2. RAINFALL AND SOIL TEMPERATURE ANALYSIS – A REVIEW

2.1 Introduction

A review of studies related to the subject of research is purposeful for defining concepts, objectives and hypothesizes to select the tools of analysis and to specify the model. It also sheds light on various dimensions of the problem studied and enables the determination and sources of data. Therefore, the review of the related studies is presented in this chapter.

2.2 Review of Literature

2.2.1 Rainfall

Hastings (1965) suggested that one need not consider coefficient of variation (C.V) as a normal statistics at all. The author found C.V. giving real degree of meaning in terms of precipitation probabilities of seasonal precipitation in arid and semi-arid regions of Baja California, U.S.A.

Dhar et al, (1966) have studied floods and the associated meteorological conditions causing some heavy spells of rain in Assam.

Palmer’s (1965) method of quantifying drought was later applied to Indian conditions for mapping (George et al, 1973). Aridity anomaly indices were later used to measure the extent, intensity and dissipation of agricultural drought (George and Ramasastri, 1975 and George et al, 1975), adopting correlation technique to study some aspects of drought. As the timing of rainfall or the interval between two rainfall spells is one of the most important reasons of agricultural drought. Raman (1974) has adopted the inter-spell duration to evaluate agricultural drought over Maharashtra.
The time series models with a hydrology point-of-view have been discussed by Salas et al, (1980).

Sikka and Gadgil (1980) have shown that cloudinees over an extensive zone in the Asian summer monsoon domain shows a periodic oscillation in the time scale of 30-50 days. It has also been claimed that this mode is capable of explaining the major active-break cycle in monsoon rainfall.

Lal et al, (1983) used synoptic analogue method for prediction of quantitative rainfall in Gomti river catchment in Uttar Pradesh using five years of data.

Murakami et al, (1984) have shown that over the monsoon region spectral peaks with periods shorter than 10 days are quite prominent in the lower troposphere, in the v’ spectrum, while at 200 hPa, u’ fluctuations in the 40-50 days period are not significant over the Indian sub-continent.

De and Vaidya (1987) on intra-seasonal variations during the summer monsoon have been documented. Recently, low frequency oscillation in the time scale of 10-15 days and 30-50 days have been extensively studied. The morphology of intra-seasonal fluctuations on a regional scale (over the Indian sub-continent) has been studied using mean circulation parameters. The low frequency oscillation (30-50 days) and its contribution to the fluctuations of rainfall have been discussed. Synoptic scale (3-5 days) oscillation and the quasi-biweekly oscillation appear more relevant as a tool of explanation for the major intra-seasonal oscillation in rainfall.
Ramanamurthy et al, (1987) perceived that a detailed hydro meteorological study of the catchment upto the Karanja dam site has been made to estimate the design storm depths of different return periods and the probable maximum rainfall is likely to be experienced by the catchment using rainfall data of the period 1891-1984. It has been found that the catchment experienced maximum rainfall of 193, 258, and 312mm during 1, 2 and 3 days period respectively during the last 94 years of record. Severe rainstorms of September 1908 and July 1965 which occurred in a homogeneous region round the catchment were transposed to estimate probable maximum rain depths (PMP). The PMP for 1, 2 and 3 days durations were found to be 338, 406 and 424mm respectively which are about 1.4 to 1.8 times the corresponding maximum rain depths experienced by the catchment. There design estimates will be useful for the re-assessment of the spillway capacity of the existing dam across the Karanja river at Halhalli.

Sivaramakrishnan (1987) studied the statistical aspects of rainspells for Mohanbari considering four years data. Weeks and Boughton (1987) reviewed applications of time series models to hydrology and showed that a number of well-known hydrologic models are special cases of the ARIMA model.

Rupa Kumar et al, (1992) furthered the analysis of longterm rainfall data over different locations of India and concluded that the monsoon rainfall is trendless.

Jeffery (1995) has developed Acoustical Rainfall Analysis Algorithm (ARA) and tested it for several dozen rainfall events and found to provide excellent estimates of rainfall rate, rainfall accumulation, and rainfall reflectivity. High temporal
resolution variations in drop size distribution within the rain can be studied using ARA.

Martin Zwick et al, (1995) have explored an information-theoretic/log-linear approach to multivariate time series analysis. The method was applied to daily rainfall data, originally quantitative but here treated as dichotomous. The analysis ascertains in particular that lagged variables were most predictive of future rainfall and how season can be optimally defined as an auxiliary predicting parameter.

Chattopadhyay and Bhatla (1996) showed simultaneous significant correlation of SOI, i.e., Tahiti minus Darwin pressure with performance of Indian monsoon.

Roy Abraham et al, (1996) have observed the simulation of monsoon circulation and cyclone with different type of orography. The study is aimed to know and gaining insight into analysis of variability and mean monthly rainfall amounts during the period.

