CHAPTER 6

Summary and Conclusions

Western Ghats separates the states of Kerala and Tamilnadu by passing through the study area with an orientation of SE to NW with a length of about 700 km and an average height of 1 km in the study region. There is two Gaps for this mountain ranges in the study region, which is called Palghat Gap and Aryankavu Gap. Palghat Gap is a major Gap of about 25 km wide and connecting the Palghat and Coimbatore districts centered along the latitude belt of 10.7°N. While the Aryankavu pass is situated more southward along 9.04°N connecting the Kollam district of Kerala and the Madurai district of Tamilnadu. This pass is about half the width of Palghat Gap and the length also is very small.

The study region of the present research work extends from 8°N to 14.5°N and 75°E to 80°E. The southern part of the study region is very narrow and the terrain is less than 1000 m height which is known as the Cardamom hills or the Agasthya range. As move northwards, the height of the mountain increases. The highest peak in the Western Ghats is known as Anamudi in the Anamalai range. The height of the Anamudi is 2677
m and then it sharply decreases towards the Palghat Gap. In the north of the Gap, the terrain sharply increases and reaches the second highest mountain ranges in the Western Ghats known as Doda Beta of Nilgiri range which is about 2647 m. The northern part of the range is merging with the southern tip of the Deccan plateau. At those latitudes the slope in the western side of the mountain is sharp and it slowly declines as part of small mountain ranges in the eastern side.

The average distance of the coast from the 200 meter terrain of the Ghat in the western side is 100 km and that at the eastern side is about 200 km. The proximity of the high slope mountains in the western side especially at the northern end of the study region in Kerala is beneficial for the places thereby getting torrential rain in the major rain giving months of south-west monsoon. Eastern coast of the study region is in the regime of tropical cyclone and getting rainfall during the passage of these tropical systems through Bay of Bengal. Thus both sides of the Western Ghats are constantly influenced by Arabian Sea and Bay of Bengal and the ocean-land interaction is playing a major role in the weather and climate of the region as a whole. The high mountain ranges passing through the study area is also imparting its own influence on the climate system of the area and modifies the weather pattern in different seasons.

Since the study area covers by 5°latitude in the north-south direction, the variation of the surface meteorological parameters in the meridional direction is very small. Maximum variation is occurring due to the altitude of the stations. Spatial distribution of the temperature of the region shows that the northern part of the study area is cooler than the southern region generally. During the south-west monsoon months the western coast will be cooler than the eastern side of the mountain. The diurnal variation of temperature shows a marked difference in the north-south direction. The maximum temperature is not
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Persisting for long hours in the southern stations. In summit regions, the persistence of the maximum temperature is only for short period and decreasing thereafter. Mean deviation of temperature in the Winter and the Spring shows that there is sudden change in the atmospheric temperature after crossing the Western Ghats from west to east. A critical level of 1200 m height is influencing the temperature of the air column to great extent and above that level a mountain type of temperature variation can be seen over Western Ghats. Penetration of the monsoon rainfall reduces the subsurface soil temperature at 10 cm level in Kerala, also seen at summit region but with reduced intensity and not at all seen over Tamilnadu.

In the study region, the horizontal variation of the mean sea level pressure in the plain land is minimum. But along the high terrain the variation is maximum. As the elevation increases the mean sea level pressure also increases over the region. Since the density and the temperature over the summit stations in the Western Ghats are slightly higher than the surrounding free air, the mean sea level pressure is found to be higher than the plain land. Due to the steepness of the terrain, the value of the pressure gradient will be higher in the western side of the mountain than the eastern side and this difference in gradient between western and eastern side of the mountain is maximum in Winter than any other season. The semi-diurnal pressure wave is very clear in all stations in the region and the amplitude of this wave is about 1 hPa every where. The amplitude is same for both oscillations during the day and the phase also matches with the temperature variation.

The presence of strong westerlies will be there over the study region for the 5 months in an year. The easterlies coming over the eastern side of the study region finds the Palghat and Aryankavu Gaps for a smooth passage to the western side of the mountain. Northerlies also will be channelized towards more southern latitudes by the Western Ghats. The
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strengthening of wind over the region is seen between 1130 and 1430 hrs LT in a day. Wind speed generally increase from May onwards and it has a dramatic reduction during October in most of the stations. November also brings strong winds over the eastern region of the mountain. The average annual wind speed is found to be 3 ms$^{-1}$ over Kerala, 4.8 ms$^{-1}$ over Tamilnadu and 5 ms$^{-1}$ over the summit regions. The zonal component of the wind is stronger than the meridional component throughout the region in most of the season and it undergoes larger variability than the meridional. Summit regions are characterized by the undulating high winds.

