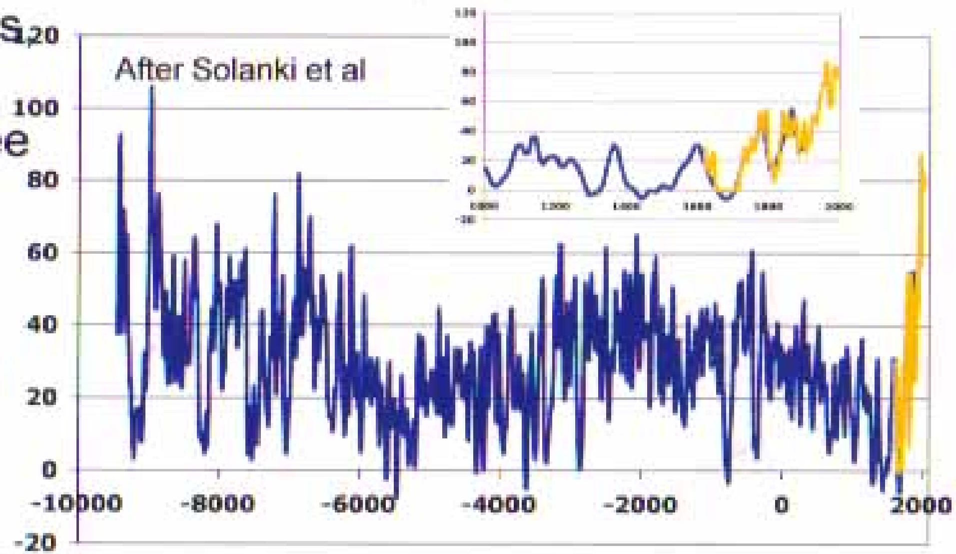
Does the Sun vary and how do we know?

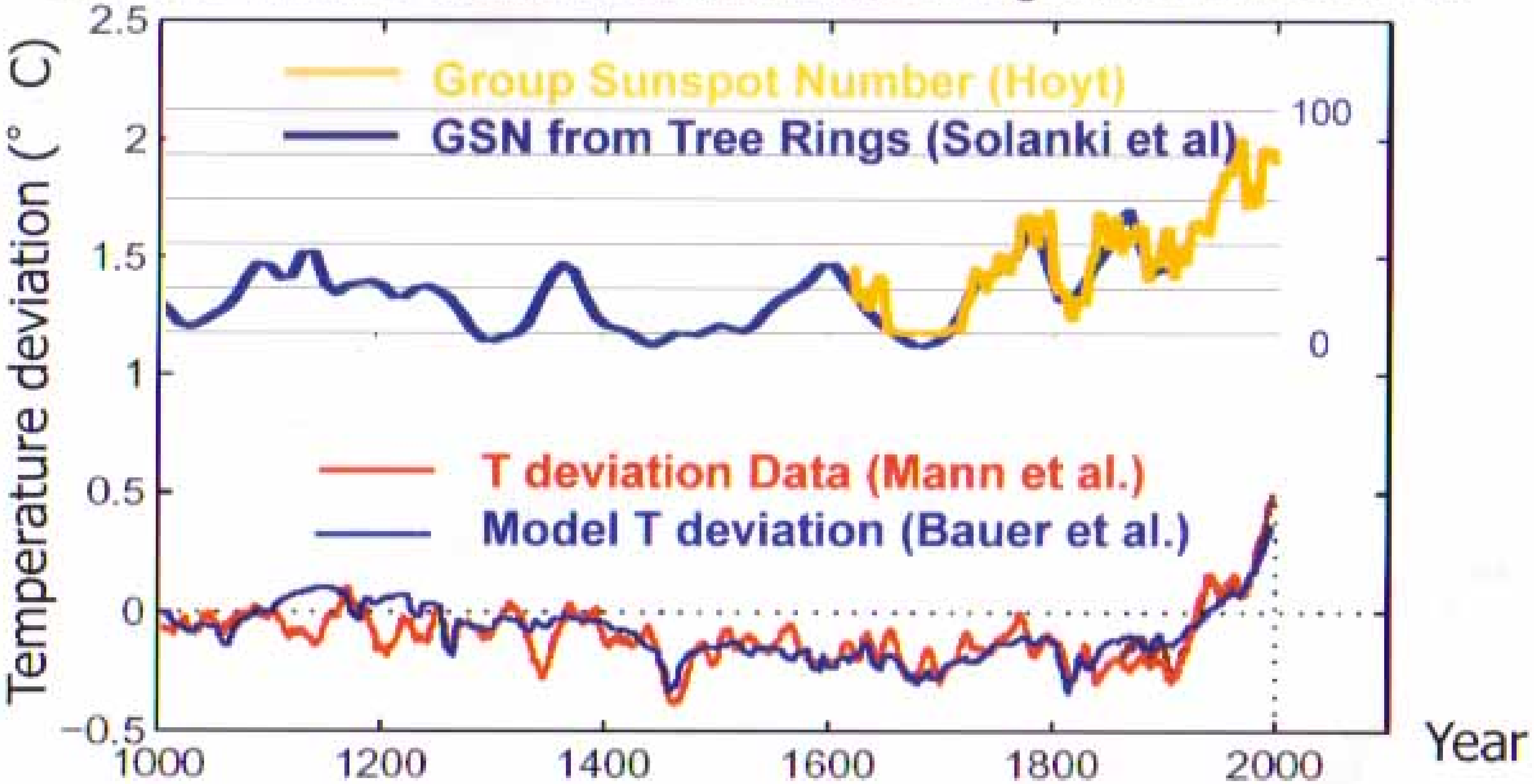
- The Sun's output has remained nearly constant for tens of millennia.
- It does vary by a small fraction of a percent, due to fluctuating magnetic activity that causes solar flares and dark sunspots.
- Sunspots are relatively easy to observe, and astronomers have been doing so for hundreds of years. In the plot below, the yellow lines shows actual observations of sunspots.
- To understand the variability of the Sun over much longer time frames, scientists use isotopic measurements, for example in tree rings, which are sensitive to the Sun's magnetic activity.
- The blue data is reconstructed from the tree ring analysis, dating back more than 11,000 yrs.
- In the overlap period (insert), it agrees with direct observations.

