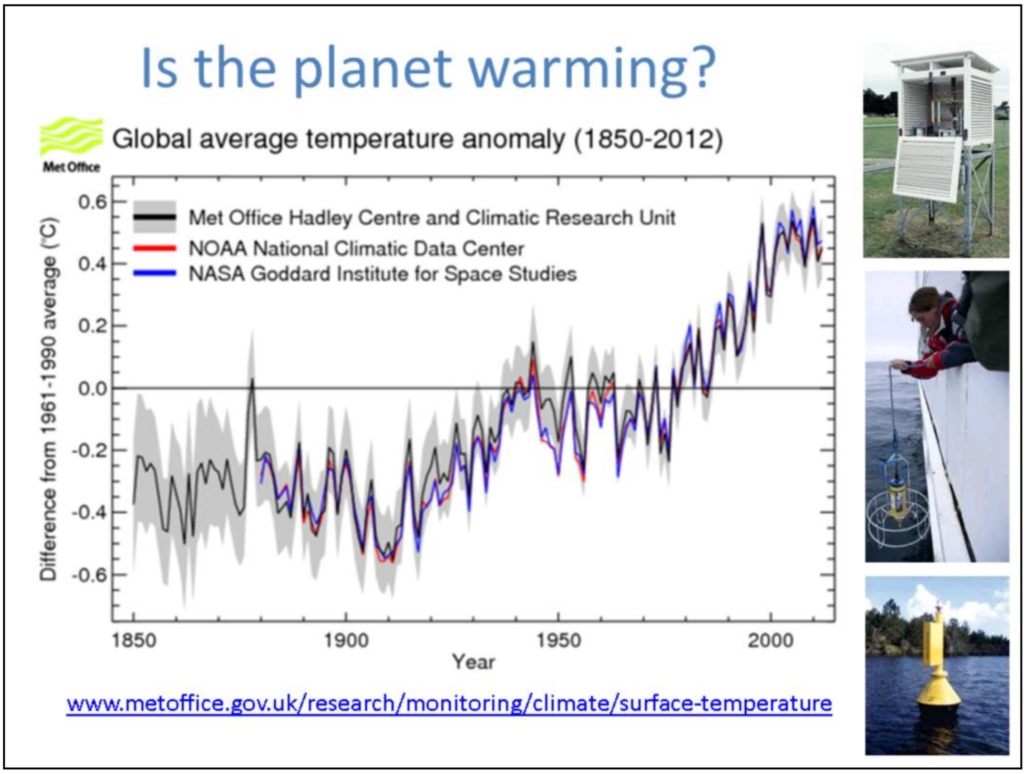
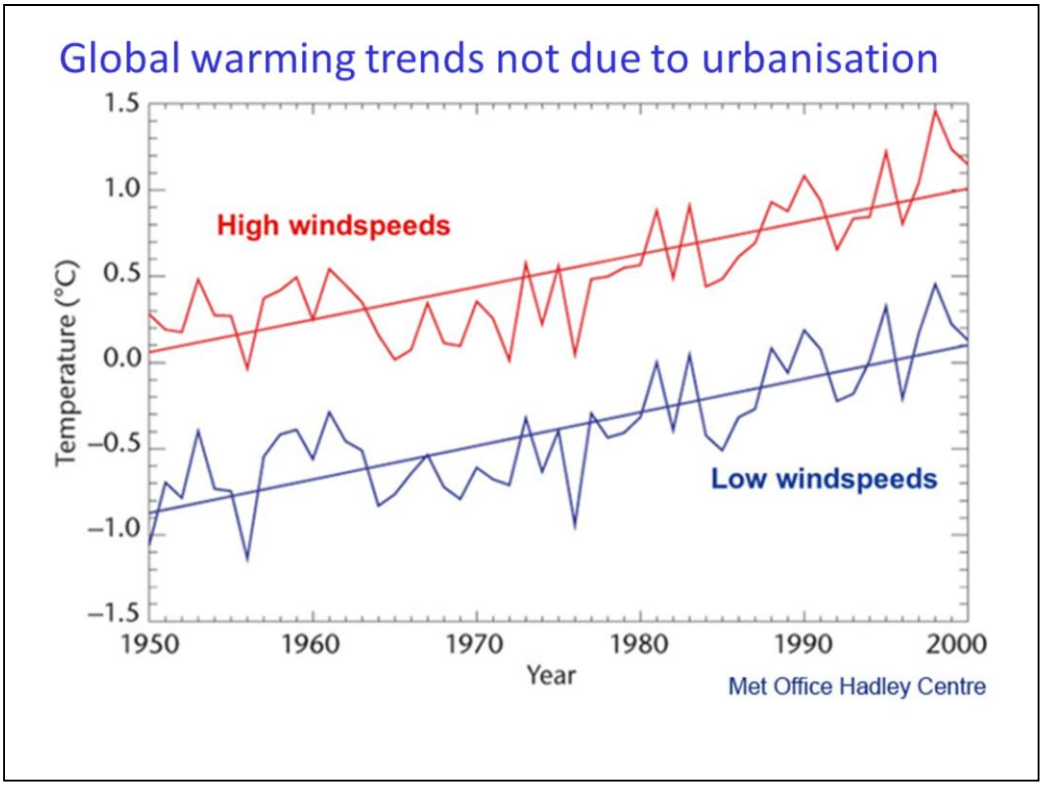
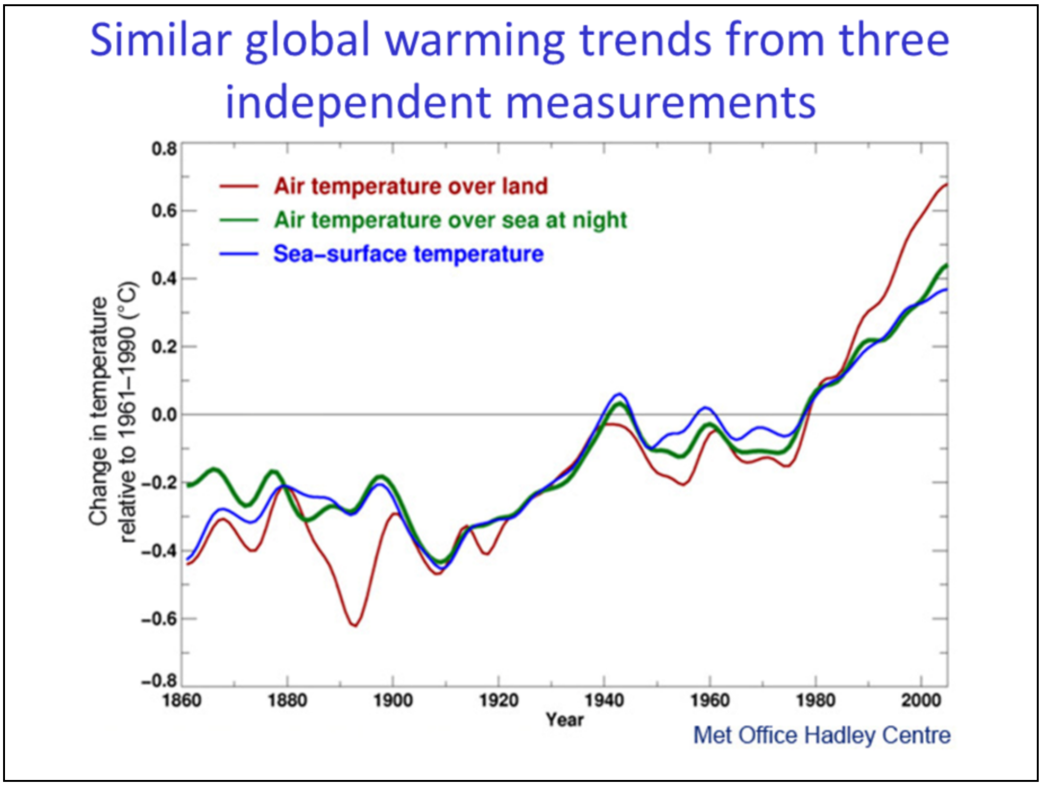


The instrumental record goes back to about 1850. A few areas of the globe have not warmed in recent decades, mainly over some parts of the Southern Hemisphere oceans and parts of Antarctica. The rate of surface warming is not smooth; there are lumps and bumps in the record and this rate has slowed in the recent decade.

The global average surface temperature (the average of near surface air temperature over land, and sea surface temperature) has increased since 1861, the earliest year for which a robust global estimate is possible. Over the 20th century the increase has been about 0.8°C. The record shows a great deal of variability; for example, most of the warming occurred during the 20th century, during two periods, 1910 to 1945 and 1976 to 2000. Continents in the northern hemisphere have warmed the most.

