Greenhouse warming?
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by

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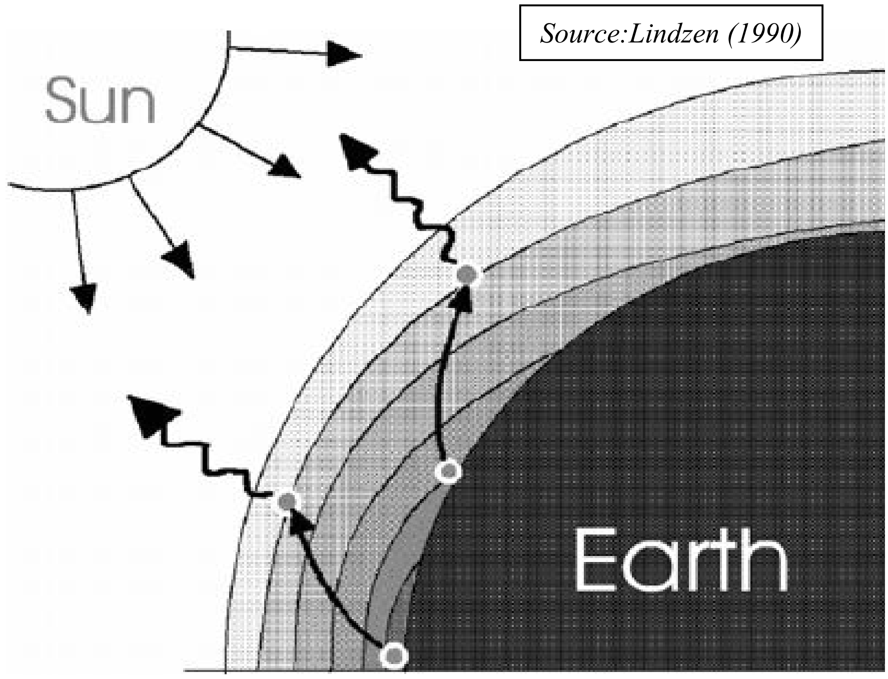
THE FACT of warming tells us nothing of the cause. Yet the scientific "consensus" is that, though the rapid climatic warming from 1906 to 1940 was a natural recovery from the historically low temperatures of the Little Ice Age, it is we who are chiefly to blame for the equally rapid warming from 1975 to the present.

Since some climatologists challenge this consensus, can we settle the debate by predicting with models and then detecting by observation a characteristic "signature" in the climate data that allows us definitively to distinguish between anthropogenic and natural warming of the Earth's atmosphere? This paper answers that key question.

To identify the distinctive signature of anthropogenic warming caused by greenhouse-gas emissions, we begin with a little elementary atmospheric physics.[1]

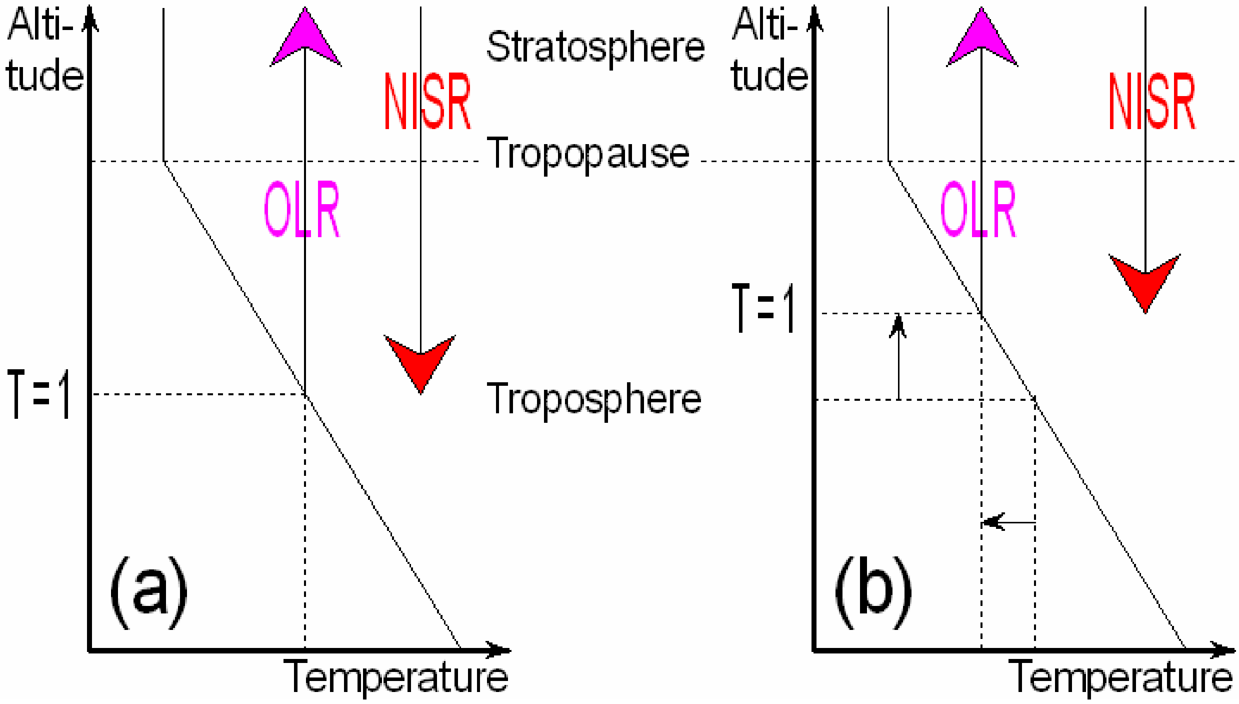
The surface of the Earth does not cool primarily by thermal radiation. The main greenhouse gas, water vapor, generally maximizes at the surface in the tropics and sharply decreases with both altitude and latitude. There is so much greenhouse opacity immediately above the ground that the surface cannot effectively cool by the emission of thermal radiation.



