Regional Temperature Modeling for the Upper Mojave Desert

Alexander K. Rogers, MA, MS, RPA
Archaeology Curator

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ABSTRACT
This paper develops a method for estimation of temperature parameters for effective hydration temperature (EHT) computations. The method is based on publicly-available meteorological records, and permits computing EHT for sites which are not in proximity to current meteorological stations. No emplaced sensors are used. Equations are presented relating the three required temperature parameters (annual average temperature, annual variation, and diurnal variation) to site altitude. The model developed here is valid only for the upper Mojave desert and southwestern Great Basin, but the same technique can be applied in other areas.

INTRODUCTION

This paper develops a method for estimation of temperature parameters for effective hydration temperature (EHT) computations for obsidian hydration dating analyses, based on publicly-available meteorological records. Computation of EHT by the method of Rogers (2007) requires three temperature parameters for the site: annual average temperature (T_a); seasonal variation of the monthly mean temperatures (V_a), defined as difference between the hot-month average temperature and the cold-month average temperature; and diurnal variation (V_d). Diurnal variation can be approximated by the mean, defined as the average of the daily temperature ranges for July and January; however, inclusion of a time dependence is more accurate.

Frequently there are no long-term meteorological records for the area of an archaeological site, so the parameters must be estimated from a surrogate site which lies in a similar weather pattern and does have records. Traditionally, scaling has been done for altitude, using the mean adiabatic lapse rate of -1.9ºC/1000 ft altitude change; however, this lapse rate strictly applies only to T_a, so the other variables are still an issue to be addressed by this analysis.

The parameters must be computed from a sufficiently long run of data to be representative of long-term climate. Sensors emplaced at a site do not provide this, so all of the computations discussed here are based on data covering a period of 30 years, in accordance with standard meteorological practice (Cole 1970). All the temperatures used in this study are air temperatures, measured five feet above the ground in an enclosure which shelters the sensor from direct sunlight, again normal meteorological practice.

DATA BASE

The analysis is based on monthly temperature data from the Western Regional Climate Center (WRCC). Table 1 summarizes the sites used in the temperature scaling analysis. All are from desert or desert mountain environments in the Mojave Desert and southwestern Great Basin weather patterns; complete data are in Appendix A.

Table 1. Sites used in the Scaling Analysis.

Site	**Altitude, ft above mean sea level**
Baker	940
Trona	1700
Daggett Airport	1930
Cantil	1960
Barstow	2140
China Lake NAF Armitage Field	2240
Inyokern	2440
Mojave	2740
Haiwee	3282
Randsburg	3570
Wildrose	4100
Bishop	4150
Mountain Pass	4700
White Mountain 2	12470

ANALYSIS

ALTITUDE EFFECTS

The temperature parameters were computed from temperature data downloaded from the WRCC for the sites in Table 1. All temperatures were converted to ºC, and the computations made as follows:

T_a = annual mean temperature (1)

V_a = hottest-month mean minus coldest month mean (2)

V_d = mean of monthly temperature range (3)

Table 2 summarizes the results.

Table 2. Computed Temperature Parameters.

Site	Altitude, ft	T_a, °C	V_a, °C	V_d, °C
Baker	940	21.27	25.25	17.55
Trona	1700	19.29	24.36	16.31
Daggett Airport	1930	19.72	22.56	15.63
Cantil	1960	17.88	23.08	18.30
Barstow	2140	17.71	21.58	18.20
China Lake NAF Armitage Field	2240	17.68	23.78	18.12
Inyokern	2440	17.70	21.94	18.50
Mojave	2740	17.13	21.44	14.37
Haiwee	3282	15.38	22.31	15.02
Randsburg	3570	17.03	21.47	13.62
Wildrose	4100	14.86	21.53	14.93
Bishop	4150	13.37	21.92	20.46
Mountain Pass	4700	14.39	22.06	13.60
White Mountain 2	12470	-2.51	16.94	9.48

Figure 1 shows the scaling of the temperature parameters with altitude, and Table 3 summarizes the best fit parameters.