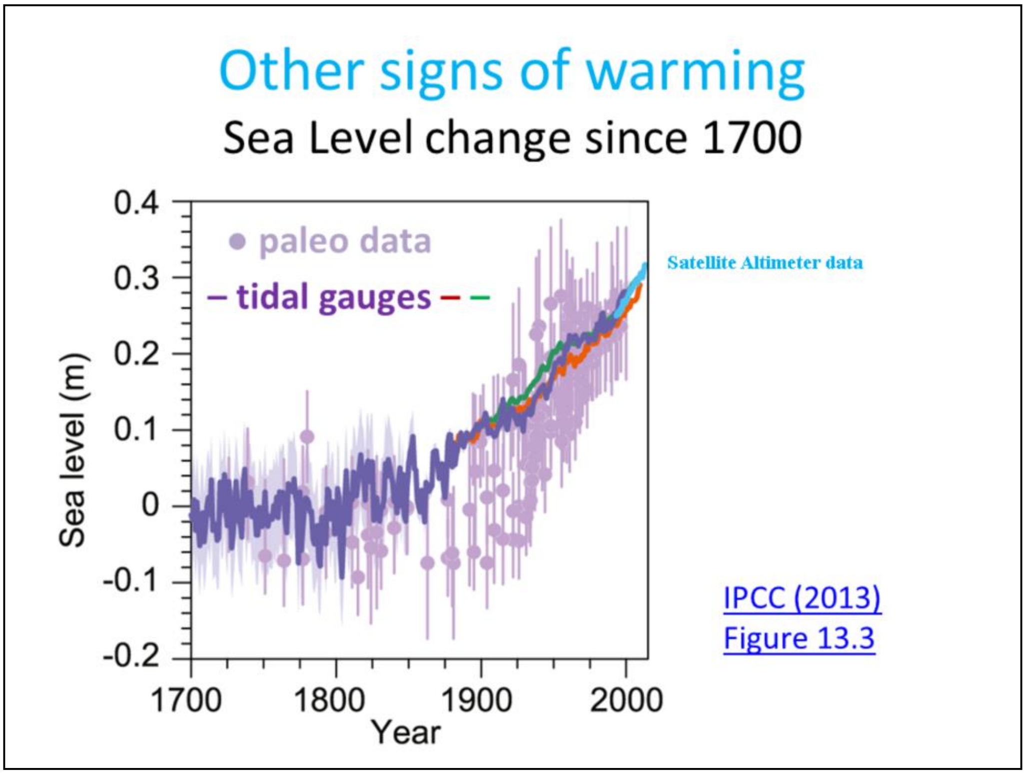


At night, temperature in a city does not fall as quickly as in the country because the concrete retains heat more effectively than other surfaces and city surfaces radiate heat more slowly than in the country. This "urban heat island effect" is weakened or destroyed when winds are strong. So if the recently observed warming is an artefact of urbanisation, then one might expect the temperature rise on calm nights to show this increasing urbanisation and, hence, to be more rapid than that on windy nights. Work at the Met Office Hadley Centre used daily night-time minimum temperature measurements at more than 250 land stations over most of the world, during the period 1950–2000. Data were taken for the top third most windy nights and the bottom third least windy nights (that is, the most calm conditions). Trends for these two subsets are plotted in the slide. Although, as expected, minimum temperatures in windy conditions are somewhat higher, the trend is the same in windy and calmer conditions. This clearly demonstrates that warming over the past 50 years has not been due to urbanisation.



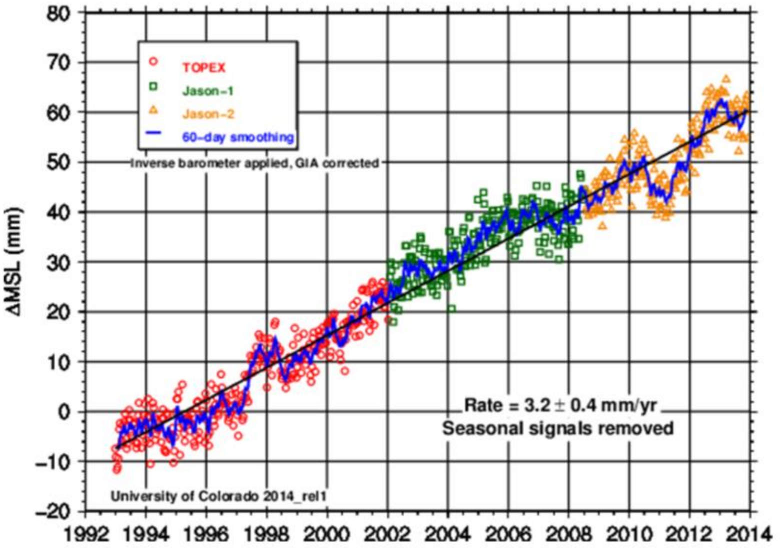
Shown in this slide are three independent measurements of global mean temperature; sea surface temperature, the air temperature over the land surface and the air temperature over the sea. For most of the time, they agree with each other reasonably well, which shows that this temperature rise is real. As can also be seen, warming since the 1970s has been more rapid over land than over the oceans, as would be expected from an increasing man-made greenhouse effect.

The amount of warming observed varies considerably from place to place, because natural variability of climate can add to man-made warming in some places, or subtract from it in others. Local factors (such as aerosol cooling) may also come into play. That the Earth's surface has experienced a recent warming is also supported by the widespread recession of mountain glaciers over the last few decades, and by measurements made at different depths in boreholes, which can be used to estimate the historical rise in temperatures.



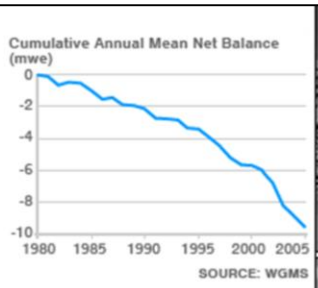
Are there other indicators of the warming? Global sea level has risen, based on historical proxy data and tidal gauges that have been adjusted to allow for rising and falling of land and other factors. Global sea levels have risen about 20cm over the past 100 years – a rate of about 2mm a year. This is faster than the rise over any of the last 5000 years (less than 1mm a year), but still slower than the average rise of 5mm a year predicted for the next 80 years. Most of this rise occurs because as the oceans get warmer, their water takes up more space (thermal expansion). Melting glaciers in the Andes, Himalayas, the Rockies and the Alps are increasingly contributing to sea level rise and melting of ice sheets at the periphery of Greenland and Antarctica are increasingly contributing.

Global average sea level rise from satellite altimetry



http://sealevel.colorado.edu/

Sea level also varies due to year to year fluctuations in the ocean and the distribution of fresh water over the land surface, much of this variability relating to El Nino Southern Oscillation. For example sea levels dropped slightly in 2011 due to La Nina conditions (relatively cool east Pacific) and associated rainfall over usually dry regions (e.g. Australia). Effectively ocean water is temporarily dumped onto the land; it takes a year or so for this water to find its way back to the oceans via the global water cycle.

