HOT TOPICS

Can the warming of the 20th century be explained by natural processes?

Summary

Over the last 100 years, global mean temperature has increased by around 0.74°C. This rapid rate of warming is very unusual in the context of natural climate variability. In the first half of the 20th century, increasing greenhouse gases, increasing solar radiation and a relative lack of volcanic activity all contributed to a rise in globally averaged temperature. During the 1950s and 1960s, global temperatures levelled off. This is most likely due to an increase in reflective particles in the atmosphere, known as aerosols, from increased industrialisation and the volcanic eruption of Mt. Agung in 1963. Since the 1970s, increases in greenhouse gases have dominated over all other factors, and there has been a period of sustained warming. It is very unlikely that 20th century warming can be explained by natural causes alone.

Importantly, almost all of the climate indicators show that climate change during the late 20th century is consistent with greenhouse gas increases. For instance, increases in solar radiation would cause warming in the troposphere *and* stratosphere. However, cooling in the stratosphere is what is actually observed, which is consistent with greenhouse gas increases.

Variations in the Earth's climate over time are caused by natural internal processes, as well as changes in external influences. External influences can be natural, such as volcanic activity and variations in solar radiation, or caused by human activity (anthropogenic), such as increases in greenhouse gases and aerosol emissions, ozone depletion and land use change (IPCC, 2007, FAQ 9.2).

Internal forcing factors

Natural oscillations within the atmosphere and ocean systems affect climate. These natural oscillations are also referred to as internal processes, since they are driven by the internal physics of the climate system itself, rather than external factors.

Natural internal processes operate on almost all time scales. For instance the El Niño/La Niña cycle describes periodic warming and cooling of the tropical Pacific on timescales of several years. This see-saw of warm and cool sea surface temperatures is driven by the interactions between surface winds, ocean currents and the physical shape of the Pacific Basin. Similarly, longer, decadal changes to deep ocean currents are also driven by internal processes within the ocean system. Changes in the ocean are typically accompanied by associated changes in the atmosphere.

The magnitude and pattern of natural internal processes can be estimated by studying observed variations in climate and through the use of climate models. Scientists have been unable to find any internal processes that explain 20th century global warming. However the effects of natural internal forcing can be seen in the instrumental record. For example, an exceptionally warm year occurred in 1998 as a result of a very strong El Niño event.[1] According to the IPCC (2007, FAQ 9.2) "Although natural internal climate processes, such as El Niño, can cause variations in global mean temperature for relatively short periods, analysis indicates that a large portion is due to external factors."

External forcing factors

External forcing factors affect the radiation-energy balance of the planet. They directly influence the amount of solar radiation (energy) reaching the Earth, the amount of radiation reflected back out to space and the amount of radiation absorbed and re-emitted by the atmosphere and the Earth's surface.

Volcanoes

Most volcanic eruptions have little effect on climate, but explosive eruptions can place large amounts of dust and sulphate aerosols into the stratosphere, where they can reflect sunlight back to space. This leads to cooling of the lower atmosphere (troposphere) and warming of the upper atmosphere (stratosphere) that peaks several months after an eruption and lasts a few years (Crowley, 2000; Bertrand *et al.*, 2002; Weber, 2005; Yoshimori *et al.*, 2005; Tett *et al.*, 2007). Volcanic eruptions had a net cooling effect over the last 100 years, because there was stronger volcanic activity towards the end of the 20th century (IPCC, 2007, Ch 9).

Solar radiation

Solar radiation received by the Earth (insolation) varies due to changes in the Earth's orbit around the Sun and changes in actual solar radiation emitted from the Sun (solar irradiance).

Variations in the Earth's orbit occur in cycles of about 20,000 years, 40,000 years and 100,000 years (Bryant, 1997). They have led to major glacial periods (Ice Ages) and warmer inter-glacial periods.[2] Changes in the Earth's orbit have had little impact on annual mean insolation over the past 1,000 years (IPCC, 2007, Ch 9). The rate of global warming over the past 50 years (0.13°C per decade) is about 100 times faster than the 4°C to 7°C warming between ice ages and interglacials, which takes about 5000 years (about 0.001°C per decade).

