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Estimation of soil temperature by Harmonic analysis

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सार - 1982-93 की अवधि में हार्मोनिक विश्लेषण द्वारा गुजरात राज्य के आनंद केन्द्र में 5, 10, और 20 से.मी. की गहराई के अभिलेखित किए गए मृदा तापमानों का वर्ष 1998 के लिए विश्लेषण और परीक्षण किया गया। विभिन्न गहराईयों पर मृदा तापमान तरंग के आयाम में पहले हार्मोनिक में अधिकतम 5.76° से. से लेकर तीसरे हार्मोनिक में 0.96° से. तक की कमी आई है। पहले, दूसरे और तीसरे हार्मोनिक में कुल भिन्नता की क्रमशः 55 से 76, 18 से 37 और 2 से 4 प्रतिशत भिन्नता दर्शाई गई है। 1982 से 1993 तक के सामान्यीकृत आँकड़ा श्रंखलाओं की अवधि के लिए विभिन्न गहराइयों पर तीन हार्मोनिकों द्वारा सम्मिलित की गई कुल भिन्नता का कुल प्रतिशत 95 से 97 प्रतिशत के आस-पास पाया गया है जिससे मृदा तापमानों को व्यक्त करने वाले हार्मोनिक विश्लेषण की उपयुकतता का पता चलता है।

हार्मोनिक विश्लेषण द्वारा किए गए साप्ताहिक प्रेक्षण और आकलित मृदा तापमानों में अनुरूपता पाई गई है। काई- स्कावॅयर द्वारा परीक्षण के दौरान उनकी भिन्नताएँ नगण्य थी।

ABSTRACT. Soil temperatures recorded at 5,10 and 20 cm depth at Anand station of Gujarat state for the period of 1982-93 were analyzed by harmonic analysis and tested it for the year 1998. The amplitude of the soil temperature wave for the various depths decreases from a maximum of 5.76° C in the first harmonic to 0.96°C in the third harmonic. First, second and third harmonic explained 55 to 76 percent,18 to 37 percent and 2 to 4 percent of the total variance, respectively. Total percentage of total variance covered by the three harmonics at different depths are in the range of 95 to 97 percentage for the period of 1982-93 normalized data series which shows the applicability of harmonic analysis in describing soil temperatures.

The weekly observed and computed soil temperatures by harmonic analysis were in agreement and their differences were non significant by Chi-Square test.

Key words – Harmonic analysis, Soil temperature.

1. Introduction

The annual soil temperature regime follows a wave like pattern which is entirely analogous to that for the diurnal one with longer period. Wave amplitude for the annual pattern decreases less rapidly with depth than it does for the diurnal wave pattern. Like wise the depth of the affected layer is much greater the annual case then it is for the diurnal case. The temperature at the depth of zero annual range is the result of long-term thermal equilibrium between the soil and the atmosphere. During the warm season, soil temperature decreases with depth and the associated downward heat flux builds up the soil's heat store. In the cold season the gradient is reversed and the heat store is gradually depleted. The spring and autumn are transitional periods when the soil temperature gradients reverse the sign. These reversals are important biological triggers to soil pathogens, soil born insects and many other chemical activities. In the spring, they may come out of hibernation and /or move upwards towards the warmer surface layer. In the autumn, they retreat to depths where the soil warmth is more favourable.

This shows the importance of soil temperature in agriculture. Measurement of soil temperatures at different depth and locations has inherent limitations. Alternatively

TABLE 1

Results of Harmonic analysis for the soil temperature (1982-93)