Group Sunspot Number vs Time



Are sunspots correlated to air temperature changes?

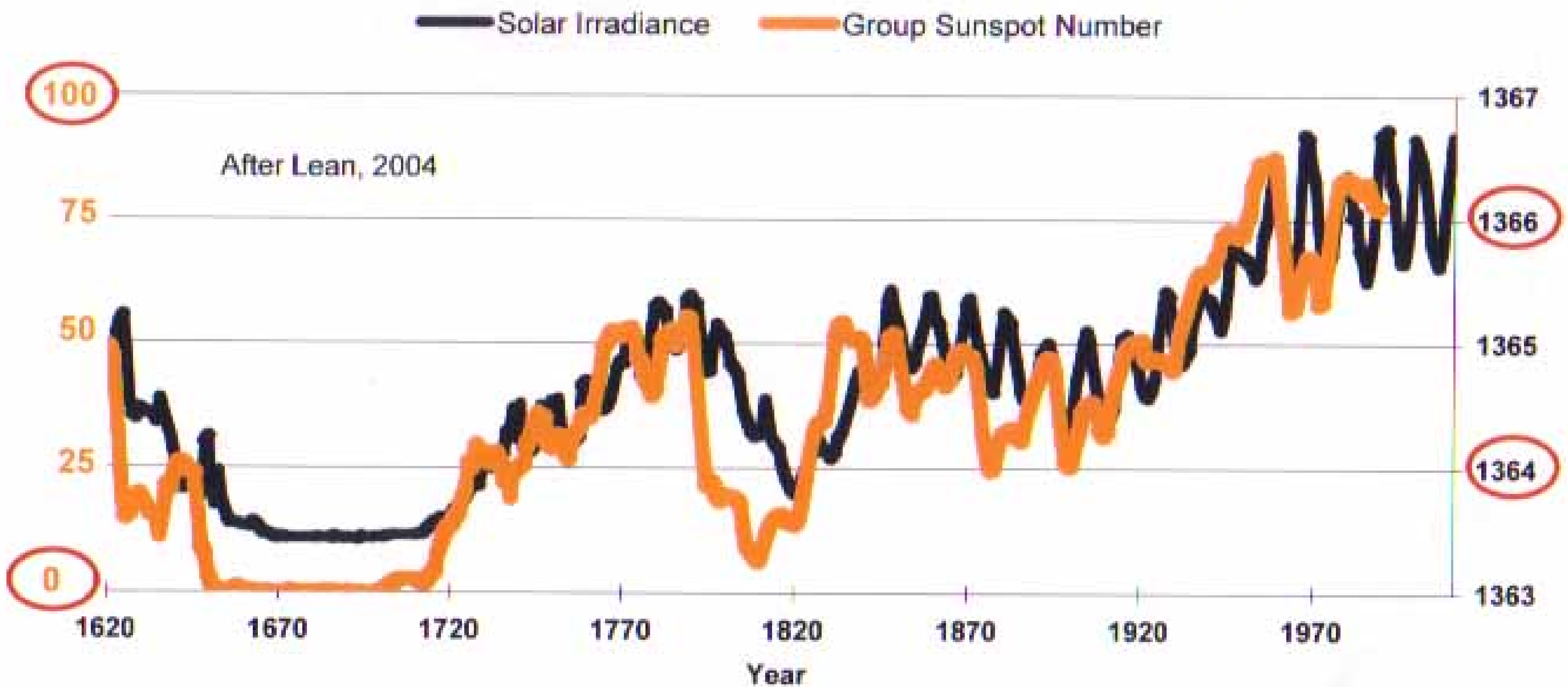
- Air temperature changes (red line) show fluctuation over the past 1000 years, with a rapid increase in temperature since about 1900.
- Sunspot activity also varies, sometimes similarly to the temperature record, sometimes not. Both have increased in the last century.
- But to what degree do sunspots relate to the total output of the Sun, and how much of that forces the climate changes we now observe?



