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RELATIONSHIP BETWEEN MEAN AND EXTREME TEMPERATURES IN DIVERSE MICROCLIMATES[1]

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Introduction

Meteorologists and biologists often view temperature from opposite directions. In microclimatology, temperature is an intensive thermodynamic variable resulting from flux/gradient relationships among radiation, evaporation, conduction, and convection. In biological applications, temperature is often used as the independent variable, thereby implying that organisms respond to temperature, rather than to energy fluxes.

Furthermore, meteorological tradition summarizes temperature data by forming an average of maximum and minimum temperatures. This procedure may be appropriate for gross climatic analysis, but it is biologically misleading. Such an averaging process seems to presume that effects of high temperatures can be offset by exposure to low temperatures. This is incorrect. Most temperature-responsive reactions are nonlinear, so any effects of exposure to one extreme cannot be undone by exposure to the opposite extreme.

The many ways that temperature can be measured multiply the chances of improperly interpreting temperatures. Easy measurements can be as easily misinterpreted. This seems especially true for measurement of daily maximum and minimum temperatures. For long-term studies, average maxima and minima are usually more appropriate than extreme maxima or minima. However, routine measurement of periodic extremes (weekly, monthly, etc.) is an attractive method of gathering temperature data, because ecological investigations often are conducted on remote locations, and usually are spread out over several sites. However, if measurement of extremes is simpler, but averaging seems better for long-range study, some logical questions then arise:

1) Does a relationship exist between extreme temperatures and average extreme temperatures?
2) If so, what is the relationship and how strong is it?

These questions do not seem to have been discussed in relation to temperature (although the meteorological literature is replete with discussions of "peak-to-mean" ratios). This paper offers an ecologically meaningful answer to both questions by empirically demonstrating such relationships for nine microclimatic sites over a 1000-m elevational gradient.

Methods

Our temperature data came from an ongoing study of microclimates on the Arid Lands Ecology (ALE) Reserve in south-central Washington (Thorp and Hinds 1977). The Department of Energy retains this large area (300 km²) for study of ecological processes in arid landscapes. The landscape is dominated by big sagebrush (*Artemisia tridentata* Nutt.) and is representative of a large region of relatively uniform shrub-steppe (Daubenmire 1970). Elevations on the Reserve range from 120 to 1090 m. Weather Measure® recording thermographs (use of brand names does not constitute endorsement by Battelle Memorial Institute) housed in standard Stevenson screens at several elevations on the Reserve have provided nearly continuous data, which we abstracted into daily maximum and minimum temperatures for this study. The lengths of record from the several stations ranged from 23 to 33 mo. We also included data from the Hanford Meteorological Tower, a Class A weather station 6 km east of the ALE Reserve.

Our analysis examined two points: first, the degree of association (or correlation) between average maximum (or minimum) and the extreme maximum (or minimum) each month; and second, the estimation of average extremes by regression analysis. This last point should allow estimation of monthly average values of extreme temperatures using simple observations of monthly maximum and minimum temperatures.

The product-moment correlation coefficient, r, provides a statistically testable estimate of the degree of association between two variables. However, we cannot control the "independent" variable (monthly extreme temperatures, in our case) in field data such as these. Therefore the independent variable remains subject to sampling error. Under these conditions, the usual least-squares regression techniques will lead to biased predictive equations. We used Bartlett's Three-Group Method which correctly estimates the slope and intercept for bivariate data with sampling errors in both variables (Sokal and Rohlf 1969).

Results and Discussion

On the average, the extremes correlate well with the means, as shown in Table 1. Two patterns can be seen:

1) correlations are higher for maximum temperatures than for minimum temperatures; and
2) slopes of the regressions tend to be closer to unity for the maximum temperatures.

The higher correlations for the maximum temperatures indicate somewhat less variability in daytime than nighttime. This may reflect an innate characteristic of atmospheric physics: micrometeorologists

TABLE 1. Correlation and regression statistics for average monthly maximum and minimum temperatures from daily records, regressed on extreme maximum and minimum temperatures.

			Regressions on maximum temperatures			Regression on minimum temperatures		
Station number	Elevation (metres)	Length of record (months)	r	Slope (b)	Intercept (a)	r	Slope (b)	Intercept (a)
5	191	33	0.942	0.92	−6.46	0.876	0.69	6.66
2	212	32	0.954	0.97	−8.41	0.828	0.74	6.66
27	223	33	0.941	1.01	−9.18	0.890	0.71	7.01
3	326	26	0.946	0.93	−5.80	0.906	0.86	6.73
19	385	30	0.940	0.88	−4.97	0.866	0.89	6.46
8	488	27	0.920	0.88	−5.23	0.892	0.85	6.47
4	539	33	0.949	0.89	−6.75	0.883	0.80	7.18
11	849	27	0.942	0.92	−6.80	0.898	0.91	6.44
15	1090	23	0.945	0.95	−6.80	0.900	0.94	7.08
All stations combined (n = 264)			0.941	0.93	−6.80	0.881	0.81	6.95

have known for a long time that daytime turbulence is easier to describe than nighttime subturbulent or quasi-laminar flow (e.g., Priestley 1959).

