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A Study of Urban/Rural Cooling Rates in Thiruvananthapuram, Kerala.

Shareekul Ansar, C.R. Dhanya, George Thomas, Aswathy Chandran[1], Liji John[1], S. Prasanthi [1], R. Vishnu, and E.J. Zachariah

Atmospheric Sciences Division, Centre for Earth Science Studies, PB 7250, Thuruvikkal P O, Thiruvananthapuram - 695 031

[1]Department of Physics, University of Kerala, Kariyavattom, Thiruvananthapuram - 695 681

Email: shareekul@ gmail.com

ABSTRACT

The inhomogeneous cooling rates in the urban centre and adjoining suburban area and its effect on the Urban Heat Island (UHI) in Thiruvananthapuram city in peninsular South India was investigated. Air temperature variations across the study area were recorded by mobile traverse method. Cooling and warming rates in the urban centre and suburban area were derived from stationary air temperature recorders installed at these locations. The UHI intensity at this location was 2.4°C. Significant difference in the urban and rural cooling rates was observed. The maximum cooling rate in the city centre was 1.5°C/hr and 3.4°C/hr in the rural area.

INTRODUCTION

Urbanization leads to micro-climate changes, particularly with regard to the thermal structure of the location. Most documented among such changes is the Urban Heat Island (UHI), which has received increasing attention during recent decades. Factors leading to the excess heat of towns are changes in the thermal characteristics of the surface, modification of the air flow patterns, reduction in evaporative cooling and heat added by human activities (Padmanabhamurthy & Bahl 1982). The relative importance of each of these factors varies from town to town and also on the time of year and time of day. The storage of solar heat during day time and its slow release at night is the major reason for UHI. High specific heat capacity of building materials and their emissivity changes in comparison to the natural surroundings, impervious engineered surfaces like roads and paved spaces, change in surface roughness, blockage of wind due to buildings, reduction in sky view factor and associated blockage of outgoing long wave radiation from surfaces, reduction in vegetation and associated reduction in cooling through evapo-transpiration, etc., are the major factors contributing to UHI. Anthropogenic heat generation including metabolic heat, domestic and vehicular heat etc., also are contributing factors.

An Urban Heat Island (UHI) develops when urban cooling rates are lower than what would have been, had there been no urbanization. Cooling becomes maximum around 3 to 5 hours after sunset (Oke et al., 1972). As night advances the cooling rates in the urban and rural sites become similar and attain steady state by midnight and then remain nearly constant until sunrise. The growth and intensity of heat island depends upon the cooling rates of urban and rural environments. The markedly different thermal properties of the surfaces make the rates of cooling of urban and rural environs differ widely and growth of the heat island intensity varies with time of the night (Oke 1989).

The proportion of urban dwellers is increasing. Current proportion of urban dwellers is 50% of total population and is estimated to reach 60% by 2030. Any changes in the urban environment can thus affect a majority of population.

METHODOLOGY

The study was carried out in the Thiruvananthapuram city and suburbs in South India covering approximately 250 km^2. Thiruvananthapuram is predominantly a residential city with a population of nearly one million. The city is situated on the west coast of peninsular India and is bounded by Arabian Sea on its west. The Western Ghats mountain range lies about 40 km to its East. The annual rainfall is over 1700 mm.

The city centre of Thiruvananthapuram consists of mainly compact built up area with moderate traffic and pavements. The reference temperature was taken from a temperature recorder installed in a Stevenson's screen at Akkulam, a suburban location in the study area.

