Thermostat and global warming

SIR — Deep convection over the tropical oceans is triggered primarily when sea surface temperatures (SSTs) exceed about 300 K. The central question is why the maximum SSTs are within a few degrees of the convection threshold temperatures in regions of convection such as the western Pacific warm pool. According to our thermostat hypothesis[1], deep convection gives rise to thick anvil clouds reflecting solar radiation back to space and limiting maximum SSTs. Wallace proposes a competing mechanism[2] in which such a thermostat is not required. In our view it is difficult to fit the availaole observations in the context of this mechanism.

Wallace explains his ideas in terms of the efficiency of tropical dynamics, which maintain spatially uniform temperatures in the troposphere. This dynamical effect is also a fundamental link in our thermostat mechanism; without it the greenhouse effect of the anvil would have balanced locally a major fraction of the surface cooling due to solar reflection and its effectiveness as a thermostat would be much weaker.

Wallace asserts that even without the reflective clouds, the evaporative cooling will increase with SST to limit SSTs to the observed values. How do we test the validity of the two hypotheses? The best recourse is to test their predictions with available observations. Here, we examine observational estimates for evaporative heat flux on several time and spatial scales. Our interest is in those oceanic regions where deep convection and warm SSTs (>300 K) occur together.

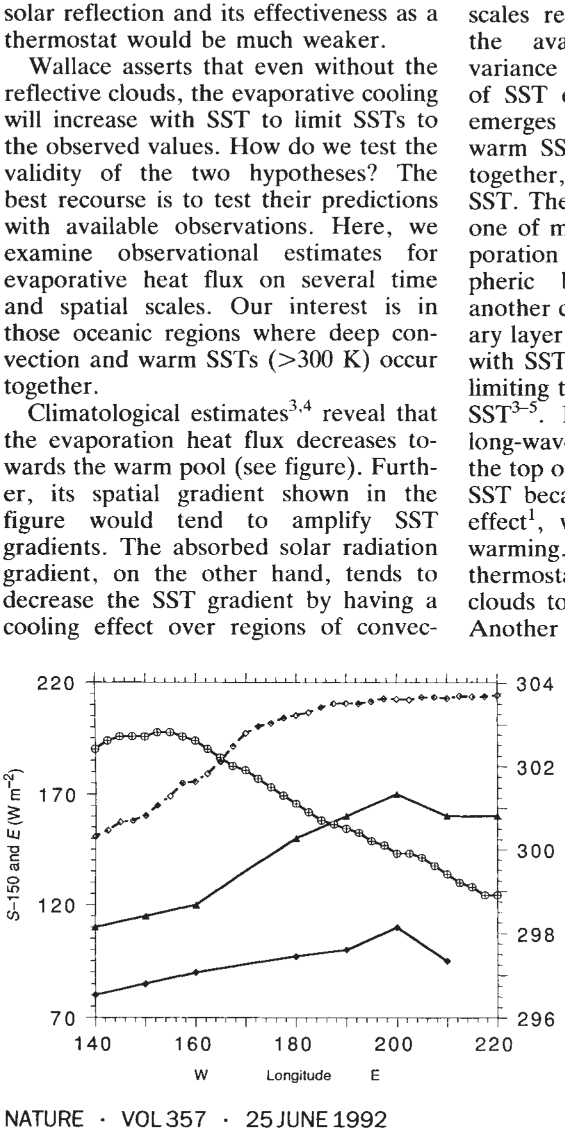
Climatological estimates[3,4] reveal that the evaporation heat flux decreases towards the warm pool (see figure). Further, its spatial gradient shown in the figure would tend to amplify SST gradients. The absorbed solar radiation gradient, on the other hand, tends to decrease the SST gradient by having a cooling effect over regions of convection, as it decreases significantly towards the warm pool.

Wallace's proposal involves 'hot patches' in the ocean giving rise to enhanced evaporation. Hot patches form in the central equatorial Pacific during El Niño events and are accompanied by deep convection. Estimates of evaporation from satellite data for winds and humidities reveal that the warming is accompanied by decreased evaporation from the central equatorial Pacific[5]. At the same time the absorbed solar energy decreases significantly[1]; this decrease lags behind the SST increase by about 2 months[6], an important delay implying a link between SST, deep convection, cloudiness and the large-scale atmospheric dynamics as suggested in our paper[1]. Even on monthly timescales, limited observations[7] in the warm pool suggest that the response of evaporation to SST changes accounts for only a small fraction of the total heat flux variances in regions of convection.