Instead, heat is carried away from the surface by fluid motions ranging from the cumulonimbus towers of the tropics to the weather and planetary scale waves of the extratropics. These motions carry the heat upward and poleward to the "characteristic emission level" one optical depth into the atmosphere, known as $\tau=1$. From here emitted thermal radiation can escape to space. Crudely speaking, the emitted thermal radiation is proportional to the fourth power of the temperature at the characteristic emission level.

In the diagram, lighter shading represents reduced opacity as water-vapor density diminishes with altitude. Largely because of the motions of the atmosphere, the temperature decreases with altitude to a level known as the tropopause. The height of the tropopause varies with latitude. In the tropics it is about 16 km, dropping to about 12 km near 30 degrees latitude, and 8 km near the poles. Beneath the tropopause, we have the troposphere.

[1] I am grateful to Richard Lindzen, Alfred P. Sloan Professor of Meteorology at the Massachusetts Institute of Technology, for his excellent lecture notes on this topic: but any errors in this paper are mine alone.



τ is infrared absorption measured from the top of the atmosphere looking down. When the earth is in radiative balance with space (a), net incoming solar radiation (NISR) is balanced by outgoing longwave radiation (OLR) from the characteristic emission level, τ=1. When greenhouse gases are added to the atmosphere, the characteristic emission level is raised in altitude (b). Since atmospheric temperature decreases with altitude at about 6.5 degrees Celsius per kilometer, the new characteristic emission level is colder than the previous level.

Therefore outgoing longwave radiation no longer balances net incoming solar radiation. The Earth is no longer in thermal balance with space. This imbalance is called "radiative forcing". To re-establish balance, the temperature at the new τ=1 level must increase to about the temperature that had existed at the initial τ=1 level, which is typically 7-8 km in the tropics and lower elsewhere. ***The warming at τ=1 is the fundamental warming associated with the greenhouse effect.***

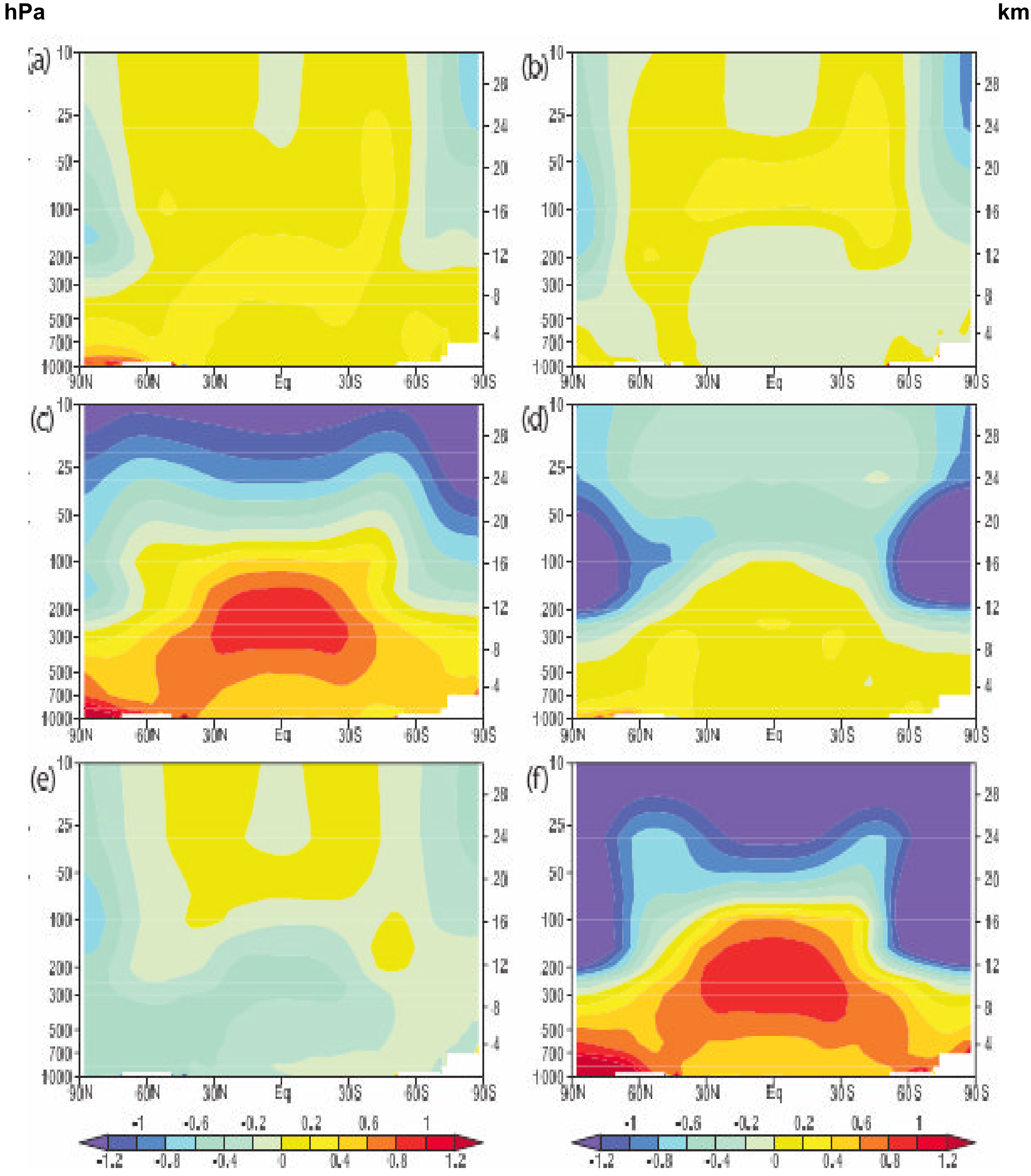
How warming at the τ=1 level relates to warming at the surface is not altogether clear. It is at this point that models prove helpful. They are able to assist us in distinguishing between the warming caused by adding greenhouse gases to the atmosphere and warming that is attributable to other causes.

The UN, in its 2007 climate assessment report, displays a series of plots of predicted rates of temperature change over the decades at altitudes from the Earth's surface to 30 km, at latitudes from the South Pole via the Equator to the North Pole. Colors are used to illustrate the rates of change in temperature which the UN's climate models predict, measured in degrees Celsius per decade. Each distinct cause of warming produces a visibly-distinct plot.