Table 3. Temperature scaling with altitude, upper Mojave Desert

Parameter	y-intercept, °C	Slope, °C/ft	R^2
T_a	22.71	-0.0020	0.9814
V_a	24.25	-0.0006	0.7949
V_d	18.49	-0.0007	0.5178

As can be seen, the fit is relatively good, so use of prediction equations should yield good accuracy.

INTER-PARAMETER DEPENDENCE

Since all three parameters correlate well with altitude, it follows that they must correlate with each other. Figure 2 shows the dependence of the temperature variation parameters on annual average temperature.

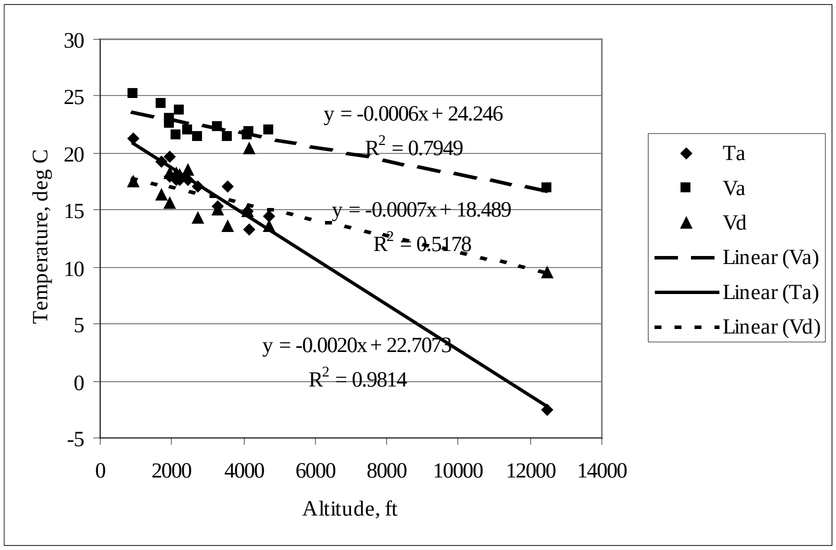

Figure 1. Temperature parameter scaling with altitude.

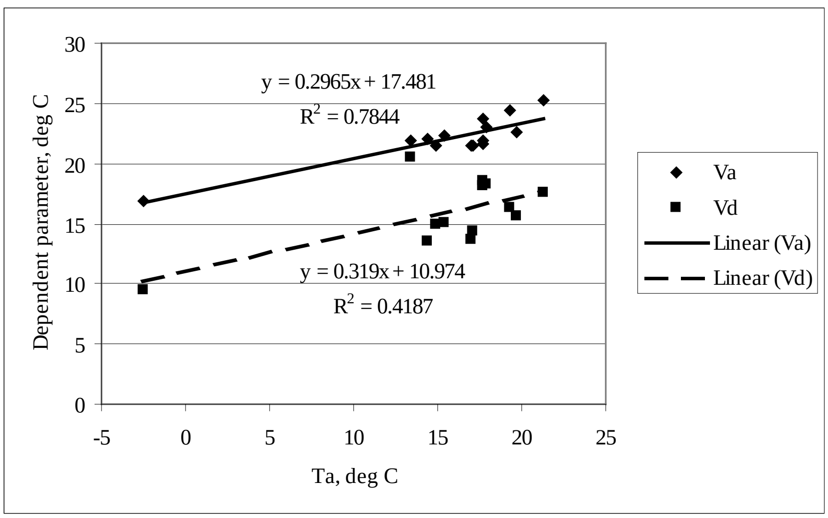

Figure 2. Scaling of temperature variation with mean temperature.

Thus, it appears that, in this climatic regime, the values of V_a and V_d can be predicted by knowing T_a.

TIME DEPENDENCE OF DIURNAL RANGE

Analysis of the monthly diurnal variation shows that it is not constant, nor does it appear random. Instead, it follows a regular pattern through the year, increasing from January through mid-summer, and then declining again. Figure 3 shows the phenomenon graphically.

