Reply

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The significant discrepancies between theoretical estimates of diurnal temperature ranges in the stratopause region and corresponding observations are of considerable concern to us, and we welcome possible explanations. It is disturbing that observational data from our bead thermistors, as well as Rofe's (1966) spheres[1] and the grenade soundings of Theon *et al.* (1966), indicate ranges of 15K (or larger) in the stratopause region while Lindzen concludes that day-night temperature differences will be 4K or less. In particular, we are continually striving for a complete understanding of the possible sources of error in our own observational techniques. Consequently, it was not without enthusiasm that we have examined Lindzen's comments.

Our first concern which was raised by Lindzen's comments was relative to the magnitude of the residual or steady difference between bead and ambient temperatures described by the first term of his Eq. (3). Lindzen stated "this may be important in explaining the large day-night temperatures" although he did not further evaluate the term. Consequently, we will evaluate it here. Lindzen's Eq. (3), under his conditions that $\Upsilon = L/2\pi \approx 1$ sec and $t > L$, gives the relationship

$$(\delta T)\ \mathrm{res} = \sqrt{2}A \qquad (1)$$

for the steady residual temperature difference between the bead and its environment and the amplitude of the oscillatory term as caused by solar radiation. Here L is the period of oscillation and A [Eq. (4) of Lindzen] is the amplitude of the oscillatory term. Now Lindzen calculates a value $A = 0.117$C and from (1) above the corresponding value of the residual temperature difference (δT) res would be equal to $\sqrt{2}(0.117\mathrm{C}) = 0.165$C, thus indicating that the value of the residual term is negligibly small in comparison with the observed diurnal temperature variation of approximately 15C. But, as he points out, the actual amplitude of the oscillation as observed on the temperature records of Beyers and Miers (1965) is 1C so that a more pertinent calculation would be the corresponding (δT) res which is raised to $\sqrt{2}(1.0\mathrm{C}) = 1.414$C. The residual is larger, but still insignificant compared to the differences between theoretical and observed diurnal temperature ranges. Furthermore, we would emphasize here that the residual as used above is defined as $(\delta T)\ \mathrm{res} = A + R$, where R is the difference between the ambient temperature and the bottom (coldest) point on the oscillation; (δT) res does not represent an error in the temperature values reported by Beyers and Miers (1965). As previously explained, it is standard procedure to use the bottom (coldest) point on the oscillation to represent the actual temperature value during the data reduction process. Thus, if we examine only this error R left after standard data reduction techniques, we find that when $A = 0.117$C, $R = 0.048$C and when $A = 1.0$C, $R = 0.414$C.

Now the estimate of the expected amplitude of the oscillation of the bead's temperature due to its swinging under the parachute in and out of direct solar radiation can be improved if one chooses a more appropriate expression for the time variation of irradiation. Lindzen's expression, $(1+\cos\omega t)/2$, has the effect of irradiating the thermistor continuously with solar radiation of varying amplitude which could result in nonrepresentative values for both the oscillations (underestimates) and residual (overestimates) terms. The experiments of Murrow and Eckstrom (1966), in which cameras were suspended as payloads on descending parachutes, verified our previous assumption that, in general, the thermistor is alternately completely exposed to and shaded from direct solar radiation. Based upon this evidence, a square wave time variation in the solar radiation incident upon the thermistor was used in the calculation of R and A for the case where $\Upsilon = L/2\pi \approx 1$ sec and $t > L$. The results were for $A = 0.15$C, then $R = 0.0165$C. Similarly, if we choose $A = 1.0$C, then the corresponding $R = 0.11$C.

We must conclude that the difference between the observed and computed oscillation (0.35 to 0.85C) remains unexplained. However, the importance of this exercise would seem to involve the evaluation of the residual error R which amounts to about 0.1C and, consequently, is trivial to the overall day-night temperature variations observed with bead thermistors. Lindzen's inference that the observed diurnal temperature variation is largely the result of "direct solar irradiation of the thermistor bead package" is considered to be unjustified.

[1] See also Rofe *et al.* (1966).

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