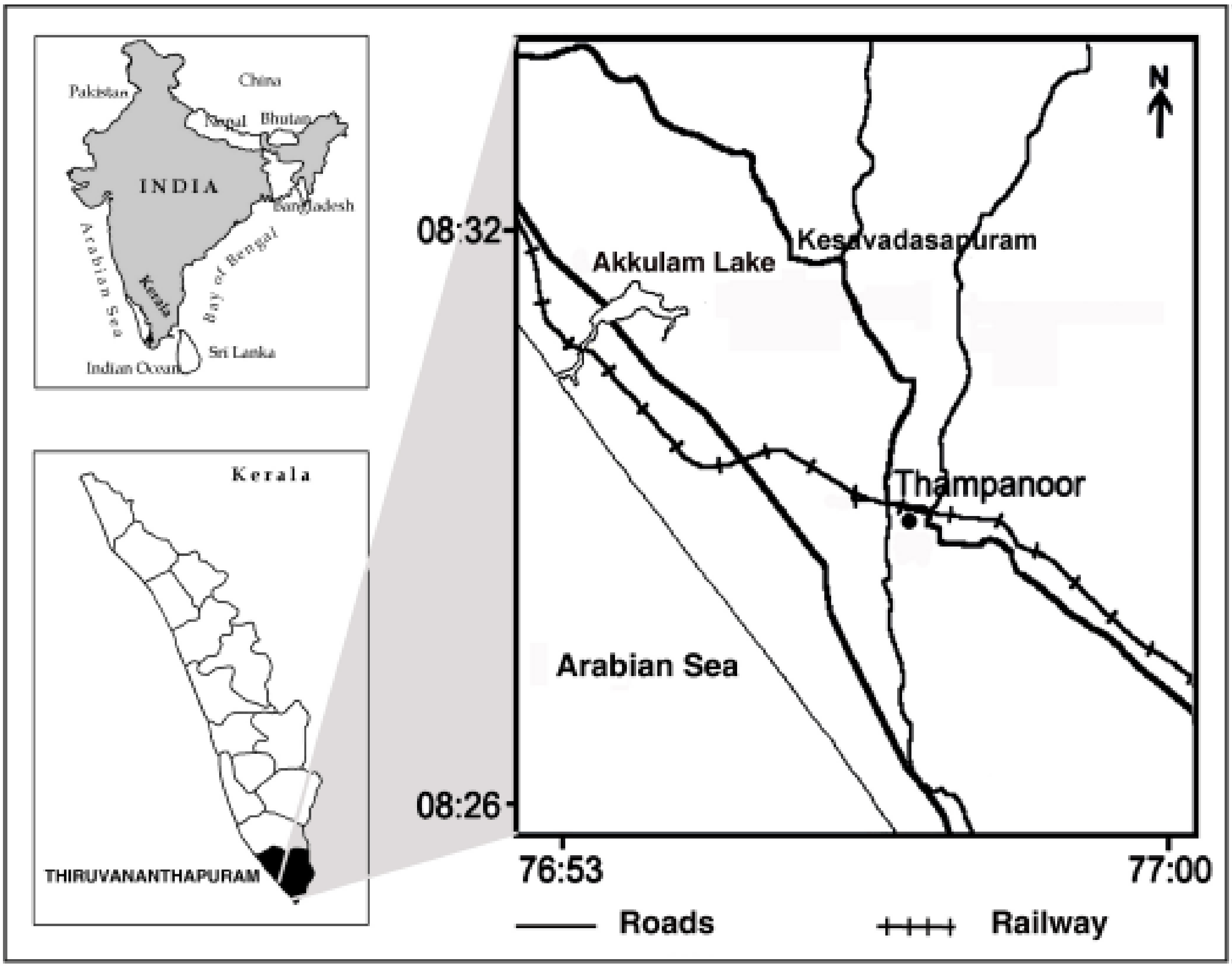

Figure 1. Sketch map of study area.

