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SOIL TEMPERATURE DISTRIBUTION WITH VEGETATION AND RAINFALL OVER SEMI-ARID REGION OF WESTERN INDIA

1. Soil temperature is a part of the energy cycle of the Earth-Atmosphere system and influences the weather, *e.g.*, ground fog, snow accumulation, soil moisture, evaporation rate etc. Soil temperature is also an important parameter in agro-meteorology for plant growth as the germination of seeds taking place at certain minimum soil temperatures. Propagation of heat through soil is also important for the plant growth. Earth surface is heated by incoming solar radiation and cooled by outgoing radiation, which causes diurnal change in soil temperature. Thus variation in soil temperature occurs due to the sensible and latent heat exchanges at the surface and heat transfer into the soil. A soil temperature depends on soil conductivity, soil moisture, incoming solar radiation etc. During daytime, heat flows insight the soil whereas in the nighttime heat flows upward to the atmosphere from the depth of soil. The distribution of soil temperature at different depth is a unique parameter useful in understanding the surface energy processes and regional environmental and climatic conditions. The detailed studies on soil temperature distribution in different seasons are very few from the Indian sub-continental region. The routine soil temperature measurements are done for the top 10-20 cm layer only as this layer is important from the agricultural point of view. In deeper region, soil temperature was monitored in LASPEX campaign throughout the year over different types of soil.

The performance of prognostic model for convective boundary layer over LASPEX region is sensitive for the potential temperature gradient above the entrainment zone

TABLE 1

Soil properties of the LASPEX site (Pandey *et al*., 2001)

Station	Soil type	Bulk density (10^3 kg m^{-3})	Thermal conductivity (Wm^{-1}K^{-1})	Thermal diffusivity (10^{-6} m^{2}s^{-1})	pH	EC (mhos cm^{-1})	WHC (%)	PWP (%)
Anand	Loamy sand	1.50	0.944	0.508	8.3	0.22	17.0	5.0
Derol	Sandy loam	1.50	1.230	0.677	8.3	0.22	17.0	5.0
Sanand	Clay loam	1.60	0.946	0.591	7.01-8.31	0.14-2.4	14.0	3.0
Arnej	Loamy clay	1.24	0.718	0.304	8.2	0.48	28.0	12.2
Khandha	clay	1.28	0.699	0.287	7.3	0.94-1.05	34.4	15.9

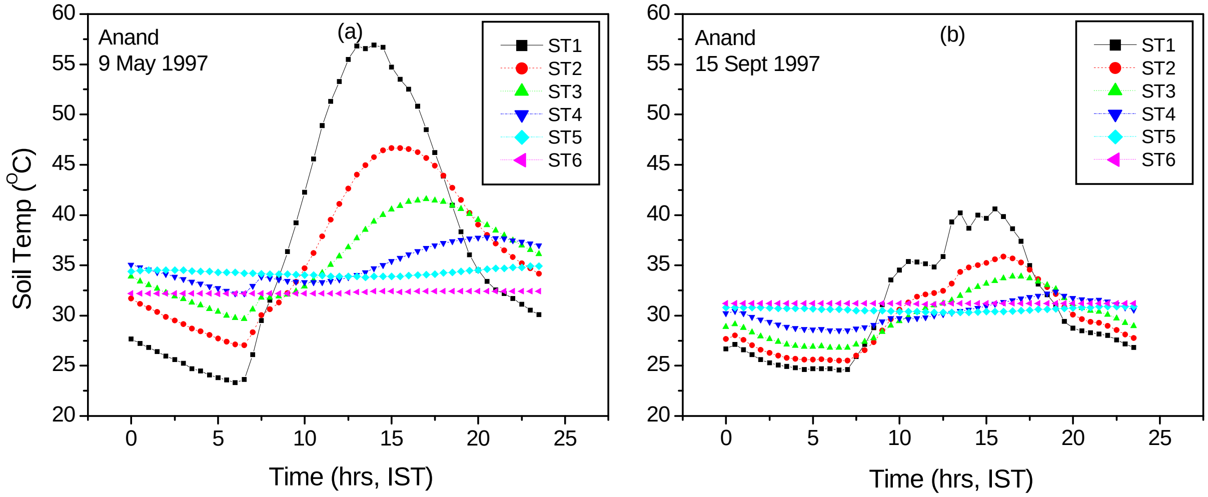
EC: Electrical conductivity; WHC: Water holding capacity; PWP: Permanent wilting point