Thus, for the monthly to yearly timescales relevant to the coupled system, the available observations are at variance with the evaporation hypothesis of SST equilibration. The picture that emerges is that, in regions where the warm SSTs and deep convection occur together, evaporation decreases with SST. The implication is that SST is only one of many variables that control evaporation from the ocean surface. Atmospheric boundary layer humidity is another controlling variable. The boundary layer humidity increases significantly with SST in regions of convection, thus limiting the increase of evaporation with SST[3–5]. In addition, the net outgoing long-wave emission at the surface or at the top of the atmosphere decreases with SST because of the 'super greenhouse' effect[1], which would also amplify the warming. Thus, we are led to a thermostat-type mechanism involving clouds to explain the equilibrium state. Another independent three-dimensional atmospheric model simulation shows that, in the central Pacific during El Niño events, SSTs are negatively correlated with solar insolation at the sea surface, and that changes in solar radiation rather than changes in evaporation dominate the heat flux variance at the sea surface[8].

We are not questioning the importance of evaporative cooling to the surface energy balance. At issue is the sign and magnitude of the feedback between SST and evaporation in regions of convection such as the warm pool. How warm would the sea surface be compared with observed values without the cloud reflection of solar energy? Wallace believes it would be about the same[2]. A recent study[9] using a dynamical ocean model coupled to a simple atmospheric model indicates that the warm pool SST is very sensitive to heat flux anomalies. A 10 W m^{-2} anomaly produces a 1 K change in the model SST. The reduction in solar radiation due to the clouds in the warm pool is of the order of 50–100 W m^{-2} (refs 1,6). The maximum SST derived by us[1] is for the present climate and we have yet to establish its validity. It is premature to extrapolate our thermostat to the global warming problem, a point which we did not make explicit in our earlier paper[1]. However, the radiative–convective linkages in the thermostat hypothesis, if proved, would become vital pieces of the puzzle of global warming.

V. Ramanathan
W. Collins
Center for Clouds, Chemistry and Climate,
Scripps Institution of Oceanography,
University of California, San Diego,
La Jolla, California 92093, USA



Annual mean values averaged between 2.5° N and 2.5° S. *S*, solar energy absorbed by the surface–atmosphere column, is measured by the Earth Radiation Budget Experiment (ERBE). We subtract 150 W m^{-2} from *S* to plot it on the same scale as evaporation heat flux, *E*. *S* (open diamonds) and SST (open circles) are observed values for 1985 and are from ref. 1. Climatological estimates of *E* are obtained from ref. 3 (black triangles) and ref. 4 (black diamonds).

1. Ramanathan, V. & Collins, W. *Nature* **351**, 27–32 (1991).
2. Wallace, J. M. *Nature* **357**, 230–231 (1992).
3. Weare B. C., Ted Strub, P. & Samuel, M. D. *J. phys. Oceanogr.* **11**, 705–717 (1981).
4. Reed, R. K. *J. Clim. appl. Meteorol.* **24**, 833–840 (1985).
5. Liu, T. W. & Gautier, C. *J. geophys. Res.* **95**, 13209–13217 (1990).
6. Chertock, B. & Frouin, R. Somerville, R. C. J. *J. Climate* **4**, 639–650 (1991).
7. McPhaden, M. J. & Hayes, S. P. *J. geophys. Res.* **96**, 3331–3342 (1991).
8. Barnett, T. P., Kirk, E., Latif, E. & Roeckner, E. *J. Climate* **4**, 487–515 (1991).
9. Gent, P. R. *J. geophys. Res.* **96**, 3323–3330 (1991).

Scientific Correspondence

Scientific Correspondence is a relatively informal section of *Nature* in which matters of general scientific interest, not necessarily those arising from papers appearing in *Nature*, are published. Because there is space to print only a small proportion of the letters received, priority is usually given according to general interest and topicality, to contributions of fewer than 500 words, and to contributions using simple language.