DATA

Automatic temperature recorders (Madge Tech, USA, Model: Temp101) with 0.1°C resolution were used for reading air temperature. The temperature sensor and recorder were calibrated in the range 20 °C to 40 °C with an expanded uncertainty of ±0.17°C. The recording interval could be programmed between 2 sec to 12 hrs, and was set at 5 sec for mobile traverses. Mobile temperature recording was done on June 29th 2010. Automatic temperature recorder was installed inside a radiation screen on a vehicle, taking care to keep away from the engine heat. The vehicle was stopped for 2 minutes at each point on the survey route. The temperature recorder was logging temperature data along with time stamp automatically at 5 second interval. At each point of observation, the co-ordinates were taken from a hand held GPS and time of observation was noted with a chronometer synchronized with the temperature recorder and GPS. The reference temperature was taken from a temperature recorder installed in Stevenson's screen at Akkulam, a suburban location in the area. The instantaneous temperature difference between all observational points and the reference site was calculated in order to determine UHI intensity.

RESULTS AND DISCUSSION

The UHI profile across the city was plotted and shown in the Fig.2. The existence of a moderate urban heat island is clearly visible in the plots. The growth and the intensity of heat island depend up on the cooling rates at urban and rural environments. Heat island intensity is enhanced by dense building materials that are slow to warm and cool. They store considerable heat energy during the day time and release it during night.

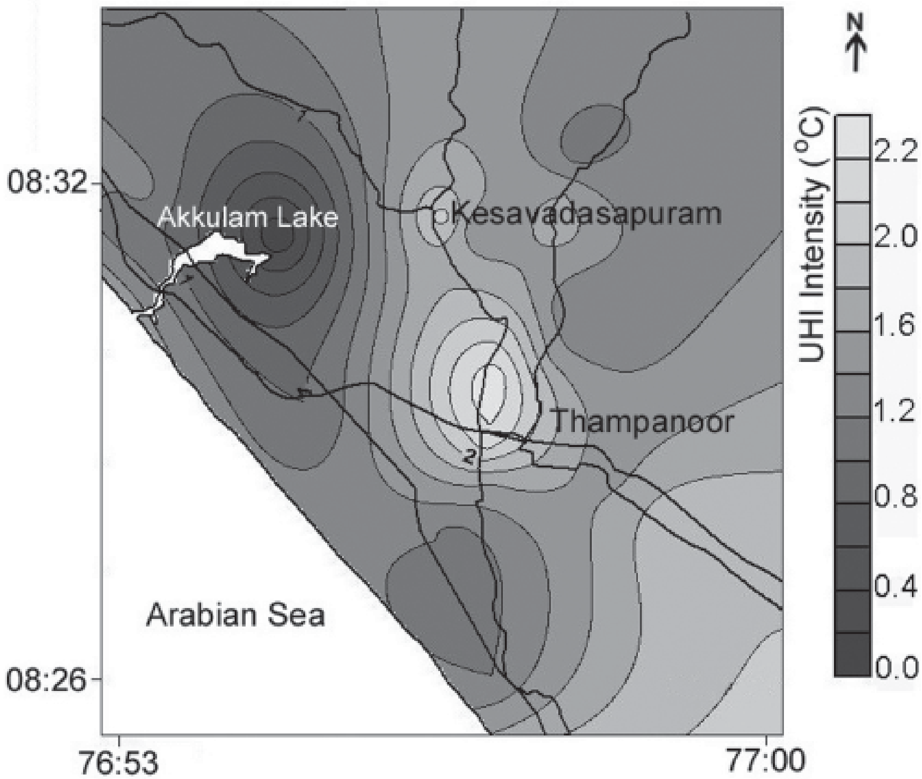

Figure 2. UHI in Thiruvananthapuram City.