(Nagar *et al*., 2001). Simulations of boundary layer parameters using boundary layer models (Sathynarayana *et al*., 2000; Rajagopal, 2001, Murthy *et al*., 2004) suggest that there is a need of improvement in the parameterizations of soil heat flux, radiation and soil-vegetation interactions. Soil moisture distribution up to a depth of 1 m (Patil *et al*., 2001) over this region shows that, over the soil of loamy clay or clay loam, top layer (surface – 40 cm depth) was dry and bottom layer (40-90 cm depth) was wet. Opposite trend was noticed where the soil type was sandy loam. The double mixing line structure was observed over this region using LASPEX data (Murthy and Parasnis, 2002). In this study, diurnal distribution of soil temperature at different depths up to 1 m has been investigated. An attempt has been made to bring out the changes in soil temperature at different depth due to change in soil conditions associated with precipitation and surface vegetation. Seasonal effect on the penetration of heat into the deeper depth has also been studied.

2. *Experiment* - Land Surface Processes Experiment (LASPEX) was conducted during 1997-98 in the semi-arid region of Gujarat situated in the *Sabaramati* river basin. Total five observational stations *viz*., Anand (22° 35′ N, 72° 55′ E), Derol (22° 40′ N, 73° 45′ E), Sanand (23° 04′ N, 72° 22′ E), Arnej (22° 40′ N, 72° 15′ E) and Khandha (22° 02′ N, 73° 11′ E) were selected for this experiment. All stations are under semi-arid climatic type. The soil properties of the experimental stations of LASPEX network were different and are given in Table 1. Tower of 8 m height was erected at each station and the observations on temperature using RTD elements (PT1000), humidity using solid state capacitive type sensor, wind speed using three cup anemometer and wind direction using wind vane connected to potentiometer were recorded at the sampling of every seconds. Soil temperature was measured at surface and under the depth of 5, 10, 20, 40 and 100 cms. Soil temperature sensor was also the standard platinum RTD elements. Being a central station, Anand, some additional measurements using sonic anemometer and radiosonde observations were taken to detect the height of boundary layer and turbulence parameter directly. The details on instrumentations used in the experiment can be found in Vernekar *et al*. (2003).

3. *Diurnal variation of soil temperature* **-** The heat entering into the soil causes diurnal variation in soil temperatures. Dark soils will absorb more energy from the sun than light colored soils. Soil is bare or covered with vegetation is important as this affects the amount of insolation that is received by the earth surface. Bare soils warm more quickly and cool off more rapidly than those covered with vegetation. Soil moisture is one of the major factors in respect to the heat capacity of a soil, and hence, has much to do with its rate both of warming up and cooling off. The vaporization of soil water is caused by an increased molecular activity and requires the expenditure of a certain amount of energy, which results in a cooling effect especially at the surface where most of the evaporation occurs.

On the normal undisturbed dry conditions, the soil temperature in the top layers (0-20 cm) showed high diurnal variation depicting peak in the afternoon hrs. As we approach deeper, the diurnal pattern becomes weaker. At 1 m depth, this variation with time disappears and the soil temperature at this depth remained nearly constant throughout the day. The soil temperature at 1 m depth does not show much change even after a period of a week. This soil temperature distribution at various depths *viz*., surface, 5, 10, 20, 40 and 100 cms corresponding to ST1, ST2, ST3, ST4, ST5 and ST6 over Anand for the



Figs. 1(a&b). Soil temperature at different depth observed over Anand on (a) 9 May 1997 and (b) 15 September 1997. ST1, ST2, ST3, ST4, ST5 and ST6 corresponds to surface, 5 cm, 10 cm, 20 cm, 40 cm and 1 m depths

