Reports

Factors Governing Tropospheric Mean Temperature

Abstract. *Two possible factors, which in addition to Pacific sea surface temperatures might affect the mean temperatures of the tropical troposphere are Atlantic sea surface temperatures and volcanic aerosol. The Mt. Agung eruption in March 1963 produced a decrease of about 0.5°C in the mean temperature of the tropical troposphere. The contribution of the Atlantic is not significant.*

We have reported elsewhere that the mean temperature of the tropical troposphere (TMT) is closely related to Pacific sea surface temperature (*1*). To characterize TMT, we used values reported by Angell and Korshover (*2*) derived from differences in the monthly mean geopotential heights for 14 stations near 20°N and 20°S. Their results are in the form of deviations from long-term 3-month seasonal means for the period 1958 through 1973. As a measure of the Pacific sea surface temperature, we used the time coefficients of an empirical orthogonal function which represents the most important mode of year-to-year variations and which accounts for 23 percent of the total variance after the seasonal variation has been removed (*3*). This function is the best linear representation of the data (*4*) and therefore has a pattern whose form is determined by the interrelationships within the data being analyzed. The analysis of the empirical orthogonal function presented here is based on monthly mean temperatures for 1949 through 1973 at 160 grid points, each representing an area 10° in longitude by 5° in latitude covering the region from 50°N to 20°S. A map of the first Pacific component (hereafter termed PNS1) (*1, 3*) shows that the function is dominated by the variations of the eastern tropical Pacific. The time series of its coefficients clearly indicate the warmer-than-average water in that region in certain periods, often referred to as El Niño.

We found a correlation coefficient between these two variables of 0.74 when the sea temperatures lead the air temperatures by 6 months (two seasons). The correlation is weak in the period 1964 through 1965 and we suggested two possible reasons for the breakdown, both of which are examined here.

Our first hypothesis was that changes in the sea temperature in the Atlantic also contribute to the observed air temperature changes. Weare has recently completed an analysis of the empirical orthogonal function of Atlantic sea surface temperature for both the region 50°N to 30°S and the tropical region 30°N to 30°S (*5*). The time series of the most important function for the tropical analysis when the seasonal variation has been removed (hereafter called ANS1) is used here as an independent variable. It was only available up to 1969.

Our second hypothesis was that volcanic aerosol influenced the air temperature; the largest injection in the period of interest was that due to the Mt. Agung eruption of March 1963. As a measure of the volcanic aerosol we use the atmospheric transmittance measured at Mauna Loa Observatory, Hawaii (MLT), which was reported by Ellis and Pueschel (*6*) for the period 1958 through 1970.

We thus have TMT as a dependent variable and the three possible independent variables PNS1, ANS1, and MLT. We carried out correlations between TMT and the three variables for a series of phase lags, ranging from three seasons leading to three seasons lagging. The highest values of the correlation of TMT with the other variables were found when PNS1 and ANS1 lead by two seasons and MLT leads by three. Each of these correlations was found to be highly significant, but for the latter two the differences between the correlations for the selected leads and other leads from zero to three seasons are not significant. The correlations between the four variables at these lags for the period in which all the data are available, 1958 through 1969, are given in Table 1.

In order to isolate the effects of MLT, PNS1, and ANS1 on TMT, we carried out a multiple linear regression analysis for data for the period 1958 through 1969. The partial correlation of TMT and ANS1 accounts for only 2 percent of the variance and is not therefore significant. Hence, our hypothesis that the Atlantic sea surface temperature influences TMT is not verified, a conclusion we drew

Table 1. Correlations of each of the identified parameters with each of the others. Phases are referred to the season (S) of the TMT so that MLT leads by three seasons, PNS1 by two, ANS1 by two, and EMT lags by one season.

	MLT (S − 3)	PNS1 (S − 2)	ANS1 (S − 2)	TMT (S)	EMT (S + 1)
MLT (S − 3)	1.				
PNS1 (S − 2)	.23	1.			
ANS1 (S − 2)	.40	.17	1.		
TMT (S)	.65	.65	.40	1.	
EMT (S + 1)	.43	.52	.05	.69	1.

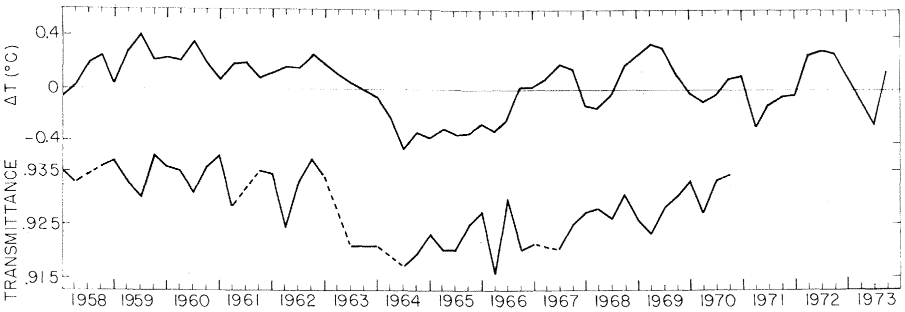

Fig. 1. Difference between seasonal TMT obtained from an analysis by Angell and Korshover (2) and a linear prediction of that mean based on the values of PNS1 two seasons ahead for the years 1958 through 1973 (top). Seasonal mean apparent MLT (6) for the years 1958 through 1970 (bottom). The beginning point is for the season winter 1958 defined as December 1957 through February 1958.