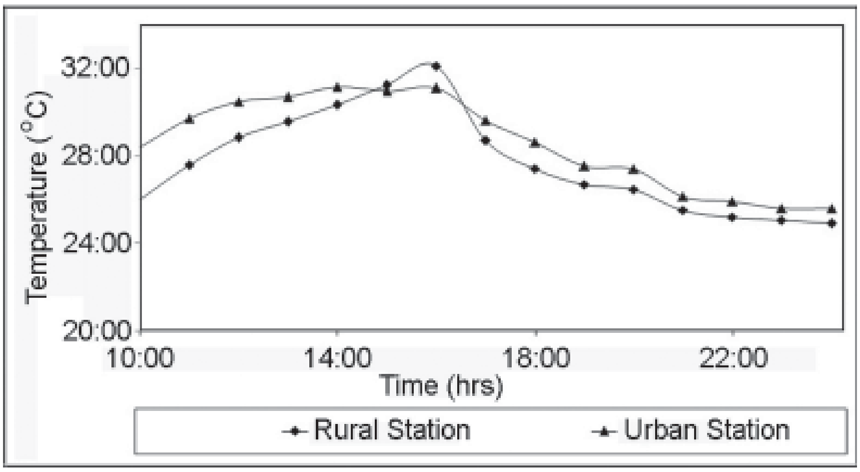

Figure 3. Air temperature observed at Urban and Rural stations.

The maximum UHI intensity is 2.4 °C in the city centre. The map (fig.2) shows a variation from high in the southern urban area to low in the northern suburban area. The profile shows relationship between building density, presence of vegetation, etc., and the intensity of UHI.

The UHI here shows good correlation with the local climate zone classification (Stewart & Oke 2009). The regions showing higher temperature come under compact low rise and compact mid rise class. Major physical characteristics of these classes are regions having dense compact sky line buildings of 1-3 stories (low rise) or 3-8 stories (mid-rise) with narrow streets. Because of this sky view is significantly reduced. The higher temperature is also contributed by the street canyons, heavy construction materials, paved streets etc. Regions showing lower temperature fall under Open set low rise and sparsely built classes. Zone definition of these classes are the regions with small, low rise buildings of 1-3 stories tall separated by natural surfaces and set along medium- width streets, low space heating/ cooling demand, high sky view factor etc. Reduction in the vegetation and decrease in the surface water / soil moisture in the city also influence the intensity of UHI.

Air temperature at urban and rural areas plotted as function of the time of the day is shown in Fig.3. The heating rates in the city and reference site are shown in Fig.4. The heating and cooling rates shown in Fig.4 and Fig.5 are the average cooling rates computed for three hour intervals. Heating rates show a higher value in the rural area, as expected. The dense buildings restrict the sky view factor in cities. This reduces the heating rates there.

Cooling rates in the city and the rural area have been obtained and are given in Fig.5. Maximum cooling rate is observed immediately after sunset. As night advances, the cooling rate decreases and a low steady rate is attained by midnight.

Significant cooling is observed in rural environs whereas the dense urban areas showed a much lower cooling rate after sunset. The maximum cooling rate of 3.4 ^{o}C/hr was found in the rural area, observed immediately after sunset. The corresponding value at the city centre was 2.4 ^{o}C/hr. The difference in the cooling rates at rural and urban areas reduced as night advanced.

Wind is a major influence upon the cooling rate at any location. An increase in cooling rate observed during 20:00 hrs to 21:00 hrs in Fig 5, is due to the increase in wind speed at this time as observed in Fig 6. High building density in the city centre blocks the wind flow within the Urban Canopy Layer and reduces cooling. The street alignment in terms of the predominant wind direction also will have an influence on the wind flow within the Urban Canopy Layer (UCL) and cooling there. Wind speed and direction were recorded with an automatic weather station. A record of wind speed is given in Fig. 6.