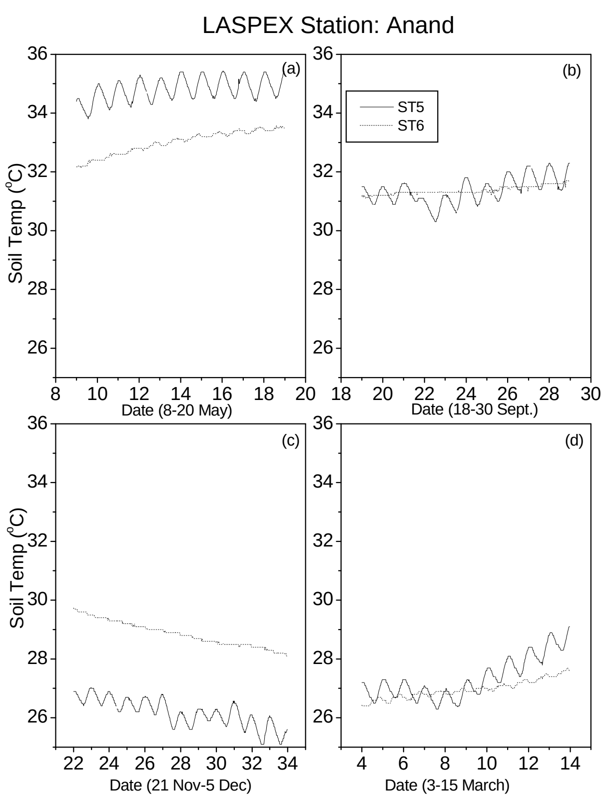


Fig. 2. Observed soil temperature at 40 cm (ST5) and 1 m (ST6) depths in different seasons over Anand