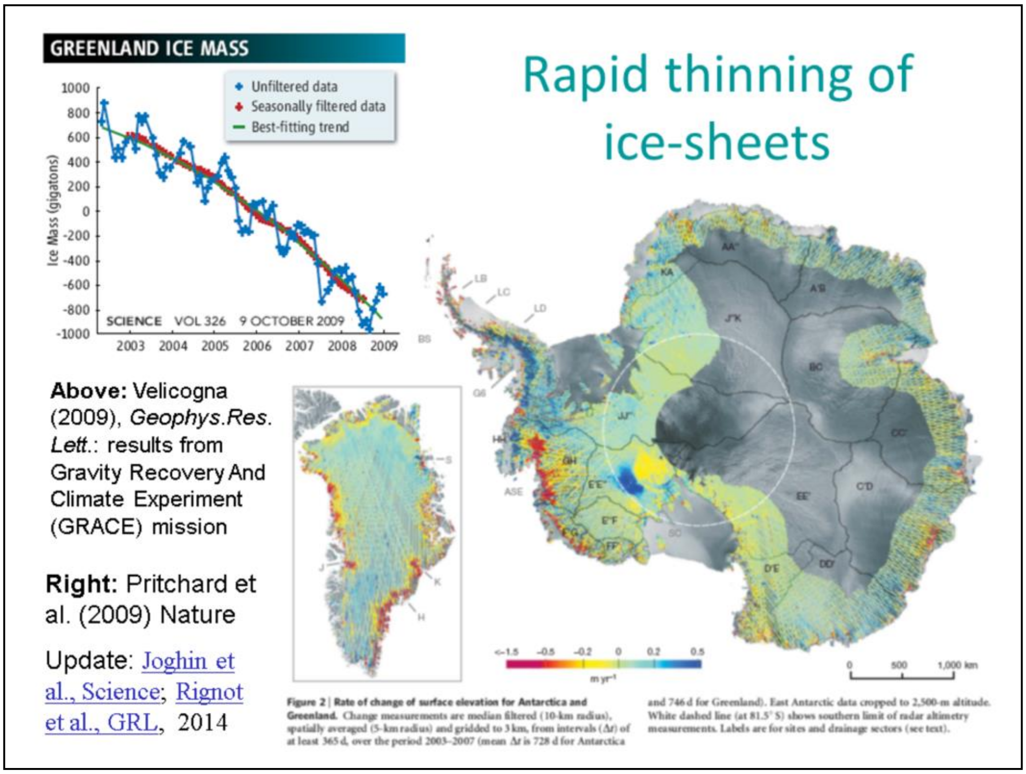


metres of water equivalent (~1.1m of ice) for 30 mountain glaciers

See also:
IPCC (2013)
Figure 4.12

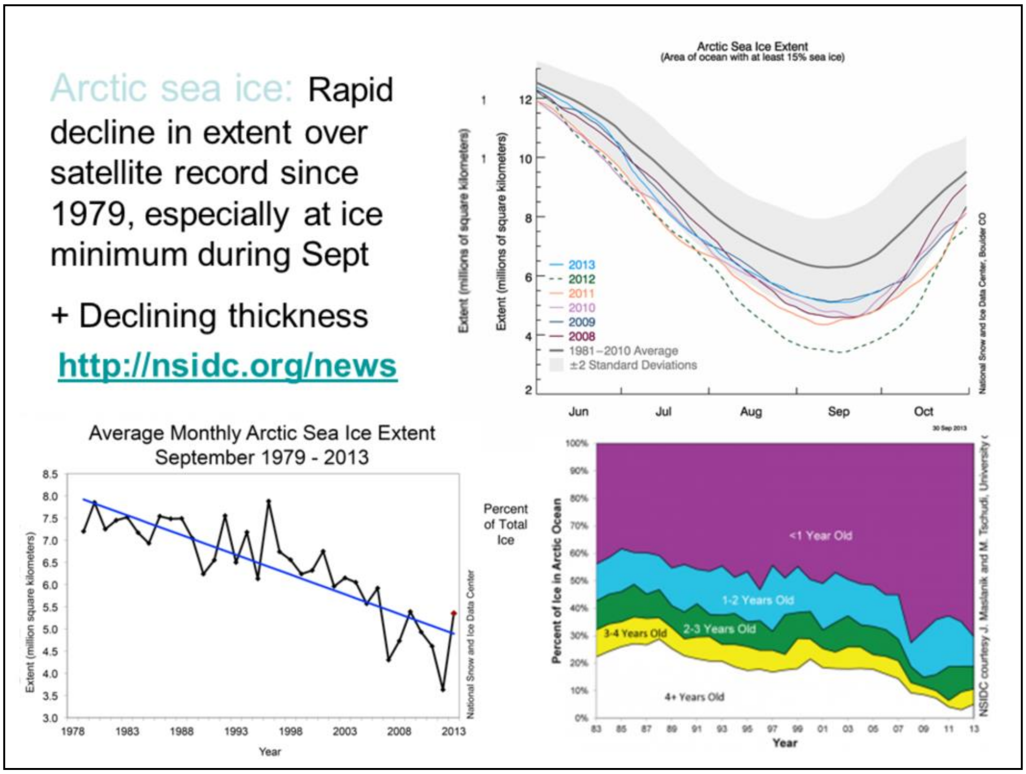
Three photographs, taken in 1912, 1968 and 2003, show how a glacier at Vernagtferner in Austria has shrunk. It lost over half a metre in thickness during 2005.

The majority of the world's glaciers are receding. The melting is making a significant contribution to global sea level rise (thermal expansion of the oceans is the cause of most of the sea level rise). The World Glacier Monitoring Service in Switzerland surveyed 88 glaciers in 2002 and 2003. They found 79 were melting and only four were growing. The nearly worldwide decrease in mountain glacier extent and ice mass is consistent with worldwide surface temperature increases. A few recent exceptions in coastal regions are consistent with atmospheric circulation variations and related precipitation increases. In the short term this could cause more flooding, in the long term it could add to the drought problems in some areas as rivers dry up. Average Arctic temperatures have increased at almost twice the global average rate in the past 100 years [IPCC 2007]



Although the interior of Antarctica and Greenland are gaining mass through increased snowfall, there is rapid melting of many coastal glaciers across Greenland and West Antarctica. Recent research indicates that key West Antarctic glaciers are melting rapidly and may have passed a “tipping point”: see http://www.antarcticglaciers.org/

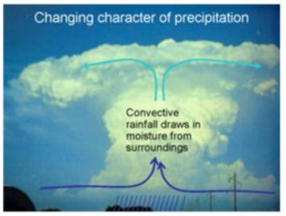
Note that “collapse” of such glaciers are slow relative to human time-scales, many hundreds of years.



Changes in atmospheric and oceanic circulation cause variability in the coverage of Arctic sea ice. However, the declining coverage in the satellite record (passive microwave measurements made since 1979) is robust and further, there has been a drop in “old” ice (older than 2 years for example) since the grand minimum coverage in 2007 with a larger fractional coverage of young <1 year old ice (which is more transient in nature meaning that it can melt and reform more quickly). Satellite’s are now measuring ice volume which is also diminishing.

Antarctic sea ice has been increasing in extent due to changes in atmospheric and oceanic circulation patterns but the changes are smaller in size than the Arctic losses.

Changing water cycle



- Increasing atmospheric water vapour (around 1%/yr)
- Increases in heaviest rainfall in many regions (inc. Europe and N America)

- Changes in drought less clear.
  - Some evidence for wet periods becoming wetter and dry periods drier
- Changes in tropical cyclones not clear.
  - Increases in strength over Atlantic

Atmospheric moisture has been increasing with warming as expected from basic physics. This strengthens the greenhouse effect and also supplies additional moisture for heavy rainfall events which have been observed to increase over many land regions, in particular North America and Europe. Apart from over northern latitudes where rainfall has been increasing, there have been less coherent changes in rainfall and drought indicators. There is some evidence increasing rainfall intensity in the wettest regions and drying of the driest portions of the tropical atmospheric circulation; this is backed up over the ocean by observations showing salty ocean regions are becoming more saline and fresher regions fresher. While the strength of damaging tropical cyclones have been observed to increase in the North Atlantic, evidence from other ocean basins is less clear.

Biological Signs

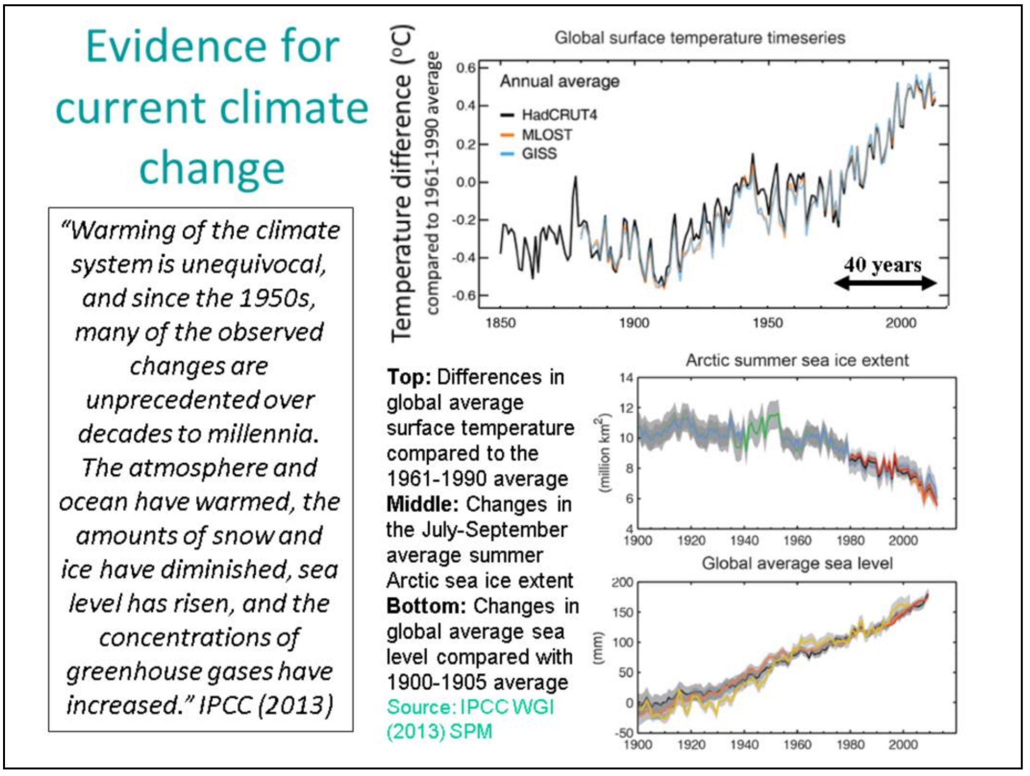
- Shorter winters
- Plant and animal ranges shifting
  - e.g. fish stocks moving north