S. No.	Temp. at depth (cm)	Morning / Afternoon	Mean (°C)	Variance (°C)	Amplitude (°C)	Phase Angle (°C)
1	5	Average	32.83	26.18	$C_1 = 5.62$	$A_1 = 289.15$
					$C_2 = 4.22$	$A_2 = 225.13$
					$C_3 = 1.48$	$A_3 = 000.97$
2	10	Morning	26.82	21.73	$C_1 = 5.76$	$A_1 = 273.75$
					$C_2 = 2.87$	$A_2 = 219.92$
					$C_3 = 0.96$	$A_3 = 356.22$
		Afternoon	34.29	20.21	$C_1 = 5.26$	$A_1 = 285.77$
					$C_2 = 4.30$	$A_2 = 225.64$
					$C_3 = 1.45$	$A_3 = 003.26$
3	20	Morning	29.27	24.81	$C_1 = 5.39$	$A_1 = 276.61$
					$C_2 = 3.00$	$A_2 = 216.48$
					$C_3 = 1.18$	$A_3 = 354.50$
		Afternoon	31.02	20.77	$C_1 = 5.33$	$A_1 = 270.89$
					$C_2 = 3.22$	$A_2 = 219.99$
					$C_3 = 1.31$	$A_3 = 354.5$

TABLE 2

Statistics of Harmonic analysis (1982-93)

S. No.	Depth (cm)	Morning / Afternoon	Variance	Percentage of variance accounted by the harmonics			Total percentage
				I	II	III	
1	5	Average	26.18	59.12	33.27	4.10	96.49
2	10	Morning	21.73	76.37	18.90	2.10	97.27
		Afternoon	20.21	55.77	37.27	4.22	97.26
3	20	Morning	24.81	71.76	22.22	3.43	96.81
		Afternoon	20.77	68.34	24.97	4.10	97.41

harmonic analysis of soil temperature is a useful tool to describe annual soil temperature cycle Krishnan and Kushwaha 1972, Bocock *et. al.*, 1974, and Liakatas, 1994 have pointed out that harmonic analysis affords the most precise and accurate estimation of soil temperature. Harmonic equation is a solution of the classical Fourier heat transfer equation which allows estimation of soil temperature for any time and for any depth. However, in regions served by monsoon considerable deviation from the harmonic is produced by monsoon season lasting from July to mid September. Hence, the third harmonic has also to be considered for representing the actual and observed variation of soil temperatures at 5, 10 and 20 cm depths based on actual measurements the variations as obtained through harmonic analysis.

2. Data used

The soil type at Anand is inceptisol texture loamy sand of alluvial origin. Soil temperatures were recorded daily at 7-30 and 14-30 hrs by standard soil thermometers at the depths of 5,10 and 20 cm in the agro meteorology observatory of the B. A. College of Agriculture, Anand and their weekly means were normalized for the period 1982-93. The soil temperatures predicted for the year1998 were subsequently compared with the actual observed once and such comparison has been discussed.

The weekly mean soil temperatures at various depths followed the pattern of a periodic function, which could be represented by the general form of the series as

$$T = T_o + C_k \sin(kZ + A_k) : k = 1,2,3....N \qquad (1)$$

Where T_o is the mean temperature of the data series. C_k is the amplitude of the k th harmonic and $Z = (6.28)\ i/P$; $i = 0,1,2.....51$; $P = 52$. N is the total number of harmonics. The values of phase angles A_k were estimated according to procedure described by Panofusky, Conard and Pollock(1950), Panofusky and Brier(1958).

3. Result and discussion

3.1. *Weekly analysis*

Results on the harmonic analysis of the weekly averages of soil temperatures at 5,10 and 20 cm depths