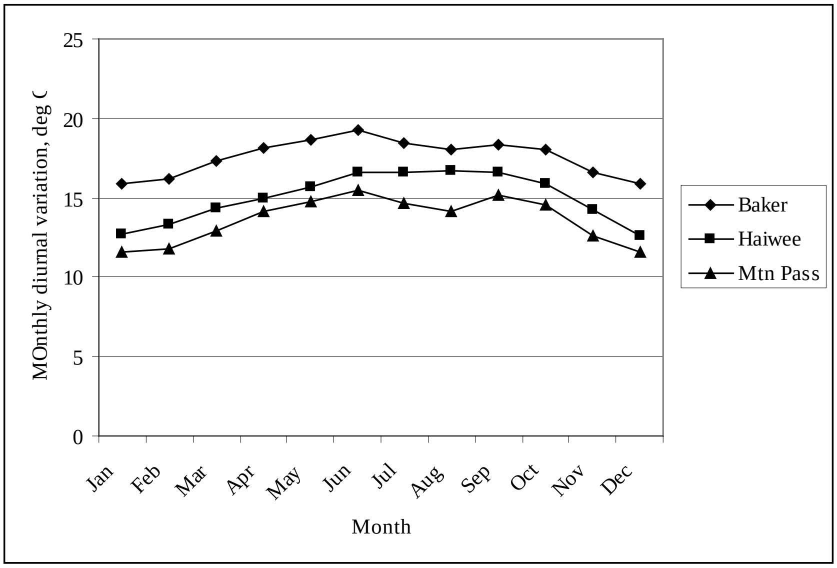

Figure 3. Time variation of diurnal temperature range.

The variation can be approximated by a cosine curve,

$$V_d(t) = V_d + V_{da}*\cos(\pi m/6) \quad (4)$$

where V_d is the mean value of diurnal variation over the course of a year, predicted by Table 3, m is the number of the month (1 – 12), and V_{da} is an amplitude given by

$$V_{da} = [\max(V_d) - \min(V_d)]/2 \quad (5)$$

Analysis of V_{da} shows there is no consistent variation with altitude, and for the upper Mojave desert it is best approximated as a constant value of 2.08°C.

ROCK SHELTERS AND CAVES

Rock shelters and caves create their own micro-climates. In general, they have no effect on annual average temperature, T_a, but they moderate temperature fluctuations, which is why they were attractive. Measurements by the author at Ray Cave, Inyo County, California, showed the cave environment resulted in a value of V_a which was approximately 75% of the outside value. The value of V_d is attenuated even more, and studies have shown that V_d seldom exceeds 5ºC (Everett-Curran et al. 1991).

CONCLUSIONS

The annual average temperature was shown to decrease by 2.0ºC/1000 ft altitude increase, which is within the limits of measurement error for the mean adiabatic lapse rate. It was also shown to be predicted by the equation

$$T_a = 22.71 - 0.0020x \quad (6)$$

where x is altitude in feet. The accuracy of this model is 0.75ºC, 1-sigma, for the data set of Table 2.

The annual temperature variation was found to decrease by 0.6ºC/1000 ft. altitude increase, and to be predicted by

$$V_a = 24.25 - 0.0006x \quad (7)$$

with x defined as above. The accuracy of the prediction is 0.83ºC, 1 – sigma, for the data set of Table 2.

Mean diurnal variation is predicted by

$$V_d = 18.49 - 0.0007x$$

with a 1 – sigma accuracy of 1.88°C, 1 – sigma for the data set in Table 2.

Effective hydration temperature can be computed by an algebraic approximation

$$EHT = T_a + 0.0062*(V_a^2 + V_d^2) \quad (8)$$

The temperature models here predicts EHT with an accuracy of 0.63°C, 1 – sigma, for this data set.

