been accentuated by widely known natural factors[13,14] and could at least partially be explained by them.

In conclusion, the main patterns described by Santer *et al.*[1] — interpreted by some as a sign of a human impact on the climate system — are either not permanent features of the climate system or cannot be ascribed to an increase of man-made greenhouse gases. The possible human impact on climate appears to be restricted to CFCs and the Southern Hemisphere stratosphere.

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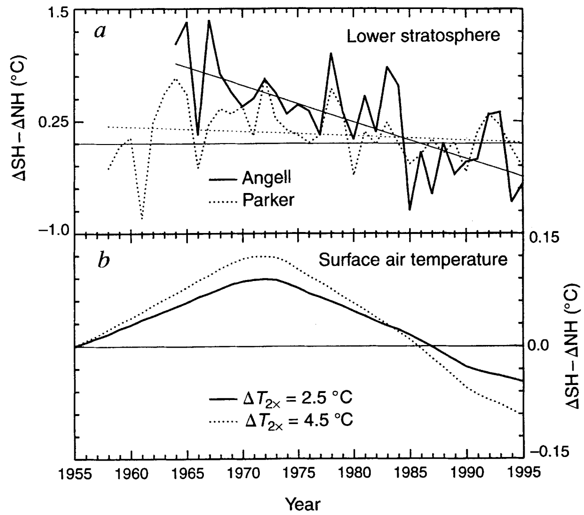
SANTER *ET AL.* REPLY — Michaels and Knappenberger, and Weber, in their contributions above, criticize our study[1] in which we attempted to identify human influences on climate.

Weber states that the increasing pattern similarity between a model signal and observed data (over 850–50 hPa) that we found may "largely be attributed to stratospheric cooling by CFCs...". He bases this conclusion on larger stratospheric cooling in the Southern Hemisphere. Both Weber and Michaels and Knappenberger argue that the hemispheric asymmetry in 850–500-hPa temperature trends identified in our study is a transient feature unrelated to anthropogenic influences.

To support their arguments, Michaels and Knappenberger and Weber use the virtual temperature data set of Angell[5], which has instrumental biases[15] and known deficiencies in its spatial representativeness[16]. Angell's large asymmetrical cooling in the lower stratosphere (greater cooling in the Southern Hemisphere) is not substantiated by analysis of other data sets — only a small long-term asymmetry trend is evident in the Parker radiosonde data[17] (*a* in our figure). Furthermore, lower stratospheric temperature trends computed from satellite data[18] and a reanalysis of operationally produced climate data[19] show an asymmetry of the opposite sign (greater lower-stratospheric cooling in the *Northern* Hemisphere).

Thus, the basis for Weber's argument for a dominant effect of CFCs is not supported by other available estimates of lower stratospheric temperature change. Furthermore, his proposed mechanism of stratospheric ozone depletion leads to a cooling of the troposphere[20], not a warming as observed. Our own[1] and more recent[20] work finds closest agreement between modelled and observed vertical temperature-change patterns when multiple anthropogenic forcings are considered.

Both Michaels and Knappenberger and Weber claim that our pattern-correlation ($R(t)$) results for the lower atmosphere are merely a manifestation of natural variability. To support this claim, Michaels and Knappenberger use the hemispheric temperature-change difference in the lower atmosphere (850–300 hPa) from Angell's data. They contend that this time series is a reasonable 'proxy' for our 850–500 hPa $R(t)$ results, and hence can be used to extend our correlation analysis beyond 1987.



a, Comparison of annual mean changes in hemispheric temperature contrast (Southern Hemisphere minus Northern Hemisphere) in the lower stratosphere in two observed data sets. Data from Angell[5] are virtual temperatures for the 100–50-hPa layer. The Parker radiosonde data[17] are actual temperatures for eight pressure levels; Australian and New Zealand stations were corrected for instrumental biases[20]. To facilitate comparison with Angell's and other data sets, the Parker temperature data were sampled with the channel-4 weighting function of the satellite-based Microwave Sounding Unit (which monitors temperatures in the 120–40-hPa atmospheric layer[18]). Both time series are expressed as anomalies relative to a common reference period average (1979–95). Overall linear trends (over 1964–95 in ref. 5 and 1958–95 in ref. 17) are also shown. *b*, Time series of hemispheric surface air temperature-change differential (Southern Hemisphere minus Northern Hemisphere) predicted by a simple climate model[24] in response to IPCC 'best guess' anthropogenic forcing[25]. Results are shown for two different values of the climate sensitivity. The model prediction in response to purely anthropogenic forcing is qualitatively similar to the observed hemispheric temperature-change contrast in Michaels and Knappenberger's figure *b*.

To test this claim, we used the newly available Parker radiosonde data to extend our $R(t)$ results for the low- to mid-troposphere to the period 1958–95. The time series of $R(t)$ and hemispheric temperature contrast computed with the Parker data are highly correlated ($r = 0.80$), thus confirming Michaels and Knappenberger's supposition. Like the hemispheric temperature-change contrast in the Angell and Parker data sets, the 'updated' $R(t)$ does decrease after 1988.

Contrary to Michaels and Knappenberger's claim, however, such behaviour is consistent with our current understanding of anthropogenic causes. This is because there are temporal changes in the relative strengths of the greenhouse-gas and aerosol forcings, and in their associated (asymmetrical) climate response patterns. Thus, both $R(t)$ and its 'proxy' are *expected* to show periods of increase and decrease (as in Michaels and Knappenberger's figure *b*) as part of an anthropogenic signal[21,22]. Model-based results for the hemispheric temperature-change contrast, based on anthropogenic forcing alone (our figure *b*), are qualitatively similar to the observations shown in Michaels and Knappenberger's figure *b*. Thus, the decadal timescale fluctuations in both the hemispheric temperature differential and in $R(t)$ most probably reflect an anthropogenic signal plus superimposed natural variability noise, and not noise alone, as Michaels and Knappenberger, and Weber, contend.

In summary, the claim by Weber that our 850–50-hPa results reflect only CFC-related stratospheric ozone effects is incorrect and based on suspect data. Nevertheless, stratospheric ozone is an important component of the climate system, and its depletion may well contribute a significant part of the anthropogenic climate-change signal in the lower stratosphere[23]. With regard to the claims in both contributions above that our results depend on the choice of data period, on the contrary, the use of a longer observed record fully supports our earlier 850–50-hPa results. For 850–500 hPa, the changes in $R(t)$ are similar to changes in the hemispheric temperature contrast shown by Michaels and Knappenberger. This is not surprising: we ourselves interpreted our significant 850–500 hPa $R(t)$ results primarily in terms of warming of the Southern Hemisphere relative to the Northern Hemisphere. However, both the recent change in hemispheric temperature contrast and the decline in $R(t)$, rather than being in conflict with the expected effects of anthropogenic forcing, are consistent with those expectations, and the primary conclusions of ref. 1 stand.

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