3.

How is the sunspot signature related to solar output?

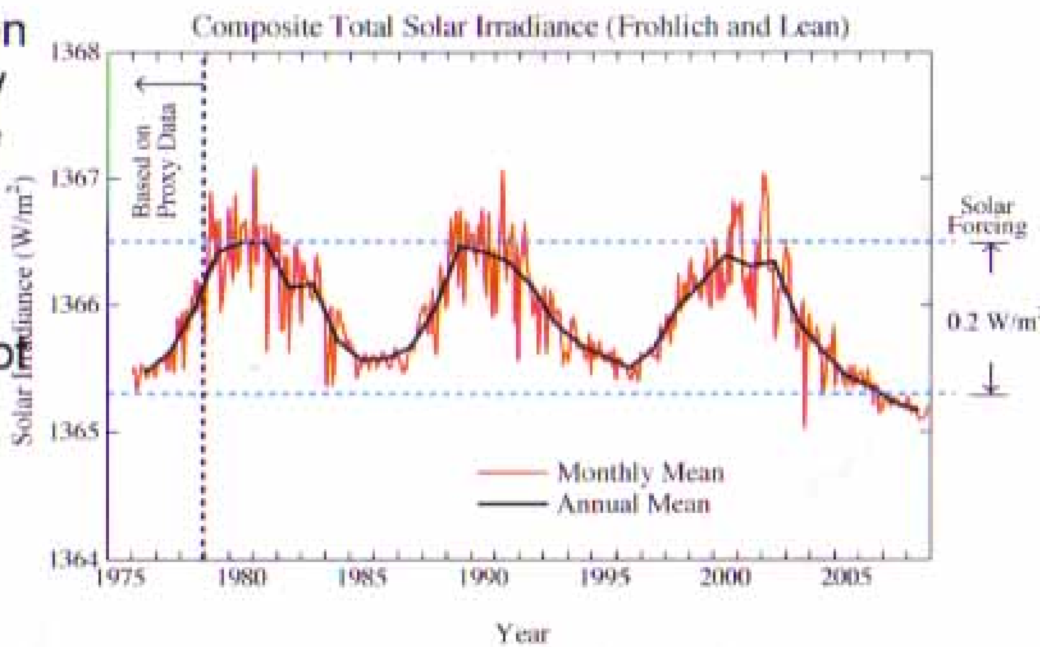
- Group sunspot number (GSN, yellow) and total solar irradiance (black) are related. But the magnitude of the changes are very different.
- While GSN has changed from 0 to nearly 100 over 400 years, the total solar radiation (irradiance) arriving at the top of the Earth's atmosphere has been relatively constant varying between slightly less than 1364 and slightly more than 1366 W/m^2, ie, by about +/- 0.1%.



Is the sunspot signature related to solar output?

- Not all of the Sun's irradiance penetrates down into the Earth's lower atmosphere, this is value is about 343 W/m^2. *Changes* in this value are known as climate forcing, and has both natural and human causes.
- The sum of all climate forcing since about 1750 is 1.7 Watts/m^2.

- The forcing due to changes in the Sun's flux has been estimated by many climate scientists, and varies between 0.06 and 0.3 Watts/m^2, only a small part of the total value of 1.7.
- Furthermore, direct measurements of the Sun's irradiance confirm that it is not responsible for the largest part of the temperature changes over the last 30 years.



