*CEFE–CNRS, 1919 route de Mende, 34293
Montpellier, France
†LSCE–CEA–CNRS CE Saclay l'Orme des
Merisiers, 91191 Gif-sur-Yvette, France
e-mail: pascal.yiou@cea.fr
‡INRA Site Agroparc, domaine Saint-Paul, 84914
Avignon Cedex 9, France
§Collège de France, 75231 Paris Cedex 05, France

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Climate

Large-scale warming is not urban

Controversy has persisted[1,2] over the influence of urban warming on reported large-scale surface-air temperature trends. Urban heat islands occur mainly at night and are reduced in windy conditions[3]. Here we show that, globally, temperatures over land have risen as much on windy nights as on calm nights, indicating that the observed overall warming is not a consequence of urban development.

Observations of the minimum temperature ($T_{\min}$) over 24 hours at 264 stations worldwide since 1950 were expressed as anomalies, relative to the period 1961–90 where possible. Coverage of $T_{\min}$ data was good north of 20° N, in Australasia and in the western tropical Pacific, but poor in Africa, South America, Antarctica and parts of southern Asia. Reanalysed[4] daily-average near-surface wind components were used to classify the $T_{\min}$ anomalies into 'windy' (upper tercile) and 'calm' (lower tercile) conditions. Daily average wind speeds were used because the timings of temperature extremes are not known. For stations between 140° E and the dateline, $T_{\min}$ — which occurs most frequently in the early morning — was matched with the previous day's speed. This is because the early morning in terms of universal time (equivalent to Greenwich Mean Time) is still in the previous day in the Far East.

Annual and seasonal anomalies of $T_{\min}$ were gridded on a 5°×5° resolution for windy, calm and 'all' conditions. Coverage was at least 200 grid boxes (equivalent to more than 27% of global land area) in 1958–99. For 1950–2000, the trends of global annual average $T_{\min}$ for windy, calm and all conditions were identical (0.19 ± 0.06 °C per decade; Fig. 1a). So, urbanization has not systematically exaggerated the observed global warming trends in $T_{\min}$. The same can be said for poor instrumental exposure and microclimatic effects, which are also reduced when instruments are well ventilated[5].

When the criterion for 'calm' was changed to the lightest decile of wind strength, the global trend in $T_{\min}$ was unchanged. The analysis is therefore robust to the criterion for 'calm'. To assess the effect of time differences between the reanalysis[4] daily-average winds and $T_{\min}$, I repeated the analysis using 26 stations in North America and Siberia that have hourly or six-hourly reports of simultaneous temperature and wind. Again, windy and calm nights warmed at the same rate, in this case by 0.20 °C per decade.

Because a small sample was used, I compared global trends for the reduced period 1950–93 with published all-conditions trends for that period based on a sample of over 5,000 stations[6]. All differences were within ±0.02 °C per decade. This robustness arises because of the spatial coherence of surface temperature variations and trends[7].

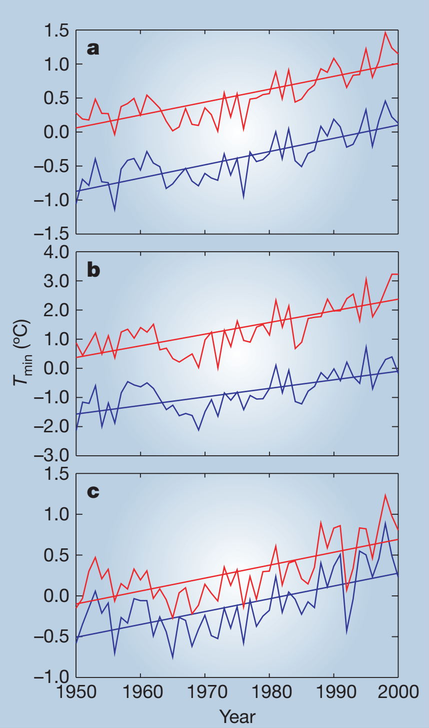

Figure 1 Anomalies in $T_{\min}$ for windy (red) and calm (blue) conditions. **a,** Annual global data; **b,** winter data (December to February) for Northern Hemisphere land north of 20° N; **c,** summer data (June to August) for Northern Hemisphere land north of 20° N. The linear trend fits, and the $\pm 2\sigma$ error ranges given in the text, were estimated by restricted maximum likelihood[10], taking into account autocorrelation in the residuals. As expected from the reduced stratification of the boundary layer, $T_{\min}$ is, on average, warmer on windy nights than on calm nights.

