SOIL TEMPERATURE PREDICTION OF THE REGION OF THE SOUTHERN PART OF THE KOREA

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ABSTRACT

The optimal equations to predict the soil tempratures of twelve cities in the region of the southern part of the Korea such as Changhung, Cheju, Chinju, Kwangju, Masan, Miryang, Mokpo, Muan, Pusan, Sogwipo, Ulsan, Yoosu, were suggested as function of time and soil depth and the time dependent variation and soil depth dependent distribution of temperature were analyzed for the back data of the geothermal energy utilization system design and agricultural usages. The equation form is $T(x,t) = T_m - T_{so} \cdot Exp(-\xi) \cdot \cos\omega(t - t_o - x / \sqrt{2\alpha\omega})$ and it can predict the soil temperatures well with the correlation factor of 0.98 or upwards for most data. The range of mean soil temperature was 14.99~18.53℃ and soil surface temperature swing, 11.65~14.54 days, soil thermal diffusivity, 0.025~0.069 m^2/day except Mokpo of 0.100 m^2/day, and phase shift, 19.66~27.81 days. During about thirty years from 1960s to 1990s, the mean soil temperature was increased by 0.04~1.25℃. The temperature difference depending on soil depth was not significant.

Key Word : Soil, Temperature, Prediction, soil temperature prediction

INTRODUCTION

The soil temperature is an important factor for the growth and activity of the plant and microorganism. The information about the variation depending on time and distribution depending on the soil depth of the the soil temperature have to be considered for the design of the equipments to utilize the geothermal energy.

The soil surface is heated during daytime and cooled during night. The heat is transferred by conduction in soil as the thermal wave with the cycle of a day. The heat wavelength is about 0.9~1.2 m for a frequency of one cycle per day and 18~21 m for one cycle per year(Carslaw(1959)). The mean earth temperature can be assumed to be constant for all depths up to about 66 m(NRECA(1988)). Below that depth the increase per 100 m is 2~3℃(Jun(1990)). The mean earth temperature can be assumed equal to the groundwater temperature or the annual air temperature plus 1.1℃(NRECA(1988)). Underground soil temperature is effected by the annual air temperature, soil moisture content, soil type, and vegetative cover. To predict underground soil temperature, Hanks et al.(1971) used the finite difference method to descretized the one dimensional transient heat conduction equation and Wierenga et al.(1970) used the Runge-Kutta Variable Step method. Kimball and Jackson(1979), van Wijk(1963) used the sine function and Danil(1980) suggest the equation considering both of the yearly and daily temperature variation. Choi(1983) used Fourier series to predict the soil temperature of the Chinju of the year of 1981. Kim(1998) used the cosine function to decide the optimal equation of Chinju and Pusan and the equation represented the soil temperatures well with the coefficient of determination of 0.96 or upwards for Pusan. In this study, the optimal equations to predict the soil tempratures of several cities in the region of the southern part of the Korea such as Changhung, Cheju, Chinju, Kwangju, Masan, Miryang, Mokpo, Muan, Pusan, Sogwipo, Ulsan, Yoosu, were suggested as function of time and soil depth and the time dependent variation and soil depth dependent distribution of temperature were analyzed for the geothermal energy utilization system design and agricultural usages.

MATERIALS AND METHODS

Heat conduction equation in soil by using apparent thermal diffusivity(Wierenga(1969)) can be expressed as Eq. (1) (Carlslaw(1959)).

$$\frac{\partial T}{\partial t} = \alpha \cdot \frac{\partial^2 T}{\partial x^2} \text{-------------------------------} (1)$$

The analytical equation for estimating soil temperature as a solution of the Eq. (1) can be written as Eq. (2) for the condition that the soil temperature varies periodically like the cosine curve as the yearly cycle(Kim(1998), NRECA(1988).

$$T(x,t) = T_m - T_{so} \cdot Exp(-\xi) \cdot \cos\omega((t - t_o - x / \sqrt{2\alpha\omega}) \text{-------------} (2)$$

in Eq. (2), Tm is the mean earth temperature, Tso is the annual soil swing temperature at soil surface, yearly temperature amplitude of month means in this paper, and to is phase shift at the surface. ξ is the non dimensional phase lag, which is caused of spending time for heat transfer in soil. By using Eq. (2) for a certain value of the variables in it, we can calculate the temperature on any day of the year for any depth.