Solar irradiance is directly affected by sunspot activity. Periods of low sunspot activity correspond with low Earth temperatures, e.g. the Oort Minimum (1010–1050), Wolf Minimum (1280–1340), Spörer Minimum (1420–1530) and Maunder Minimum (1675–1715) (Bryant, 1997). The timing of past changes in solar irradiance is highly uncertain (Lean *et al.*, 2002; Gray *et al.*, 2005; Foukal *et al.*, 2006). While the magnitude of solar changes is also subject to uncertainty, it has been estimated that solar changes over the 20th century were far too small to explain observed global warming. Climate model simulations show that it is not possible to reproduce the large 20th century warming when using a range of plausible solar forcing scenarios (Bauer *et al.*, 2003; Hegerl *et al.*, 2003, 2007; Lockwood and Frolich, 2008). The total solar irradiance, monitored from space for the last three decades, reveals a well-established sunspot cycle of 0.08% (cycle minimum to maximum) (IPCC, 2007, Ch 2). From 1750 to the present, there was a net 0.05% increase in total solar irradiance, which had a much smaller impact on climate than observed increases in anthropogenic greenhouse gases (see below).

About 1% of the Sun's energy is in the UV part of the spectrum, which creates and modifies the ozone layer. Changes in ozone affect the temperature of both the troposphere and the stratosphere (IPCC, 2007, Ch 2). Various scenarios have been proposed whereby solar-induced cosmic ray fluctuations might influence climate through enhancing or decreasing cloud cover (Gray *et al.*, 2005). While associations between solar-modulated cosmic ray ionization of the atmosphere and globally averaged low-level cloud cover remain ambiguous (IPCC, 2007, Ch 2), it is thought that this forcing mechanism is far too small to explain large changes in climate.

[1] For more information see Hot Topic 'Has global warming stopped?' available online at www.climatechange.gov.au

[2] For more information see Hot Topic 'Understanding current climate change in a palaeoclimatic context' available online at www.climatechange.gov.au

Anthropogenic influences

In general, the contribution of different climate change mechanisms is expressed as a 'radiative forcing' and is measured in units of power (Watts per square metre: Wm^{-2}). Positive radiative forcing acts to warm the Earth's atmosphere, while negative radiative forcing has the opposite affect. Over the period 1750–2005, radiative forcing from greenhouse gases was +2.3 Wm^{-2} (IPCC, 2007, Ch 2), about 20 times greater than the forcing from changes in solar radiation (Figure 1). Other factors over the same period had a cooling effect. The forcing was +0.34 Wm^{-2} from halocarbons and +0.35 Wm^{-2} from tropospheric ozone. Aerosols also contributed a total direct forcing of -0.5 Wm^{-2} and an indirect effect on cloud albedo (reflectivity) estimated at -0.7 Wm^{-2} but the uncertainty ranges are large. Changes in surface albedo due to land-cover change and deposition of black carbon aerosols on snow had a forcing of -0.2 Wm^{-2}.