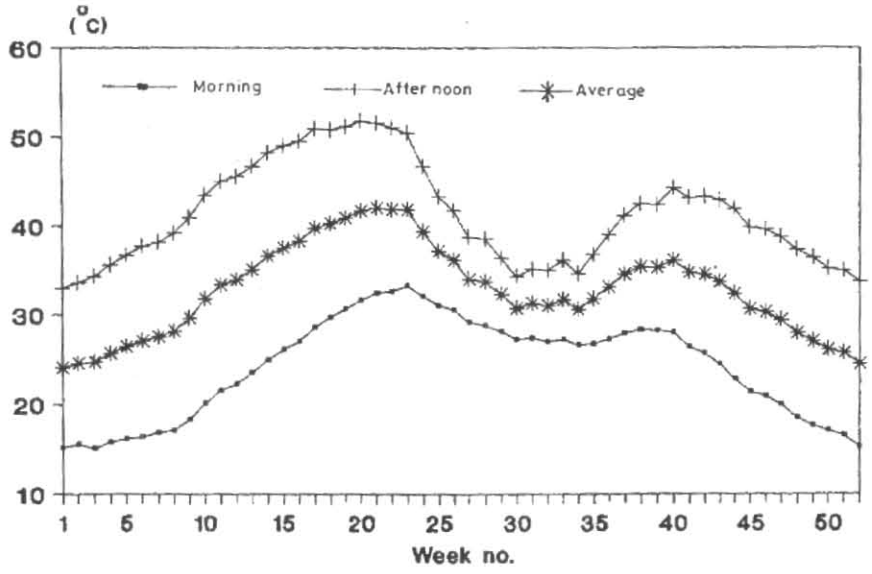

Fig. 1(a). Normal soil temperature values at the depth 5cm (1982-93)

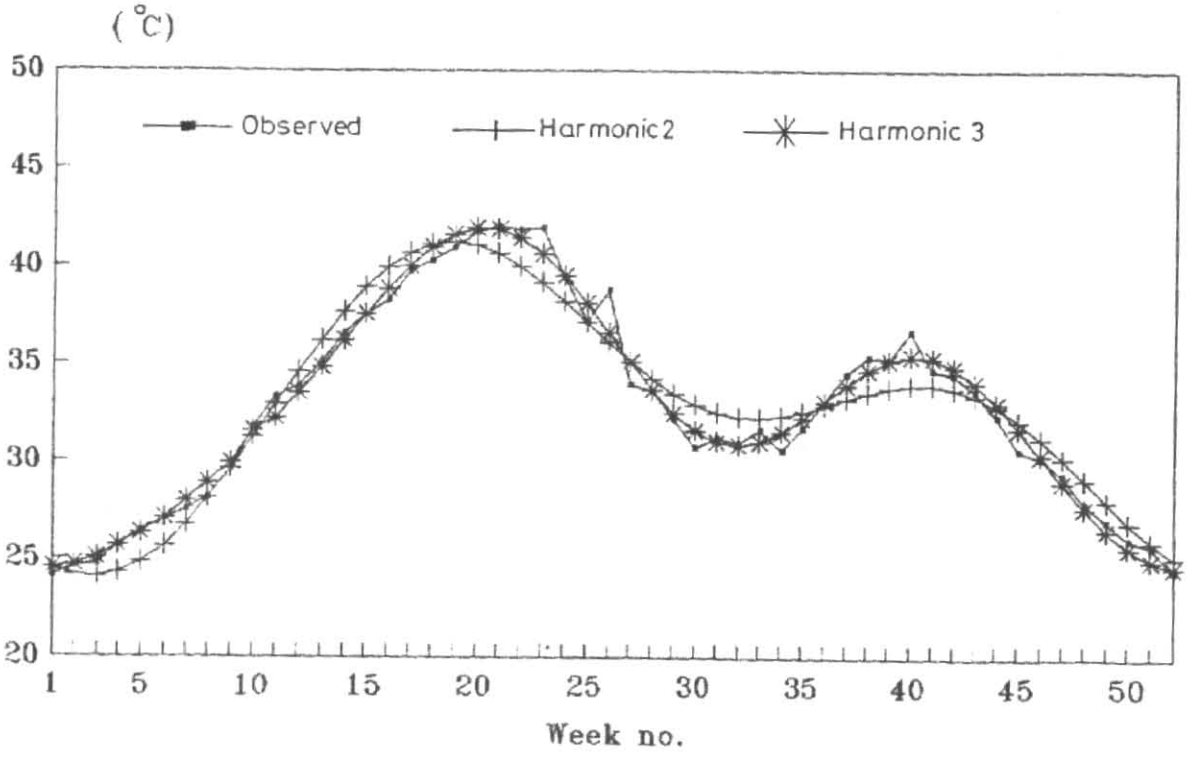

Fig. 1(b). Observed and estimated soil temperature with first two and three harmonics (1982-93)