Sontakke and Singh (1996) presented a time series of rainfall dividing India in six homogenous zones but within the zones there are number of incoherent catchment of high variability of rainfall due to regional and local complexities; viz., geography, topography and diverse atmospheric processes.

Richard Chandler et al, (1997) presented a method for improving the spatial resolution of rainfall fields generated by atmospheric General Circulation Models. They used from Bayesian image analysis to improve the resolution of the binary wet/dry image, and showed the clear advantage over the existing methods that incorporated both the spatial and the temporal memory of the rainfall field.
Kripalani and Kulkarni (1997) found that there was no one-to-one correspondence between monsoon rainfall and El Nino because peak of EL Nino/La Nina phases do not coincide with monsoonal peak. Pant and Hingane (1998) found slight increase in monsoon rainfall, inspite of the large variability in the arid zone.

Stewart et al, (1999) have presented the use of rainfall growth extension methods. A growth factor is the ratio of the T-year extreme value to an index extreme value such as the mean of annual maxima whereas a record length of ten or more years may suffice to estimate the index variable. It was generally necessary to blend data from several sites if estimates of exceptional extreme values were to be obtained. Methods of rainfall growth estimations were reviewed, including traditional methods which extend frequency curves to long return period by a distributional assumption and methods which studied spatial dependence in extreme rainfalls.

Bhatti and Barbra Mahood (2000) have been exhibiting scale invariance behaviour over a range of space and timescales. Although various approaches have been taken to investigate and model the various scaling aspects of rainfall and floods, theoretical work has been done on the relation between the scaling of rainfall and flood. They used a two-step approach to investigate the relationship between exponent of peak flows and the scaling of rain.

Neil and Christopher (2000) developed a methodology for the disaggregation of numerical model fields of convective rainfall using a physically based procedure. The scheme used surface sensible heat flux values derived from high-resolution multi-channel satellite radiometer observations.
Andreas Gunter et al, (2001) suggested that a temporal rainfall disaggregation model was to be applied to convert daily time series into an hourly resolution. The model was based on the principles of random multiplicative cascade processes. Its parameters were dependent on the volume and the position in the rainfall sequence of the time interval with rainfall to be disaggregated. The aim was to compare parameters and performance of the model between two contrasting climates with different rainfall generating mechanisms, a semi-arid tropical and a temperate climate. In the range of time scales studied, the scale-invariant assumptions of the model were approximately equally well fulfilled for both climates. The model parameters differ distinctly between climates, reflecting the dominance of convective processes in the Brazilian rainfall. Transferability of parameters in time was associated with larger uncertainty in the semi-arid climate due to its higher inter-annual variability and lower percentage of rainy intervals. For parameter transferability in space, no restrictions were found between the Brazilian stations whereas in the UK regional different restrictions were found and pronounced. The overall high accuracy of disaggregated data supported the potential usefulness of the model in hydrological applications.

Cintia Bertacchi et al, (2001) developed linear regression models based on singular value decomposition (SVD) with the aim of downscaling atmospheric variables statistically to estimate average rainfall. The SVD analysis preceding the model development highlighted three important features of the rainfall regime in Southern Japan (i) the so called Bai-u front which is responsible for the majority of summer rainfall, (ii) the strong circulation pattern associated with autumn rainfall and (iii) the strong influence of orographic lifting creating a pronounced east-west
gradient across Kyushu island. Results confirm the feasibility of establishing meaningful statistical relationships between atmospheric state and basin rainfall even at time scales of less than one day.

Mackay et al. (2001) presented a method, which considers the generation of the wet areas and the simulation of rainfall intensities separately. For the first task, a nearest-neighbour Markov scheme, based upon a Bayesian technique used in image processing, is implemented so as to preserve the structural features of the observed rainfall. Essentially, the large scale field and the previously disaggregated field are used as evidence in an iterative procedure, which aims at selecting a realization according to the joint posterior probability distribution. In the second task the morphological characteristics of the field of rainfall intensities are reproduced through a random sampling of intensities according to a beta distribution and their allocation to pixels chosen so that the higher intensities are more likely to be further from the dry areas. The wet/dry scheme provides a good reproduction both of the number of correctly classified pixels and the coverage, while the intensity scheme generates fields with an adequate variance with the grid-squared, so that this scheme provided the hydrologist with a useful tool for the downscaling of meteorological model outputs.

Singh (2001) has shown that lag correlation with multivariate ENSO index and Southern Oscillation Index (SOI) is insignificant over Bihar plains during the monsoon season and also found that ENSO does not have any adverse impact on monsoonal rain in eastern India.
Sivakumar (2001) studied the behavior of rainfall dynamics at different temporal scales identified the type of approach most suitable for transformation of rainfall data from one scale to another. The correlation dimension method is employed to identify the behavior of rainfall dynamics. A possible implication of this might be that the rainfall processes at these scales are related through a chaotic (scale-invariant) behavior. However, a comparison of the correlation dimension and coefficient of variation of each of the time series reveals an inverse relationship between the two. The presence of a large number of zeros in the higher resolution time series and the possible presence of a higher level of noise in the lower resolution time series might account for such results.