Six causes of atmospheric warming are plotted. First, plots of natural warming caused by changes in total incoming solar radiation and changes in volcanic activity are shown, followed by plots of anthropogenic warming caused by emissions of greenhouse gases, changes in tropospheric and stratospheric ozone concentration, and the radiative forcing caused by sulphate aerosol particles (which actually cause cooling). Finally, the five plots of predicted warming are combined to create a single, sixth plot.

It is at once visible that the predicted warming caused by greenhouse-gas concentrations produces a pattern strongly distinct from other causes of warming. A "hot spot" appears between 8km and 12km of altitude in or near the tropics. At this computer-predicted "hot spot" high above the Earth, the UN's models project that greenhouse warming will cause temperature to rise over the decades at a rate up to three times faster than at the surface.

Greenhouse warming is distinguishable from other forcings



Zonal mean simulated atmospheric temperature change (ºC per century, 1890-1999), from two natural causes, three anthropogenic causes and one combined cause, simulated by the UN's PCM model. The "hot-spot" signature of greenhouse warming is visible in (c) and (f). (IPCC, 2007, p. 675, based on Santer et al, 2003. See also IPCC, 2007, Appendix 9C).

The UN's diagram shows the pattern of zonal mean simulated atmospheric temperature change from 1890 to 1999, in °C per century from six causes –

(a) natural radiative forcing from changes in solar activity;
(b) natural radiative forcing from changes in volcanic activity;
(c) anthropogenic radiative forcing from emissions of CO_2 and other well-mixed greenhouse gases;
(d) anthropogenic radiative forcing from changes in tropospheric and stratospheric ozone;
(e) anthropogenic radiative forcing from pollutant sulphate aerosol particles emitted to the atmosphere; and
(f) all natural and anthropogenic forcings combined.

These six plots, from 1,000 hPa to 10 hPa barometric pressure (left scale), equivalent to 0-30 km (right scale), demonstrate that anthropogenic emission of well-mixed greenhouse gases, whether on its own (c) or combined with all other natural and anthropogenic forcings (f), is predicted to produce a signature distinct from that of other forcings alone.

The reason why the combined-forcings plot (f) appears so similar to the greenhouse-gas forcing plot (c) is that the UN's computer models predict that the impact of greenhouse-gas emissions on temperature is greater than that of all other forcings.

This instantly-recognizable "hot-spot" on the altitude-vs-latitude plot of predicted rates of temperature change is the unmistakable signature or characteristic fingerprint of greenhouse warming which we have been looking for. The warming which the computer models predict will arise from growing emissions of greenhouse gases is visibly distinct in its magnitude and in its altitudinal and latitudinal distribution from any other cause of natural or anthropogenic warming.

Following common meteorological practice, height is represented in these plots by atmospheric pressure level. Atmospheric pressure decreases approximately exponentially with height: 100 millibars corresponds roughly to 16 km; 200 mb to 12 km; 500 mb to 6 km; and 1000 mb to the surface. Predicted greenhouse-gas warming visibly peaks strongly in the tropical troposphere near the $\tau=1$ characteristic emission level, which differs from one computer model to another because the amount of water vapor differs among the models.

Within the tropical "hot-spot" at about 8 to 12 km altitude, the rate of increase in warming is more than twice and up to three times the rate of increase in warming at the Earth's surface. This does not mean that absolute temperature in the mid-troposphere is greater than at the surface. Far from it: the temperature at altitude is very much colder than at the surface. But the rate at which temperature is predicted to increase in the "hot-spot" over the decades is two or three times the rate at which temperature is predicted to increase at the surface.

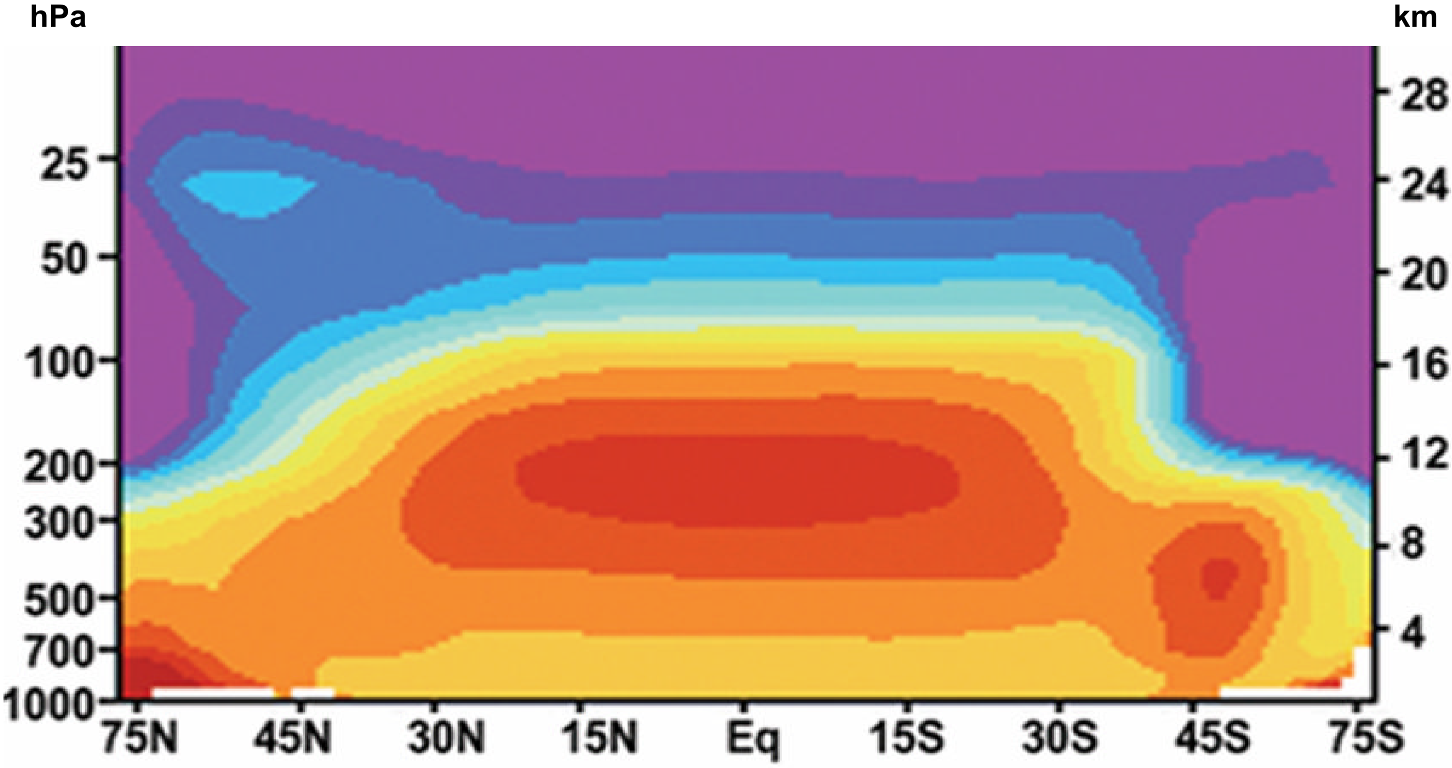
To put it another way, if we observe warming in the tropical upper troposphere, then the models predict that the contribution to warming at the surface that is caused by our greenhouse-gas emissions should be between less than half and one third of the warming seen in the upper troposphere.