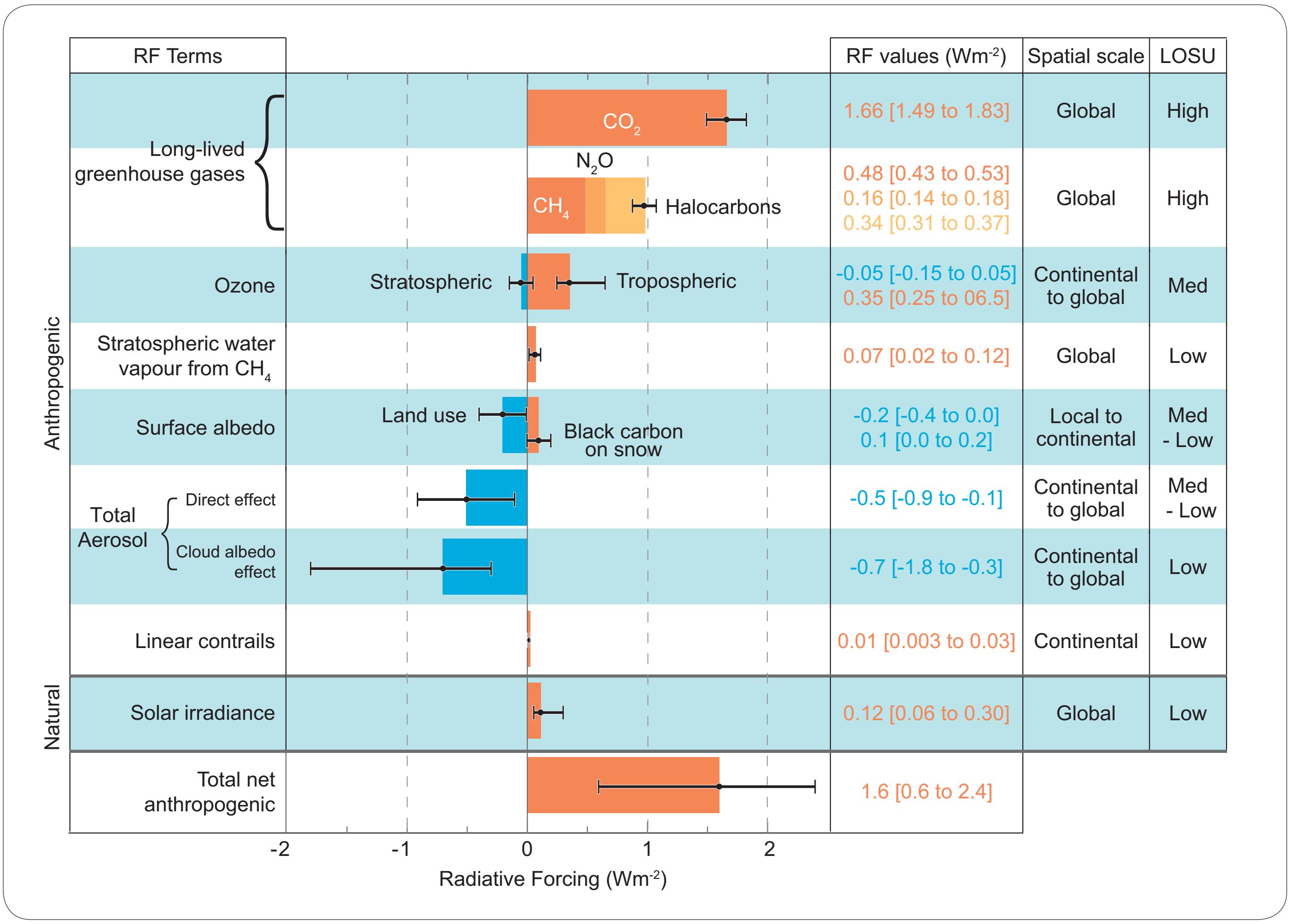

Figure 1: Changes in radiative forcing (RF) due to different anthropogenic factors and natural solar irradiance from 1750–2005. Volcanic aerosols contribute an additional natural forcing but are not included in the figure due to their episodic nature. The assessed level of scientific understanding (LOSU) is given in the right column. (IPCC, 2007, Fig SPM2).