To determine the optimal equations which give a best fit to the measured data, the method of least squares was used. In Eq. (2), the mean earth temperature, Tm, and the annual soil swing temperature, Tso, are calculated statistically from the measured data. The phase shift, to, and soil thermal diffusivity, α, were decided by the method of the least squares, that is, the sum of the squares of the deviation between the measured and predicted data is a minimum. The procedure to find the phase shift and soil thermal diffusivity is as follows. The values of phase shift of 0~50 days which is referenced from the Kusuda' analysis, 35±10 days (NRECA(1988)) and soil thermal diffusivity of 0.02~0.09 m^2/day(NRECA(1988), Carslaw(1959)) were substituted to the equqtion (2) from the lower values to the higher values by the increments successively, respectively. Around the best value which gives the best curve fit, the increment was reset to a small value than the last one and was substituted to the equation from the lower value by one old increment from the best value to the higher value by one old increment from the best value after the optimal value was converging to a certain value. The same way was continued until the difference of the squares of the deviation of the predicted data from the measured data between the last step of the old increments and present step of new increments become less than 10^{-4}. The procedure was coded by using the computer language of Qbasic. The converging time was less than one minute for six hundred data by the Pentium PC. The weather data for making equation was that of the period of 1991~1998 and the soil depth of 0~5 m. The period and the soil depth for calculation could not be all the same for cities because the monthly weather data was not reported with the same format.

RESULTS AND DISCUSSION

The optimal coefficients of the equations were established as table 1. The The equations can predict the soil temperatures well with the correlation factor of 0.98 or upwards for most data. The predicted and measured data for soil depth of 1, 3, 5 m in Mokpo from 1991 to 1998 was showed in Fig. 1 as an example.

Table 1 Constants of the equations

	Period(Year)	Tm	Tso	a	to	Correlation factors
Changhung	1998	16.36	12.95	0.033	21.01	0.982, 0.985, 0.989, 0.993
Chinju	1991-1996 (0, 0.1, 0.5, 1.0)	15.45	14.13	0.034	22.01	0.985, 0.988, 0.989, 0.973
Kwangju	1989-1990 (0, 0.1, 0.5, 1.0)	15.77	12.90	0.038	22.98	0.988, 0.989, 0.992, 0.994
Miryang	1992-1996 (0, 0.1, 0.5, 1.0)	14.99	14.54	0.033	19.66	0.984, 0.989, 0.990, 0.990
Muan	1993-1996 (0, 0.1, 0.5, 1.0)	15.77	14.06	0.025	24.64	0.986, 0.990, 0.990, 0.990
Sogwipo	1991-1996 (0, 0.1, 0.5, 1.0)	18.53	11.65	0.024	27.81	0.977, 0.983, 0.988, 0.992
Ulsan	1989-1990 (0, 0.1, 0.5, 1.0)	16.30	13.15	0.030	21.00	0.988, 0.987, 0.991, 0.939
Masan	1989-1990 (0, 0.1, 1.5, 3.0)	16.86	13.20	0.057	23.30	0.981, 0.984, 0.992, 0.991
Cheju	1992-1998 (0, 1.0, 3.0, 5.0)	17.72	12.91	0.069	25.61	0.981, 0.985, 0.958, 0.920
Mokpo	1991-1998 (0, 1.0, 3.0, 5.0)	15.95	13.01	0.100	24.00	0.987, 0.991, 0.991, 0.957
Pusan	1989-1998 (0, 1.0, 3.0, 5.0)	16.52	13.23	0.042	24.05	0.979, 0.990, 0.987, 0.899
Yosu	1991-1998 (0, 1.0, 3.0, 5.0)	15.87	13.27	0.046	25.49	0.984, 0.993, 0.993, 0.958