TABLE 3

Results of Harmonic analysis for soil temperature 1998

S. No.	Temp. at depth (cm)	Morning / Afternoon	Mean (°C)	Variance (°C)	Amplitude (°C)	Phase Angle (°C)
1	5	Morning	24.38	34.94	$C_1 = 4.71$ $C_2 = 3.94$ $C_3 = 0.32$	$A_1 = 270.65$ $A_2 = 226.38$ $A_3 = 020.61$
		Afternoon	40.90	47.71	$C_1 = 5.79$ $C_2 = 4.03$ $C_3 = 0.77$	$A_1 = 331.94$ $A_2 = 230.97$ $A_3 = 043.52$
2	10	Morning	26.97	26.40	$C_1 = 5.76$ $C_2 = 2.87$ $C_3 = 0.96$	$A_1 = 278.68$ $A_2 = 221.23$ $A_3 = 037.23$
		Afternoon	34.45	29.73	$C_1 = 5.19$ $C_2 = 3.91$ $C_3 = 0.20$	$A_1 = 297.98$ $A_2 = 224.10$ $A_3 = 010.88$
3	20	Morning	28.80	24.34	$C_1 = 5.00$ $C_2 = 3.88$ $C_3 = 0.55$	$A_1 = 286.69$ $A_2 = 222.95$ $A_3 = 031.50$
		Afternoon	31.63	23.58	$C_3 = 4.94$ $C_2 = 3.84$ $C_3 = 0.36$	$A_1 = 283.26$ $A_2 = 220.10$ $A_3 = 019.47$

TABLE 4

Statistics of Harmonic analysis for the year 1998

S. No.	Depth (cm)	Morning / Afternoon	Variance	Percentage of variance accounted by the harmonics			Total percentage
				I	II	III	
1	5	Morning	34.94	82.97	09.81	1.04	93.82
		Afternoon	47.71	58.10	25.20	1.40	84.70
2	10	Morning	26.40	76.45	13.45	2.22	92.12
		Afternoon	29.73	57.98	28.51	0.66	87.15
3	20	Morning	24.34	74.28	16.46	1.39	92.13
		Afternoon	23.58	69.14	21.23	1.03	91.40

were presented in Tables 1 & 2 separately for the morning and afternoon hours of observations. The afternoon soil temperatures changed in a haphazard manner at the 5 cm depth in the period between 23rd to 35th standard weeks due to cloudy conditions [Fig 1(a)]. Also the near surface temperature varied with the incidence of solar radiation and its absolute differences ranged from 1.57 to 3.72° C and hence could not be explained satisfactorily by Harmonic Analysis. In view of these facts, the analysis was performed for the average values of the morning and afternoon soil temperatures at 5 cm depth for the period 1982-93 [Fig. 1(b)] and was used to test the soil temperatures at 5 cm depth separately for the morning and afternoon timings for the year 1998. The total variance of the afternoon data series at 5 cm depth was high *viz.* 47.71° C (Table3). It was observed from the table that the amplitude decreased with the depth in case of the morning observations. The amplitude of the second harmonic found to decrease by 20 to 50 % of that of the first harmonic. It was maximum (5.76°C) for morning observations at 10 cm depth (Table 1). Variation contributed by each harmonic showed the extent to which one had to go for higher level harmonics. The variances obtained are presented in Tables 2 & 4.

The ratio of $C_k^2 / 2$ to total variance which explains the fraction of variability accounted for by each harmonic has also been presented in column number five of the Tables 2 and 4. It was observed that the first harmonic explained a maximum of 76.37% variance at 10 cm depth for normal data series (1983-93) and 82.97% for the morning observations at 5 cm depth for the year 1998. However for the afternoon observations at 5 and 10 cm depths percentages of the total variance as explained by the first harmonic were minimum namely 58.10 and 55.77 respectively (Tables 2&4). The second and third