Variation in the seasonal pattern or spatial pattern of vapour pressure is very small over the region. Palghat Gap plays a major role in transporting the vapour to the mouth of the Gap on both sides. The relative humidity value rarely goes below 60% over the region except in Spring season over the summit. There is an increase of 0.005 kg m$^{-3}$ density over the summit region. A small increase in RH is seen in the after noon hours over the study area which is a slight change from the midle latitude mountain environment. RH increases with height over all stations in the Winter season.

Summer and Autumn season creates a blanketing effect on the study region by generating more clouds and a reduction in the net radiative flux. Summit region also shows a reduction in the net radiative flux due to the increased clouding. As far as the noctural radiation is considered, the eastern side of the Western Ghats is found to be cooling faster than the western side in the night time. Presence of low cloud are more through the study region and a higher concentration is seen in particular at the summit region. A small diurnal variation can be seen for low and medium clouds and none for higher clouds in the study region. The surface meteorological parameters predicted by the model has been undergone ground truth check and the result is encouraging.
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The potential vorticity adjustments makes the circulation around a summit more complex. The wind blowing at the surface level should have a minimum energy to overcome a mountain in its flow path. But usually in the upper levels there will be a layer of air, that will try to cross over the mountain. During this process the potential vorticity readjustments will occur for the air flow and it will create a diffluence pattern of wind over the summit region and thereby creates cyclonic and anticyclonic vorticities over the mountain peaks. These patterns are quite visible over the Western Ghats in all season. It is generally called the curvature effect due to the generation of rotation of the flow over the region. It is found that the Coriolis adjustments are one order less than the vorticity adjustments over the mounatin in the Western Ghats. Hence the curvature effect is more dominant over the region.

Western Ghats modifies the synoptic scale meteorological parameters like relative humidity and temperature over the windward side. Ascend of air over the windward side creates more humid condition and the temperature is reduced by 2 to 3°C when compared with the lee side. All these changes makes considerable variations in the climate of the adjoining areas. Similarly an objective criteria has been developed for the surface air flow to cross over the Western Ghats. The condition prescribes that (1) there should be a minimum wind speed of 12 ms\(^{-1}\) at 950 hPa level (2) the minimum potential temperature of the air should be 28°C and (3) the positive vertical wind shear should be there from surface to the height of the mounatin.

The parameters like Froud’s number, Scorer’s parameters are calculated for the months having high wind speed to know about the capacity of the air flow to make a hydraulic jump over the Western Ghats. It is found that only in July all the three conditions are
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satisfied and the possible wavelength of the lee waves have been found as 55 m during that period. Capturing of lee waves in the model is very difficult with this resolution of the data. The chances of the formation of lee waves on the easterly regime is found to be a rare event over the Western Ghats.

The modification of the wind by the peaks are common over the Western Ghats region. The accumulation of the pressure gradients and the wind pattern towards the left side of the ridge of the Western Ghats are common and this is called the Corner effect of the mountain by Bergeron in the mid-latitudes. These corner effects are developing both in the westerly and easterly regime over the mounatin and creates unusual gusty winds over the valley regions. The developement of Fohn wind over the Western Ghats mountain region is found during the day time and it increases the potential temperature and reduces the relative humidity pattern over the lee side. These conditions disappear within hours in a day over the mountain.

Like Fohn wind, the developement of Anabatic and Katabatic wind systems are also very prominent over the Western Ghats region. The maximum wind speed of 2.1 ms\(^{-1}\) is seen for the gravity flows over the valley region. This occurs at the 10 m level. The calculated value of the gravity flows using the Reiher's formula is 2.6 ms\(^{-1}\) which is very near to the model value. Thus the night time Katabatic and day time Anabatic wind systems are creating a high wind zone over the valley regions of the Western Ghats in all season.