- Declining animal populations
  - Cannot migrate as fast as movement of climatic zones
  - Habitat being affected by changing climate
  - Ocean acidification due to ↑CO_2

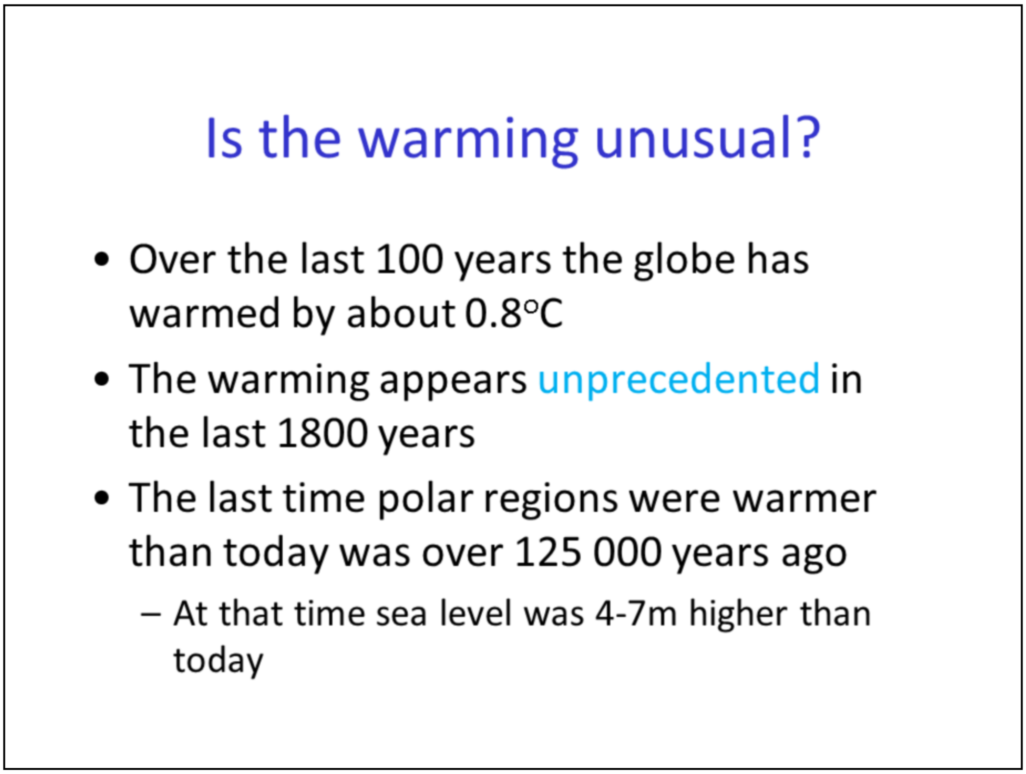
More details in IPCC WG2 report

The seasons are changing. Spring arrives earlier: bees and butterflies can now appear in late winter, and people have seen daffodils at Christmas. Plant and animal ranges are shifting – fish are moving further north, the black kite and snow egret are expanding their ranges into the UK from southern Europe. Some plant and animal populations are declining, such as the capercaille, the snow bunting and various arctic flowers. Where the changes in latitude of a particular climate move more quickly than flora or fauna can adapt, they will die out.

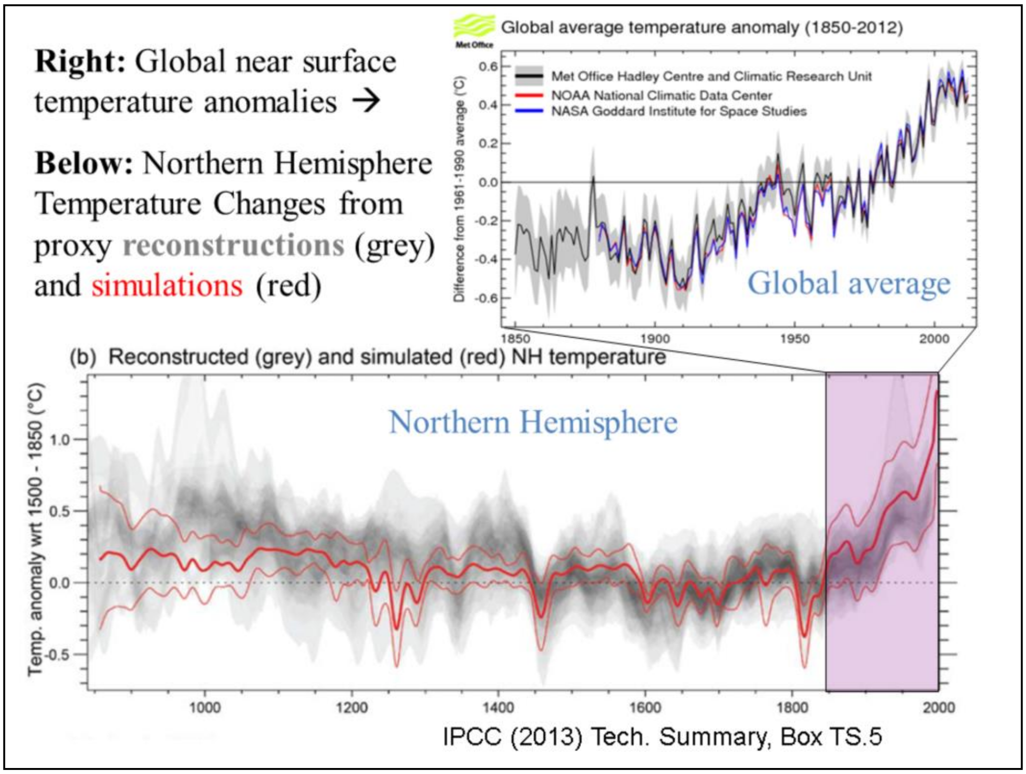
IPCC 2013: “Many terrestrial, freshwater, and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances, and species interactions in response to ongoing climate change.”



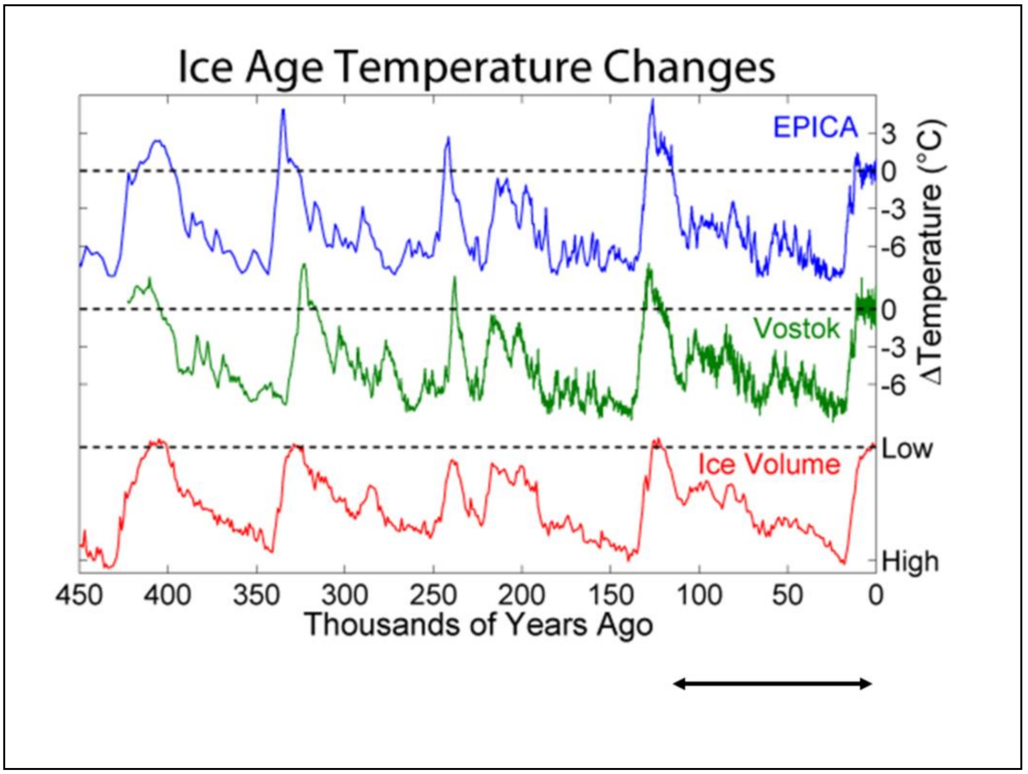
The globally averaged combined land and ocean surface temperature data show a warming of 0.85°C over the period 1880 to 2012 and observations show that heat is accumulating in the ocean down to 2km depth. Sea level has risen by around 20cm since 1900. Atmospheric moisture is increasing and the frequency or intensity of heavy precipitation events has likely increased in North America and Europe. Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent.