Franks (2002) showed that in the case of the Australian climate, previous studies on the climate conditions of the Indian and Pacific Oceans had indicated marked multi-decadal variability in both mean Sea Surface Temperatures (SST) and typical circulation patterns. In this light, data from 40 stream gauges around New South Wales were examined to determine whether flood frequency data were indeed independent and distributed identically. Given likely correlation in flood records between gauges an assessment of the regional significance of observed changes in flood frequency was required. To achieve this, flood observations were aggregated into a regional index. A simple non-parametric test was then employed to identify the timing and magnitude of any change in mean annual flood. Finally, it was shown that the identified change in flood frequency corresponds directly to an observed shift in SST circulation. The performances of the models are then compared and the improvement in the efficiency of the discharge forecasts achievable is demonstrated when (i) short term rainfall forecasting is performed, (ii) the discharge is updated and
(iii) both rainfall forecasting and discharge updating are performed in cascade. The proposed techniques, especially those based on ANNs, allow a remarkable improvement in the discharge forecast, compared with the use of heuristic rainfall prediction approaches or the not-updated discharge forecasts given by the deterministic rainfall-runoff model alone.

Littlewood (2002) established a rainfall-streamflow modeling methodology employed a six-parameter unit hydrograph based rainfall-runoff model structure which was developed further to give an improved model fit to daily flows for the river Teifi and at Glan Teifi. Using the model as a starting point the combined application of a non integer pure time delay and further adjustment of a temperature modulation parameter in the loss module, using the flow duration curve as an additional model fit criterion, gave a much improve model fit to low flows, while leaving the good model fit to higher flows essentially unchanged. The further adjustment of the temperature modulation loss module parameter in this way was much more effective at improving model fit to low flows than the introduction of the non integer pure time delay.

Nath and Deka (2002) reported decrease in average annual rainfall in north-eastern states. Himalayan region is quite fragile to understand trends in temperature and rainfall. Pandey et al, (2002) seventy percent rainfall occurs during the monsoon period, out of which the crops use only small amount and a large portion is lost as surface runoff.

Thiam et al, (2002) have used long term data on rainfall and annual runoff and investigated the spatial and temporal variability of rainfall and runoff in the Casamance River basin located in southern Senegal, West Africa. A five-year moving
average had been employed to identify trends in the data. They found monthly and annual rainfall trends have been decreasing, and the annual maximum temperature rising from around the mid-1960s. The analysis also showed a simultaneous runoff decline as a result of the rainfall decline. Available data on rainfall, temperature, and surface runoff from two upstream stations were used to develop a procedure of estimating runoff from the annual surplus values of precipitation minus reference evaporation.

Buishand et al, (2003) have compared daily and monthly downscaling models for precipitation in three places. Moreover they have also used Generalized Linear Models for the statistical description of rainfall occurrence, the wet-dry precipitation amounts and the monthly precipitation totals. Fitting a generalized linear model to daily rainfall data generally results in larger regression coefficients than fitting the same model to monthly data. For rainfall occurrence this can be attributed mostly to the non-linearity of the function that links the wet-day probabilities to the predictor variables, whereas for rainfall amount there is, apart from non-linearity, also a bias in the estimated regression coefficients of the monthly models caused by averaging predictor variables over both wet and dry days. Due to the squared correlation coefficient results from these models to monthly values gives the coefficient values comparable to those in the direct fit to the monthly data. The temporal variation of the predicted annual amounts from the daily and monthly relationships is almost the same. They have shown that the daily models are more preferable.
Bidin and Chappell (2003) observed a high degree or variability in seasonal totals across a very small area. They have shown that systematic, stochastic structure was present for the rainfall.

Pathirana et al, (2003) suggested a multiracial model based on the scaling properties of temporal distribution of rainfall intensities, which was formulated to investigate the intensity distribution relationships in the available scaling regime. Using a discrete cascade algorithm based on the log-Levy generator, synthetic hourly rainfall series were generated from the multiracial statistics of daily accumulated rainfall. Several properties of rainfall time series that are relevant to the use of rainfall data in surface hydrological studies were used to determine, statistically, the degree of agreement between the synthetic hourly series and observed hourly rainfall.