The modification of the winds by the major Gap like Palghat is phenomenal. Palghat Gap reduces the wind speed over the upwind mouth and increases over the peripheral of the downwind mouth. The annual mean wind speed is calcualted by the model through
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the Palghat Gap is about 3 m s\(^{-1}\) at the surface. A fanning out of the wind is observed near the boundary of the mouth at the downwind side. The adjustment of the dynamic pressure and static pressure of the air flow through the Gap creates intense subsidence over the downwind side and which in turn causes the reduction of the rainfall activity over that region. In this regard Coimbatore faces much problem than the Palghat side because of the high wind speed of the Westerlies. The arid condition is severe over Coimbatore and which is not that much even in the extreme boundary of the funnel mouth of the Gap.

The net radiative flux shows there is a surplus amount of about 700 W m\(^{-2}\) over most of the region except during Summer. Summit faces an unusual deficit of net radiative flux during the Spring season, which can also be attributed to the formation of clouds. The energy budget of the region shows that the availability of the latent heat flux will be half of the net radiative flux value and that of sensible heat is quarter times. The diurnal pattern in the variation of the net radiative flux is also there in the region.

Observed rainfall data of IMD shows that Kerala is getting about 298 cms of annual rainfall whereas it is only 94 cms for Tamilnadu. Only in December the rainfall in Tamilnadu exceeds that of Kerala by about 15 cms. The long term trend in rainfall indicates that the rainfall over Kerala is decreasing by about 2.4 mm per year, whereas Tamilnadu annual rainfall is decreasing at the rate of 1.4 mm per year.

The slope of the Western Ghats shows that the maximum slope is at the Western side of the Anamalai hills over Kerala (75.9\(^{\circ}\)) and on the eastern side it is around 73.7\(^{\circ}\) at the eastern side of the Nilgiri hills. The Malayattur-Neriamangalam stretch is having a slope of 14.5\(^{\circ}\) and is quite favourable for the rainfall activity. Along the Gaps, the rainfall is found to be decreasing dramatically with height. The relationship between the rainfall and
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The terrain height in the Western Ghats region shows that more rainfall in the windward side of the Western Ghats (Kerala region) is getting at the medium class (between 200-600 m) whereas in the eastern side it is in the high class (between 600-1000 m). The coastal rainfall shows a high negative correlation of -0.8 with the terrain of 1000 m or more over Kerala and -0.5 in Tamilnadu. This shows that the rainfall decreases as the high terrain moves away from the station. The increased rainfall activity over the northern Kerala during south-west monsoon months are due to the influence of these terrain effect.

Spatial variation of the rainfall over the region is complex due to the orographic effect and also due to some other dynamical reasons of the air flow. Over Kerala there is an increase of 270 mm per deg latitude and over Tamilnadu 5 mm per deg latitude of rainfall is seen during the south-west monsoon period from south to north of the study region. Valley regions of the Western Ghats on windward side receives more rainfall during the south-west monsoon months over Kerala. The downwind regions of the Gaps receives more rainfall during easterlies. Southern districts like Trivandrum is highly deficient of rainfall. Maximum rainfall is found to be getting at places away from the peak of the mountain by 20-40 kms. Places like Neriamangalam and Vyttiri gets maximum rainfall and minimum rainfall regions are located at the lee side of the Western Ghats. Maximum rainfall over Tamilnadu is getting at the southern district of Tamilnadu and the eastern coastal stations. Western and central region of Tamilnadu comes under severe shadowing effect of the Western Ghats.

The importance of the convective and non-convective rainfall is clear from the model results. The total rainfall in the study area is decided by the convective rainfall from the plain stations whereas the rainfall during the north-east monsoon is decided by the combined effect of plain as well as the summit stations. The contribution of the evaporation
and condensation of the different region towards the total system is calculated by the model. Evaporation from Kerala region shows maximum input of 44% and minimum (11%) by the condensation over Tamilnadu towards the total input of the region. Thus Kerala is in the front run than Tamilnadu in evaporaton and condensation of the region. The negative correlation of the frictional velocity and the rainfall activity has been established over the region and the minimum frictional velocity over Neriamangalam and Vyttiri are the cause of the high amount of rainfall activity over the region.

Precipitation rate increases with orographic lift and it is found a high positive correlation of about 0.8 over the Western Ghats region at a height of 1700 m. Above this altitude precipitation rate decreases. Larger variability of the latent heat flux and sensible heat flux are seen over Tamilnadu compared to that of Kerala. The increase of 60 Wm$^{-2}$ of sensible heat flux in the atmosphere is creating the high temperature pattern over the mouth of the Gap region. Bowen’s ratio shows the increased moisture stress over the region, and the value is comparable to that of an arid condition.