It is worth noticing that if we considered only global temperatures, as many climatologists do, this signature of anthropogenic as distinct from natural warming would not become visible. Accordingly, the objections of Essex and McKitrick (2002) and Essex *et al*. (2007) to the use of globally averaged temperature are justifiable.

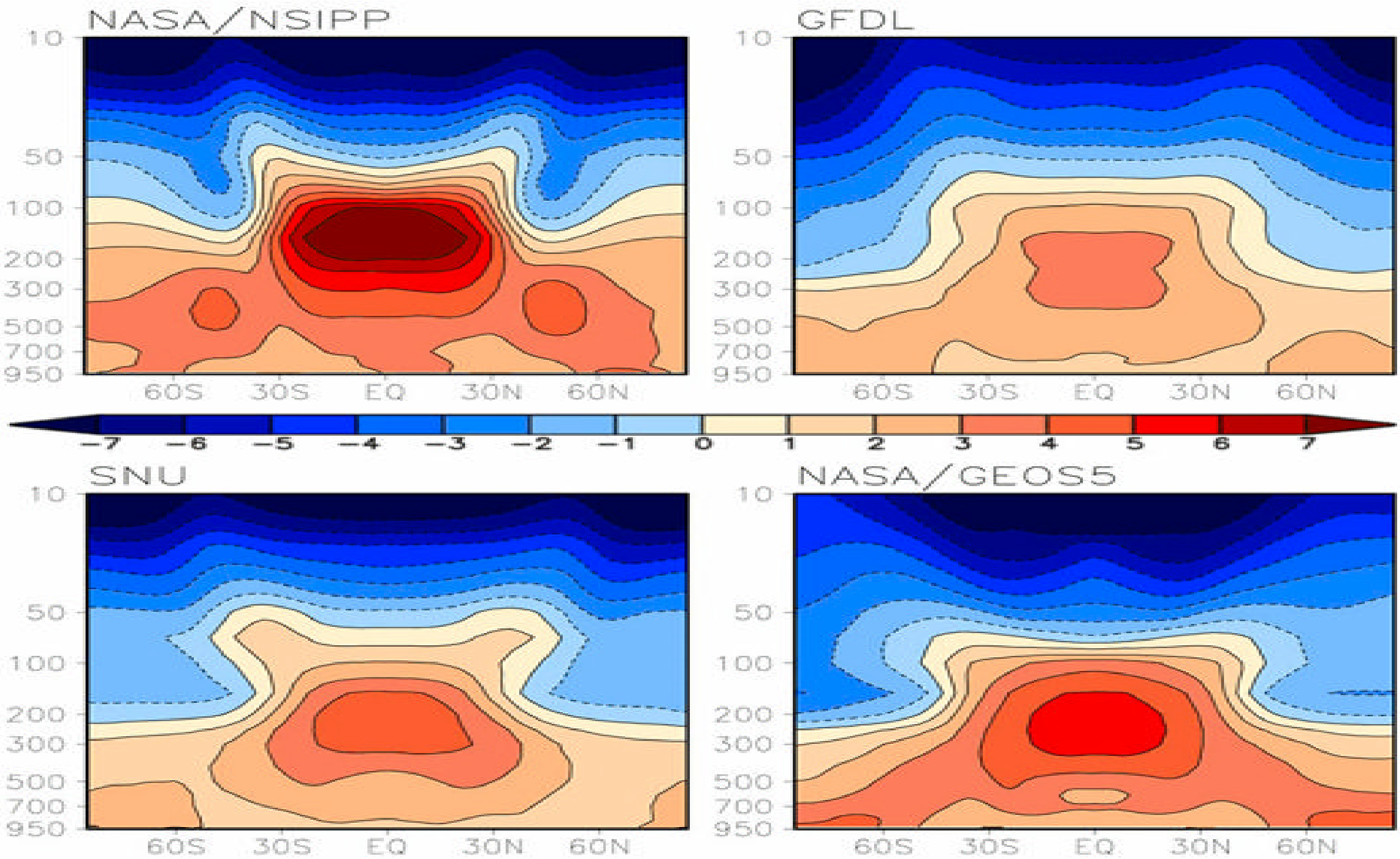
Had we used globally averaged temperatures, it would have been almost impossible correctly to relate the underlying physics to the observations.

We shall now demonstrate that several of the atmosphere-ocean general-circulation models relied upon by the UN do indeed predict the "hot-spot" in the mid-troposphere at low latitudes that is the signature of anthropogenic "global warming".