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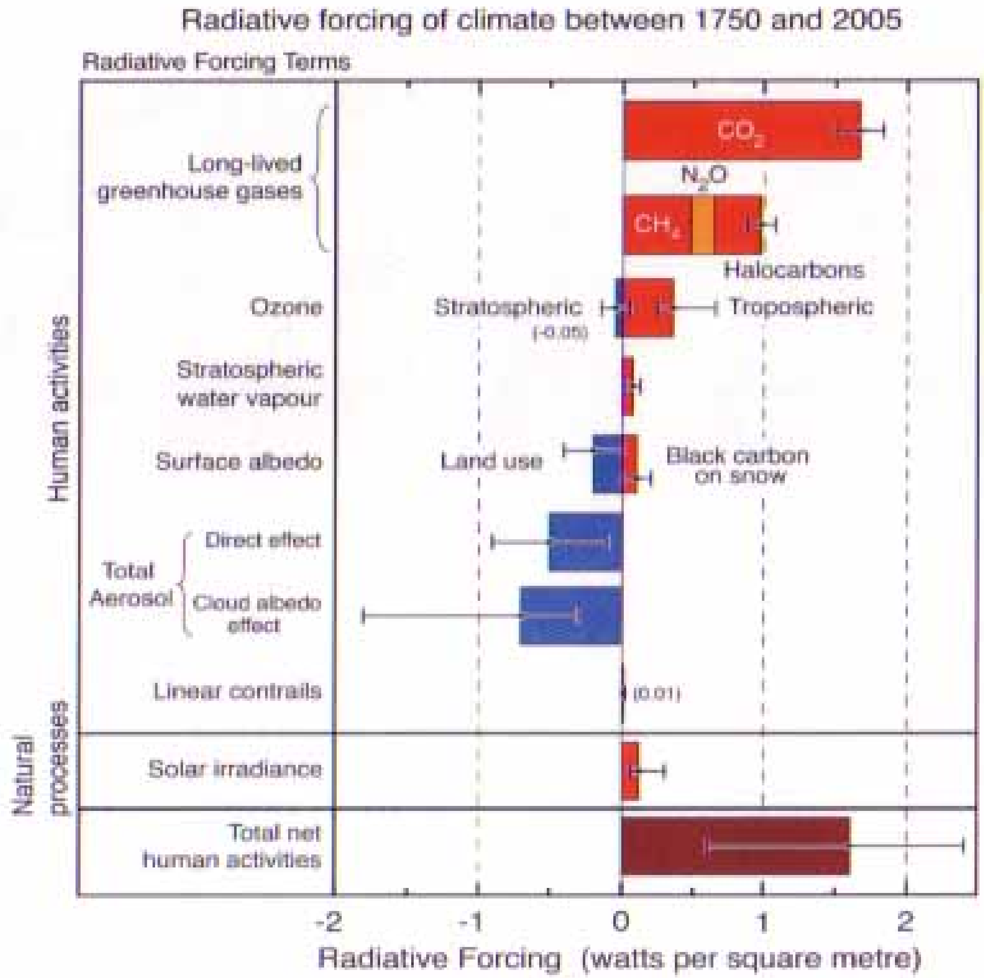
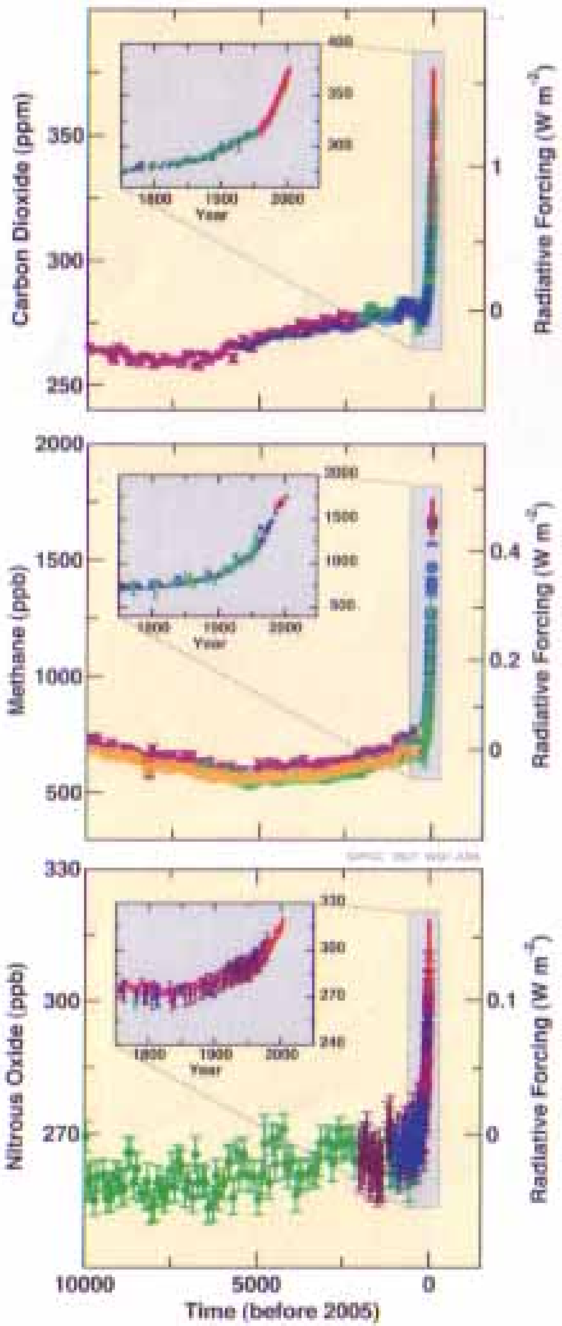