Furthermore, if T_a is known for a site, V_a and Vd are predicted by

$$V_a = 17.49 + 0.297T_a \quad (9)$$

and

$$V_d = 10.97 + 0.319T_a \quad (10)$$

A more accurate model for diurnal variation is

$$Vd\ (t) = 18.49 - 0.0007x + 2.08* \cos[2\pi h/(24*365)] \quad (11)$$

where h is the number of the hour within a 365-day year, 1 – 8760.

If the site is in a rock shelter, use T_a as is, multiply V_a by 0.75, and use 5°C for V_d.

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APPENDIX A
Western Regional Climate Center Data

BAKER, CALIFORNIA (040436)												
12/01/1971 to 08/31/2013												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max F	63.1	68.6	76.8	84.3	94.9	104.8	110.2	107.9	100.2	87.1	72.6	62.4
Min F	34.6	39.4	45.6	51.7	61.3	70.2	77	75.4	67.2	54.7	42.8	33.9
Max C	17.28	20.33	24.89	29.06	34.94	40.44	43.44	42.17	37.89	30.61	22.56	16.89
Min C	1.44	4.11	7.56	10.94	16.28	21.22	25.00	24.11	19.56	12.61	6.00	1.06
Mnthly Ave	9.36	12.22	16.22	20.00	25.61	30.83	34.22	33.14	28.72	21.61	14.28	8.97
Range	15.83	16.22	17.33	18.11	18.67	19.22	18.44	18.06	18.33	18.00	16.56	15.83

TRONA, CALIFORNIA (049035)												
01/01/1920 to 01/20/2015												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max F	58.2	64.7	71.4	79.2	88.5	98.5	105.5	103.4	96.3	83.8	69.1	58.3
Min F	32.9	38	43.6	50	58.3	66	73.3	71.8	64.2	52.8	40.4	33.2
Max C	14.56	18.17	21.89	26.22	31.39	36.94	40.83	39.67	35.72	28.78	20.61	14.61
Min C	0.50	3.33	6.44	10.00	14.61	18.89	22.94	22.11	17.89	11.56	4.67	0.67
Mnth Ave	7.53	10.75	14.17	18.11	23.00	27.92	31.89	30.89	26.81	20.17	12.64	7.64
Range	14.06	14.83	15.44	16.22	16.78	18.06	17.89	17.56	17.83	17.22	15.94	13.94

BARSTOW DAGGETT AP, CALIFORNIA (042257)												
07/01/1948 to 01/20/2015												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max F	60.8	65.6	71.3	79	88.2	98.1	104.2	102.4	95.3	83.3	69.7	60.8
Min F	35.9	40.1	44.9	50.8	58.9	66.8	73.3	71.9	65.4	54.6	42.9	35.5
Max C	16.00	18.67	21.83	26.11	31.22	36.72	40.11	39.11	35.17	28.50	20.94	16.00
Min C	2.17	4.50	7.17	10.44	14.94	19.33	22.94	22.17	18.56	12.56	6.06	1.94
Mnth Ave	9.08	11.58	14.50	18.28	23.08	28.03	31.53	30.64	26.86	20.53	13.50	8.97
Range	13.83	14.17	14.67	15.67	16.28	17.39	17.17	16.94	16.61	15.94	14.89	14.06

CANTIL, CALIFORNIA (041488)												
03/01/1955 to 07/31/1974												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max F	60.20	65.10	69.90	76.30	85.70	96.20	103.60	102.40	94.80	84.00	68.80	60.70
Min F	29.50	35.20	40.20	45.70	54.20	63.30	69.10	66.60	57.70	46.40	35.70	28.90
Max C	15.67	18.39	21.06	24.61	29.83	35.67	39.78	39.11	34.89	28.89	20.44	15.94
Min C	-1.39	1.78	4.56	7.61	12.33	17.39	20.61	19.22	14.28	8.00	2.06	-1.72
Mnth Ave	7.14	10.08	12.81	16.11	21.08	26.53	30.19	29.17	24.58	18.44	11.25	7.11
Range	17.06	16.61	16.50	17.00	17.50	18.28	19.17	19.89	20.61	20.89	18.39	17.67