Agashe and Padgalwar (2005) investigated information in processed form, is often needed to meet the demands in agriculture, hydrology and rainfall which, when accumulated gives weekly, monthly or seasonal totals. This paper deals with some of the characteristic features of daily rainfall at nine selected stations in Madhya Maharashtra. The study is based on daily rainfall data of June to September months for 10 years (1991-2000). Depending upon rainfall amounts, a day has been categorized as rainy day or dry day. Making use of the concept of evapotranspiration, rainy day has been further divided into crop rainy day (CRD). Distribution of these various classes of days, their contribution to monthly totals arid relationship among them, have been obtained and discussed. The rainy days have been used to obtain mean daily rainfall intensity (MDI) and its association with monthly rainfall, examined through a series of regression equations. Frequency of heavy falls i.e.,
rainfall exceeding 25mm in a day have been determined and its contribution to monthly rainfall, evaluated. There seem to be a tendency for the rainy days and the rainfall to be below normal in recent years. Perfectly dry weather could prevail nearly half of June months over the region. Heavy rainfall contributes substantially to the monthly total. During June and September mean daily rainfall intensity is perhaps weekly related with the monthly rainfall.

Das and Sharda (2005) in their study of weekly rainfall data in a sub-humid climate of India, fitted two or three parameter probability distributions and compared the same to identify the most appropriate distribution that describes weekly rainfall data and found that no single probability distribution has been found to fit most of the data sets.

Immaculate Mary et al, (2005) in their study “Climatological study of dry zone” used regression models and probability distributions to forecast the daily rainfall in dry zones of Tamilnadu.

Immaculate Mary et al, (2005) in their study on “Harmonic Analysis and Probability Distributions – An application to rainfall forecast “used Harmonic Analysis and probability distributions to forecast the rainfall.

Immaculate Mary (2005) in her study on stochastic processes - An application to rainfall data analysis has used regression and probability distributions for predicting the rainfall in all the eight zones of Tamilnadu.
Immaculate Mary et al, (2005) in their study on Harmonic analysis and probability distributions has shown that the period of convergence of the harmonics coincides with the drought season in rainfall.

Jenamani and Dash (2005) studied role of synoptic and semi permanent system during different phases of EL Nino vis-à-vis Indian monsoon rainfall and found that the highest monsoon rainfall is strongly correlated with highest number of monsoon disturbances and trough days.

Mehfooz Ali et al, (2005) investigated the onset, withdrawal dates and rainfall of southwest monsoon corresponding to east and west Rajasthan sub-divisions have been examined statistically for the past 63 years (1941-2003) to bring out some major aspects of their variability and trend to predict these parameters of southwest monsoon over Rajasthan. Various correlation coefficients have been worked out. Study reveals, shift in monsoon activity, enhancement of monsoon duration, early onset and late withdrawal enhances monsoon duration and seasonal rainfall over Rajasthan. Early onset over east Rajasthan certainly brings onset over west Rajasthan.

Mohammadi et al, (2005) applied different methods for predicting spring inflow to the Amir Kabir reservoir in the Karaj river watershed, located to the northwest of Tehran (Iran). Three different methods, artificial neural network (ANN), ARIMA time series and regression analysis between some hydroclimatological data and inflow, were used to predict the spring inflow. The spring inflow accounts for almost 60 percent of annual inflow to the reservoir. Twenty five years of observed data were used to train or calibrate the models and five years were applied for testing. The performances of models were compared and
the ANN models was found to models the flows better. Thus, ANN can be an effective tool for reservoir inflow forecasting in the Amir Kabir reservoir using snowmelt equivalent data.

Kalsi et al, (2006) studied various features of monsoon such as onset, progress, stagnation, different synoptic and semi-permanent features and characteristics of rainfall of southwest monsoon in 2002 over India have been discussed. A comparison of these features with those in the earlier drought years has been made. Large-scale mean monthly anomalous ocean and atmospheric conditions over Indo- Pacific region have also been investigated to find out the possible causes for drastic failure of the monsoon during July 2002. Results show that many abnormal and unique features during 2002 have resulted into all India drought. Study also shows that absence of favorable regional intra-seasonal features like monsoon disturbances and semi-permanent systems, presence of very weak low level jet, penetration of strong mid-latitude westerlies, weak to moderate El-Nino with most intense warming over Nino 4 region of pacific Ocean during monsoon months together with higher frequency of typhoon formation over the region are the main causes that led to one of the highly pronounced rainfall deficiencies in the month of July.

Uruya and Sudajai (2005) aimed to develop a mathematical model for forecasting annual rainfall in Thailand. ARMA and ARIMA model were used to fit the time series of annual rainfall during 1951 to 1990 of 31 rainfall stations distributed in all regions of Thailand. It has been found that ARIMA model is more suitable to describe inter-annual variation of annual rainfall in Thailand, i.e., most of the rainfall
stations better fitted with ARIMA model, while only 8 stations are better fitted with ARMA model. The models proposed in the study are able to forecast annual rainfall for all regions of Thailand, providing an acceptable accuracy for planning purposes, i.e., with mean relative error ranging from 8% to 27% during the verification period (1991-2003).

