SCIENTIFIC CORRESPONDENCE

FIG. 2. Change in ERBE[2] shortwave cloud forcing vs. change in SST for April 1987 (El Niño) minus April 1985 in the domain 10° N–10° S. The open circles represent the west Pacific (124° E–160° E; correlation coefficient $r = -0.05$) and the dots represent the central/east Pacific (160° E–90° W; $r = -0.29$). Each point represents a difference in monthly mean values for a 2.5 × 2.5° region.

FU ET AL. REPLY — The existence of a spatial correlation between deep moist convection and warm sea-surface temperatures (SSTs) in certain regions of the tropical Pacific is well documented[3,4,8]. The validity of the thermostat hypothesis[2] depends on whether interannual or decadal changes in SST and convective cloudiness are correlated, whether such correlations are universal, whether the correlations indicate a temporal feedback or merely reflect spatial relationships invariant with time, and whether other more important feedbacks exist. We have challenged the thermostat hypothesis on each of these counts[1]. Here we present further evidence for our assertions from more recent analyses of satellite data sets.

Both Zhang[3] and Waliser et al.[4] argue that convection decreases with increasing SST above 29.5 °C; the latter paper also shows good agreement amongst three satellite data sets, including ISCCP. Furthermore, the variance of convection near the 32 °C upper limit of SST is fairly small. In other words, the warmest waters may not always be associated with convection at all, and must therefore be limited by some other physical process. We have shown that these warmest waters are locations of west Pacific subsidence compensating surrounding regions of intense convection on either side of the Equator[9]. Thus, the correlation between convection and SST breaks down at the warmest SSTs, because of the non-local effect of dynamics.

Ramanathan and Collins cite correlations between ERBE shortwave cloud forcing anomalies (δC_s) and SST anomalies (δT) as the basis of their hypothesis that δC_s is a response to δT. What they actually show in their paper, however, is the correlation of the product $\delta C_s \delta T$ versus $(\delta T)^2$. We have repeated their analysis, but correlating δC_s with δT directly, using the same domain and spatial resolution of ERBE data as do Ramanathan and Collins.

We separate the data into a west Pacific segment in which small SST anomalies occur, and a central/east Pacific domain with substantial SST anomalies. Figure 2 shows that in the west Pacific, where the warmest SSTs occur, there is no correlation: $\delta T \approx 0$ while δC_s takes on various values, mostly positive but encompassing almost the full range of observed C_s variability. In the central and east Pacific, two populations exist: a $\delta T \approx 0$ cluster like that in the west, and a second group with positive δT and constant (independent of SST), slightly negative δC_s. When combined these two populations yield a negative correlation between δC_s and δT (correlation coefficient −0.29). However, this correlation is spurious because it is derived from two individual populations for which δC_s and δT are different but uncorrelated. Some of the δC_s is due to low-level cloud rather than cirrus anvil variations[1] and the magnitude of δC_s is similar in east and west Pacific. A correlation consistent with the thermostat hypothesis actually occurs over only a small fraction of the domain.

We also note that Ramanathan and Collins' Fig. 1 is the result of defining the anomaly as warm minus cold for one pair of years and cold minus warm for the other pair. Thus, points which would cluster in the same quadrant are artificially shifted into the diametrically opposite quadrant, spuriously increasing the correlation.

Furthermore, to act as the thermostat, changes in cloud should also cause a change in the upper ocean heat balance through radiative heating of the ocean. The ocean should cool significantly after solar heating is reduced by increasing cloud. This would result in a positive contemporary correlation between the anomalous radiative flux into the ocean and the temperature tendency $\delta(dT/dt)$, or a positive lag correlation between the anomalous radiative flux and SST[10].

However, our analysis shows that in both west and east Pacific, anomalies in temperature tendency ($\delta(dT/dt)$) are not correlated with δC_s (correlation coefficients are −0.03 and 0.02 for the west and east Pacific, respectively) in the same spatial domain as that studied by Ramanathan and Collins for the period March 1985–July 1988, consistent with Liu and Gautier's[10] findings in the east Pacific for the 1982–83 El Niño. In contrast, the latent heat flux anomalies are well correlated with $\delta(dT/dt)$ over a large area of the equatorial and south Pacific (correlation coefficients 0.6–0.9) that covers "the area where intense warm anomalies were found during the 1982–1983 ENSO episode" according to Liu and Gautier's observations[10]. Anomalous increase in evaporation was found to cause a significant cooling trend and vice versa, but no significant cooling trend was found as a result of anomalous decrease in surface solar irradiance.

This evidence further suggests that changes in evaporation cannot be ignored as an important process in regulating tropical SST. We therefore stand by our original assertion that cirrus clouds are not the primary inhibitor of SST warming associated with El Niño in the tropical Pacific.

Rong Fu*
W. Timothy Liu
NASA Jet Propulsion Laboratory,
Pasadena,
California 91109, USA
* Also at
Department of Atmospheric
 Sciences,
University of California,
Los Angeles, California 90024, USA
Anthony D. Del Genio
William B. Rossow
NASA Goddard Institute
 for Space Studies,
2880 Broadway,
New York,
New York 10025, USA

1. Fu, R., Del Genio, A. D., Rossow, W. B. & Liu, W. T. Nature **358**, 394–397 (1992).
2. Ramanathan, V. & Collins, W. C. Nature **351**, 27–32 (1991).
3. Zhang, C. J. Climate (in the press).
4. Waliser, D. E., Graham, N. E. & Gautier, C. J. Climate **6**, 331–353 (1993).
5. Chertock, B., Frouin, R. & Somerville, R. C. J. J. Climate **4**, 639–650 (1991).
6. Houze, J. D. J. Meteor. Soc. Japan **60**, 396–409 (1982).
7. Harrison, D. E. J. Climate **4**, 539–549 (1991).
8. Fu, R., Del Genio, A. D. & Rossow, W. B. J. Climate **3**, 1129–1152 (1990).
9. Fu, R., Del Genio, A. D. & Rossow, W. B. J. Climate (submitted).
10. Liu, W. T. & Gautier, C. J. geophys. Res. **95**, 13209–13217 (1990).