The computer-predicted signature of greenhouse warming



Zonally-averaged distribution of predicted temperature change (CCSP, 2006, p25, fig. 1.3)



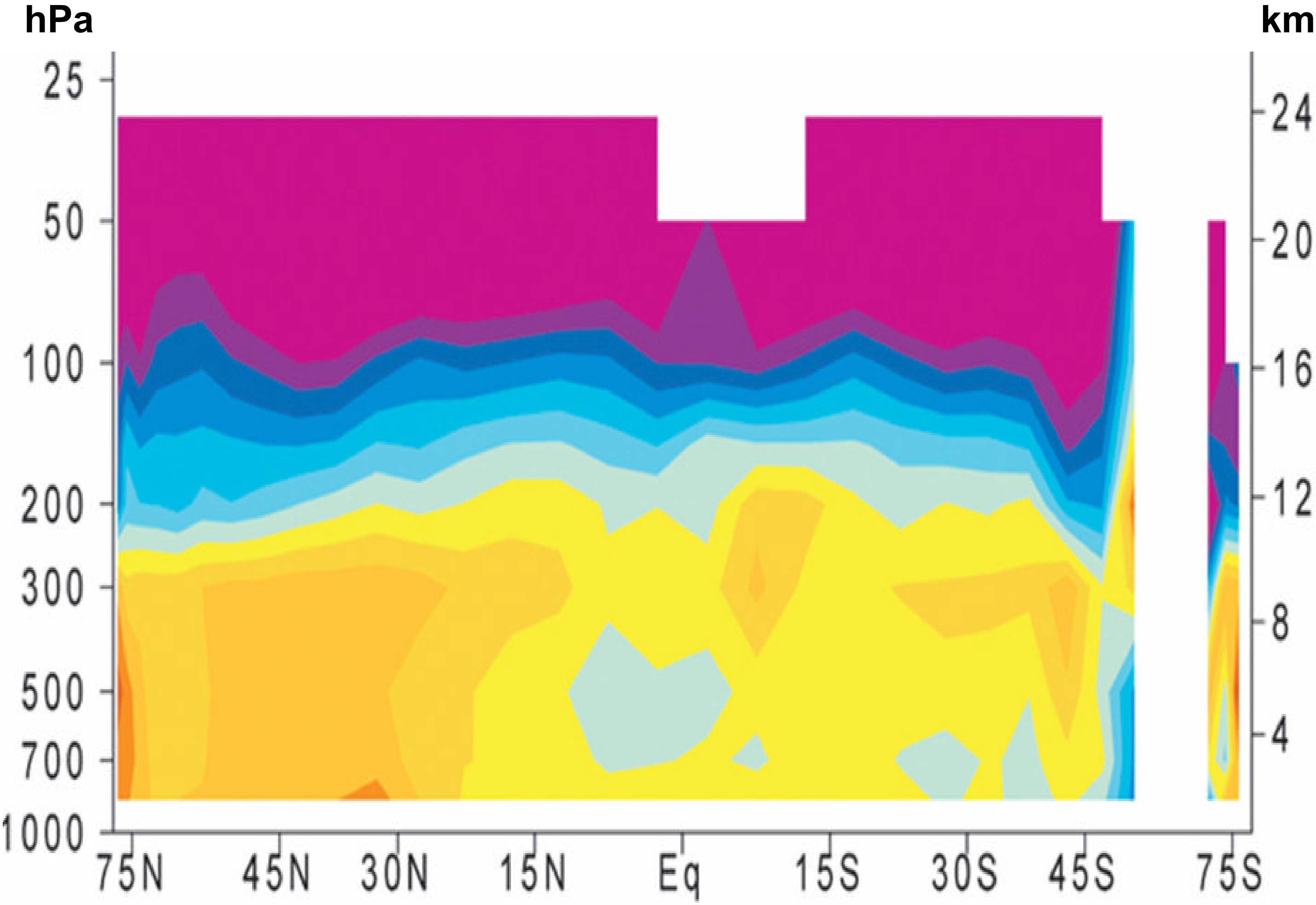
Zonally-averaged distributions of predicted temperature change in ºK at CO_2 doubling ($2xCO_2$ – control), as a function of latitude and pressure level, for four general-circulation models (Lee et al., 2007).

Predicted acceleration in the rate of temperature increase in tropical mid-troposphere in response to continuing emission of well-mixed greenhouse gases, compared with surface temperature change, generates a distinctive "hot-spot" graph that is the signature of anthropogenic as opposed to natural "global warming". All general-circulation models show this characteristic amplification of the decadal rate of change in temperature with altitude at low latitudes, up to a factor of ~ 3 at 10 km over the equator.

All five of the computer models whose plots are shown above unmistakably predict the characteristic "hot-spot" signature that UN's graphs show to be unique to warming of the atmosphere caused by emissions of greenhouse gases. But does observation demonstrate what the models predict?

Real-world temperatures in the upper atmosphere have been measured with balloons since at least the 1960's and with microwave satellite sensors since 1979. However, the Hadley Centre's plot of real-world radiosonde observations does not demonstrate the "global warming hot-spot" at all. The predicted phenomenon is startlingly and entirely absent from the observational record –

No "greenhouse warming" signature is observed in reality



Source: HadAT2 radiosonde observations, from CCSP (2006), p116, fig. 5.7E.