Bhargava et al. (2010) have daily been analyzed for the probability and variability to evolve rainfall based cropping system with minimum risk. The mean rainfall, standard deviation, coefficient of variation for annual, seasonal, monthly and weekly period were worked out. Markov chain probability (>30 mm rainfall per week) were computed. Annual and Kharif rainfall of 1514.2mm and 1278.4mm were the highest in 2000, compared to mean of 983.5mm. The rainfall amount of 1514mm (2000) could be expected with 97 per cent probability while 1164mm (1995), 948.9 mm (1997) and 824.4mm (1993) of rainfall may be expected with 75, 50 and 25 per cent probability respectively. July was the wettest month (272.4mm) followed by August (271.4mm). November was the least rainfall (6.0mm) contributing month. Sowing of kharif crop is advanced from 2\textsuperscript{nd} week of June is regarded suitable for transplanting of rice crop in Roorkee region. Each standard week from 23\textsuperscript{rd} to 39\textsuperscript{th} received rainfall more than 20mm indicating the crop growing period from June 2\textsuperscript{nd} week to September last week.

Jha and Ram (2010) extended their study on rainfall departure and variability in Kosi, Kamala/ Bagmati/ Adhwaras and Gandak/ Burhi, Gandak during monsoon season. Station and catchmentwise rainfall time series have been made to compute rainfall departure and coefficient of variation. Southern Oscillation index,
Multivariate ENSO index and ENSO strength based on percentile analysis are used to ascertain their impact on rainfall distribution in the category as excess, normal, deficient and scanty. Results indicate that the variablility is greater over Kosi as compared to the other catchments. Probability of normal rainfall is found 0.75 and there is no possibility of scanty rain over the catchments during El Nino and La Nina year.

Nadarajah et al, (2007) applied the skewed Bessel distribution function to the rainfall data for Orlando, Florida and derived the estimation procedure by the method of maximum likelihood.

Avik Ghosh et al, (2010) studied seasonal, monthly and daily rainfall characteristics of meteorological sub-divisions of sub Himalayan West Bengal (SHWB) and Gangetic West Bengal (GWB) have been studied using rainfall data of 23 stations of India Meteorological Department (IMD) over the state of West Bengal. The two subdivisions have distinctive characteristics, though two stations lying in the plain region of SHWB have behavior more alike the stations of GWB. Krishnagar is a station with least seasonal rainfall in the entire state. Kurtosis and Skewness of the seasonal rainfall distribution have been computed and found that, for most of the stations they lie within reasonable limits. From the time series analysis, it is found that the seasonal rainfall has no trend.

Metri and Khushvair Singh (2010) analysed the rainfall features at different rain gauge stations of Goa state for the period of 30 years. The statistical parameters such as mean monthly rainfall, standard deviation and coefficient of variation have been computed for each rain gauge station of Goa. Some heavy rainfall events during
the period have also been studied. The study shows the significant rising trend of rainfall towards the eastern parts of Goa. Goa experiences an average rainfall of about 3300mm annually and around 90% of annual rainfall occurs during southwest monsoon season. It is revealed that most of heavy rainfall events caused due to active off-shore trough and low pressure systems formed over southeast Arabian Sea. It has also come out from the work that the orography of Goa plays an important role in rainfall distribution. Valpoi receives maximum rainfall due to its orographic effect.

Seetharam (2010) studied that the Pearsonian system of curves were fitted to the monthly rainfall from January to December, in addition to the seasonal as well as annual rainfalls totaling to 14 data sets of the period 1957-2005 with 49 years of duration for the station Gangtok to determine the probability distribution function of these data sets. The study indicated that the monthly rainfall of July and summer monsoon seasonal rainfall did not fit into any of the Pearsonian system of curves, but the monthly rainfalls of other months and the annual rainfalls of Gangtok station indicated to fit into Pearsonian type-I distribution which in other words is an uniform distribution. Anderson-Darling test was applied to for null hypothesis. The test indicated the acceptance of null-hypothesis. The statistics of the data sets and their probability distributions are discussed.

Suman Jangra and Mohan Singh (2011) investigated that Kullu valley is famous for tourism and agricultural activities but recently it has assumed important on the studies of climate variability. There is an increasing trend in minimum and maximum temperatures but no trend in annual rainfall. The slope of regression line for annual rainfall was negative at Bajaura and positive at Katrain but both were Non
significant. The coefficient of variation for annual rainfall (22%) and for monsoon rainfall (33%) was showing the consistence of annual and southwest monsoon rainfall but, a shifting of monsoon from its wettest months was observed. The rainfall was most variable during post monsoon season at Bajaura and in winter at Katrain. The decreasing rate in rainfall was higher during the recent period than the decadal period. Monthly, seasonal and annual average minimum temperature was showing decreasing trend at Katrain, but, maximum temperature is increasing at both the stations. The minimum temperature was most variable during the winter season whereas the maximum temperature was during summer. Higher the altitude higher the variability in minimum temperature. Both maximum and minimum temperature were showing a higher rate of increasing during the recent period.