Computer modelling and understanding climate variability

By studying both the observed climate and output from climate models, scientists have been able to estimate the contribution of different forcing factors to 20th century climate variability. Climate models are based on the fundamental physics and chemistry of the atmosphere, ocean and sea-ice system.[3] Such modelling allows scientists to simulate so-called control climates (where external forcing factors are held at fixed levels) as well as many different climate change experiments, such as doubling atmospheric carbon dioxide or changing solar radiation. Through

[3] For more information see Hot Topic 'How reliable are climate models?' available online at www.climatechange.gov.au

comparison with the instrumental record, it is possible to piece together a record of climate forcing over the last 100 years, during which time the global average temperature has risen by 0.74°C.

In the first half of the 20th century, increasing greenhouse gases, increasing solar radiation and a relative lack of volcanic activity all contributed to a rise in globally averaged temperature. During the 1950s and 1960s, global temperatures levelled off. Climate scientists have shown that this levelling off is most likely explained by an increase in reflective particles in the atmosphere, known as aerosols. More aerosols entered the atmosphere as a result of increased industrialisation and from the eruption of Mt. Agung in 1963. Since the 1970s, increases in greenhouse gases have dominated over all other factors, and there has been a period of sustained warming (IPCC, 2007, Ch 9).

Greenhouse gas forcing alone during the past half century would likely have resulted in greater than the observed warming if there had not been an offsetting cooling effect from aerosol and other forcings (IPCC, 2007). The warming took place at a time when natural external forcing factors would likely have produced cooling (IPCC, 2007; Lockwood and Fröhlich, 2007).

In summary, scientists have looked very closely at all of the natural external forcing factors that have affected climate over the 20th century. Through these studies, they have been able to determine that none of these processes can explain the sustained rise in global temperature that has been observed. Rather, changes due to natural forcing have been superimposed on a background warming trend, and it is very likely that most of the observed global warming since the mid 20th century is due to anthropogenic increases in greenhouse gases (IPCC, 2007) (Figure 2). Hence, we can say that greenhouse gases have been the main driver of global warming over recent decades, while a range of natural processes have affected shorter-term temperature variability.

Multiple lines of evidence for attribution of 20th century climate change

As well as global averaged temperature, climate scientists use a range of other climate indicators to monitor and understand climate change and variability. These other indicators form additional lines of evidence that can be used to understand and determine cause and effect in the climate system. Some of the climate indicators have been chosen to explicitly test the presence of an enhanced greenhouse effect. Such indicators are also known as greenhouse 'fingerprints', since detection of these characteristic patterns in the climate system would indicate that increasing greenhouse gases are the likely cause. Comparison of these indicators between the instrumental observations and climate model experiments allows more detailed examination of climate forcing mechanisms.

Some of the key observed climate changes are (IPCC, 2007; Nicholls, 2007; Santer *et al*., 2007):

- More rapid warming near the poles, especially in the Arctic, compared to the tropics
- Warming in the lower atmosphere (troposphere) and cooling in the upper atmosphere (stratosphere)
- More hot days and nights, fewer cold days and nights
- A reduction in the difference between daytime and night-time temperatures
- More warming over land than oceans
- Warming in the upper several hundred metres of the ocean
- Retreating glaciers and reduced Arctic sea-ice extent
- Sea level rise
- Changes in atmospheric pressure
- Increases in atmospheric moisture content
- Shifts in the patterns of precipitation over land
- More heavy precipitation events
- More of the most intense tropical cyclones.

Importantly, almost all of the climate indicators show that climate change during the late 20th century is consistent with greenhouse gas increases. For instance, increases in solar radiation would cause warming in the troposphere *and* stratosphere. However, cooling in the stratosphere is what is actually observed, which is consistent with greenhouse gas increases (IPCC, 2007, FAQ 9.2). Greater warming over land than the oceans indicates that the cause of the warming is from changes in the atmosphere (a radiative process) rather than changes in the ocean. Similarly, warming of the upper oceans shows that the warming is not being driven by long timescale, internal ocean processes.