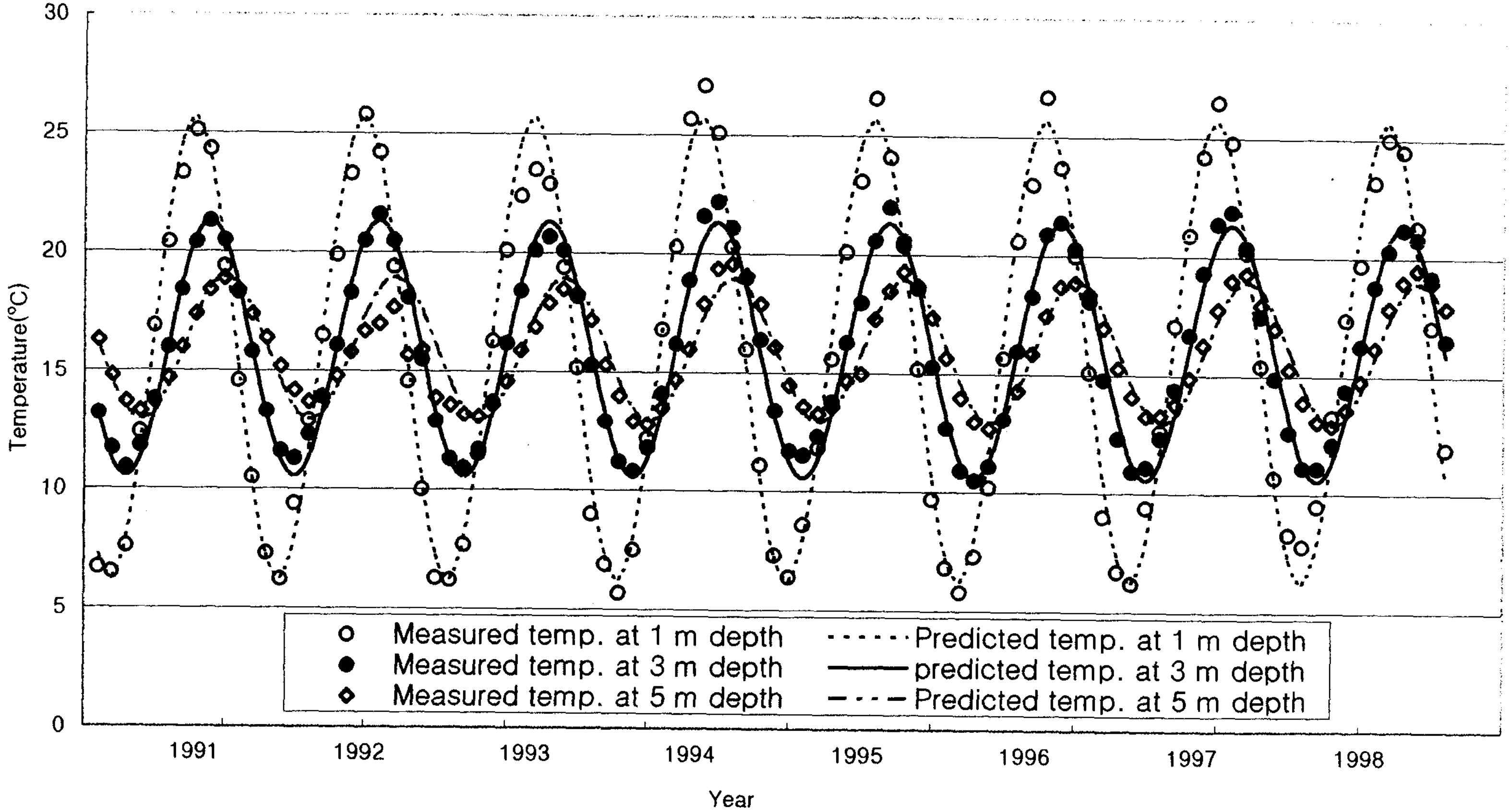

Fig. 1 Measured and predicted temperature for soil depth of 1, 3, 5 m, Mokpo, 1991–1998

The correlation factors was 0.991, 0.991, 0.957, respectively. The range of mean soil temperature was 14.99~18.53℃ for twelve cities and soil surface temperature swing, 11.65~14.54 days, soil thermal diffusivity, 0.025~0.069 m^2/day except Mokpo of 0.100 m^2/day, and phase shift, 19.66~27.81 days. The mean soil temperature of Sogwipo and Cheju was higher than the others because they are located in cheju island, the southern end of Korea.