2.2.2 Soil-air Interface

All interface with the atmosphere have a thin layer of air adhering to them called the laminar boundary layer. The thickness of this layer depends mainly on the roughness of the surface and external wind speed. With high wind speeds the layer becomes very thin or can even be temporarily absent. Within the layer any motion is laminar and thus convection is not present i.e., all non-radiative transfer across this layer is by means of molecular diffusion and since the molecule of air is very small, this layer provides an important insulating barrier between the surface and the atmosphere (Oke, 1978). During clear and calm nights the within- canopy heat differs considerably from the above- canopy state (Jacobs et al, 1994).

Land-surface processes strongly influence the dynamics of the atmosphere over a wide range of space and time scales through exchange of momentum, moisture
and energy. Soil surface temperature and moisture are key parameters of the energy balance between the land and atmosphere. Reliably modeling of surface temperature and soil moisture is crucial to simulate land-surface interactions (Yuei-An Liou and England, 1996).

Giorgi (1997) discussed a series of sensitivity experiments aimed at testing the surface heterogeneity representation. The temperature heterogeneity representation mostly affects the process of snow formation and therefore, the winter and spring energy and water budgets. The soil water heterogeneity primarily influence the processes of soil water movement and runoff generation, thereby modifying the surface hydrologic budget. Soil texture can be heterogeneous; however for land-surface atmospheric modeling purposes, it is often considered homogeneous.

Land-surface heterogeneity affects surface energy (Song et al, 1997). An analytical approach is presented to study the effects of spatial heterogeneity of land-surface parameters in climate models (Zhenglin Hu and Islam, 1980). Land-atmosphere interactions are examined for three different synoptic situations during a 21-day period in the course of the first ISLSCP (international satellite land surface climatology project). The objective is to better understand the relationship between biophysical feedback processes (Wai and Smith, 1998). Rodriguez-Camino and Avissar (1998) explored land-surface parameters such as soil wetness, roughness length, leaf area index that are mainly playing a role in land surface interactive models.

Land-surface interaction is greatly improved by Betts et al, (1998) through reanalysis of a previous model. An air-soil layer coupled scheme is developed by Xu
et al, (1999) to compute surface fluxes of sensible heat and latent heat. Bao et al, (2002) realized that the surface sensible and latent heat fluxes under a few roughness length schemes have been developed to fit observations under conditions maximum surface wind speed.

2.2.3 Temperature Profile

Temperature generally decreases with height but it must be modified for conditions near the ground. Temperature of the atmosphere can be achieved by introduction of temperature gradient known as dry adiabatic lapse rate that based on the concept, variation of temperature may be either due to change of pressure or conduction and radiation of and from the surrounding air.

In clear weather the temperature profile in the first hundred meters exhibits a marked variation whose character is best revealed by an examination of the vertical temperature gradient of atmosphere during the course of the day light shortly after dawn to about an hour before sunset, the temperature decreases with height, rapidly in the lowest layers and more slowly at greater heights, the gradient again being greater in the lowest layers.

In overcast conditions, the diurnal variations of the temperature profile, the function of temperature with height, almost entirely disappears, the gradient being small at all heights. The curves showing temperature profiles above and below the earth’s surface during day and night is given by Oke (1978). Also, temperature profile within the close ranges during clear and overcast conditions of soil-air boundary has been discussed in chapter 5.
2.2.4 Soil Moisture

The most important characteristic of the soil is the soil moisture, which regulates the strength of the heat flux between atmosphere and the ground. The presence of adding water to soil and at the point of contact between particles not only to improve thermal contacts but also to replace the air in the soil space with water. The greatest rate of increase in conductivity occurs at low moisture content (Baver et al, 1972). Yadav and Saxena (1973) theoretically derived a linear relation between heat capacity and soil water and verified it experimentally on Jobner sand and Udaipur clay.

Tripathi and Ghildial (1974) observed that heat capacities of the soil increased linearly with moisture up to 85% of saturation. The air content of soil is important since air is a poor conductor and has a low heat capacity. Thus, the surface layer of a dry soil is warmer during the day and cooler during the night than that of wet soil of the same type. Also ground that is covered by vegetation is protected from direct solar rays and therefore has a low daily range of temperature.

Soil temperatures are not only influenced by air temperatures but also by the presence or absence of an insulating layer of snow on the surface (Sturm et al, 1997).

Samu et al, (2002) in a comparative study of radiation and balance components on soybean crop and bare soil found that net and reflected radiation and albedo over canopy were higher by 7, 26 and 25% respectively than bare soil. The net short wave radiation and net long wave radiation evaluation over the canopy were less than those over bare soil by 5 and 20% respectively.
Pious *et al.*, (2009) studied the thermal mapping of seasonal variation of soil temperature at four locations of increasing altitudes in Central Kerala, India during cold and hot weather is presented based on special observations carried out during 1998. Subsurface characteristics like soil temperature, such as time lag, range of temperature, soil heat flux and speed of the seasonal variation of annual soil temperature are determined and it is seen that lower annual rainfall at Chinnar WLS has influenced temperature range and time lag at different soil depths. The loss or gain of heat either in cold or hot weather periods are totally location based. The velocity of annual wave during cold weather is lower than hot weather as the presence of soil moisture dampens the penetration of the wave into downward layers of the soil except at Silent Valley. Non-linear behavior of seasonal soil temperature characteristics gives the impression that localized effect due to homogeneous soil pattern would have played a part, apart from soil moisture.