The radiative forcing of greenhouse gases is measured in watts per m^2. The additional forcing from the human-driven increases of these gases since 1750 in shown above. The natural radiative forcing (e.g., solar flares) is also shown for comparison. The blue bars on the left of the 0 line are human-driven changes that act to cool the climate: (i) emission into the air of aerosols (tiny particles) that scatter incoming solar radiation so less reaches the surface, and (ii) Changes in land cover (e.g., deforestation) that change the reflectivity of the Earth's surface. These cooling effects balance the warming effects of non-CO_2 greenhouse gases so that the net change in radiative forcing (bottom bar) is equivalent to that of CO_2 alone.

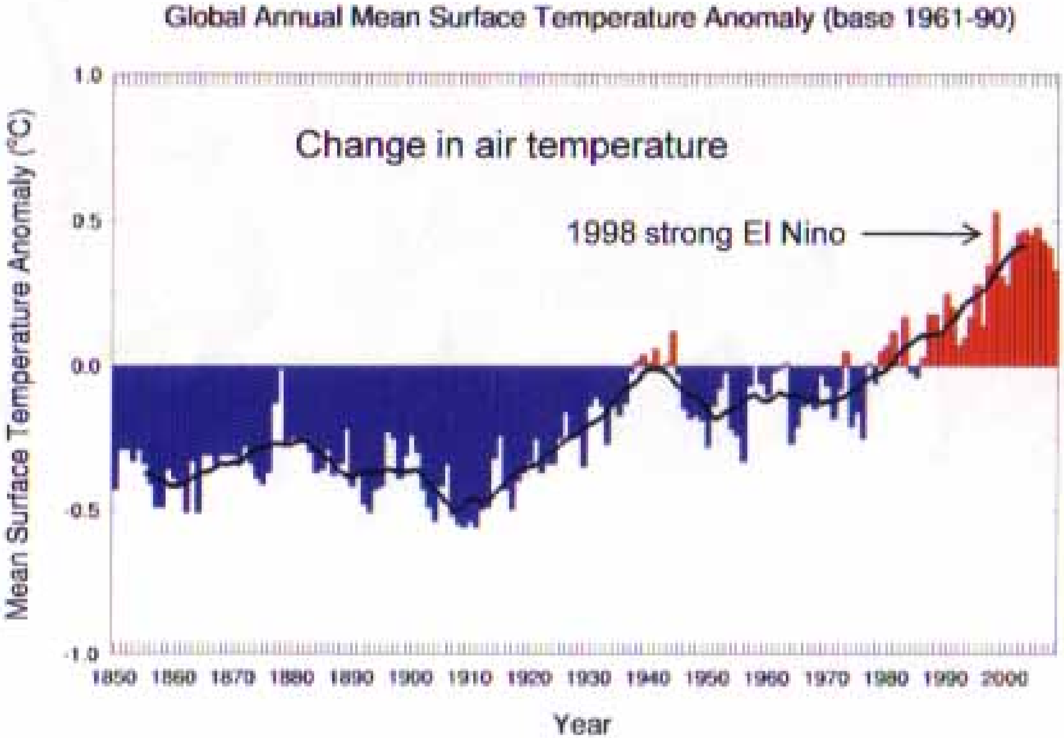
Observed change in greenhouse gas concentrations



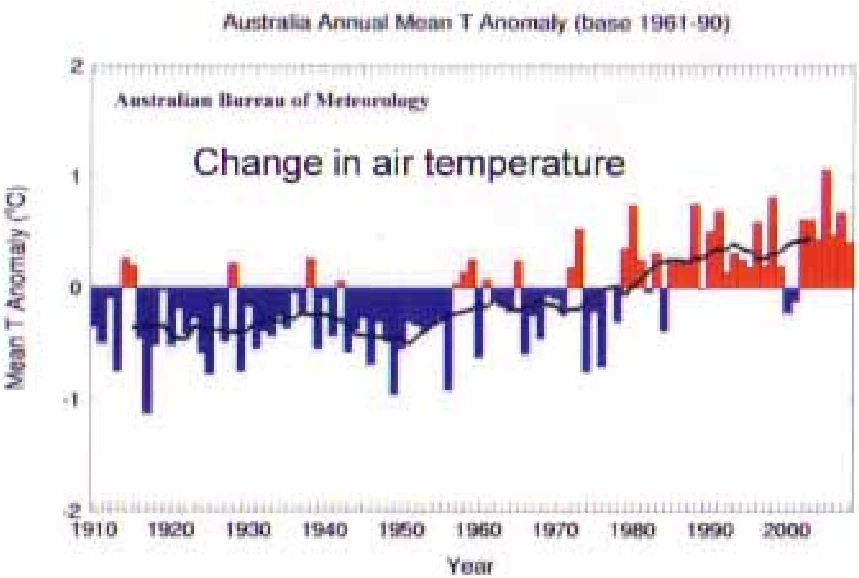
The concentrations of CO_2, CH_4 and N_2O are now much higher than they have been at any other time during the last 10,000 years - the current interglacial (warm) period called the Holocene. The large, rapid increase in the concentration of all three gases has occurred since the beginning of the industrial revolution (around 1800) and is undoubtedly due to human activities.