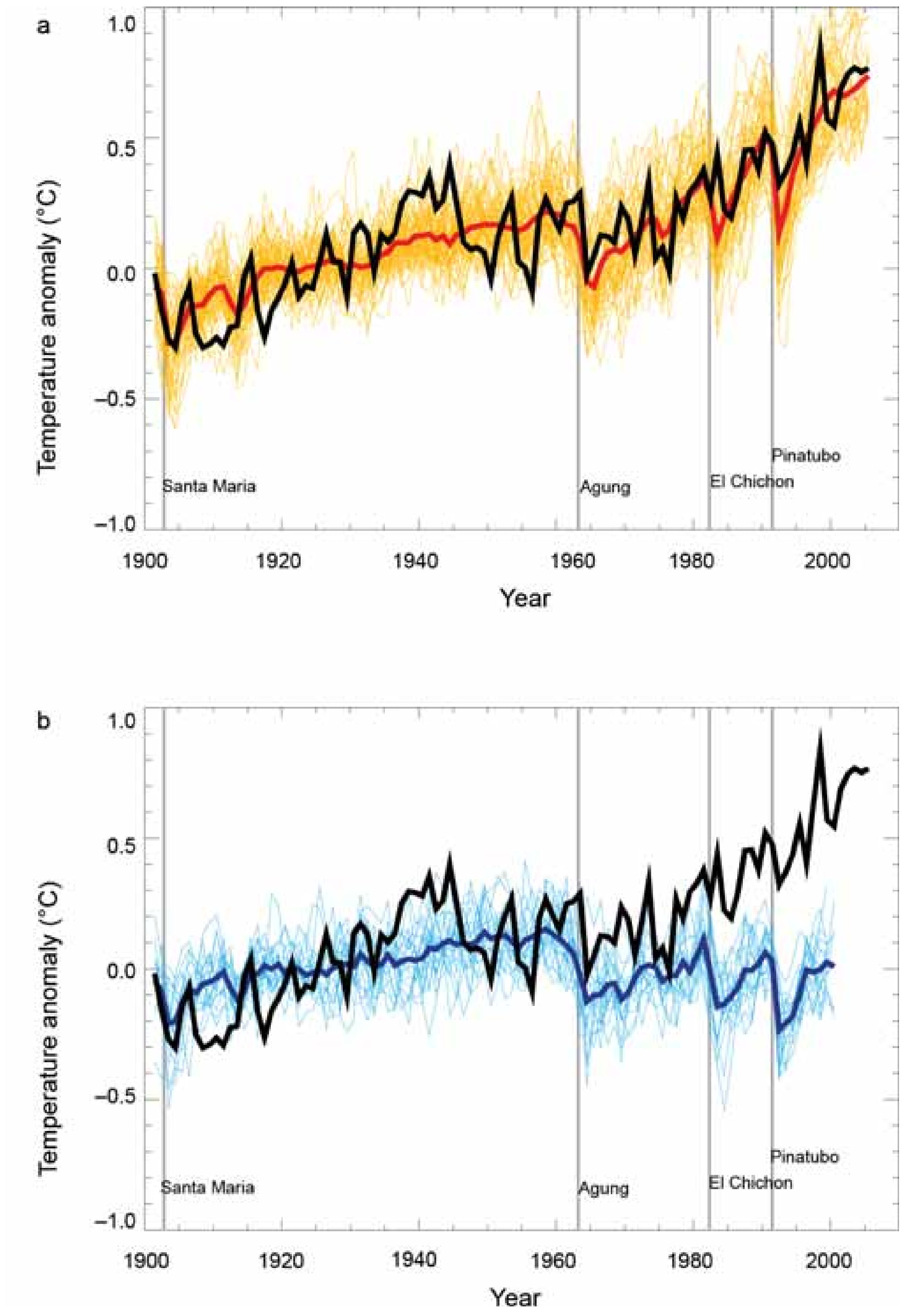

Figure 2: Comparison between global mean surface temperature anomalies (°C) from observations (black) and model simulations forced with (a) both anthropogenic and natural forcings and (b) natural forcings only. All data are shown as global mean temperature anomalies relative to the period 1901 to 1950, as observed (black, Hadley Centre/Climatic Research Unit gridded surface temperature data set (HadCRUT3)) and, in (a) as obtained from 58 simulations produced by 14 models with both anthropogenic and natural forcings. The multi-model ensemble mean is shown as a thick red curve and individual simulations are shown as thin yellow curves. Vertical grey lines indicate the timing of major volcanic events. Those simulations that ended before 2005 were extended to 2005 by using the first few years of the IPCC Special Report on Emission Scenarios (SRES) A1B scenario simulations that continued from the respective 20th century simulations, where available. The simulated global mean temperature anomalies in (b) are from 19 simulations produced by five models with natural forcings only. The multi-model ensemble mean is shown as a thick blue curve and individual simulations are shown as thin blue curves. (IPCC, 2007, Figure 9.5).

References

Bauer, E., M. Claussen, V. Brovkin, and A. Huenerbein, (2003). Assessing climate forcings of the Earth system for the past millennium, *Geophys. Res. Lett.*, **30**(6), 1276 pp.

Bertrand, C., M.F. Loutre, M. Crucifix, and A. Berger, (2002). Climate of the last millennium: a sensitivity study. *Tellus,* **54A**(3), 221–244 pp.

Bryant, E. (1997). *Climate processes and change*. Cambridge University Press, 209 pp.

Crowley, T.J., (2000). Causes of climate change over the past 1000 years. *Science,* **289**(5477), 270–277 pp.

Foukal, P., C. Froehlich, H. Sruit, and T.M.L. Wigley, (2006). Variations in solar luminosity and their effect on Earth's climate. *Nature,* **443**, 161– 166 pp, doi:10.1038/nature05072.