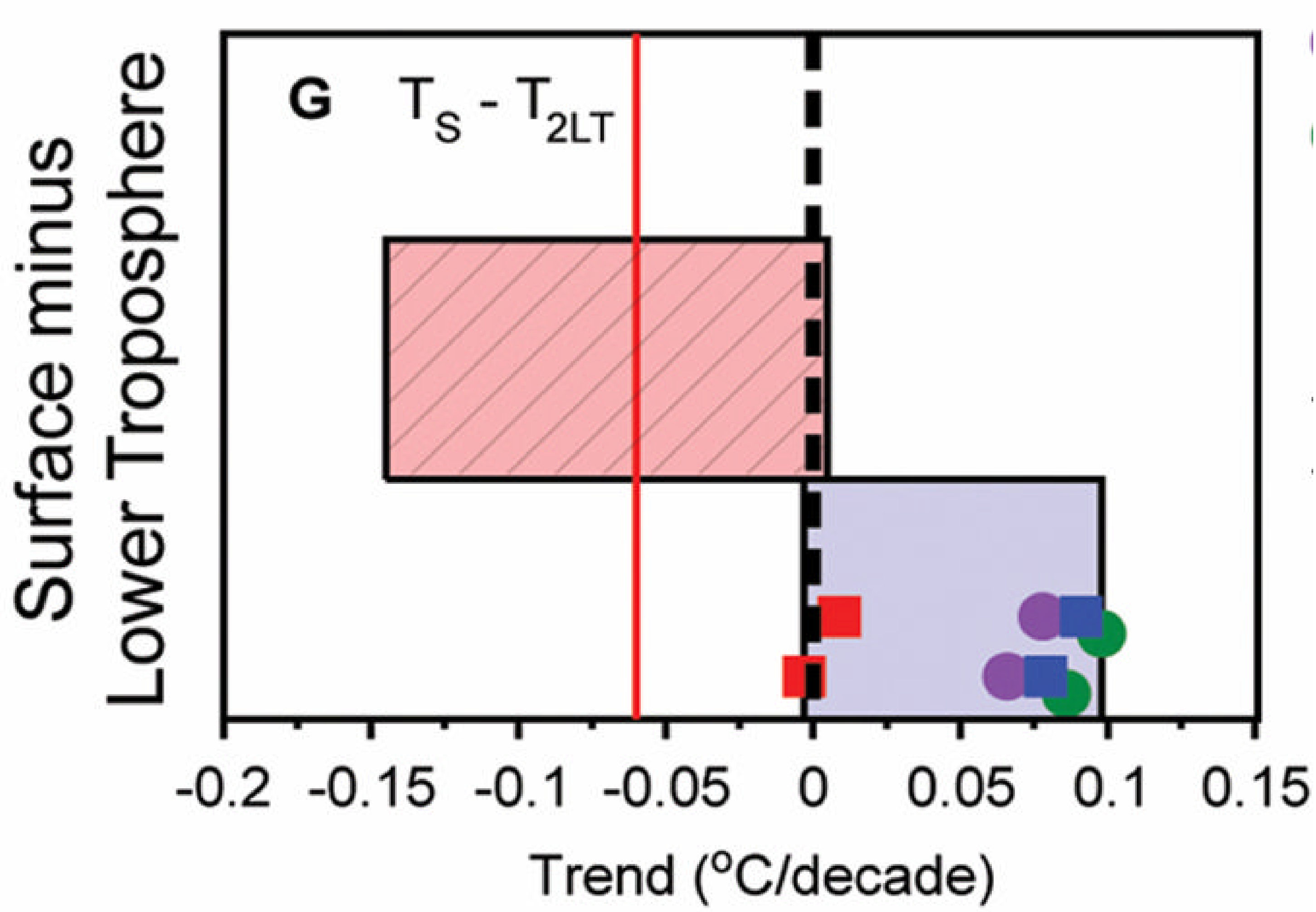
The contrast between the five computer models' predicted signature of greenhouse warming and the Hadley Centre's plot of observed decadal rates of change in temperature could not be starker. This result is explicitly confirmed by the UN's 2007 assessment report, which describes the near-total absence of its own predicted "hot-spot" signature of anthropogenic greenhouse warming in the observed temperature record, but apparently without appreciating its significance –

"9.4.4.1 Observed Changes

"... All data sets show that the global mean and tropical troposphere has warmed from 1958 to the present, with the warming trend in the troposphere slightly greater than at the surface. Since 1979, it is likely that there is slightly greater warming in the troposphere than at the surface, although uncertainties remain in observed tropospheric warming trends and whether these are greater or less than the surface trend. The range (due to different data sets) of the global mean tropospheric temperature trend since 1979 is 0.12°C to 0.19°C per decade based on satellite-based estimates (Chapter 3) compared to a range of 0.16°C to 0.18°C per decade for the global surface warming. "

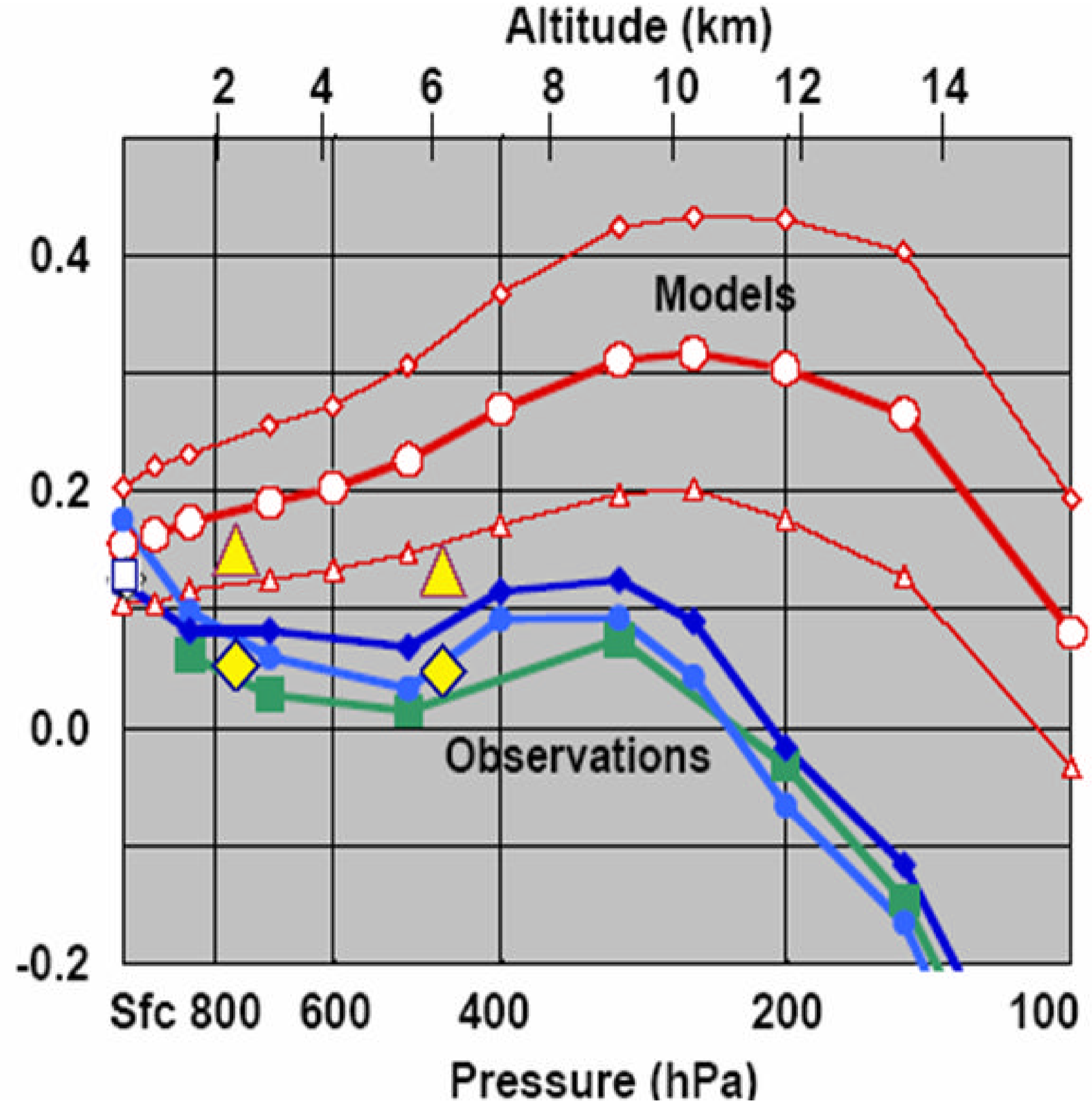
Global observation of tropospheric temperatures by balloon-borne radiosondes has been available since 1958, and by satellite telemetry since 1979. Therefore there are several multi-decadal observational rate-of-temperature-change datasets that demonstrate the absence in reality of the "hot-spot" signature that the general-circulation computer models predict in theory –

