

## HOT TOPICS

### Is there an inconsistency between observed and modelled patterns of warming in the lower atmosphere?

#### Summary

Climate models predict that increasing greenhouse gases should warm the lower troposphere slightly more (in relative terms) than the surface. However, until recently, observed temperature datasets did not show this level of warming in the tropical troposphere. Using revised satellite-based estimates of tropospheric temperature changes, there is no longer a discrepancy between modelled and observed trends in the tropics.

#### Evidence for warming in the troposphere

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average land and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (IPCC, 2007, Ch 2; Domingues *et al.*, 2008).

Temperatures in the troposphere have been measured using radiosondes (attached to weather balloons) and satellites. Radiosonde data are available regionally from the 1940s, but the dataset is limited to land areas and coverage is poor over the tropics and Southern Hemisphere (IPCC, 2007, Ch 2). The satellite data start in 1978 with global coverage every few days. Changes in instrumentation and protocols affect both radiosonde and satellite records, and the inferred long-term temperature trends (IPCC, 2007, Ch 2). It is difficult to determine which of these independently derived estimates of temperature is closer to the truth.

Considerable effort has been devoted to assessing and improving the quality of the radiosonde temperature record. Inhomogeneous behaviour can be caused by changes in site location, measurement time, instrumentation, and the effectiveness of thermal shielding of the temperature sensor (Santer *et al.*, 2008). A particular aim has been to reduce artificial changes arising from instrumental and procedural developments during the seven decades (1940s–2000s) of recording (Free and Seidel, 2005; Thorne *et al.*, 2005; Karl *et al.*, 2006). These efforts have resulted in various adjusted data sets (e.g. Figure 1). Despite these efforts, recent analyses of radiosonde data indicate that large uncertainties remain (Lanzante and Free, 2008; Sherwood *et al.*, 2008; McCarthy *et al.*, 2008; Haimberger *et al.*, 2008; Allen and Sherwood, 2008; Santer *et al.*, 2008).

Satellite data have better spatial coverage than radiosondes, but data from a number of satellites must be merged together and known errors include (IPCC, 2007, Ch 2):



- offsets in calibration between satellites;
- orbital decay and drift, and associated long-term changes in the time of day that the measurements are made at a particular location, leading to diurnal drifts in the estimated temperatures;
- drifts in satellite calibration that are correlated with the temperature of the onboard calibration target.

Correcting for these errors removes much of the discrepancy between climate models and observed tropospheric temperatures. Taking uncertainties into account, the range of global tropospheric warming since 1979 is 0.12 to 0.19°C per decade from satellite data, compared with a global surface warming of 0.16 to 0.18°C per decade (IPCC, 2007, Ch 2). The large spread in satellite-based trends stems from differences in the inter-satellite calibration and merging techniques, and corrections for orbital drift and diurnal cycle change (IPCC, 2007, Ch 2).

## Consistency between observed and modelled temperature trends in the stratosphere and troposphere

The lower stratosphere sits above the upper troposphere. Lower stratospheric temperatures exhibit cooling of between 0.3°C and 0.6°C per decade since 1979. Longer radiosonde records (since 1958) also indicate cooling but the rate of cooling has been significantly greater since 1979 than between 1958 and 1978. It is likely that radiosonde records overestimate stratospheric cooling, owing to changes in instrumentation not yet accounted for (IPCC, 2007, Ch 2). Because of the stratospheric warming episodes following major volcanic eruptions, the trends are far from linear (Figure 1).

Warming of the troposphere and cooling of the lower stratosphere is a ‘fingerprint’ of increased greenhouse gases and ozone-depleting chemicals. This pattern is not, for example, a ‘fingerprint’ of an increase in radiation from the Sun, which would have warmed all levels of the atmosphere (IPCC, 2007, Ch 9). The distinct pattern of tropospheric warming and lower stratospheric cooling is captured in all climate simulations of the 20<sup>th</sup> century driven by observed changes in solar radiation, volcanic aerosols, anthropogenic aerosols, greenhouse gases and ozone depletion. The models cannot reproduce the pattern of warming and cooling based on natural changes alone (solar radiation and volcanic aerosols).

Climate models also simulate what the vertical structure of temperature change *within* the troposphere should look like due to increasing greenhouse gases. They predict that the lower troposphere should warm slightly more than the surface. It is in this aspect of the vertical temperature profile that an apparent discrepancy between observations and models occurred (Karl *et al.*, 2006). Based on all other available evidence, scientists reasoned that either the models were incorrectly characterising the vertical structure of warming in the troposphere or that the observed datasets were biased (Karl *et al.*, 2006; Douglass *et al.*, 2007).

One analysis of 22 climate model simulations claimed poor agreement between the observed and modelled warming in the tropical troposphere, and concluded that the models were wrong (Douglass *et al.*, 2007). However, this was based on use of older radiosonde and satellite datasets, and on two methodological errors: the neglect of observational trend uncertainties introduced by interannual climate variability, and application of an inappropriate statistical consistency test (Santer *et al.*, 2008).

Trends in bias-corrected tropical tropospheric temperature from two satellite datasets and 49 climate simulations have been compared (Santer *et al.*, 2008). The adjusted confidence interval on the satellite-based trend includes 47 of the 49 simulated trends. This strongly suggests that there is no fundamental inconsistency between modelled and observed trends (Santer *et al.*, 2008). The agreement with models increases confidence in model-based predictions of future climate change (Allen and Sherwood, 2008).