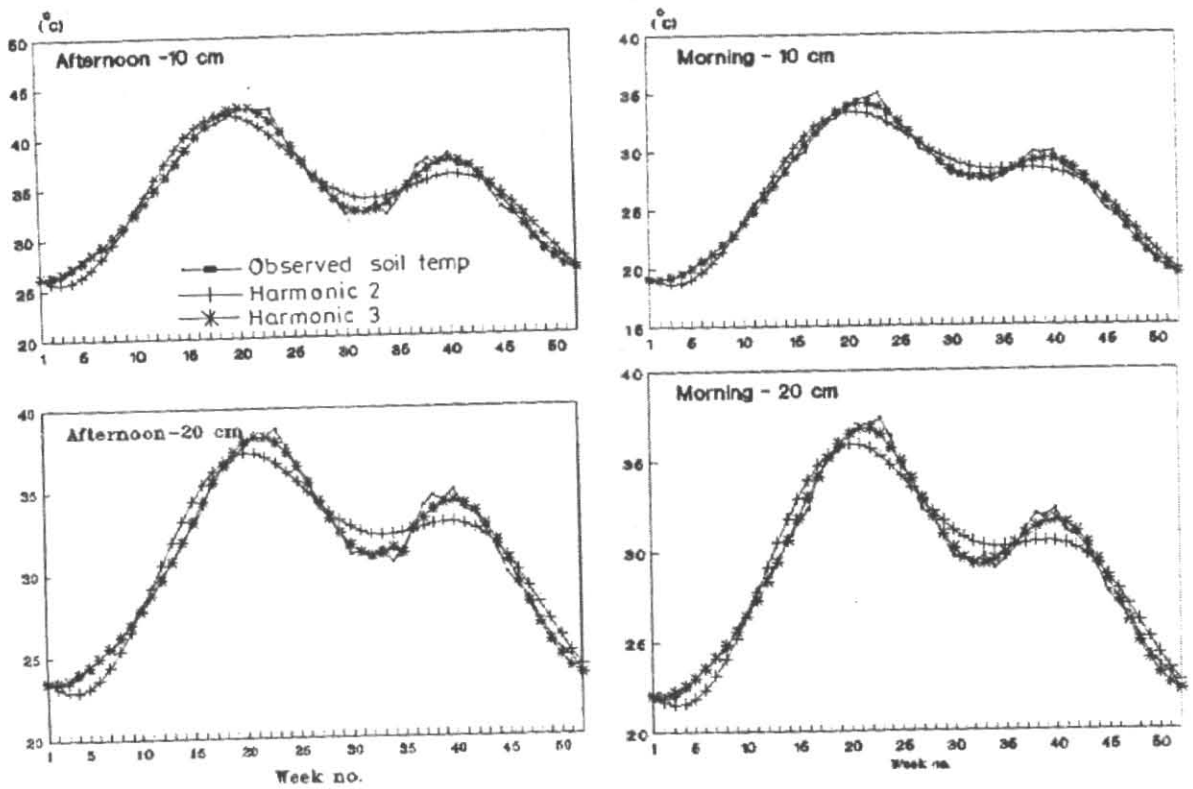

Fig. 2. Observed and estimated weekly normal soil temperature at Anand (1982-93)