Table 2 Variations of the mean soil temperature(℃)

City	Period	Mean air Temp.	Soil depth(m)				Mean Soil Temp.
			0	1	3	5	
Mokpo	1959-1962	14.25	16.03	16.11	15.78	15.74	15.91
	1991-1998	14.14	16.03	15.82	16.05	15.90	15.95
	Variation	-0.11	0.00	-0.29	0.27	0.16	0.04
Pusan	1959-1962	14.42	16.94	16.32	16.22	16.09	16.39
	1989-1998	14.91	16.83	16.45	16.50	16.30	16.52
	Variation	0.49	-0.11	0.13	0.27	0.21	0.13
Yosu	1959-1962	14.23	15.47	15.22	15.31	15.04	15.25
	1991-1998	14.41	15.67	15.74	16.06	16.02	15.87
	Variation	0.18	0.20	0.52	0.75	0.98	0.62
City	Period	Mean Air temp.	Soil depth(m)				Mean Soil temp.
			0.00	0.10	0.50	1.00	
Kwangju	1963-1968	13.13	15.05	14.69	15.31	15.29	15.08
	1989-1990	14.16	15.06	15.40	16.32	16.32	15.77
	Variation	1.04	0.01	0.72	1.01	1.03	0.69
Sogwipo	1963-1966	15.39	16.80	16.71	17.55	18.07	17.28
	1991-1996	16.32	18.19	18.39	18.66	18.89	18.53
	Variation	0.93	1.39	1.68	1.11	0.82	1.25
Ulsan	1963-1966	12.98	15.56	14.93	15.34	15.34	15.29
	1989-1990	14.56	16.63	16.50	16.27	15.81	16.30
	Variation	1.58	1.07	1.57	0.93	0.47	1.01

The long term temperature variation depending on time was calculated and the results are on table 2. The time gap for comparison is about thirty years between 1960s and 1990s. The mean soil temperature for cities was increased by 0.04~1.25℃ while the air temperature was increased by 0.49~1.04℃ except of Mokpo and Ulsan. The temperature difference depending on soil depth was not significant

CONCLUSIONS

The optimal equations to predict the soil temperatures of twelve cities in the region of the southern part of the Korea such as Changhung, Cheju, Chinju, Kwangju, Masan, Miryang, Mokpo, Muan, Pusan, Sogwipo, Ulsan, Yoosu, were suggested as function of time and soil depth and the time dependent variation and soil depth dependent distribution of temperature were analyzed for the geothermal energy utilization system design and agricultural usages. The equations can predict the soil temperatures well with the correlation factor of 0.98 or upwards for most data. The range of mean soil temperature was 14.99~18.53℃ and soil surface temperature swing, 11.65~14.54 days, soil thermal diffusivity, 0.025~0.069 m^2/day except Mokpo of 0.100 m^2/day, and phase shift, 19.66~27.81 days. During about thirty years from 1960s to 1990s, the mean soil temperature was increased by 0.04~1.25℃. The temperature difference depending on soil depth was not significant.

NOMENCLATURE

t, to : Time(days), phase shift(days)

T : Soil temperature(℃)

Tm : Mean earth temperature(℃)

Tso : Annual soil swing temperature at surface(℃)

x : Soil depth(m)

α : apparent soil thermal diffusivity(m^2/day)

ζ : Phase lag. $x \cdot \sqrt{\omega / 2\alpha}$

ω : Radial frequency. 2π /365 (radian/day)

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