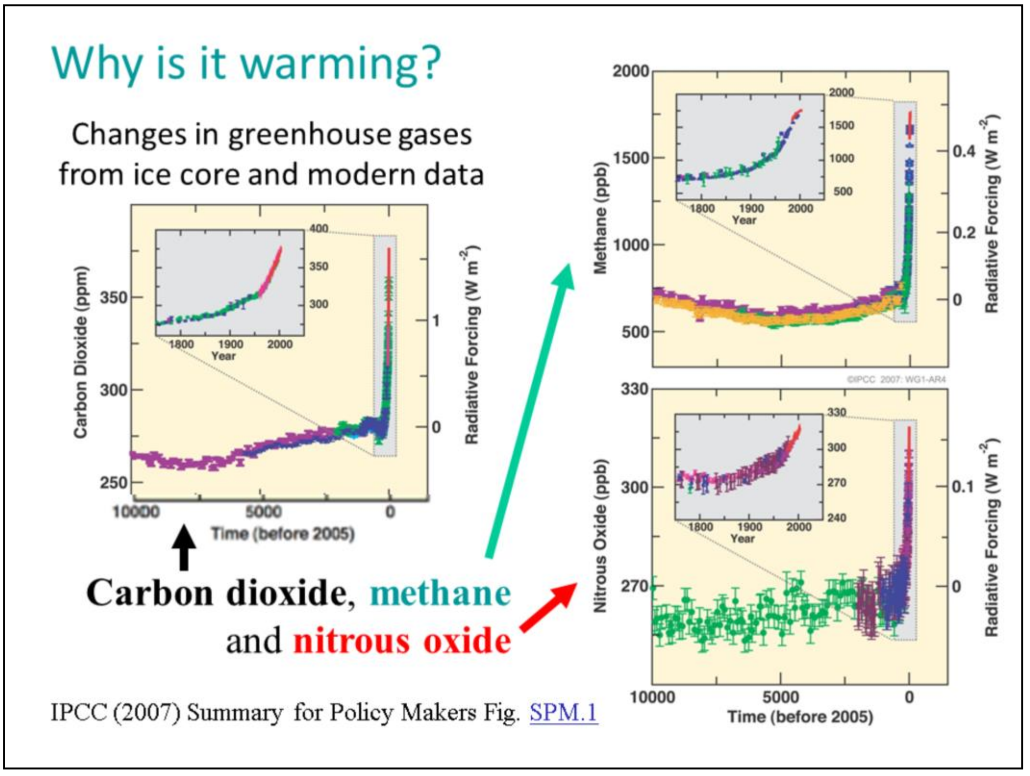
Based on a multitude of proxy data it is possible to compare the recent warming found in the instrumental record, and corroborated with the proxy data, with the last 1400 years for a northern hemisphere dataset and for nearly 1 million years using polar ice core data in Antarctica. The global average temperatures and the rate of warming today are unprecedented over the last millennium.



The current warming is highly unusual in the context of the last 1800 year record based on data from climate proxies such as tree rings, ice cores and historical records. In the Northern Hemisphere, 1983–2012 was likely the warmest 30-year period of the last 1400 years. Although periods during the Medieval Climate Anomaly (950 to 1250 AD) were in some regions as warm as in the late 20th century, they did not occur as coherently across regions as the warming in the late 20th century [IPCC 2013]

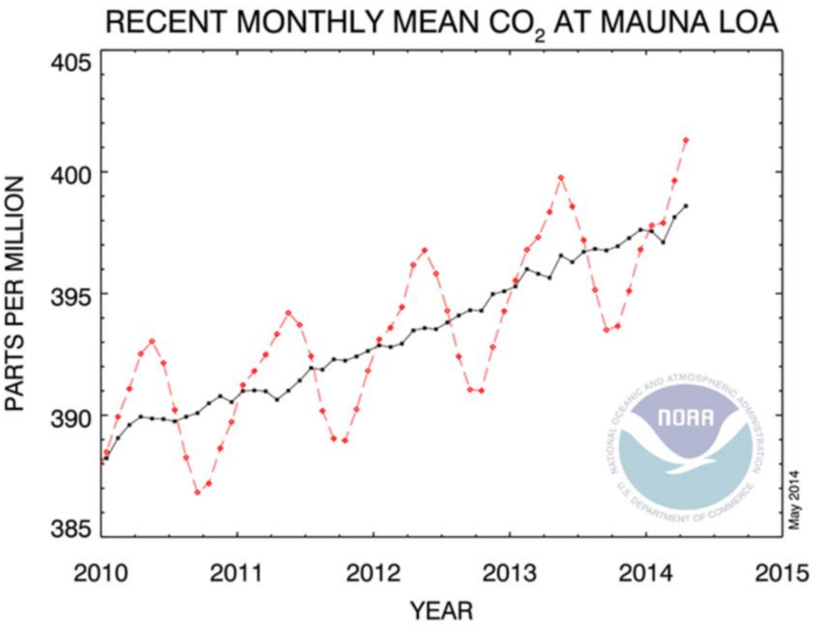


The last time the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 metres of sea level rise.



Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years (above). The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land-use change, while those of methane and nitrous oxide are primarily due to agriculture.

• Carbon dioxide is the most important anthropogenic (human produced) greenhouse gas. The global atmospheric concentration of carbon dioxide has increased from a pre-industrial value of about 280 ppm to 400 ppm in 2014, which exceeds by far the natural range over the last 800,000 years (180 to 300 ppm) as determined from ice cores.

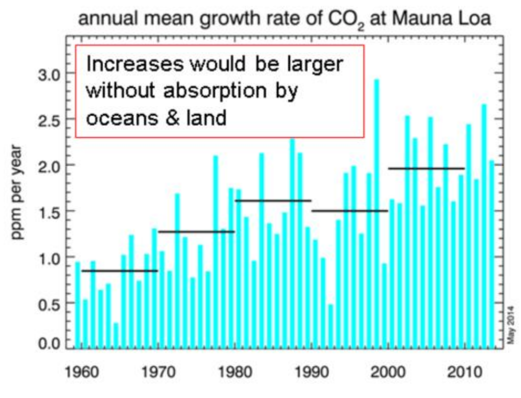


http://www.esrl.noaa.gov/gmd/ccgg/trends/index.html

Globally, concentrations of CO2 will surpass 400ppm by 2015 (April 2014 was the first full month above 400 ppm observed at Mauna Loa and much of the northern hemisphere).

CO_2 levels and rate of increase

- *Today's CO_2 concentration has not been exceeded during the past 800,000 years and likely not during the past 15 million years*
- *The rate of increase over the past century is unprecedented, at least during past 10,000 yrs*
- Recent rates of **increase** in CO_2 are also increasing



Rate of increase in parts per million/year

The graph shows annual mean carbon dioxide growth rates based on Mauna Loa observations. Variations relate to volcanic eruptions and El Nino Southern Oscillation which cause year to year fluctuations in global temperature, rainfall patterns and carbon fluxes between the atmosphere and the land/ocean surface.