It is somewhat easier to explain the fact that the regression slopes are nearer unity for maximum than minimum temperature. The data reveal a nonlinear relationship at very low temperatures (below −20°C): the average minimum tends to remain constant while the extreme minimum decreases. However, at high temperatures, the extremes and averages increase together. The most direct interpretation of these observations is this: extreme minima occur on only a very few nights in individual brief cold snaps, whereas extremely hot weather lasts several days in a row, long enough to affect the average value. The nonlinearity in minimum temperatures is not pronounced enough to benefit from nonlinear regression. We found no increase in r^2 using either polynomial or logarithmic regressions.

The results displayed in Table 1 show conclusively that a strong relationship exists between average and extreme maxima and minima. However, caution is necessary. The slopes of the regression equations exhibit a considerable range, from ≈0.7 to 1.0. This range points to a variety of microclimates in this landscape probably commensurate with the detail discussed in an earlier paper (Rotenberry et al. 1976).

The most evident determinant of the slope of the regressions in Table 1 is time of day. However, both day and night regressions are functions of elevations, as shown in Fig. 1. The functions converge near 600 m, but the significance of this is not obvious. Possibly this convergence reflects some characteristic of the mountain-valley inversion that occurs nearly every night; the top of the inversion typically occurs at ≈600 m (Thorp and Hinds 1977).

The relatively wide range of regression slopes prevents simplistic application of the information in Table 1 to a landscape. Still, the high correlations lead to the very useful conclusion that after "calibration" of a given microsite, simple maximum and minimum temperature measurements over a month's time can allow estimates of average maximum and minimum temperatures which are ecologically and meteorologically meaningful.

Calibration of a site is probably best achieved by plotting the slope of the regression line against the number of months of record. Obviously, as the length of record increases, fluctuations between progressive estimates of the regressions become smaller, yielding progressively better descriptions. The point at which continuous or daily recording for site calibration should cease depends on a variety of local factors, such as seasonality in the slope vs. time plot, degree of precision required, or manpower availabil-

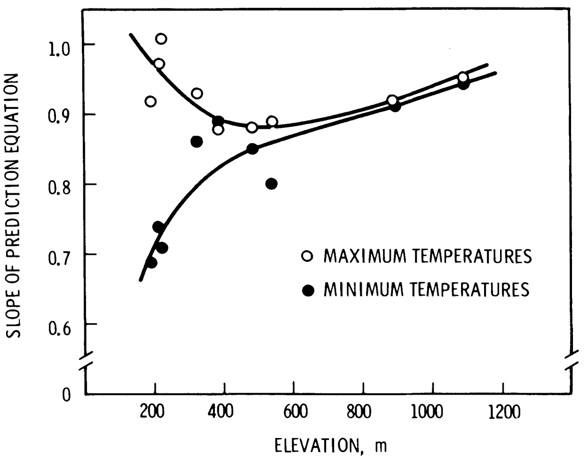

Fig. 1. Slope of the regression relating monthly average temperature maxima and minima to monthly extreme maxima and minima as a function of elevation. The curves are suggested, rather than fitted.

ity. For long-term studies in large areas we suggest a bilateral approach. We have used an extensive network (26 sites in 260 km^2) of simple max-min thermometers visited monthly (Thorp and Hinds 1977), and a much smaller number of strategically placed continuous recorders. We deduced microclimatic associations within the broad study area covered by the max-min thermometers by cluster analysis (Rotenberry et al. 1976). A single thermograph appropriately located then serves to calibrate a larger number of the simpler stations.

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SESTON REMOVAL BY FILTER-FEEDERS[1]

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It was kindly pointed out to us recently by Jackson R. Webster that in our recent publication (McCullough et al. 1979), the percentage removal of seston per metre by all filter-feeders was in error (page 594). The correct value is ≈0.01%/m which is derived using the mean biomass for *Hydropsyche* and *Simulium* (2.45 and 0.22 g DW/m^2, respectively) as given in paragraph three, page 594. The values for mean annual biomass and numbers of filter-feeders given in paragraph two, page 594 should be struck. They refer to total invertebrates instead of simply filter-feeders. With a removal rate of 0.01%/m, the distance required for 100% removal assuming a linear model with no replacement of seston is 9.21 km; assuming an exponential model, 46.05 km are required for 99% removal. Under normal stream conditions with a relatively constant rate of replacement of seston from the substratum and with such a low rate of removal by consumption, the linear model would seem more appropriate. It is unknown at what point ingestion rate becomes limited by decreasing seston concentrations.

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