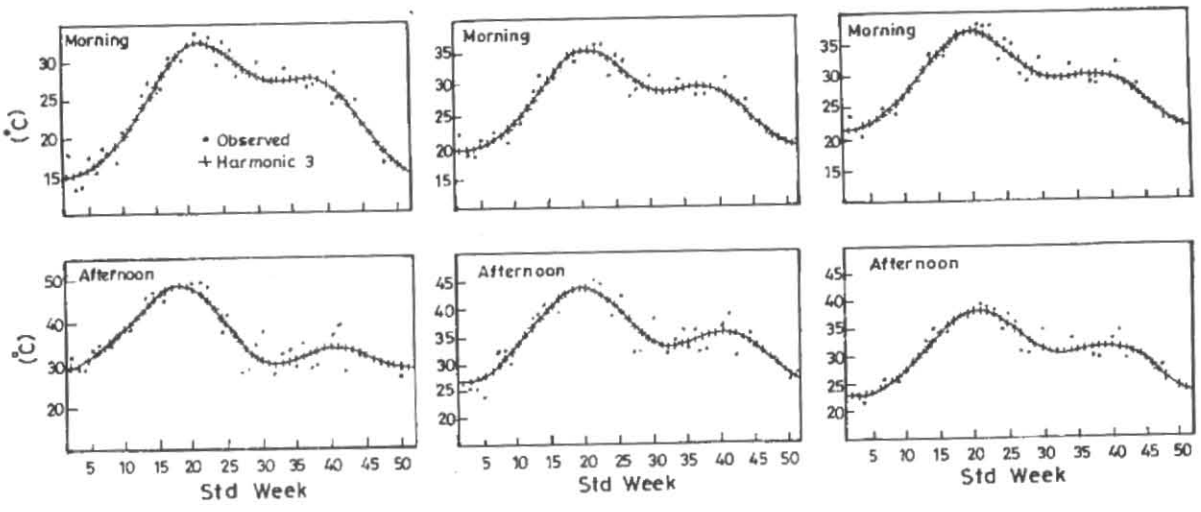

Fig. 3. Observed and estimated soil temperature by three harmonics for 1998 at Anand

harmonic represented 18 to 37 % and 2 to 4 % of total variance respectively (Table2). These results were found to be analogous to those reported by Krishnan and Kushwaha (1972) for Jodhpur.

The total variance explained by the three harmonics ranged from 96.47 to 97.41 were 96.47 to 97.41 % for the various depths and thus higher harmonics did not show large improvement.

3.2. *Estimation of soil temperatures*

First three harmonics explained more than 96 % of the total variance (Table 2). Hence, the original data of weekly mean soil temperature at various depth could be represented with fairly good accuracy in terms of the first three harmonics. This could be possible through using the values of the mean temperature (T_0) amplitude (C_k) and the phase angle (A_k) in respect of the first three harmonics as obtainable from Tables 1 and 2 and substituting them in Equation (1). Normal soil temperatures values for the period 1982-93 were thus computed for each of the standard meteorological weeks by taking in to account the first two as well as the third harmonics. The results have been presented in Fig. 1(b) for the depth 5 cm and in Fig. 2 for the depths of 10 and 20 cm. Since the calculated values using the first three harmonics were in good agreement with the normal observed soil temperatures of the period 1982-93, only three harmonics were taken for computing the same for the year 1998. The results are shown in Fig. 3 for all the depths of 5,10 and 20 cm respectively. These figures revealed that differences between the observed and calculated temperatures were large for the monsoon period *i.e.* 23 to 35 standard weeks. Monsoon activity therefore does not allow a simple sine curve to explain the complete annual cycle. It appears to be of the bi-model nature of the time series of soil temperatures at Anand. Besides the soil temperature profiles during monsoon were different from those of other seasons due to infiltration of rain water and their retention in capillaries.

The differences between the values obtained through use of the first two harmonics and the observed and with only first two harmonics to observed weekly means soil temperatures from 1982-93 were higher to the tune of 1 to 2.5°C during the period of 1-6, 11-15 and 20-35 standard weeks for 10 & 20 cm depths. This was because of the fact that the use of only two harmonics could not account for the maximum percentage of the total variance of the data series as Anand station which has subtropical climatic conditions. So higher harmonics were required (Liakatas, 1994).

The differences between the observed at different depths soil temperatures and those obtained by using different harmonics for the period of 1982-93 and 1998 were tested by Chi-Square test. The differences were non significant at 1% level of probability.

4. Conclusion

Soil temperature is an important agro-meteorological element which influences seed germination, soil microbial activity and chemical activity in the soil. Measurement of soil temperature at a large number of places in a region is difficult, this difficulty could be over come by estimating soil temperatures through the Harmonic analysis of a series of soil temperature data of selected stations to estimate soil temperature. The following conclusions were drawn from the present analysis.

(*i*) The total variation contributed by the second and third harmonics were up to the tune 97%.

(*ii*) The testing the results of the harmonic analysis on an individual year 1998 resulted in good agreement between the observed and estimated soil temperatures at different depths.

(*iii*) The use of higher harmonics gave good results in a subtropical region like Anand.

(*iv*) Soil temperatures at different depth could be estimated with fairly good accuracy by Harmonio Analysis.

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