Ecosystem respiration has been found to increase in response to a 1°C soil warming in a subarctic bog (Dorrepaal *et al.*, 2009) and to vary depending on seasonal temperature patterns (Lund *et al.*, 2010).

### 2.2.5 Thermal Diffusivity and Thermal Conductivity

The thermal properties of soil that govern flow of heat into or out of a layer of soil are thermal conductivity and thermal diffusivity. Study of heat flux is important for understanding the microclimate. The value of ground emissivity depends very much on the nature of the surface, and can often be rather less than unity. The primary heat source of soil comes from its absorptivity of solar radiant energy and the secondary heat source of soil come from the interior of the earth, known as
geotherms. Volumetric heat capacity of a Kharagpur sand clay loam showed a linear positive relation with bulk density and parabolic relation with soil water (Ghildyal and Tripathi, 1971). Singh and Sinha (1977) suggested that an appropriate approximation of boundary condition is essential for a reliable estimate of thermal diffusivity using heat conduction equation.

Soils with high diffusivity allow penetration of surface temperature changes. By the day, the surface heating is used to warm a thick layer of soil and at night the surface cooling can be partially offset by heat from a similar thick stratum. Soil with poor diffusivity consequently experience relatively extreme diurnal temperature fluctuations. Therefore, a wet day is conservative, whereas an almost dry peat is its thermal climate (Oke, 1978). The parameter soil conductivity is important because it determines how fast the ground cools. The coupling between heat fluxes in the air with that in the soil due to thermal conduction have been incorporated into the mathematical model given by Narasimha and Vasudevamurthy (1995).

Banta and Gannon (1995) found that the soil thermal conductivity is greater in moist soil and the higher thermal conductivity allows warmer soil temperature to diffuse upward to the soil surface and prevents the surface temperature from becoming as cold in the moist run as in the dry run. Using soil Vegetation Atmosphere transfer (SVAT), Peters-Lidard et al, (1998) demonstrated the sensitivity of sensible and latent heat fluxes and surface temperatures to the parameterization of the soil thermal conductivity.
Tessy Chacko and Renuka (2002) computed diffusivity from combined effect of first and second harmonics amplitude and phase angles that showed consistency with that calculated from time lag and range methods.

The total thermal response of the soil is directly proportional to its ability to transmit heat and it is viewed as a measure of the time required for the temperature changes to travel within the soil, i.e., in the morning the surface heat input penetrates rapidly in a soil where the thermal diffusivity is large.

The temperature rise within the top layers of the soil depends on the soil. Lower is the thermal conductivity of the soil, shallower is depth through which heat penetration occurs. Time lag of the thermal wave, which was lagging in maximum temperature of the succeeding level, i.e., 0.05m depth (Padmanabhamurthy et al, 1998) was used to work out thermal diffusivity of the soil (Oke, 1978). The computed values of thermal conductivity from observed data during the occurrence of Ramdas layer for winter 1994 and premonsoon 2001 were respectively found as $0.845*10^{-6}$ $m^2s^{-1}$ & $0.59*10^{-6}$ $m^2s^{-1}$ and 2.5 $Wm^{-1}K^{-1}$ & 1.05 $Wm^{-1}K^{-1}$ the thermal conductivity ($k_s$) was computed from the thermal diffusivity ($K_s$) using the equation given by Oke (1978) as,

$$k_s = K_s C_s.$$ 

Thermal conductivity during winter’ 94 is as 2.2$Wm^{-1}K^{-1}$ quoted by Oke (1978) against sandy soil (40% pore space-saturated). It is realized that high thermal conductivity of soil causes occurrence of the Ramdas layer.
The response of soil temperatures to changes in air temperature strongly depends on the temporal distribution, depth, and density of the snowpack during the winter (Lawrence and Slater, 2010).

2.2.6 Surface Energy Budget

Since Indian soils are highly variable in surface features such as chemical composition and physical characters, it is natural to expect significant variations in energy balance at the soil surface. Estimation of ground temperature and surface fluxes, prediction of minimum temperature near the soil surface were studied by Michael and Roger (1981). Hoskins and Bretherton (1972) showed analytically the dynamical important analysis. The role played by the surface temperature on heat exchanges between soil and atmosphere interface and its further import on plant growth and soil and formation have been studied by many workers in the past (Garatt, 1992 and Gupta et al, 1993).