The recent <u>rate</u> of increase in concentration of the gases is much greater than at any other time during the 10,000-year record. The inset shows the increase in concentration of the gases since 1750. The concentration rises, particularly that for CO_2, have accelerated since about 1950, with the post-World War II surge in population and economic activity.

The "radiative property" of these gases - their ability to absorb and re-emit heat emitted from the Earth's surface - is a well-known and understood physical fact.

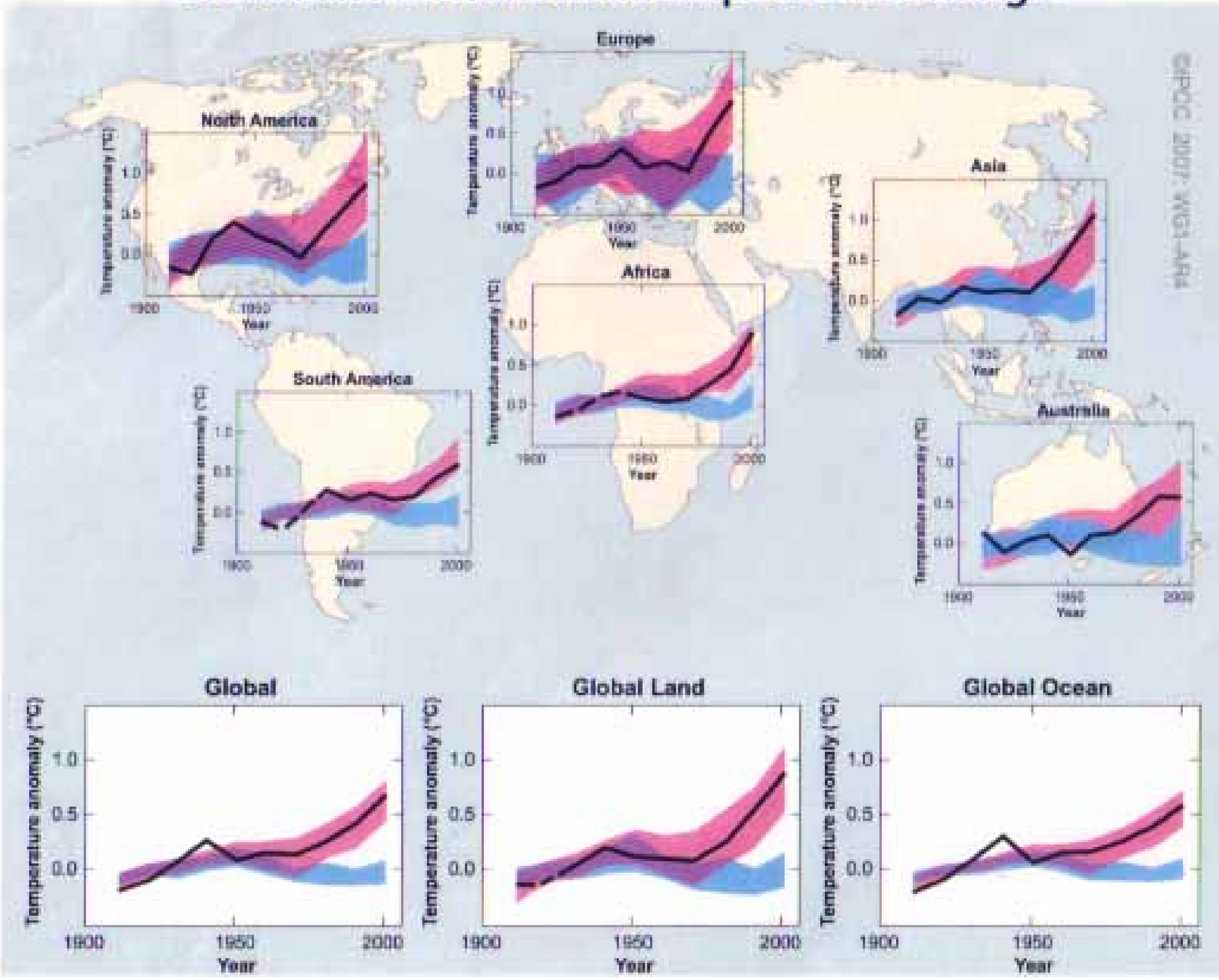


As expected, global average temperature has increased over the past 150 years. Most of the increase has occurred since 1950, the period during which greenhouse gas emissions have increased most rapidly. Note, however, the variability between years and over decades. The former is related to phenomenon like ENSO and the latter to changes in ocean circulation and aerosol emissions. Time periods of 50 years or longer are required to discern long-term trends in climate with confidence.