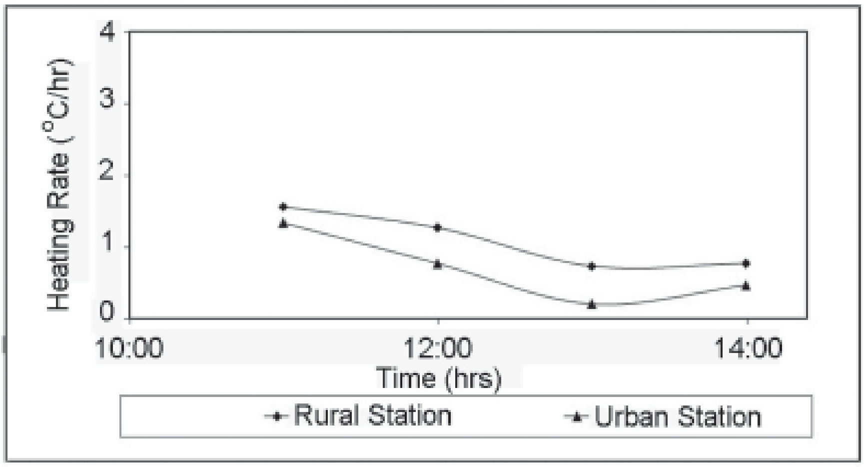

Figure 4. Urban and Rural heating rates.

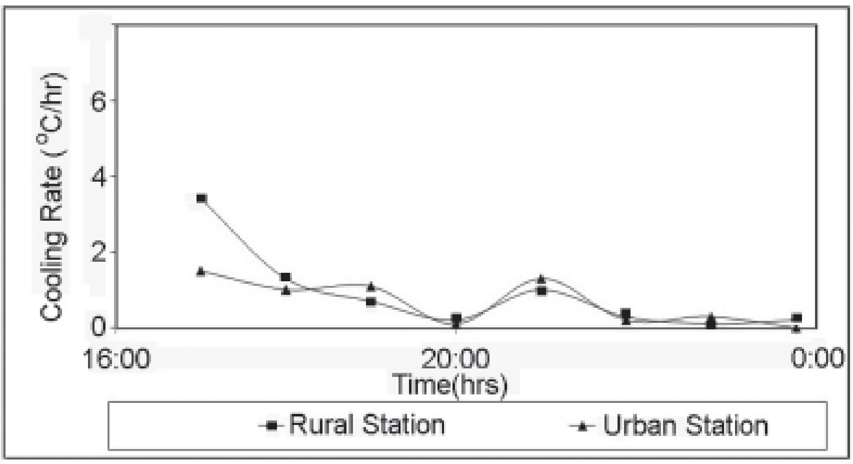

Figure 5. Urban and Rural cooling rates.

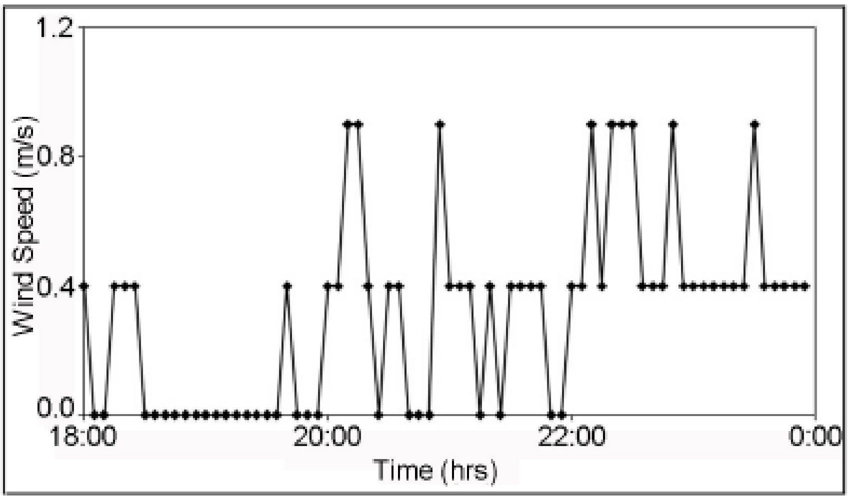

Figure 6. Wind speed recorded at the study area.

The influences of urbanization on meteorological parameters and UHI in many urban centers of the world, including major cities in India, have been studied by several authors (Rao et al., 2004, De et al., 2001). These studies show a non-uniformity of meteorological parameters for various urban agglomerations.