Little overlap between prediction and observed reality



Model-predicted differentials between decadal rates of increase in temperature at the surface (T_S) and in the lower troposphere (T_{2LT}) from latitude 20° N – 20° S in response to anthropogenic enhancement of the natural greenhouse effect by emission of carbon dioxide and other well-mixed greenhouse gases (pink hatched rectangle) do not overlap at any point with real-world observations from RATPAC radiosondes (purple circles); HadAT2 radiosondes (green circles); University of Alabama at Huntsville satellites (blue squares); and RSS satellites (red squares). Source: CCSP (2006), Executive Summary.

Observed temperature change is less than predicted



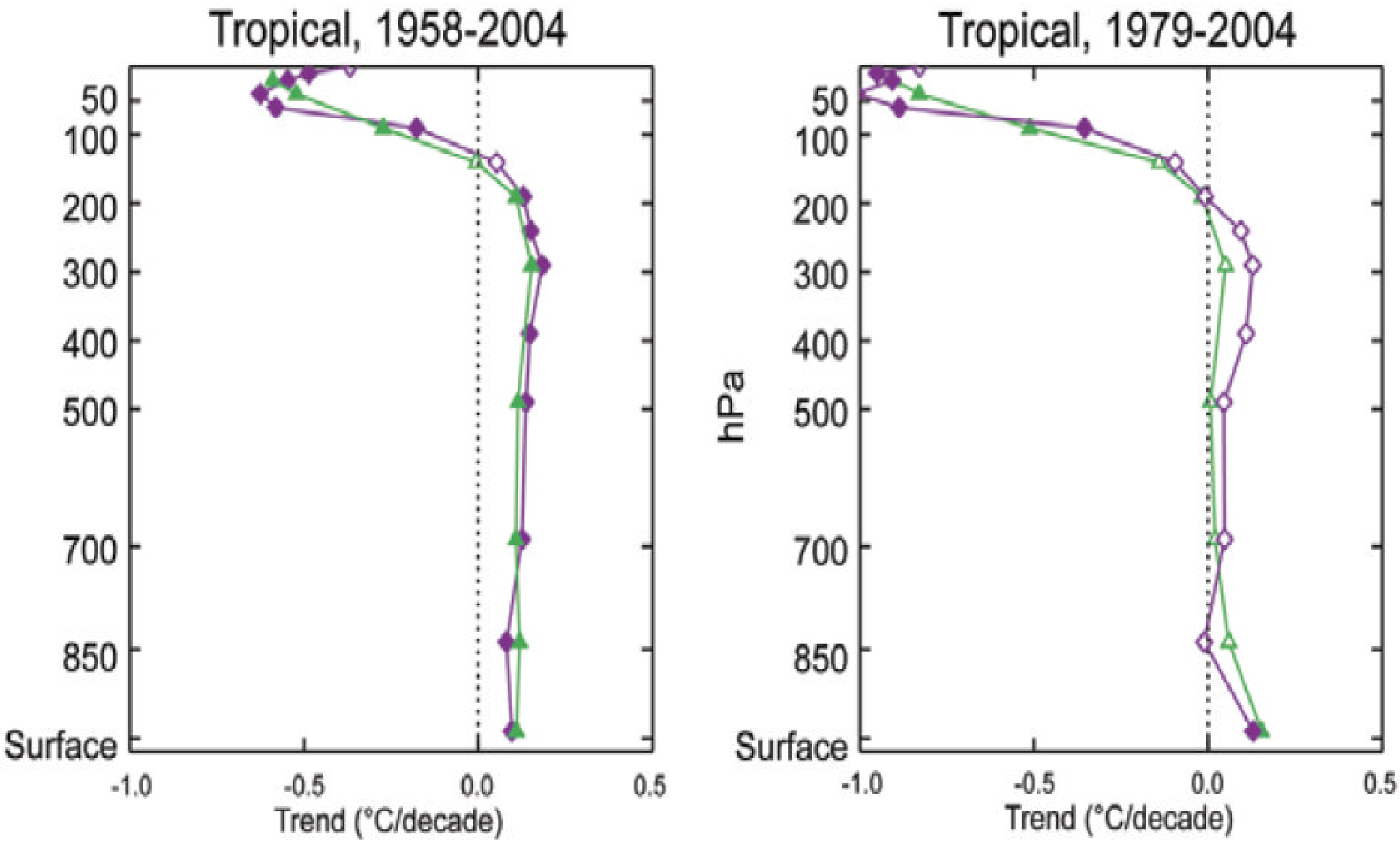
The significant shortfall between the magnitude of modeled and observed altitude-vs-latitude trends of decadal temperature increase in the tropics. Prediction and observation overlap only in the first mile of the atmosphere, demonstrating that the observed temperature forcing by anthropogenic greenhouse-gas emissions is considerably less than the forcing predicted by the models and accepted by the IPCC.