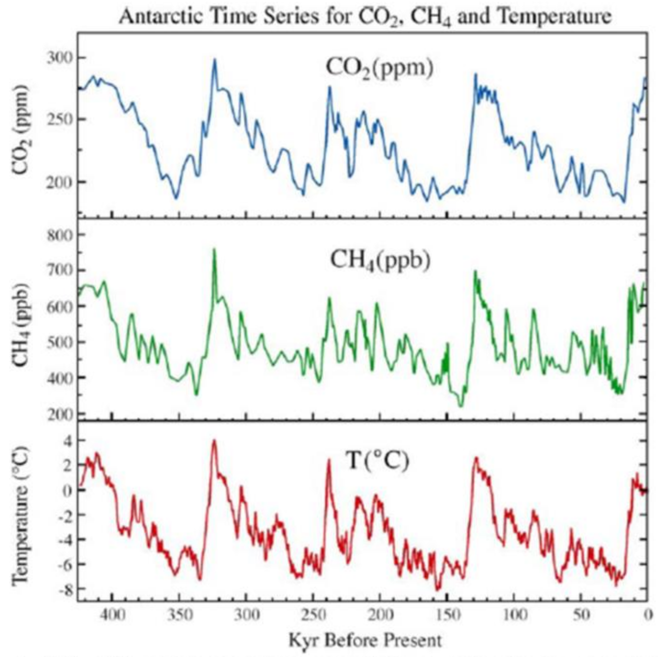
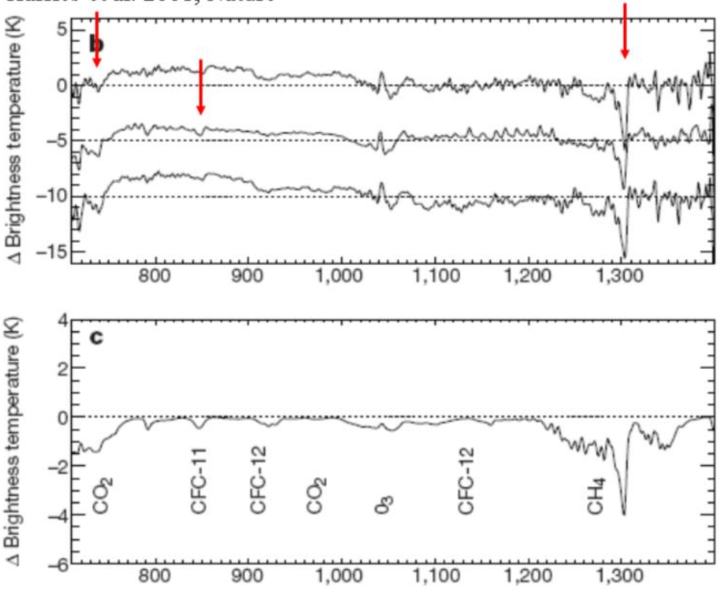


Fig. 4. CO_2, CH_4 and temperature records from Antarctic ice core data.
Source: Vimeux et al., Earth Plan. Sci. Lett., 203, 829, 2002.

There is an undoubted correlation between greenhouse gases and temperature over the glacial cycles of the last million years. However, correlation is not causation. For example, carbon dioxide is more soluble in colder water and changes in carbon dioxide over thousands of years are *caused* by changes in temperature. Note that the current concentrations of carbon dioxide and methane are well off the scale in the above figure, indicating that an unusual mechanism is operating.

The difference in outgoing longwave or thermal spectra between two satellite instruments: 1997-1970

Harries et al. 2001, Nature



These results showed for the first time experimental confirmation of the significant increase in the greenhouse effect from trace gases such as carbon dioxide and methane

It is undoubtedly true that greenhouse gases act to warm the planet via the natural greenhouse effect.

Increases in these greenhouse gases have been shown, using satellite data, to have reduced the planets cooling from 1970 to 1997, in line with their predicted effects on the radiation budget.

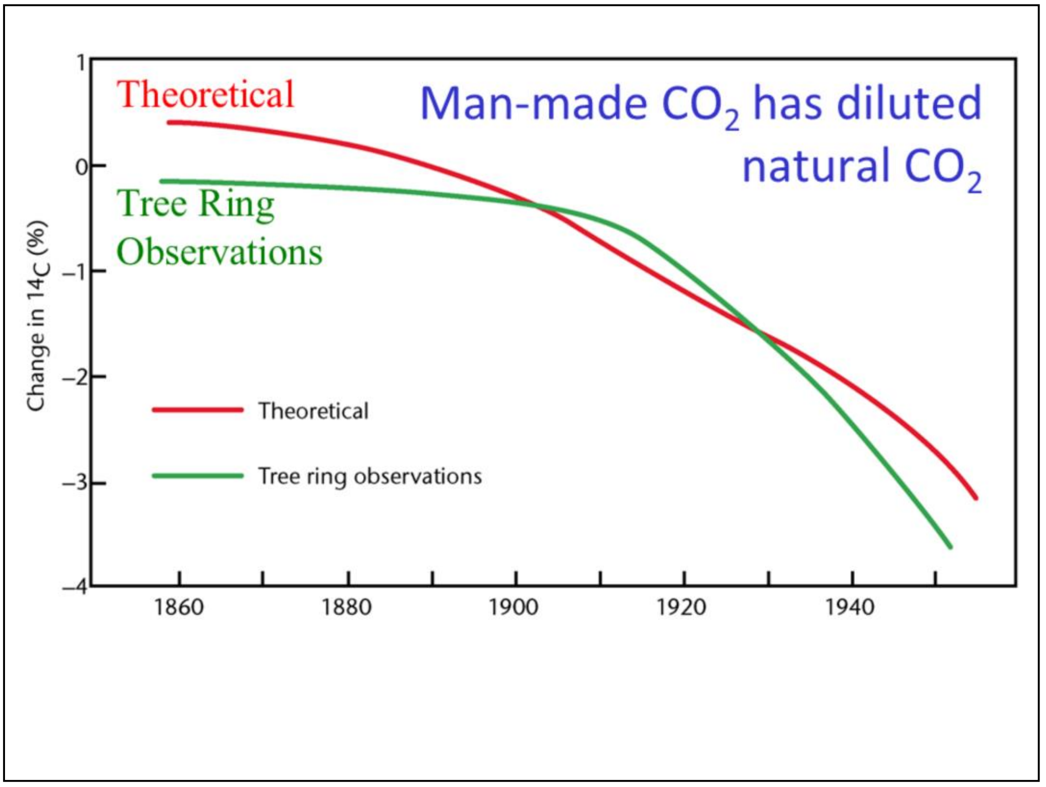
Only by including the forcing of these greenhouse gas increases on the Earth’s radiative energy balance in sophisticated climate models, can the current warming trend be simulated…

Is the warming due to increased greenhouse gases?

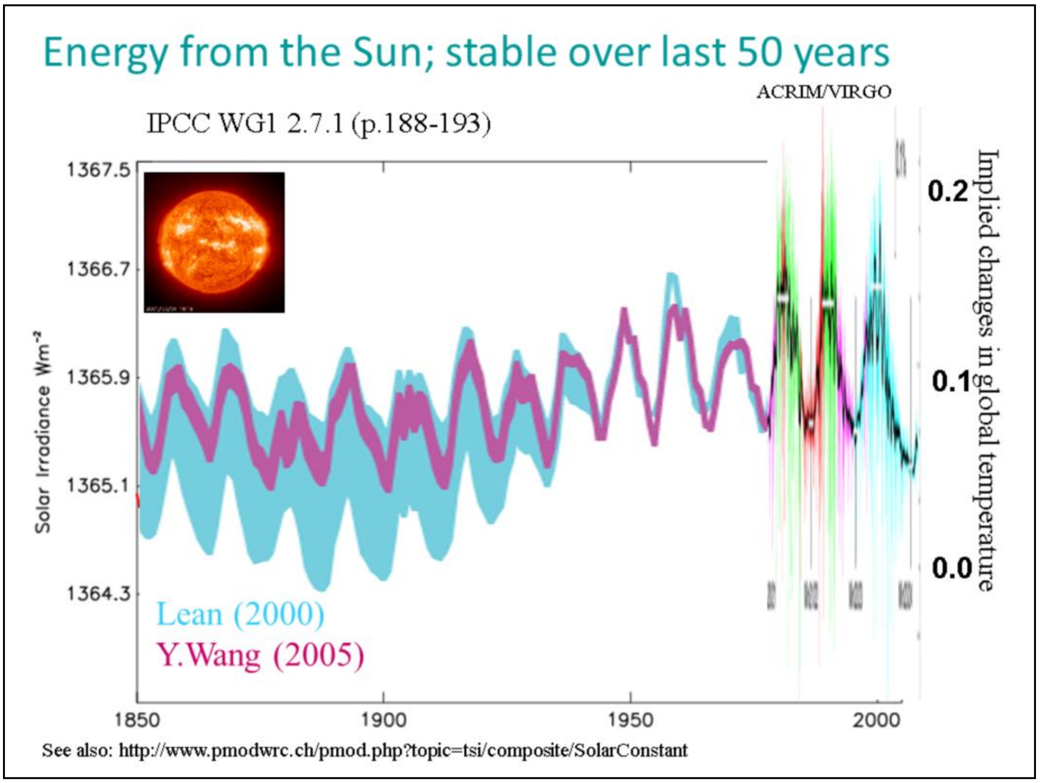
- There is a strong correlation between greenhouse gases and temperature over glacial cycles
  - …but correlation is not causation
  - Their estimated effect in amplifying the warming/cooling due to changes in the Earth's orbit over glacial cycles is in line with the current warming estimates
  - Today, the greenhouse gases are not merely passively responding to warming – they are driving it
  - The greenhouse gases, carbon dioxide and methane, are at their highest levels for at least the last 800,000 years.
- Recent satellite measurements confirm that the rapidly rising greenhouse gas concentrations are enhancing the greenhouse effect in line with theory

Carbon dioxide is responsible for 60% of human-induced greenhouse warming, methane 20%, and nitrous oxide and other gases 20%. In addition to the changes in greenhouse gases, important amplification mechanisms are required to generate the current warming trend and are critical for predicting future warming.