The result attained by numerical tests on the planetary boundary layer model and further comparison with measured temperature profile and surface data inferred that the surface temperature controls the evolution of the whole profile (Salerno and Gianotti, 1995). Analysis of the observations and the surface energy budget for typical Bowen ratio provides a better understanding of the role of radiation in maintaining and destroying stable layers.

Land surface with fractional vegetation cover possess distinctive micrometeorological properties that complicate the use of energy balance models to simulate surface fluxes. A canopy level soil vegetation atmosphere transfer model was used to simulate component of the daily surface energy budget (Lee et al, 1995). The
energy and moisture states in the soil and near surface atmosphere evolve due to fluxes that are themselves a function of these states. Because the soil moisture and negatively correlated (dry warm and cool moist), physical mechanisms that tend to restore each state individually act as anomaly enhancing feedback mechanisms for the other state (Brubaker and Entekhabi, 1996).

Betts et al, (1996) assessed the diurnal and seasonal cycles of the surface energy budget, which used the summer 1995 version of the Medium Range Forecast (MRF) model. In order to improve and validate the SVAT parameterizations employed in meteorological models, Calvet et al, (1999) performed intensive measurements for three years over fallow farmland land-atmosphere exchange, the local climate was fully characterized, and surface water and surface and energy fluxes, vegetation biomass, soil moisture profile, surface-soil moisture and surface and soil temperature were monitored.

Best (1998) designed a model to predict the surface temperature of a variety of surface. This solves the surface energy balance equation using meteorological data. Simulations by atmospheric general circulation models at different atmospheric conditions show similar results for surface temperature and total net radiation when compared with observations. But, they underestimate latent heat flux and overestimate sensible heat flux in summer (Schulz et al, 1998).

Delire and Foley (1999) used five sets of biophysical and hydrological measurements from across the globe to test the performance of the integrated Biosphere Simulator (IBIS) in reproducing short-term evolution of soil moisture and temperature, Surface energy fluxes and CO$_2$ fluxes. Jegede (2002) found that the
variation of the surface energy fluxes balance with the amount of cloudiness appeared most dominant. Meijninger et al., (2002) observed a full account of the heat balance at the surface is difficult, mainly because of the complication arising from evaporation and condensation, the first operational weather predication, using an IBM 701 computer, began in May 1955 in the US in the joint force, and navy Weather Bureau project.

Statistical models are more analytical in nature. IMD also uses mathematical models based on thermodynamics and fluid mechanics to measure physical relationships between climatic conditions. These models are run on super computer because of the vast amount of numbering cringing involved. However, Indian prediction of models still falls short of accuracy. This is mostly because the data provided from imaginary satellite imagery is not always accurate and there is a problem of data correlation (Jennings, 2001).

The knowledge of climate variability over the period of instrumental records and beyond on different temporal and spatial scales is important to understand the nature of different climate system and their impact on the environment and society (Borgaonkar and Pant, 2001).

Despite climatic contract and variation from region to region, the monsoon provided a rhythmic cycle of the season year after year. Around this seasonal rhythm, the Indian landscape, the animal and plant life, its entire agriculture calendar and total life of Indian people revolve. The monsoon are characterized by their uneven distribution of rainfall in the country.
2.2.7 Variation of Soil Temperature

Soil temperature at various depths can be useful for many purposes like agriculture, meteorology, hydrology, climatology and the heat flux across soil-atmosphere interface. Guild (1950) carried out studies in the Arizona desert shows how calculation of the flux to or from the soil temperature reading gives the better understanding of the gain or loss of heat by the temperature at critical points during the diurnal exchange use of this information improve the calculation of minimum air temperature for frost and fog forecasting.

Energy balance at the soil surface and both temporal and spatial temperature variations within the soil are greatly affected by its specific heat and thermal conductivity. Lower heat capacity of the soil enhances the magnitude of the diurnal temperature changes. Chowdhury et al, (1991) using three hourly observations at Pune estimated and discussed heat balances at various depths. Soil temperature is dependent on incoming solar radiation, convective, latent radiative heat exchange between soil and atmosphere, spectral characteristics of the earth’s surface and thermal properties of soil profile. The diurnal and seasonal periodicities of radiation causes corresponding temperature cycles in soils.

Betts and Ball (1995) analyze the diurnal cycle of the 2m thermodynamic data averaged over the First International Land-Surface Climatology Project Field experiment site near Manhattan, Kansas, during 1987, using supporting data they present a summer mean stratified into dry and wet days, and the monthly seasonal cycle.
At several forested sites, systems are deployed to determine net ecosystem exchange rate and soil respiration. The implicit assumption is that the soil respiration estimated at the forest floor is the representative of the mean air surface exchange for a region directly comparable to above the canopy (Kell and Tilden, 2001). Wave decreases whereas the time lag between two adjacent waves increases with depth (Chaudhary and Sandhu, 1982).