graphic for temperature. All models experience the same increase in GHG concentration. They all show an increase in global precipitation by 2100 of about 3%. Like with temperature, the magnitude of the precipitation increase varies between the models. Some suggest a 6% increase in global precipitation. Others show about a 1.5% increase.

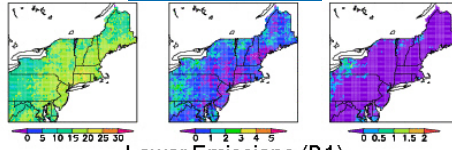
## Geographic Precip. Change



This figure shows how precipitation changes will vary geographically by 2100. Some locations (primarily in subtropics) show decreases in precipitation (brown and red shading). Large areas of the middle latitudes and tropics see increases in precipitation. Projections of global precipitation are less certain than temperature since many of the physical processes that govern the generation of precipitation in climate models must be parameterized instead of being solved mathematically.

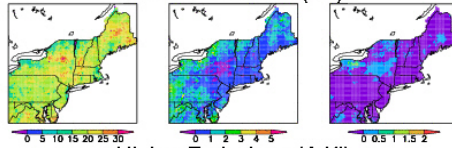
# Drought

1961-1990



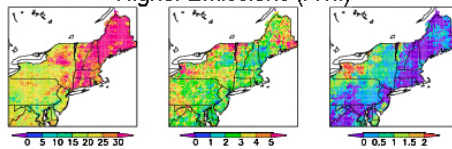
Lower Emissions (B1)

2070-2099



Higher Emissions (A1fi)

2070-2099

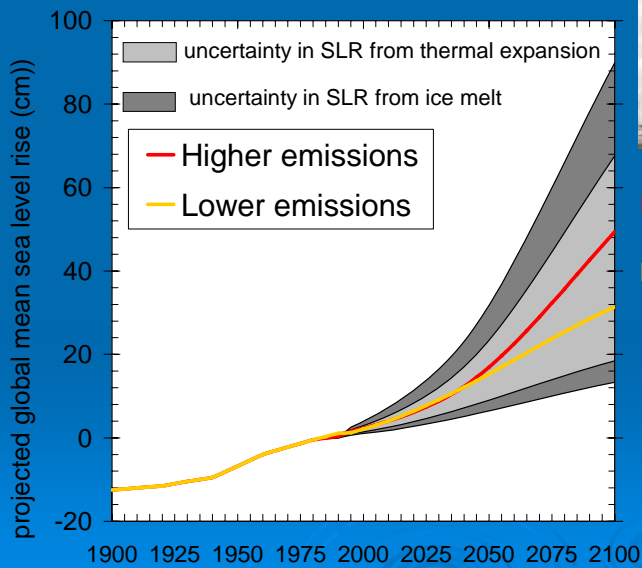


SHORT  
(1-3 months)

MEDIUM  
(3-6 months)

LONG  
(6+ months)

# Global Sea Level Change

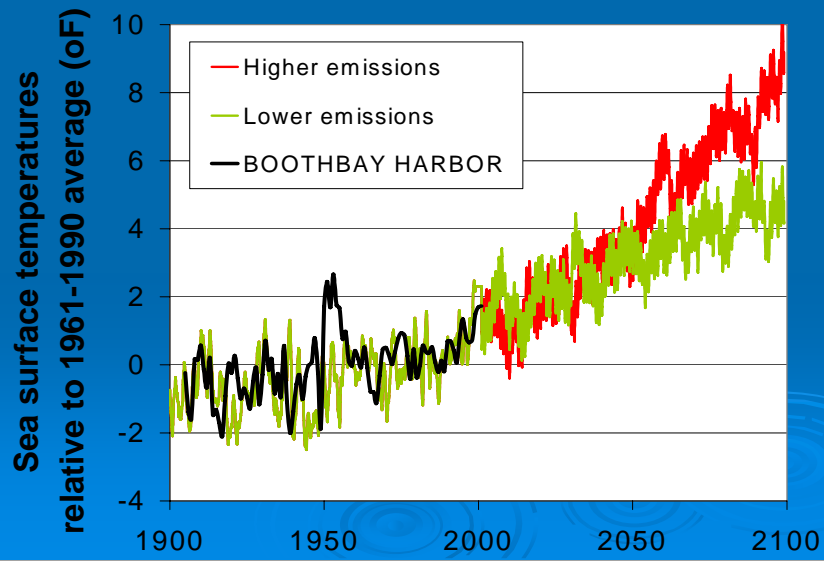


Higher: 8-33 inches

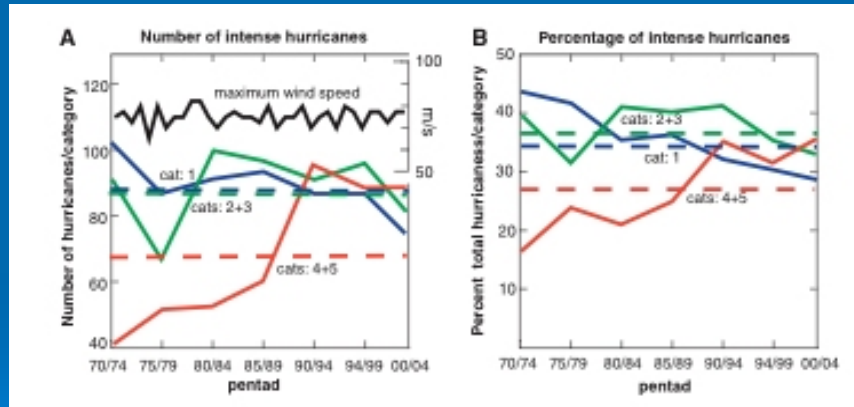
Lower: 4-21 inches

These estimates do not include the potential for additional increases due to more rapid melting of major polar ice sheets.

# Ocean Temperature Change



# Hurricanes



## Summary

With VERY HIGH levels of certainty

GHG concentrations have increased markedly

In isolation these changes must result in warming

With HIGH CERTAINTY

Observed global temperatures have increased 1°C

Observed changes in precipitation character

Observed impacts

CO<sub>2</sub> not this high for 100s of thousands of years

Climate model projections show continued increases in temp

With Limited Certainty

Magnitude of Temperature Rise (1.5 - 5+ °C)

Precise regional changes and impacts

A summary of what we have learned about global warming,

The two statements shown in orange are very certain. We have seen large increases in GHG concentrations in recent years. Given these increases **IF ALL OTHER COMPONENTS OF THE CLIMATE SYSTEM ARE HELD CONSTANT**, physics requires that the temperature of the earth has to increase.

Scientists are highly certain of those aspects shown in yellow. Observation differences and changes, as well as a relatively sparse network of observing sites, cast a small amount of doubt on the observed temperature and precipitation records. Temperature is perhaps one of the best models components of the climate system. The many available models all agree on temperature increases, and only differ in the magnitude of the increase.

In Blue are aspects of climate change that only have limited certainty. Inadequate representation of many of the climate systems feedbacks in models, currently prevent scientists from specifying the magnitude of temperature rise. This is further complication by the uncertainty associated with future fossil-fuel emissions. Climate feedbacks and limitations in climate model resolution make it difficult to project regional climate changes.