Hence, the apparent discrepancy seems largely due to a number of data quality issues. Most of these issues are related to calibration and interpretation of radiosonde and satellite instruments. While the initial expectations of satellite derived data were high, in reality changes in instrumentation for different satellite missions, and factors such as slow changes in satellite orbits, have meant that interpreting the data has been difficult. Compared with the surface based instruments, much less work has been done on understanding climate variables that are remotely sensed from space.

Climate scientists do not believe that the remaining uncertainties regarding remotely sensed tropospheric temperature are large enough to alter the conclusion that increasing greenhouse gases have very likely been the main cause of the late 20<sup>th</sup> century warming. Rather, there are multiple lines of independent evidence that support this conclusion.<sup>1</sup>

<sup>1</sup> For more information see Hot Topic ‘Can the warming of the 20th century be explained by natural processes?’ available online at [www.climatechange.gov.au](http://www.climatechange.gov.au)



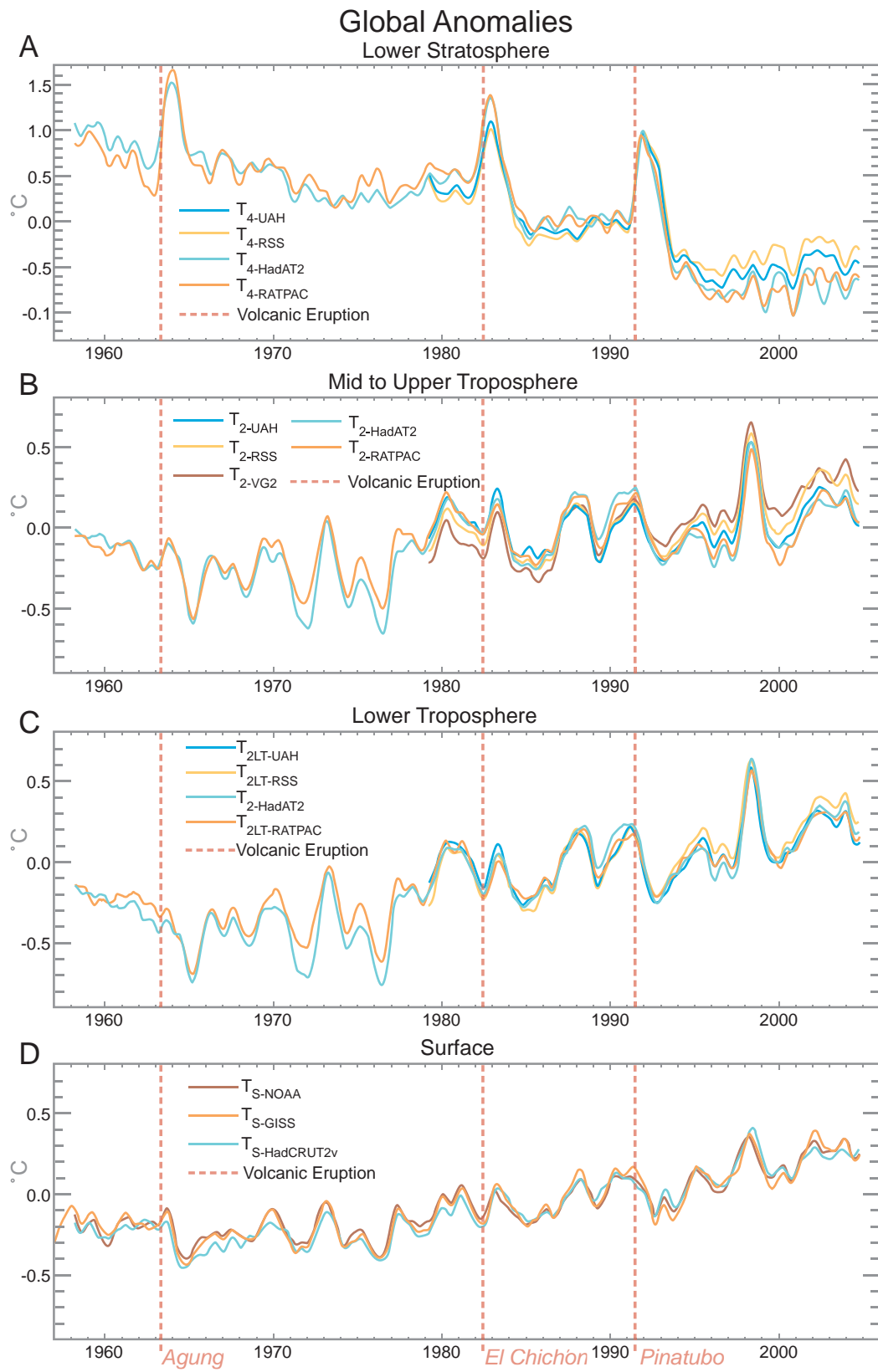


Figure 1: Observed surface and upper-air temperature anomalies ( $^{\circ}\text{C}$ ). (A) Lower stratosphere T4, (B) Troposphere T2, (C) Lower troposphere T2LT from UAH, RSS and VG2 MSU satellite analyses, and UKMO HadAT2 and NOAA RATPAC radiosonde records, and (D) surface records from NOAA, NASA-GISS and UKMO/CRU (HadCRUT2v). All time series are monthly mean anomalies relative to the period 1979 to 1997 smoothed with a seven month running mean filter. Major volcanic eruptions are indicated by vertical orange dashed lines. (Adapted from Karl *et al.*, (2006); IPCC (2007) Figure 3.17).



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