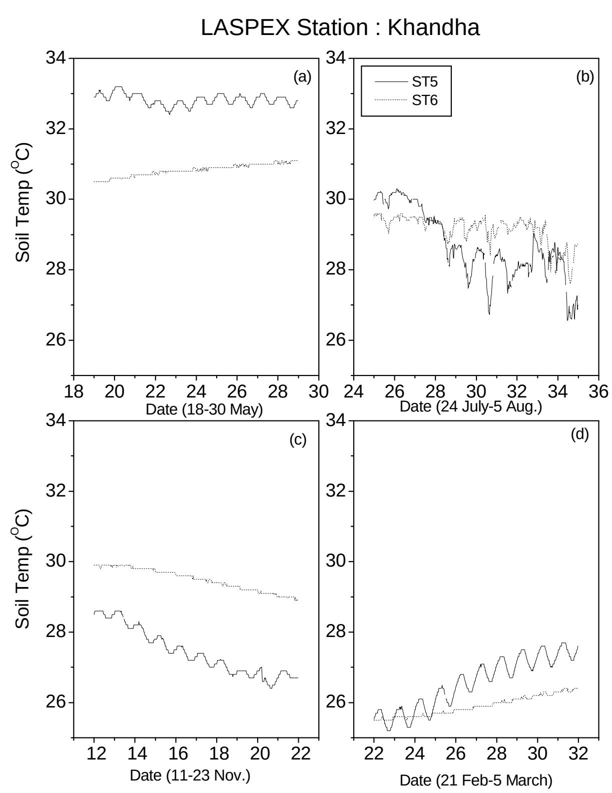


Fig. 3. Same as in Fig. 2 but over Khandha

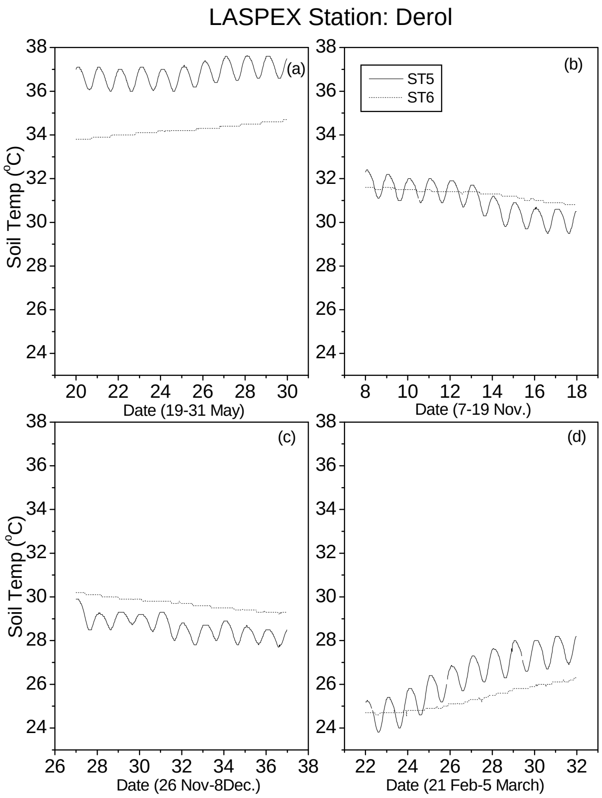


Fig. 4. Same as in Fig. 2 but over Derol

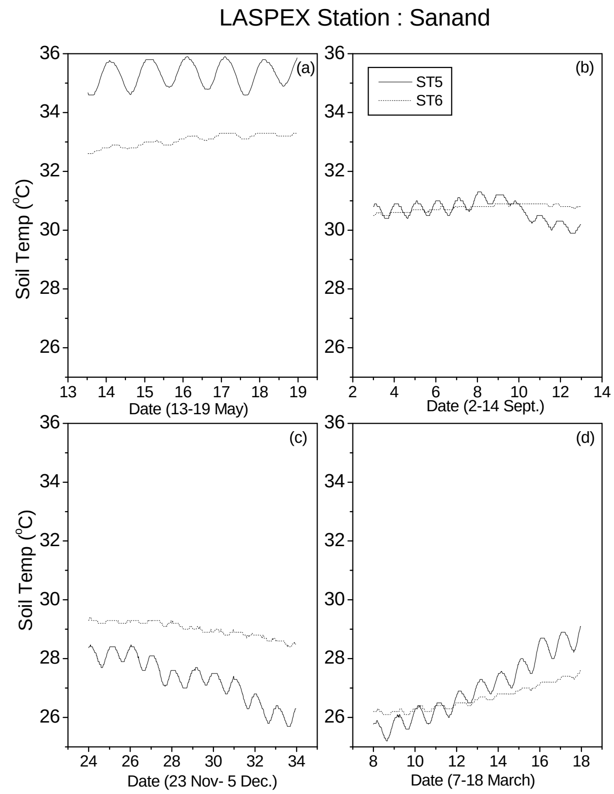


Fig. 5. Same as in Fig. 2 but over Sanand

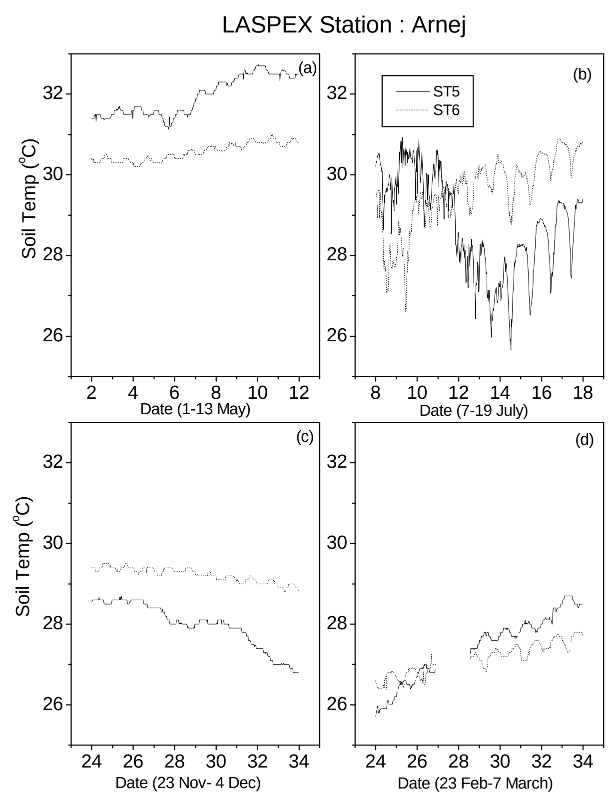
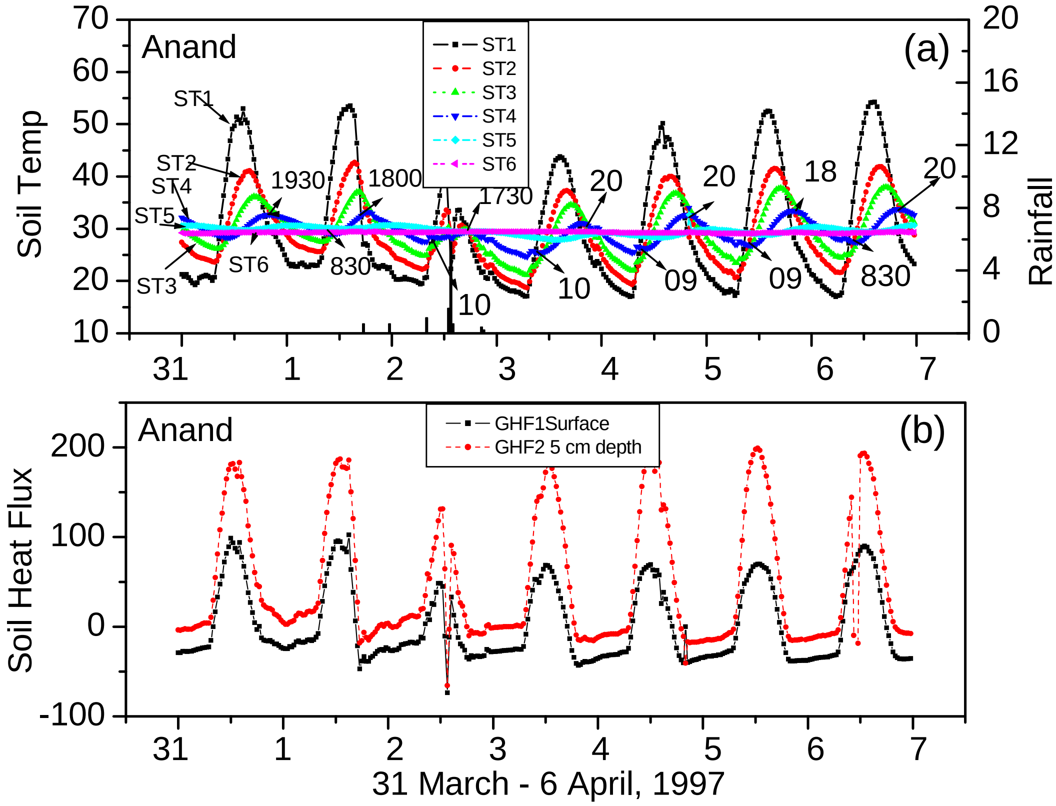