The magnitudes of heat island in Chicago city was characterized by diurnal and seasonal cycles. The heat island intensity of 3 °C is most pronounced during the summer particularly in August when there were few clouds and relatively low winds. While for broken to overcast skies and winds in excess of 3.5 m/s it was found to be 1 °C (Ackerman 1985). UHI in Athens, Greece, shows intensity of 2° C to 3° C. This is seen more in minimum temperatures than in the mean and maximum temperatures. This has been explained by physical mechanisms such as heat production from anthropogenic activity and the heat release during the night (Katsoulis 1985). Toledo's Urban Heat Island is most intense in summer when mean monthly temperature is 2.5 °C to 2.6 °C warmer than the downtown area. However, this is least evident during winter and spring. This seasonal variability in the heat island is attributed to seasonal changes in radiation, cloud cover, wind speed and the effects of Lake Erie on local temperatures, etc. (Schmidlin 1989).

The UHI in Chennai, a coastal city in South India shows a maximum intensity of 2.48 °C during summer and 3.45 °C in winter respectively. The study assesses the relationship between the increase in urban air temperature and the urban built up spaces, vegetation, parking lots etc. Construction activities, anthropogenic heat emissions, high density built up spaces, thermal properties of materials, transportation modes contribute significantly to UHI (Devdas & Lilly 2009).

Delhi reported a UHI intensity of 5 – 7 °C. The UHI intensity is found to be nearly 5 °C during December and about 7 °C in the months of January and March. Though the extent of UHI over an area is found to be depending on the prevailing wind, topographical features and local effects, the centre of heat island formation is seen in the areas having maximum build up and mobility (Padmanabhamurthy & Bahl 1979). Increased low cloud and windy conditions have been identified as reasons that can reduce UHI. The proximity to the Yamuna River is also found to affect the heat island in Delhi (Padmanabhamurthy & Bahl 1981). Measurements of heat island in Delhi during1982 showed that the early morning heat island is stronger than the early night. It is also observed that Humidity Island in the early morning was in phase with heat island but the early night peak has shifted by one hour (Padmanabhamurthy & Bahl 1982). The UHI intensity in Delhi during summer, 2009 shows peak values in night at 9 PM (8.3°C) and afternoon hours at 3 PM (7.6 °C) respectively. The higher UHI observed during summer increases the energy demand which would eventually generate more anthropogenic heat and thereby amplify the UHI. During the rainy season also UHI in the city shows a significant value in the range 2.2 - 3.7 °C (Mohan et al., 2009).

Pune showed heat island intensity of the order of 6 °C on a calm day but reduced significantly to 2 °C on a day with wind of 5 to 10 kt. Maximum difference in the temperature between the urban and adjacent rural areas in Bombay also shows a high value of the order of 6 °C. It is also reported that the rural lapse rate corresponding to the urban temperature excess of 6 °C in Bombay during March 1972 was -0.54°C / mb (Daniel & Krishnamurthy 1973). A high UHI intensity of about 11 °C was observed over Bombay during cold night in 1975. The spatial temperature distribution is found to be influenced by proximity to the sea, concentration of population, tall buildings, industry and prevailing wind field (Mukherjee & Daniel 1976). UHI mobile survey over Brihan Mumbai in 1997 has shown that the temperature distribution in the city and suburbs has been significantly modified during the preceding two decades due to rapid urbanization, industrialization and the population growth in the city of Mumbai. It is reported that the intensity of the heat island during summer was 5.5 °C and during winter was 12 °C. It is noted that the average UHI here is quite high of the order of about 8.5 °C (Kumar et al., 2001).