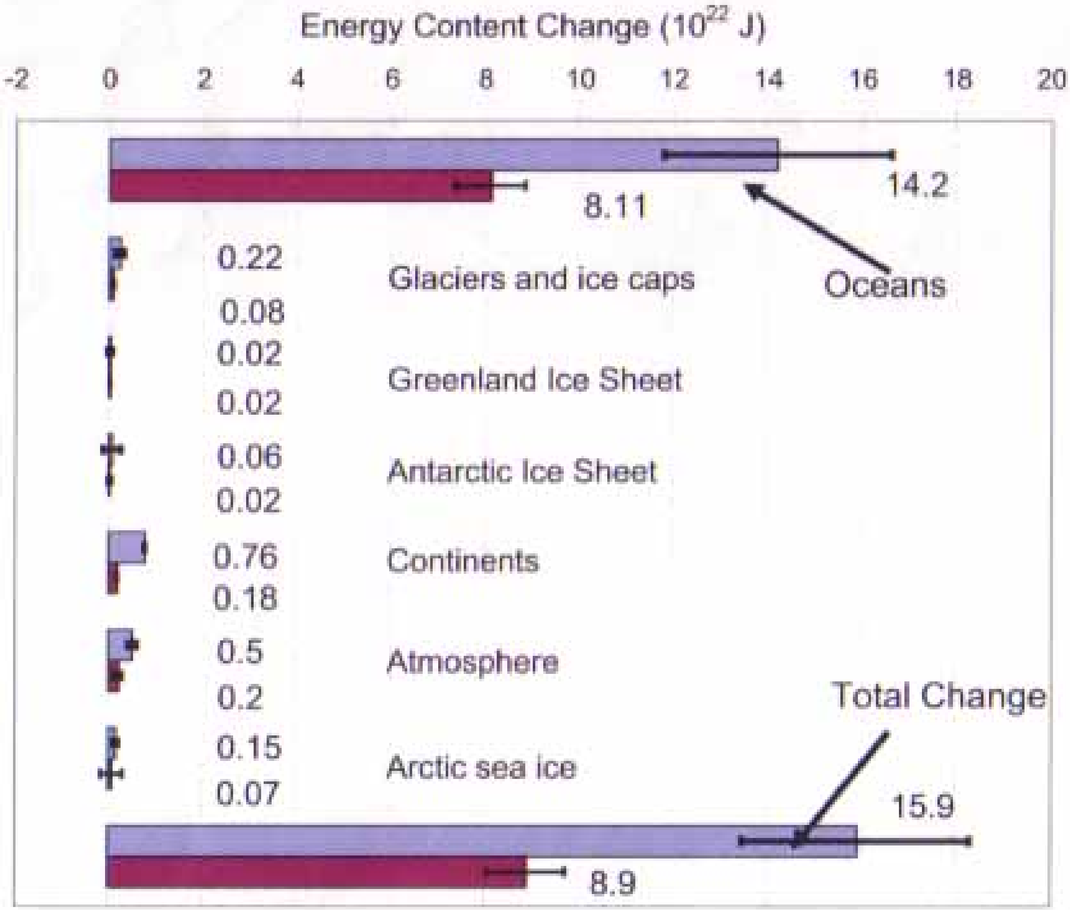


The bottom graph shows the change in temperature for Australia for the past century (note change in scale for the vertical axis). The Australian record shows more variability than the global record but the overall trend is the same. The warmest year on record in Australia so far has been 2005.

Global and Continental Temperature Change



Global air temperature has changed consistently over each continent and over the ocean through the past century. The black lines are observations. The blue bands are model simulations using natural radiative forcings only (changes in solar radiation and aerosols from volcanoes). The pink bands are model simulations using both natural and human changes to radiative forcing. The observed change in air temperature since 1950 is thus dominated by the human changes to radiative forcing.



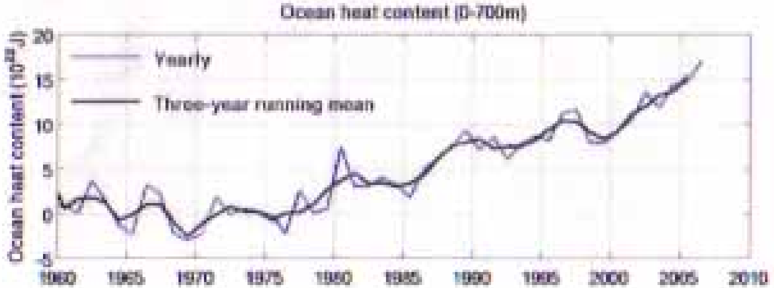
Blue bars: 1961-2003 period – 42 years
Purple bars: 1993-2003 period – last 10 years

As noted earlier, changes in ocean circulation can cause multi-year periods, up to a decade or so, of no change in air temperature or even slight cooling. This is because nearly 90% of the extra heat (energy) at the Earth's surface due to human-driven changes in radiative forcing goes into the ocean. Less than 5% goes into the atmosphere.