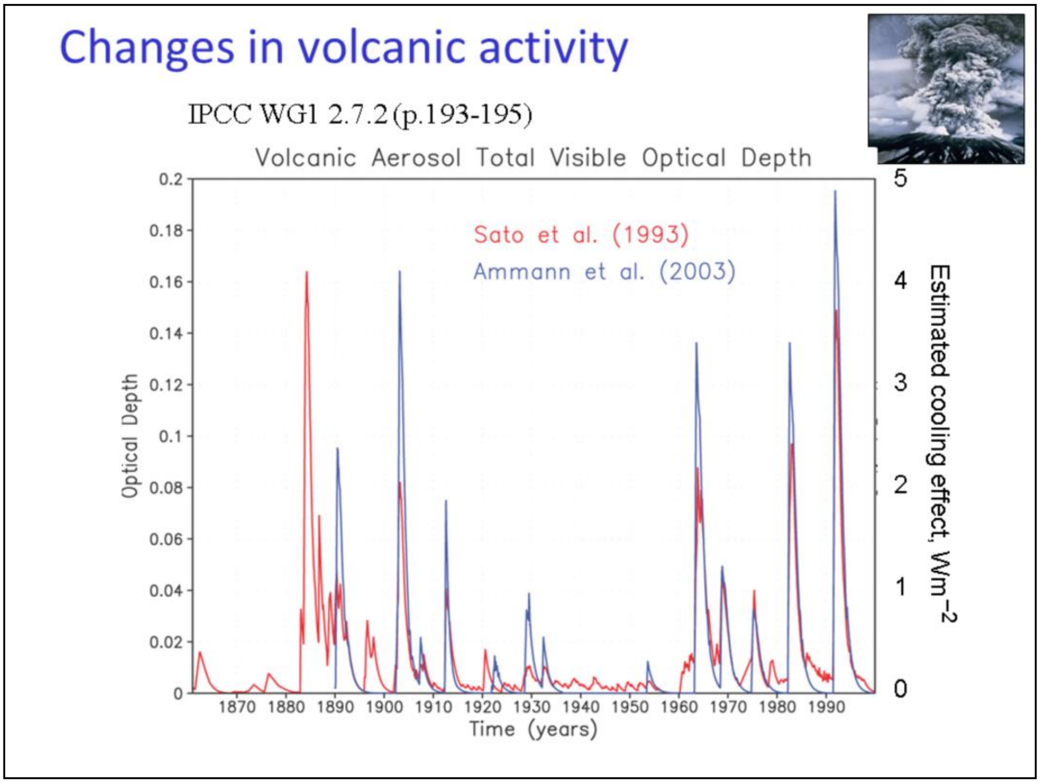
Paleoclimate information supports the interpretation that the warmth of the last half century is unusual in at least the previous 1400 years.



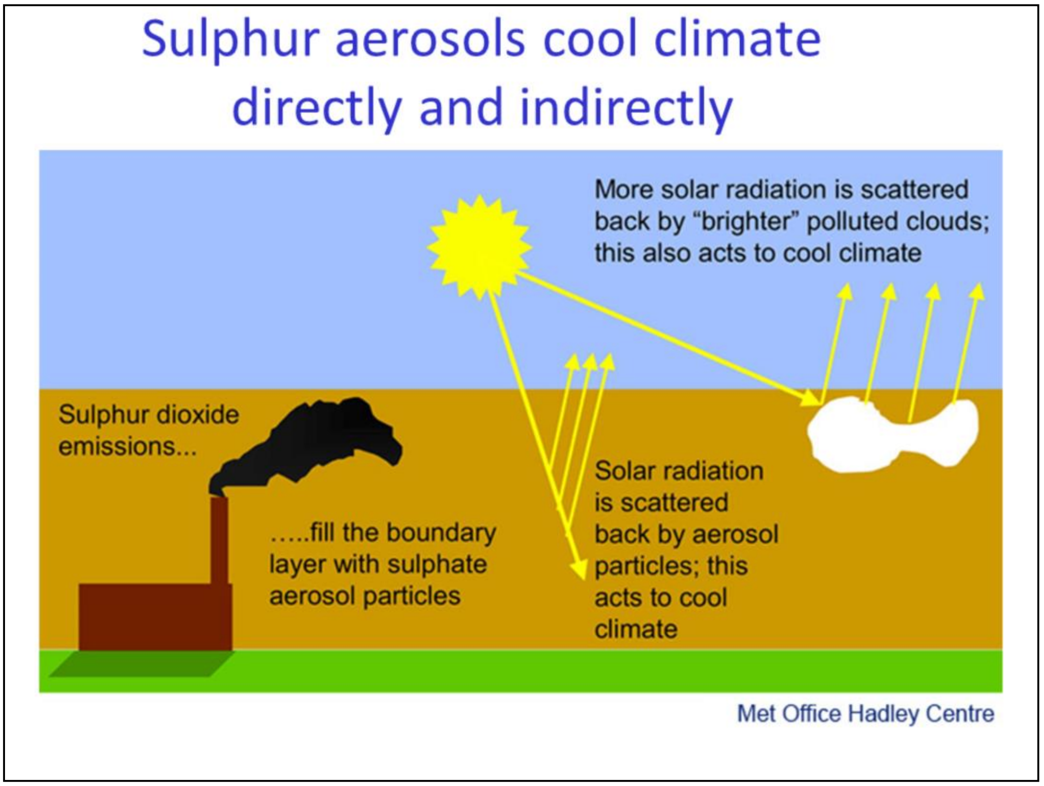
How do we know that the rise in carbon dioxide concentrations since the Industrial Revolution is due to emissions from man's activities? The carbon in CO_2 has several different forms; the most common (about 99%) is called ^{12}C, but there is a very small fraction of ^{14}C, which is radioactive, with a half life of about 5,700 years. Because fossil fuels are so old, the ^{14}C in them has decayed, so the CO_2 given off when we burn them has very much less ^{14}C in it. So the amount of ^{14}C in the air is being diluted by CO_2 emissions from burning coal, oil and gas, known as the 'Suess effect'. We can estimate the change in ^{14}C in the air from 1850 to 1950 by measuring it in tree rings; this estimate is shown above in green. When we calculate what this should be, based on man-made CO_2 emissions, the calculation (red line) agrees well with the measurements. This is proof that the rise in CO_2 concentration is due to fossil fuel burning. The technique fails to work after about 1950, because radioactivity from atomic bombs corrupts the technique. There is other supporting evidence, such as the consistency between the rise in concentration (unprecedented over the last several hundred thousand years) and man-made emissions, and the north-south gradient of CO_2 concentration and stable ^{13}C measurements.



Solar irradiance before 1978 is estimated from proxy data (sunspots, etc) and is less reliable than that measured since then by satellites. However, proxy data combined with the satellite record shows clearly the 11-year solar cycle and a general rise from 1900-1950. This rise can only account for a 0.1 oC increase in temperature. There are some theories that the solar influence on global climate could be amplified by an indirect route, for example involving stratospheric ozone or cosmic rays or clouds. A review of current understanding was prepared for the Hadley Centre by the University of Reading and Imperial College, London. This concluded that there is some empirical evidence for relationships between solar changes and climate, and several mechanisms, such as cosmic rays influencing cloudiness, have been proposed, which could explain such correlations. These mechanisms are not sufficiently well understood and developed to be included in climate models at present. However, current climate models do include changes in solar output, and attribution analyses that seek to understand the causes of past climate change by comparing model simulations with observed changes, do not find evidence for a large solar influence. Instead, these analyses show that recent global warming has been dominated by greenhouse gas-induced warming, even when such analyses take account of a possible underestimate of the climatic response to solar changes by models.