Fig. 6. Same as in Fig. 2 but over Arnej

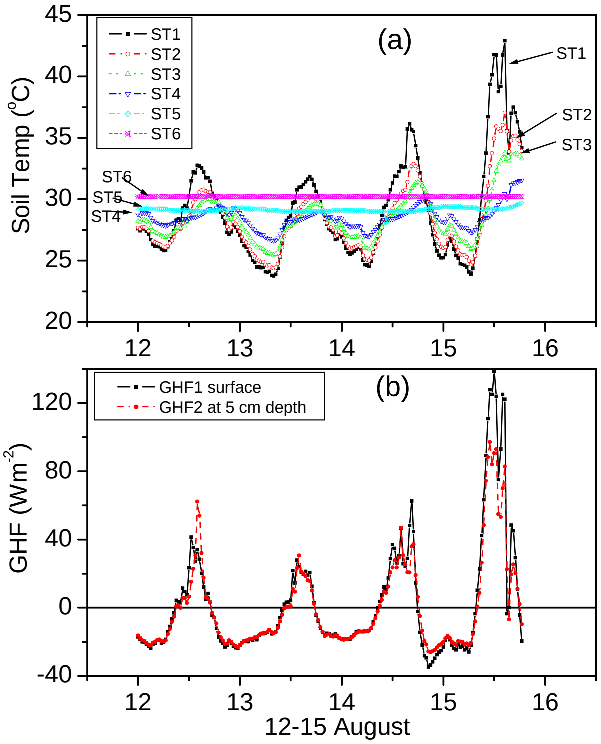
representative day of May and September is shown in Figs. 1(a&b). The greater temperature wave amplitude was observed in the month of May while weak amplitude in the month of September (monsoon months). A peak in soil surface temperature occurred at 12-13 hrs in the month of May whereas in the month of September it occurred at 14-15 hrs. As the depth increases, peak hrs in soil temperature at the respective depths is delayed by 2-3 hrs. It is seen that peak of the soil temperature at 20 cm depth occurred at 2000 hrs (*i.e.*, at night). This time delay in observing the maximum soil temperature at different depths of soil is attributed to the time taken to penetrate the heat into the deeper region of the soil. It is also seen that during daytime, the surface soil temperature was maximum compared to that observed at other depths showing the heat transfer towards inside the ground. During night hrs, this trend is reversed, indicating heat transfer towards the atmosphere. Thus, during daytime heat energy penetrates into the ground and during nighttime, heat gets transferred towards the air in the surface layer.