earlier on less stringent grounds (1). We then carried out a multiple linear regression analysis with MLT and PNS1 for the period 1958 through 1970. Changes in PNS1 account for 47 percent and the MLT variations for 21 percent of the variance of TMT. Both of these values are highly significant, and therefore this result supports our second hypothesis that volcanic aerosols are related to the TMT.

It is of considerable interest to assess the change in tropospheric temperature due to a large volcanic eruption. We therefore used the best linear fit between TMT and PNS1 (leading by two seasons) to estimate the contribution of the sea temperature to the air temperature changes and subtracted this from the observed seasonal air temperature changes. The difference is an approximate measure of the contribution of the volcanic aerosol to the temperature change (Fig. 1); also included in Fig. 1 is the apparent MLT (6). Variations in the direct solar radiation at the ground at four Japanese stations (7) follow the same pattern. Comparison of the curves suggests that the eruption of Mt. Agung in 1963, which Ellis and Pueschel (6) argued was the cause of the sharp decrease in transmittance in 1963, is related to a decrease of about 0.5°C in TMT. A more direct estimate may be obtained from the multiple regression analysis, which yields a tropospheric temperature change of about 0.4°C. These estimates may be contrasted with observed increases of up to 5°C in the tropical stratosphere during the same period (8).

Temperature changes in the extratropical troposphere have also been investigated by Angell and Korshover (2), based upon geopotential data from 31 stations poleward of 20° latitude. They pointed out that the major temperature fluctuations of the extratropical troposphere follow those of the tropical troposphere by about 6 months. We include in Table 1 cross-correlations between deviations in the extratropical tropospheric temperature (from long-term seasonal means) (EMT) and the variables considered above, taking EMT as lagging TMT by one season. The correlation between EMT and TMT for one season's lag is 0.69 and is almost the same for two seasons' lag. A multiple regression analysis indicates that PNS1 and MLT are responsible for about 24 and 20 percent of the variance of the extratropical means, respectively, when PNS1 leads by three and MLT by four seasons.

The physical chain of events through which these interrelationships occur is not completely clear, particularly with regard to the observed phase lags. An analysis of the factors controlling the temperature in the tropical troposphere shows three main effects: latent heat liberation, radiative cooling, and vertical motion. In the rising motion region of the Hadley cell circulation, adiabatic cooling coupled with radiative cooling is offset by the liberation of latent heat (9). In the sinking motion region there is warming by adiabatic compression and cooling by radiation.

Bjerknes suggested that the Hadley cell circulation is more intense when the tropical Pacific is anomalously warm than when it is cold, as a result of the extra heat liberated in both latent and sensible forms from the ocean to the atmosphere (10). The extra latent heat liberated in the rising motion region results in heating directly, and the increased subsidence brought about by a stronger Hadley circulation gives an indirect heating so that there is an overall increase in the temperature of the tropical troposphere. We may postulate that the volcanic aerosol brings about a decrease in solar radiation at the surface and thereby a reduction in evaporation and subsequent latent heating, and that this decrease accounts for the association between MLT and TMT. Although the latent heat process may explain a contemporary relationship between PNS1, MLT, and TMT, it does not satisfactorily account for the 6-month lag. Water molecules have a residence time in the atmosphere of about 10 days, and the transit time between the equator and 30° latitude under the influence of the mean motion is about 1 month.

Our findings of a decrease of TMT of about 0.5°C in the tropics in association with the Mt. Agung aerosol may have some bearing on the increase in the stratospheric temperature observed. A decrease in the intensity of the Hadley circulation would lead to decreased adiabatic expansion in the lower stratosphere and thus to net heating, other factors remaining constant (11). In fact, of course, there were other changes: possibly increased solar heating by aerosol absorption and decreased infrared cooling (12). The factors together act to bring about a temperature increase in the stratosphere in 1964 through 1965, and it is difficult to separate their relative roles.

Finally, the rate of change in the atmospheric content of CO_2 in the Antarctic as reported by Bacastow (13) is closely associated with sea temperature changes as characterized by PNS1. The correlation coefficient is 0.70 when PNS1 leads the CO_2 changes by one season. Apparently, warm water in the tropical Pacific is followed by increasing amounts of atmospheric CO_2, presumably because CO_2 is less soluble in warm water than in cold.

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References and Notes

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