Thus, small changes in ocean circulation can drive dramatic changes in air temperature. An example of this is the very warm year of 1998 (globally the warmest on record) due to an intense El Nino event.

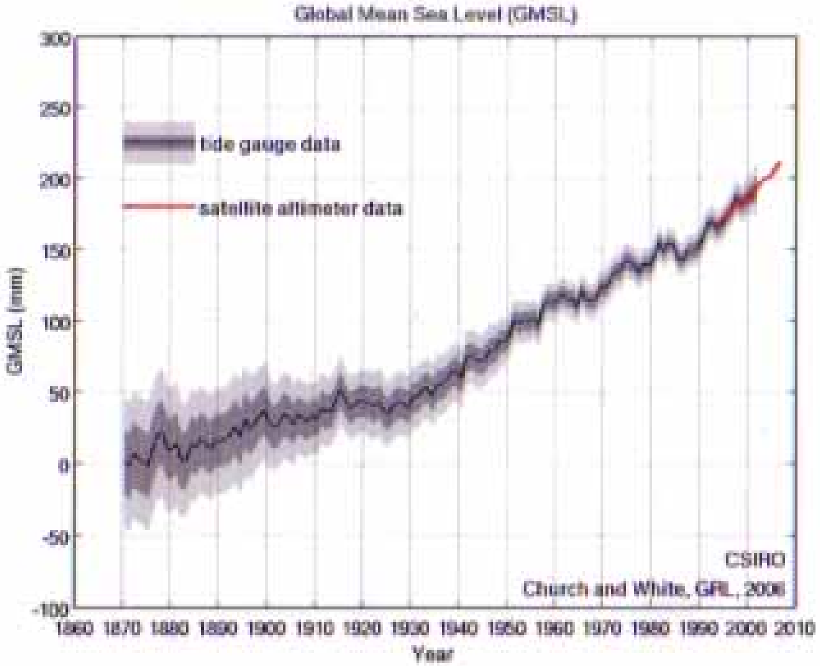
Long-term changes in ocean heat content are therefore the best single measure of change in the climate system due to human changes to radiative forcing. The warming of the Ocean has surged in the 1993-2003 decade (purple bars) compared to the earlier part of the 42-year record.

Change in Ocean Heat Content
(relative to 1961)



Observations of changes in ocean heat content (upper 300 metres of the ocean, where most of the additional heat resides) shows a clear warming trend over the past 40 years. Note the sharp increase in heat content since the late 1990s, with no sign of levelling off. This is strong evidence that the climate system is continuing to warm rapidly through this decade. 10.

Sea-level rise from 1970, relative to 1990



Observations of sea-level rise over the past half-century (solid red and blue lines) show a continuous rise, with an increase in rate since 1990. The broken lines and shading indicate the range of model projections of sea-level rise, available since 1990. Observed sea-level rise is tracking at the very upper limit of the range of projections. Most of the sea-level rise up to 1990 was due to thermal expansion of seawater. Since 1990 loss of ice from the large polar ice sheets (Antarctica and Greenland) has become more important than earlier.

Summary

1. The greenhouse effect is a well-understood physical phenomenon, like gravity. The properties of greenhouse gases such as CO_2 - their ability to absorb and re-emit heat - are also well-understood and quantified.

2. The concentrations of several important greenhouse gases - CO_2, CH_4 and N_2O - have risen significantly and rapidly over the past 250 years due to human activities. Their effect on the heat balance at the Earth's surface is much larger than changes in natural factors, such as changes in solar radiation. Most of the increases in greenhouse gas concentrations have occurred since 1950, and thus their effect on climate will be most readily discernible after 1950.

3. Many aspects of the climate system have changed dramatically over the past half-century. These include global average ocean temperature, global average air temperature and rise in sea level. About 90% of the additional heat at the Earth's surface caused by the additional greenhouse gases is absorbed by the ocean. Thus, change in ocean heat content is the best single indicator of global warming.

4. The change in global average air temperature at equilibrium caused by the current concentration of CO_2 (and other gases and aerosols) is 1.3 °C (observed + climate system inertia). The mid-range amount predicted from the human-driven change in radiative forcing at equilibrium is 1.3 °C. Thus, the air temperature is changing in proportion to carbon emissions.