4. *Seasonal variation of soil temperature* **-** It is shown in Figs. 1(a&b) that the greatest soil temperature variation was observed in summer months especially in



Figs. 7(a&b). Diurnal variation of (a) soil temperature in °C at different depth and (b) soil heat flux in Wm^{-2} over Anand during 31 March - 6 April,1997. ST1, ST2, ST3, ST4, ST5 and ST6 correspond to surface, 5 cm, 10 cm, 20 cm, 40 cm and 1 m depths. Rainfall (mm) depicted by vertical bars

the month of May whereas minimum variation is noticed in the monsoon season. The soil temperature at 40 cm and 100 cm depths over different stations of LASPEX are shown in Figs. 2 to 6. It is clearly noticed that in the month of May, soil temperature at 40 cm depth (ST5) was greater than that of soil temperature at 100 cm depth (ST6), which indicate that the heat transfer takes place towards the deeper region of the soil *i.e.*, from 40cm depth (high temperature) to 100 cm depth (low temperature). In the month of November *i.e.*, in winter months the soil temperature gradient between 40 and 100 cm is reversed and shows transfer of heat from 100 cm depth region (high temperature) to the upper part of the soil. The change in this type of transfer of heat (up and down) pattern took place in August-October. Again it regained to previous conditions *i.e.*, heat transfer taking place to the deeper regions started building up in the months of February-March. This type of behavior was observed over all the five stations of LASPEX (Figs. 2 to 6). In the month of May (summer), the solar radiation is intense. Also in this month, the soil surface is nearly bare as most of the crops are harvested by the middle of March. Thus the earth surface, which is bare, absorbs maximum solar radiation. Also the soil moisture in the month of May (summer) is reduced due to continuous large-scale evaporation. These conditions are favorable for the penetration of heat to the greatest depths of the soil. Conversely in the month of November (winter), earth surface is covered with vegetation. Also the crops are at its mature stage in this month. The cold conditions with minimum temperature of the year are occurring in this month. Also due to immediate passage of monsoon season, the earth surface holds good amount of soil moisture. These conditions allow the less radiation to absorb by the earth surface and to reduce the soil temperatures. Also the radiation is not falling straight on ground (it falls on vegetations), thus the heat is penetrating upto the limited depth *i.e.*, nearly 30-40 cms only. But the temperature at 100 cm remains greater and allows the heat transfer from 40-100 cm region towards the upper region of the ground. It is also seen that the diurnal temperature observations were noticed at the depth



Figs. 8(a&b). Observed changes in (a) soil temperature at various depths and (b) soil heat flux at surface and 5 cm depth due to the removal of vegetation. Vegetation was removed at 1600 hrs on 13 August, 1997. ST1, ST2, ST3, ST4, ST5 and ST6 corresponds to surface, 5 cm, 10 cm, 20 cm, 40 cm and 1 m depths

of 40 cm in the form of wave but it is not noticed at the depth of 100 cm. Earlier study (Saxena *et al*., 1996) on the diurnal variation of soil temperature over Pune in the summer months showed that the soil temperature wave penetrated up to the depth of 20 cm only.

5. *Rainfall effect on distribution of soil temperature* - Fig. 7(a) shows the day-to-day variation in soil temperature during 31 March - 6 April, 1998 over Anand. About 10.80 mm rainfall was recorded on 1-2 April 1997 at Anand. (1.20 mm on 1 April at 1630 to 2340 hrs and 9.60 mm on 2 April). Due to this rainfall events, soil temperatures up to 40 cm depth decreased by increase of soil moisture in the soil. The temperature at 1 m depth did not change and remained unaffected. During daytime, the soil temperature decreases as depth of the soil increases up to 1 m depth as shown in Fig. 1(a). In the month of April, it is also seen that the soil temperature waves penetrate up to 20 cm depth as seen in Fig. 7(a). The peak hour of soil temperature was delayed as one approach to the depth of the soil. First peak in soil temperature appeared at surface, then at 5 cm depth and finally at 20 cm depth of the soil. The nearly uniform temperature time zone was established at 0830-0930 hrs and 1800-1930 hrs prior to the rainfall event. After the rainfall event, this near constant temperature time zone occurred at 09-10 and at 20 hrs. The soil temperature at 40 cm was higher than that of 1 m depth before the rainfall event. After rainfall, the reverse trend was noticed. Thus, rainfall affected the soil temperature distribution cycle. The soil temperature distribution became to pre-precipitation conditions after 2-3 days.