BARSTOW, CALIFORNIA (040519)												
01/01/1903 to 03/31/1980												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max F	59.8	64.8	70	77.6	86	95.8	102.4	100.4	93.8	82.4	69.5	60.7
Min F	31.5	35.4	39.7	45.5	52.4	60.3	66.6	64.7	57.9	47.6	37.1	31.3
Max C	15.44	18.22	21.11	25.33	30.00	35.44	39.11	38.00	34.33	28.00	20.83	15.94
Min C	-0.28	1.89	4.28	7.50	11.33	15.72	19.22	18.17	14.39	8.67	2.83	-0.39
Mnth Ave	7.58	10.06	12.69	16.42	20.67	25.58	29.17	28.08	24.36	18.33	11.83	7.78
Range	15.72	16.33	16.83	17.83	18.67	19.72	19.89	19.83	19.94	19.33	18.00	16.33

CHINA LAKE NAF, CALIFORNIA (041733)												
02/01/1944 to 01/20/2015												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max F	61.3	63.7	74.4	76.1	85.9	98.2	101.8	101.9	94.3	81.2	64.3	58.5
Min F	30.6	34.6	40.1	45.6	52.8	63.1	68.4	67.4	59.4	48.3	33.8	26.1
Max C	16.28	17.61	23.56	24.50	29.94	36.78	38.78	38.83	34.61	27.33	17.94	14.72
Min C	-0.78	1.44	4.50	7.56	11.56	17.28	20.22	19.67	15.22	9.06	1.00	-3.28
Mnth Ave	7.75	9.53	14.03	16.03	20.75	27.03	29.50	29.25	24.92	18.19	9.47	5.72
Range	17.06	16.17	19.06	16.94	18.39	19.50	18.56	19.17	19.39	18.28	16.94	18.00

INYOKERN, CALIFORNIA (044278)												
11/17/1940 to 12/27/2012												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max F	59.6	64.8	70.3	77.7	87	96.7	102.7	101.2	94.2	83.2	69	59.7
Min F	30.8	34.6	38.7	44.3	52.9	60.5	66.2	64.6	58.1	48.2	37.3	30.2
Max C	15.33	18.22	21.28	25.39	30.56	35.94	39.28	38.44	34.56	28.44	20.56	15.39
Min C	-0.67	1.44	3.72	6.83	11.61	15.83	19.00	18.11	14.50	9.00	2.94	-1.00
Mnth Ave	7.33	9.83	12.50	16.11	21.08	25.89	29.14	28.28	24.53	18.72	11.75	7.19
Range	16.00	16.78	17.56	18.56	18.94	20.11	20.28	20.33	20.06	19.44	17.61	16.39

MOJAVE, CALIFORNIA (045756)												
01/01/1904 to 01/19/2015												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max F	57.8	61.2	64.7	71.3	79.9	89.9	97.6	96.4	89	78.5	65.7	57.2
Min F	34.2	37.1	41	46.3	55.1	63.8	69.7	68	60.3	50.3	40.2	32.9
Max C	14.33	16.22	18.17	21.83	26.61	32.17	36.44	35.78	31.67	25.83	18.72	14.00
Min C	1.22	2.83	5.00	7.94	12.83	17.67	20.94	20.00	15.72	10.17	4.56	0.50
Mnth Ave	7.78	9.53	11.58	14.89	19.72	24.92	28.69	27.89	23.69	18.00	11.64	7.25
Range	13.11	13.39	13.17	13.89	13.78	14.50	15.50	15.78	15.94	15.67	14.17	13.50

HAIWEE, CALIFORNIA (043710)												
05/01/1923 to 01/07/2015												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max F	52	56.7	63.1	70.5	79.6	89.1	95.6	93.9	87.2	75.8	62.2	52.7
Min F	29.1	32.7	37.2	43.5	51.4	59.2	65.8	63.9	57.3	47.2	36.5	30.1
Max C	11.11	13.72	17.28	21.39	26.44	31.72	35.33	34.39	30.67	24.33	16.78	11.50
Min C	-1.61	0.39	2.89	6.39	10.78	15.11	18.78	17.72	14.06	8.44	2.50	-1.06
Mnth Ave	4.75	7.06	10.08	13.89	18.61	23.42	27.06	26.06	22.36	16.39	9.64	5.22
Range	12.72	13.33	14.39	15.00	15.67	16.61	16.56	16.67	16.61	15.89	14.28	12.56