The 20-model mean predicted temperature trend (heavy red curve) ± 1 standard deviation (thin red curves) is plotted against observations from RSS 2.1 (yellow triangles); the University of Alabama at Huntsville's UAH 5.2 (yellow diamonds) Hadley Centre's AT2 (green curve); IGRA (light blue curve); RATPAC (dark blue curve); and Global Historical Climate Network surface trend (blue square) (Douglass et al., 2007).

A report by the US Climate Change Science Program (CCSP, 2006), says –

> "For longer-timescale temperature changes over 1979 to 1999, only one of four observed upper-air data sets has larger tropical warming aloft than in the surface records. All model runs with surface warming over this period show amplified warming aloft.
>
> "These results could arise due to errors common to all models; to significant non-climatic influences remaining within some or all of the observational data sets, leading to biased long-term trend estimates; or a combination of these factors. The new evidence in this Report (model-to-model consistency of amplification results, the large uncertainties in observed tropospheric temperature trends, and independent physical evidence supporting substantial tropospheric warming) favors the second explanation.
>
> "A full resolution of this issue will require reducing the large observational uncertainties that currently exist. These uncertainties make it difficult to determine whether models still have common, fundamental errors in their representation of the vertical structure of atmospheric temperature change."

No difference between surface and mid-troposphere trends



Vertical profiles of temperature trend in °C per decade for 1958-2004 (left) and 1979-2004 (right) as a function of altitude expressed as pressure from 1000 (surface) to 25 hPa, computed from theRATPAC (violet) and HadAT2 (green) radiosonde datasets, and based on temperature that has been averaged over the tropics, 20° N - 20° S. Filled symbols denote trends estimated to be statistically significantly different from zero (at the 5% level) (CCSP, 2006).

The plot of the US Climate Change Science Program's latest synthesis of all corrections to satellite and balloon radiosonde data to date (CCSP, 2006), shown here, shows no significant difference between surface and mid-tropospheric temperature trends, and indicates a decadal temperature trend in the mid-troposphere of no more than 0.05 +/- 0.07 degrees Celsius per decade (Spencer *et al,* 2007).

Conclusion

The UN's fourth assessment report on climate change (IPCC, 2007) confirms that computer modeling predicts the existence of a unique and distinct signature or fingerprint of anthropogenic warming caused by our emissions of greenhouse gases. That signature is the instantly-recognizable tropical, mid-troposphere "hot spot" about 10km above the Earth's surface. In the "hot spot", the models predict that the rate of increase in atmospheric temperature, measured in degrees Celsius per decade, will be two or three times greater than at the Earth's surface. In IPCC (2007), this "hot-spot" signature of anthropogenic greenhouse warming is clearly visible on plots of modeled greenhouse forcing and of all forcings including the dominant greenhouse forcing, but is not visible on plots of solar, volcanic, tropospheric and stratospheric ozone, or sulphate aerosol forcings.

Having established that the UN's models distinguish clearly between greenhouse warming and other climate forcings, we then demonstated that five separate general-circulation computer models of the climate all predict the existence of the "hot-spot" signature of anthropogenic greenhouse warming in the tropical mid-troposphere.

The observational plot from the Hadley Centre's radiosondes, showing actual, observed temperatures in the troposphere, is presented in the same altitude-vs-latitude fashion as the predictions made by the five computer models. Yet in this observed record the computer models' repeatedly-predicted "hot-spot" signature of anthropogenic greenhouse warming is entirely absent. This surprising result was confirmed by three further graphs, each showing a startling disparity between the "hot spot" that is predicted by the theoretical models and the very much lesser rates of increase in tropical mid-troposphere temperatures that are observed in practice.

The temperature increase to be expected from a doubling of atmospheric carbon dioxide concentration will be one-half to one-third of the UN's central estimate.

These observational plots graphs contain between them a dozen different observed-temperature datasets, not one of which exhibits the "hot-spot" signature of anthropogenic "greenhouse warming" that is predicted by the computer models upon which the UN so heavily relies. In every one of the observational datasets, the trend in the troposphere is no greater, and generally smaller, than the trend near the surface. According to Spencer *et al.* (2007), the tropospheric temperature trend is now 0.05 ± 0.07 degrees Celsius per decade. Therefore, the contribution of the anthropogenic enhancement of the greenhouse effect to surface warming is somewhere between -0.02 and 0.12 degrees Celsius per decade, with a central estimate of 0.5 degrees Celsius, or approximately one-sixth of the UN's central estimate of 3 degrees Celsius for a doubling of atmospheric carbon dioxide concentration.

This result is broadly consistent with that of Monckton and Ahlbeck (2007), who calculate by an entirely different method that the temperature increase to be expected from a doubling of atmospheric carbon dioxide concentration will be one-half to one-third of the UN's central estimate.

Can the discrepancy between prediction and observation be explained, as the CCSP suggests, by uncertainties in the observed data? Ultimately this question can only be resolved by collecting further data: but the CCSP's predisposition in favor of theoretical modeling and against the results of direct observation is commonplace among official climate-science bodies.

Or does the discrepancy arise because the predictions are carried through to equilibrium climate response, while the observations are perforce carried only to a transient response? Professor Lindzen comments that this failure of observation to match prediction cannot be so easily explained, since the transient response would be likely to exceed the equilibrium response. He concludes that no more than about a third of the observed trend at the surface is likely to be due to greenhouse warming, and adds: "This is about as close as one ever gets to proof in climate physics."

On this analysis, "global warming" is unlikely to be dangerous and extremely unlikely to be catastrophic.

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