Soil heat flux was measured directly by the soil heat flux plate at surface and at 5 cm depth. Observations of soil heat flux at surface and at 5 cm depth are shown in Fig. 7(b). Prior to the rainfall event, maximum soil heat flux (peak) was observed at the surface of the order of 90-100 Wm^{-2} and at 5 cm depth it was of the order 180-190 Wm^{-2} . Due to rainfall (10.80 mm), soil heat flux maxima at surface and 5 cm depth was reduced to about 50 and 120 Wm^{-2} respectively. The soil heat flux was reduced on the day of precipitation.

6. *Effect of vegetation on the distribution of soil temperature* - The vegetation around the soil temperature sensors probe was removed on 13 August, 1997 at 1600 hrs (IST) to study the effect of vegetation of soil temperature distribution at various depths. The observed changes in soil temperature distribution are shown in Fig. 8(a). Due to this change (removal of vegetation) at surface conditions, the ground surface temperature is increased by about 12° C and the temperature at 20 cm depth is increased by about 4° C. The soil temperature at 1 m depth was not affected due to the removal of vegetation. Before the removal of vegetation, during daytime, the soil temperature at 1 m depth was higher than that of 10-20 cm depth layer temperature suggesting the direction of soil heat flux towards the upper part of the ground. But after the removal of vegetation, this trend is reversed as shown in Fig. 8(a). The soil temperature distribution in the top 20 cm layer is affected greatly by removing vegetation. These changes are noticed immediately on that day itself. Small change at 40 cm depth is also noticed after 2 days from the day of vegetation removal. The removal of vegetation allows the penetration of heat and thus temperature wave penetrate to the greater depths. Nearly uniform temperature regime was noticed at morning 1000-1030 hrs (IST) in 0-20 cm layer. Also secondary uniform temperature regime was achieved in 1900-1930 hrs (IST) in 0-40 cm layer. The

time lag between two constant temperature regimes was about 9-10 hrs. This feature was observed before the removal of vegetation. After the removing of vegetation, the first constant temperature regime occurred early *i.e*., at 0830 hrs and the second one was observed late. Thus the length of diurnal cycle is increased by 1-2 hrs by removing vegetation. This changes is attributed to the fact that bare soil surface gets heated quickly and cooled slowly. The soil heat flux was also measured directly by using flux plate at the ground and 5 cm inside the ground. The change in soil heat flux is shown in Fig. 8(b). Soil heat flux at surface and 5 cm depth was of the order of 40 Wm^{-2} in the noon hrs before the removal of vegetation (12^{th} and 13^{th} August). It is increased to about 80 Wm^{-2} on 14^{th} August and to 130 Wm^{-2} on 15^{th} August. Thus the soil heat flux at surface and 5 cm depth increased rapidly after the removal of vegetation. Amount of heat that penetrates into the soil was reduced by presence of vegetation by lowering the soil temperature.

8. *Conclusions* - The Land surface Processes Experiment was conducted in the Sabaramati river basin of Gujarat region of western India. The time series of the soil temperatures upto a depth of 1 m was studied. The diurnal variation of soil temperatures at different depths suggested that the soil temperature at the surface was maximum in the local noon hour (peak hour). This peak hour in other depths was delayed by 2-3 hours as we approach to the deeper depths due to the time taken to penetrate heat into the deeper region of the soil. The temperature at the region of 1 m depth was almost nearly constant and does not depict diurnal variation but it changes monthly/seasonally. Heat transfer into the deeper soil region showed seasonal variation. A region of 40-100 cm depth showed upward transport of heat in winter period and downward transport in summer season. The heat flow in 0-40 cm region doesn't show this type of contrast nature seasonally. The soil temperature distribution was affected due to the precipitation by reducing the soil temperature (increasing soil moisture) in upper 40 cm layer drastically. The soil temperature condition readjusted to pre-precipitation conditions after 2-3 days. The vegetation on the earth surface played an important role on the distribution of soil temperature. The soil temperature up to 20 cm depth is increased by means of removing vegetation.

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