RANDSBURG, CALIFORNIA (047253)												
09/01/1937 to 01/20/2015												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max F	54	58	63.8	71.8	81.7	91.3	98.4	96.6	89.2	76.8	63	54.4
Min F	35.7	37.9	40.8	46.2	53.9	62	68.6	67.2	61.5	52.4	42.4	36.3
Max C	12.22	14.44	17.67	22.11	27.61	32.94	36.89	35.89	31.78	24.89	17.22	12.44
Min C	2.06	3.28	4.89	7.89	12.17	16.67	20.33	19.56	16.39	11.33	5.78	2.39
Mnth Ave	7.14	8.86	11.28	15.00	19.89	24.81	28.61	27.72	24.08	18.11	11.50	7.42
Range	10.17	11.17	12.78	14.22	15.44	16.28	16.56	16.33	15.39	13.56	11.44	10.06

WILDROSE RANGER STATION, CALIFORNIA (049671)												
01/01/1969 to 01/31/2000												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max F	51.2	55.2	61.7	69.8	79.8	89.4	95.2	93.2	85.9	73.2	59.8	51.9
Min F	30.3	32.9	36.2	40.9	49.7	57.4	63.8	62.7	56.9	46.9	36.1	30
Max C	10.67	12.89	16.50	21.00	26.56	31.89	35.11	34.00	29.94	22.89	15.44	11.06
Min C	-0.94	0.50	2.33	4.94	9.83	14.11	17.67	17.06	13.83	8.28	2.28	-1.11
Mnth Ave	4.86	6.69	9.42	12.97	18.19	23.00	26.39	25.53	21.89	15.58	8.86	4.97
Range	11.61	12.39	14.17	16.06	16.72	17.78	17.44	16.94	16.11	14.61	13.17	12.17

MOUNTAIN PASS, CALIFORNIA (045890)												
02/18/1955 to 07/06/2007												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max F	50.4	53.7	59	66.4	76.3	87	92.8	89.9	83.9	72.4	58.9	51.1
Min F	29.5	32.4	35.8	41	49.8	59.2	66.5	64.5	56.6	46.3	36.2	30.2
Max C	10.22	12.06	15.00	19.11	24.61	30.56	33.78	32.17	28.83	22.44	14.94	10.61
Min C	-1.39	0.22	2.11	5.00	9.89	15.11	19.17	18.06	13.67	7.94	2.33	-1.00
Mnth Ave	4.42	6.14	8.56	12.06	17.25	22.83	26.47	25.11	21.25	15.19	8.64	4.81
Range	11.61	11.83	12.89	14.11	14.72	15.44	14.61	14.11	15.17	14.50	12.61	11.61

WHITE MOUNTAIN 2, CALIFORNIA (049633)												
10/01/1955 to 10/31/1980												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max F	22.9	23	24.3	28.3	36.3	46.3	54.2	53	47.6	39.9	30.9	25.4
Min F	7.4	6.6	6.8	9.9	18.7	28.7	36.4	35.5	30	22.9	14.7	9.7
Max C	-5.06	-5.00	-4.28	-2.06	2.39	7.94	12.33	11.67	8.67	4.39	-0.61	-3.67
Min C	-13.67	-14.11	-14.00	-12.28	-7.39	-1.83	2.44	1.94	-1.11	-5.06	-9.61	-12.39
Mnth Ave	-9.36	-9.56	-9.14	-7.17	-2.50	3.06	7.39	6.81	3.78	-0.33	-5.11	-8.03
Range	8.61	9.11	9.72	10.22	9.78	9.78	9.89	9.72	9.78	9.44	9.00	8.72