The influence of the Western Ghats over the atmospheric pressure pattern of the region is negligible over the plain stations. There is a general reduction of about 1.5 hPa pressure over the region when the orography is removed. Mountain makes kinking in the pattern of isobars and even in the isotherms. Western Ghats do not interact with the diurnal pattern of the pressure. Generally when the orography is removed the isolines will be concentrating over the coastal region. Mountain changes the temperature pattern in the vertical also. The mean deviation of the temperature over the region, especially at the eastern region is mainly controlled by the Western Ghats. The control of the Western Ghats over the soil temperature of the plain stations around is nominal. The winds will be more streamlined in the absence of orography. A general increase of about 1 ms$^{-1}$ is found all
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over the region. Frictional velocity stabilizes over the region, even if the value is higher than the normal condition by 0.1 ms\(^{-1}\).

Western Ghats generally helps to maintain the high value of RH over the plain stations on both sides of the mountain. An elevation of 1800 m reduces the precipitable water content by 2.3 kgkg\(^{-1}\). During Spring season Western Ghats helps to get some surplus energy in the western side. Western Ghats plays a major role in the formation of low and medium clouds over the plain region and have no role with the formation of high clouds. But over summit region the formation of all types of clouds are due to the influence of the Western Ghats.

The PBL formation is retarded by the impact of Western Ghats over the region and the smooth flow of the wind over the plain stations are supporting by the mountain slopes. Plain stations on both sides of the mountain receives more latent heat flux. When the Western Ghats is removed, the rainfall activity over the main land over Kerala and the coastal regions on both sides reduces. The increase in the plains of Tamilnadu is 68.6%. In the case of evaporation Western Ghats reduces the activity over Tamilnadu in all season and in Winter over Kerala. Condensation activity is reduced when the orography is absent.

The divergence and the vortex fields are changing by Western Ghats dramatically. This is clear when the changes occur in these fields in opposite directions when the orography is removed. These effects are more in the eastern side of the Ghat than the western side over Kerala. Analysis of the Turbulent Kinetic Energy shows that the mountain is not much modifying the flow characteristics over the plain stations but the change is more over the summit and also in the vertical direction.
Palghat gap also controls the climate of the nearby region considerably. When the Gap is closed there is a drop in the temperature pattern on the exit regions of the Gap. Due to Bernoulli’s effect the wind speed in the upwind regions are reducing with a magnitude of 61% over Kerala and 33% over Tamilnadu. At the downwind region the wind speed increases by 45% over Palghat and the variation over central region of Coimbatore district is negligible.

Thus in all aspects Western Ghats play its role in the weather and climate of the region. The Gaps in the Western Ghats acts as a regulating mechanism for the climate of the region near to it on both sides. Lot of perineal rivers are originating from the upper regions of the Western Ghats which makeup the shortage of the water in the regions where the rainfall deficiency is there and makes the region more fertile. The best example is the Bharathapuzha makes the Palghat region more agriculture oriented land and make it as the food granary of the Kerala state and also in the eastern side, Tiruchirappilly district is blessed with the river Kaveri which is controlling the vast agriculture land of the state. Thus by maintaining the river systems and the vast tropical rainforests over the region, Western Ghats plays a fair and remarkable role in making the southern peninsular India a beautiful land.

6.1 Future Outlook

The modelling study over the hilly terrain is needed with a high resolution data in order to study the dimensional effects and the relief effects over the terrain. The generation and impact of the Lee waves are to be studied with high priority, which also needs high resolution data set. The data sparse region of the hilly terrain makes the ground truth studies difficult and a meso-network observations should be initiated over the area to understand
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the variability of the meteorological parameters more clearly. A regular and precise obser-
vation network is needed at the valley region at least to understand the behaviour of the
gravity winds emerging through the region and which makes tremendous changes in the
local weather pattern over the region. The behaviour of the vast tropical rain forests over
the land should be studied more clearly and the effect of the green surface canopy should be
included in the model inputs at the terrain features, so that the representation of the atmo-
sphere will be genuine and most of the chaotic nature of the atmosphere over the mountain
ranges can be very well be quantified. The detailed study of the hydro-meteorological as-
pects of the main river basins of the region also should be included to the climatic studies
for the total understanding of the weather and climate of the region.