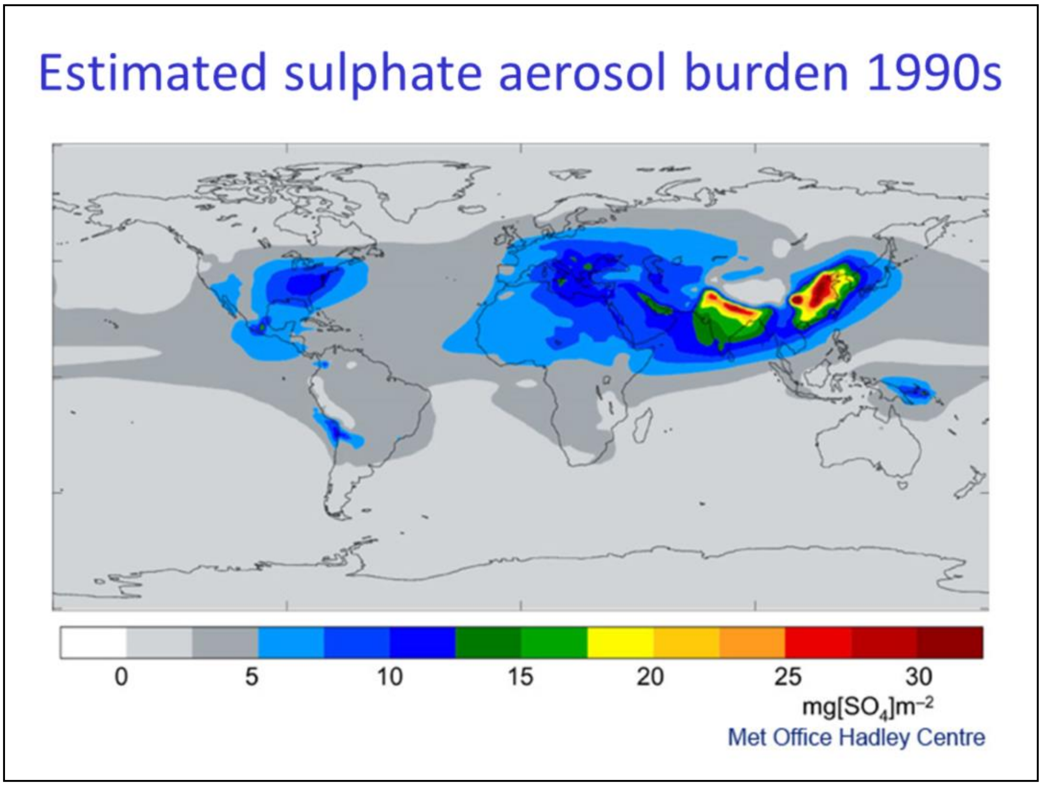


Volcanoes inject gas into the atmosphere. If they are energetic enough, this gas will reach the stratosphere and form small sulphate aerosol particles which can persist for a few years. They reflect back some of the solar radiation which otherwise would have heated the surface of the Earth, and hence act to cool the planet. The amount of volcanic aerosol in the atmosphere is very variable as is the cooling effect that this would have. Although energetic volcanoes were relatively common in the late 19th century (for example, Krakatoa in 1883) and early 20th century, and there have been substantial numbers of energetic volcanoes since the 1960s (most recently, Pinatubo in 1991), there was a period in the 1940s and 1950s when the atmosphere was relatively clear of volcanic aerosol. The amount of climate cooling due to volcanic aerosols would have been quite small in that period. This unusually low amount of volcanic cooling (together with the increase in solar radiation shown in the last slide) may have contributed to temperatures in the 1940s being relatively high compared to earlier decades. As with solar energy, optical depth due to volcanic aerosols has been estimated indirectly before about 1983 and is less certain.



Very small particles, known as aerosol, have a substantial effect on climate. Sulphate aerosol in the lowest part of the atmosphere (the boundary layer) is created when sulphur dioxide, emitted by human activities such as power generation and transport, is oxidised. Sulphate aerosol particles scatter some sunlight (as is the case following volcanic eruptions), which would otherwise reach the surface of the Earth and heat it, back out to Space. They therefore have a cooling influence on climate. Unlike volcanic aerosols that reach the stratosphere, their lifetime is limited and so require a constant source to keep concentrations up. The amount of sulphate aerosol in the atmosphere has increased by three or four times over the past 100 years or more due in part to fossil fuel burning.

Things are complicated because the sulphate aerosols are thought to make clouds more bright and to increase their lifetime, leading to an additional cooling effect.



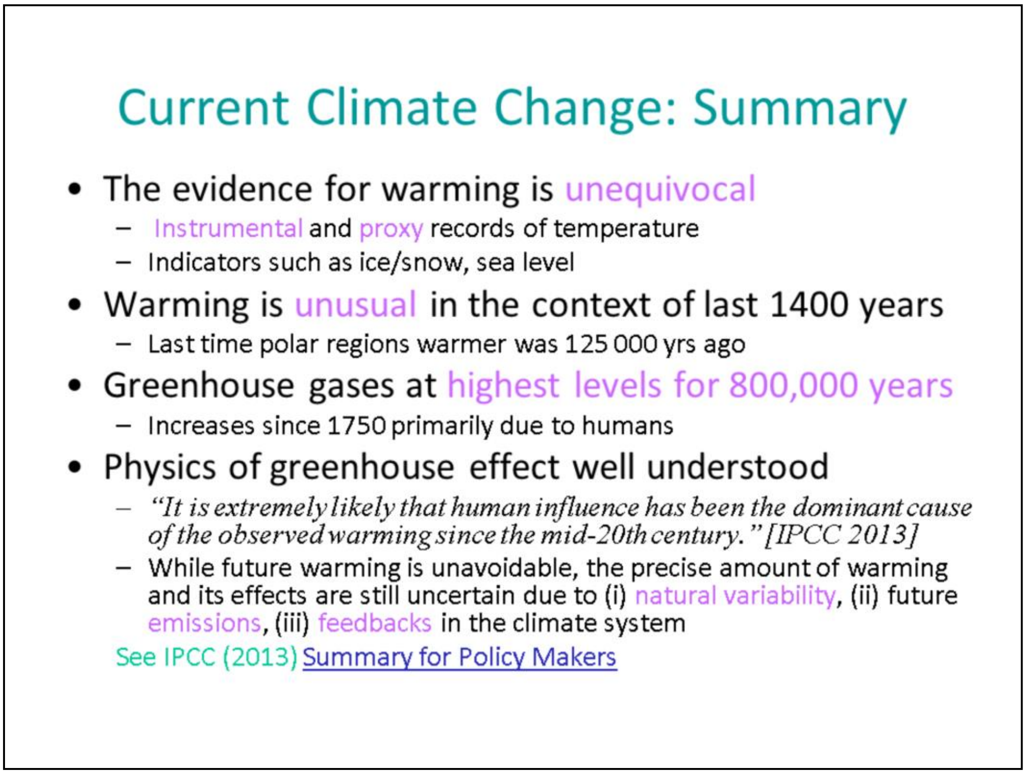
Sulphur dioxide gas and sulphate aerosols in the atmosphere can have impacts on human health, and also lead to acid rain which can fall at considerable distances from the emissions, acidifying waters such as lakes and endangering ecosystems. For these reasons, sulphur emissions have been greatly reduced in the US and Europe since the 1980s. It is expected that similar considerations will, in due course, lead to reductions of sulphur emissions in Asia and other rapidly developing parts of the world. When this happens, the current cooling effect of sulphate aerosols will be reduced, producing a warming effect which would add to that from greenhouse gases.

The above may explain why a reduction in the brightness of sunlight reaching the surface measured by ground based radiometers ("global dimming") has apparently reversed since the 1980s.

Is the warming due to increased greenhouse gases?

- Rapid rises in greenhouse gas concentrations since industrial revolution (CO_2, CH_4, N_20) are primarily due to human activity (fuel, agriculture, land use)
  - Also changes in ozone and CFCs/HCFCs important
- The warming effect of greenhouse gas increases outweighs the cooling effect from other pollution such as sulphate aerosols; this been the primary cause of a net heating of the planet since the 1950s.
  - Changes in the sun and volcanic input since 1750 are small in comparison

Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations.



Scientists are now even more certain that the majority of the global warming since the mid-20th century is due to mans impact on the atmosphere via fossil fuel burning, agriculture and changes in land-use.

Much of this certainty comes from the observations but a large component comes about applying physical laws, refined by the observations, to develop sophisticated computer models of the Earth's environment that help to understand the reasons for the warming and enable predictions of future climate change for the next hundred years…