The global annual result conceals a relative warming of windy nights in winter in the extratropical Northern Hemisphere (Fig. 1b), mainly in western Eurasia. The observed tendency to an increased positive phase of the North Atlantic Oscillation[8] implies that the windier days in western Eurasia had increased warm advection from the ocean[9], yielding greater warming. In summer in the extratropical Northern Hemisphere (Fig. 1c), there was no relative change in $T_{\min}$ on windy nights. At that time of year, atmospheric circulation changes are less influential, but an urban warming signal is still absent. In the tropics, calm nights warmed relative to windy nights on an annual average, but only by 0.02 ± 0.01 °C per decade, which is much less than the overall tropical warming in $T_{\min}$ (0.16 ± 0.03 °C).

This analysis demonstrates that urban warming has not introduced significant biases into estimates of recent global warming. The reality and magnitude of global-scale warming is supported by the near-equality of temperature trends on windy nights with trends based on all data.

David E. Parker
Hadley Centre, Meteorological Office,
Exeter EX1 3PB, UK
e-mail: david.parker@metoffice.com

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Atmospheric science

Early peak in Antarctic oscillation index

The principal extratropical atmospheric circulation mode in the Southern Hemisphere, the Antarctic oscillation (or Southern Hemisphere annular mode), represents fluctuations in the strength of the circumpolar vortex and has shown a trend towards a positive index in austral summer in recent decades, which has been linked to stratospheric ozone depletion[1,2] and to increased atmospheric greenhouse-gas concentrations[3,4]. Here we reconstruct the austral summer (December–January) Antarctic oscillation index from sea-level pressure measurements over the twentieth century[5] and find that large positive values, and positive trends of a similar magnitude to those of past decades, also occurred around 1960, and that strong negative trends occurred afterwards. This positive Antarctic oscillation index and large positive trend during a period before ozone-depleting chemicals were released into the atmosphere and before marked anthropogenic warming, together with the later negative trend, indicate that natural forcing factors or internal mechanisms in the climate system must also strongly influence the state of the Antarctic oscillation.

Until recently[6], it has not been possible to put the Antarctic oscillation index (AAOI) trends in past decades into a longer-term context, as comprehensive Southern Hemisphere data are limited to the reanalysis period (1948/58–present; NCAR–NCEP/ERA40 reanalysis). Our reconstructions are intended to cover the reanalysis period with a consistent estimate of the AAOI, as this has been questioned[7], and to extend this estimate further back. The new reconstructions are more reliable as they use more predictor stations and a statistical model fitted using ERA40 reanalysis, whose AAOI estimates are better than those from NCEP reanalysis[7].

We define the Antarctic oscillation as the first empirical orthogonal function, and the AAOI as the first principal component of the December–January mean extratropical sea-level pressure. A positive or negative AAOI indicates a strengthening or weakening, respectively, of circumpolar westerly flow. For our reconstructions, we used multiple regression to estimate the AAOI from the leading principal components of normalized station pressure. The model is fitted using detrended data, but the reconstruction is derived using undetrended data. One reconstruction (1905–2000) uses 22 stations (Fig. 1a); the second (1951–2000) uses 41 and provides improved coverage of the Antarctic oscillation centres of action (Fig. 1b). Cross-validation gives a correlation of 0.88 and 0.90 for the 1905 and 1951 reconstructions, respectively. (For methods, see supplementary information).

Both reconstructions show that the current positive values for the AAOI are not unprecedented (Fig. 1c). After the relatively stable first half of the twentieth century, there is a period of positive values (relative to the 1958–2000 mean) from 1958 to 1963, followed by a sharp drop to predominantly negative values until the mid-1980s, and then by a mostly positive phase up to the present. The maximum positive 25-year trends over recent years are of similar magnitude to those between the low values of the 1940s and the peak in the 1960s. Note that the trend over the past decades is caused by a combination of negative values in the 1970s and current positive values.

A positive AAOI around 1960, followed by a negative index, is also present in the NCEP and the ERA40 data, in a zonal index-based AAOI[7] and in earlier reconstructions[6]. Consistent with this Antarctic oscillation behaviour, station pressures around 1960 have positive anomalies in the mid-latitude centres of action and negative anomalies in the Antarctic centre of action. By contrast with our reconstructions, the 1960s peak is slightly lower than the 1990s peak in both reanalyses and the zonal index AAOI. Despite this small uncertainty about the exact values, the 1960s peak is a robust feature in all these data sets.