Gray, L.J., R.G. Harrison, and J.D. Haigh, (2005). *The Influence of Solar Changes on the Earth's Climate.* Hadley Centre Technical Note 62, The UK Met Office.

Hegerl, G.C., *et al.*, (2003). Detection of volcanic, solar and greenhouse gas signals in paleo-reconstructions of Northern Hemispheric temperature. *Geophys. Res. Lett.*, **30**(5), 1242pp.

Hegerl, G.C., *et al*., (2007). Detection of human influence on a new 1500yr climate reconstruction. *J. Clim.*, **20**, 650–666 pp.

IPCC (2007). *Fourth Assessment Report: Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. www.ipcc.ch.

Lean, J.L., Y.M. Wang, and N.R. Sheeley, (2002). The effect of increasing solar activity on the Sun's total and open magnetic flux during multiple cycles: Implications for solar forcing of climate. *Geophys. Res. Lett.*, **29**(24), 2224 pp, doi:10.1029/2002GL015880.

Lockwood, M. and C. Fröhlich, (2008). Recent oppositely directed trends in solar climate forcings and the global mean. *Proc. R. Soc. A,* **464**:1367–1385 pp.

Nicholls, N. (2007). *Detecting, understanding and attributing climate change*. A background report on research priorities prepared for the Australian Greenhouse Office, 26 pp.

Santer, B.D. *et al* (2007). Identification of human-induced changes in atmospheric moisture content. *PNAS*, **104(39),** 15248–15253 pp.

Tett, S.F.B., *et al.*, (2007). The impact of natural and anthropogenic forcings on climate and hydrology since 1550. *Clim. Dyn.*, **28**, 3–34 pp, doi:10.1007/s00382–006–0165–1.

Weber, S.L., (2005). A timescale analysis of the NH temperature response to volcanic and solar forcing in the past millennium. *Climate of the Past*, **1**, 9–17 pp.

Yoshimori, M., T. Stocker, C.C. Raible, and M. Renold, (2005). Externally forced and internal variability in ensemble climate simulations of the Maunder Minimum. J. *Clim*., **18**, 4253–4270pp.

Prepared by CSIRO for the Department of Climate Change