Heat island formation at Vishakhapatanam, a tropical coastal city of South India varies from 2 °C to 4 °C and intensity is high during winter season. The formation of heat island is controlled by topography and urban morphology. Presence of a large water body, the Bay of Bengal plays a great role in moderating the intensity of UHI (Devi 2006). The UHI in Kochi, a coastal city in peninsular India was 2.2 °C in summer and 2.4 °C in winter. The average UHI here is moderate at 2.5 °C. Whereas in other coastal cities like Chennai, Calcutta etc., UHI intensity of 4 °C and above have been reported. On the other hand UHI intensity in cities located in continental interiors like Bhopal, Delhi etc., are in the range of 6-10 °C. The UHI intensity in Kochi is seen to be substantially lower than that in other coastal cities in the region. It is inferred that the canals and wetlands which lie within the city have played a significant role in moderating the heat island intensity here (Thomas & Zachariah 2011).

It is observed that the UHI intensity in Thiruvananthapuram is comparable to the UHI observed in other cities, especially coastal cities like Kochi, Chennai, etc. The urban and rural cooling rates have been found to differ significantly, which is the primary reason for the UHI. The city centre where the UHI is most intense is heavily built up and falls under compact mid rise classification. The reduced heating rate in the city is also due to high building density and low sky view factor.

CONCLUSIONS

Cooling and warming rates in Thiruvananthapuram, a medium sized urban area in peninsular South India were investigated. Rates were found to vary with time of the day. The peak cooling rate recorded at rural area was 3.4 °C/hr while highest at the urban site was only 1.5 °C/hr. Intra urban temperature differences were observed and were accorded to the different building density and surface features. The study shows medium intensity UHI with maximum value of 2.4 °C in the city centre. The spatial pattern of the UHI is in agreement with the Local Climate Zone classification.

However, the variation due to seasonal changes in the atmospheric temperature, stability, wind and humidity may influence the cooling rates.

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Shareekul Ansar has obtained his M.Sc. in Physics from Bharathidasan University, Tiruchirapalli (2008). He had been working as Junior Research Fellow in Cochin University of Science and Technology before joining Centre for Earth Science Studies in 2010. His research topic is Urban Climate.

Dhanya.C.R. has got M.Sc in Meteorology (2009) from Cochin University of Science and technology and a recipient of CSIR Junior Research Fellowship. She is currently working as Junior Research Fellow at Centre for Earth Science Studies. Research interest is Urban Heat Island studies.

George Thomas is a Research Scholar at Centre for Earth Science Studies, Thiruvananthapuram. He has completed M.Sc. in Physics (2006) from Mahatma Gandhi University, Kottayam and is currently pursuing Ph.D. in Urban Climatology. He has three years of research experience in marine sampling and Gas Chromatographic analysis.

Aswathy Chandran has completed her graduation from All Saint's College, Trivandrum and Post graduation in Physics from Dept. of Physics, University of Kerala.

Liji John has got her B.Sc. and M.Sc. in Physics from University of Kerala. She is presently doing M.Phil. at Dept. of Physics, University of Kerala.

Prasanthi. S. has completed her B.Sc. Physics from HHMSPBNSS College for Women, Neeramankara and got her M.Sc. degree in Physics from University of Kerala.

R. Vishnu presently pursuing his Ph.D. in Physics from the University of Kerala through the Centre for Earth Science Studies, Thiruvananthapuram. He did his Masters in Physics from the University of Kerala and M.Phil from the Bharathidasan University. He has been working in the field of lightning studies and related instrumentation for the last four years. He is also engaged in cloud parameter measurements and cloud modelling studies. He has about 15 publications to his credit including national and international conference proceedings. He is a recipient of young scientist award of the year 2008 by the Gov. of Kerala.

Dr. E. J. Zachariah has been working as Scientist at Centre for Earth Science Studies, Thiruvananthapuram since 1980. He received M.Sc. (1976) in Physics and Ph.D. (1982) in Microwaves from Cochin University. His research interests are Green house gases, Urban Climate, Renewable Energy System.