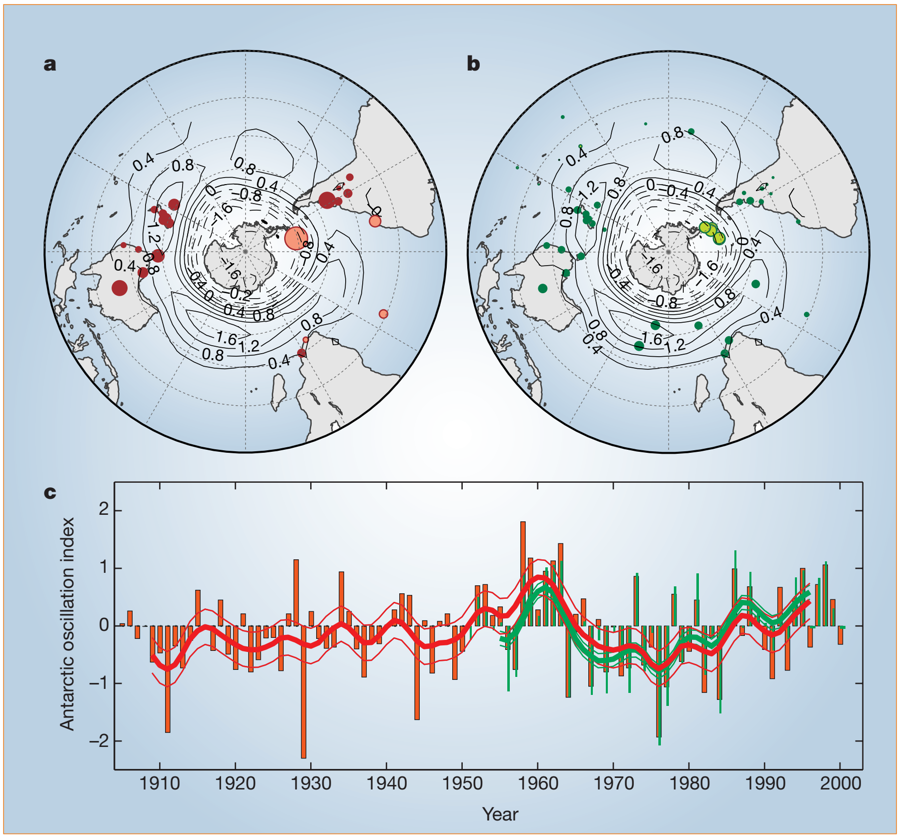

Figure 1 Reconstruction of the December–January Antarctic oscillation index (AAOI). **a,** The Antarctic oscillation pattern and regression weights for normalized station sea-level pressure used for the 1905 AAOI reconstruction. Isolines show the sea-level pressure anomaly (in hundreds of pascals) for the AAOI + 1. The red circles denote positive values and the pink circles denote negative ones; the area is proportional to the weight; **b,** as in **a**, but for the 1951 AAOI reconstruction, with dark green denoting positive values and light green denoting negative ones. **c,** Reconstructed December–January AAOI. Red bars show the 1905 reconstruction; green bars, the 1951 reconstruction. The thick red line is the nine-year low-pass-filtered 1905 reconstruction; the green, the 1951 reconstruction. The thin red and green lines show the 95% confidence intervals for the filtered data. Years are dated from December.

The fact that the austral summer behaviour of the Antarctic oscillation in recent decades seems not to be unprecedented indicates that natural forcing factors, such as solar or volcanic variability, or internal processes in the climate system, can strongly influence the state of the Antarctic oscillation. The question arises as to what the role of these factors has been over the past decades.

Julie M. Jones, Martin Widmann
Institute for Coastal Research, GKSS Research Centre, 21502 Geesthacht, Germany
e-mail: jones@gkss.de

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Corrigendum

Arrival synchrony in migratory birds

T. G. Gunnarsson, J. A. Gill, T. Sigurbjörnsson, W. J. Sutherland

Nature **431,** 646 (2004).

The line in Fig. 1a shows unity ($x = y$) and is not a regression line, as the legend describes it.

brief communications arising online

www.nature.com/bca

Copper oxide superconductors: Sharp-mode coupling in high-T_c superconductors

T. Cuk, Z.-X. Shen, A. D. Gromko, Z. Sun & D. S. Dessau (doi:10.1038/nature03163)

Reply: J. Hwang, T. Timusk & G. D. Gu (doi:10.1038/nature03164)

Asteroseismology: Oscillations on the star Procyon

F. Bouchy, A. Maeder, M. Mayor, D. Mégevand, F. Pepe, D. Sosnowska (doi:10.1038/nature03165)