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学 位 論 文 要 旨
Dissertation Summary

氏　　名 (Name) Sweata Sijapati

論　文　名: Study on Local Cloud Coverage Using Ground-Based Measurement of Solar Radiation
(Dissertation Title)

In recent years, factors such as climate change and unplanned land use might have resulted in intense and frequent localized torrential rainfall in urban areas. Urban flood has severe impacts, particularly in terms of economic losses both direct and indirect. Thus to understand about these urban phenomenon, attention has been paid on urban local climate such as heat island phenomenon and its impact on torrential rainfall. The relationship between urbanization and the increasing trend of rainfall has been documented by many researchers (Fujibe, 1988; Matsumoto Takahashi, 1999; and many more). Many studies have been done on clouds and its classification, which are the basis of the precipitation (Bornstein and Lin, 200; Williams et al., 2015). The cloud and its type in turn plays and important role by determining the amount radiation reaching the surface (Reno et al. 2012). The reduction in the solar radiation is closely associated to the thickness of the clouds (Leontyena and Stamnes, 1994; Thapa Cheetri et al., 2015). Therefore, the magnitude of the solar radiation becomes an index of the thickness of the cloud aloft. Thus, the temporal and spatial variation of solar radiation and cloud is important to understand the concept of local cloud. In past, several studies regarding the radiative fluxes and cloud cover from satellite data have been widely used. However, there are limitation when it comes to spatial resolution. Thus, the main objective of the study is to develop a new technique to monitor

the local cloud coverage using ground-based solar radiation monitoring network and to explore the potential of the method in Matsuyama plain. The first method includes the temporal and spatial analysis of solar radiation using pyranometer network and the second method include the spatially dense monitoring of solar radiation using photovoltaic (PV) network.

The amount of solar radiation varies with both time and latitude; thus we introduce the clear sky rate (hereafter CSR) to estimate the percentage of solar radiation blocked due to the presence of cloud. Here in each month, the highest amount of solar radiation per minute was taken into account to create a time series data of a virtually sunny day. Then the time series data of the virtually sunny day were compared with the time series data of the target day and the CSR was determined (Equation 1). The CSR is further used to perform the statistical analysis to study the cloud coverage and properties.

$$Clear\ sky\ rate = \frac{Radiation\ of\ a\ target\ day}{Radiation\ of\ a\ virtually\ sunny\ day} \quad (1)$$

Initially, the one-hour time standard deviation of the CSR for the 7 observation sites of the pyranometer network was considered for the analysis. The diurnal variation of the CSR showed the presence of the cloud to be more in the morning and late afternoon with maximum value around midday. Similarly, the monthly average of the CSR indicated the presence of the cloud to be more in winter as compared to other observation month. Following the manner, the spatial variation of the solar radiation in the study area was considered. The CSR at the inland area of the Matsuyama plain was found to be smaller as compared to all other observation sites. Also, the formation of cloud was observed to be high in the urban area and the inland area. Thus, the temporal and spatial distribution of the solar radiation for the entire study period shows the tendency of cloud formation to be more in the urbanized and the inland area of the study area. A similar observation was reported by Inoue and Kimura (2004) in which they explained the frequency of low-level clouds to be higher over the urban area than over the rural area

As the pyranometer network sites were limited for the monitoring of the solar radiation distribution of the entire study area. The estimation of global solar radiation using PV system was proposed and examined on the basis of in-situ measurements. The annual daily mean temperature of Matsuyama is approximately 16.6°C with annual sunshine duration of more 2000 hours making it appropriate for the production of solar energy. The use of solar panels has been increasing from houses, commercial building and schools and thus, Matsuyama plain was selected as the study site for the dense monitoring of the

radiation using the photovoltaic network.

Solar panels were installed horizontally and at a tilt angle of 20° due south. The estimated global radiation and the measured solar radiation were observed to be in high correlation for the horizontal panels. To estimate the global solar radiation using a tilted solar panel, it is necessary to convert the solar radiation on a slope to the global solar radiation on a horizontal plane. Thus, for this conversion the separation of the solar radiation into a direct beam solar radiation and diffuse solar radiation becomes necessary. In the separation model, simple assumptions were taken into consideration such as the reflected solar radiation from the ground surface are isotropic, the uniformity of the diffuse solar radiation and using the Erbs et al. model (1982) for the estimation of the diffuse solar radiation on a slope. The validity of the method proposed for the estimation of global solar radiation using solar panels at a tilt angle of 20° was confirmed with high correlation irrespective of the season.

Further, the temporal and spatial variation of the estimated global solar radiation was studied using the photovoltaic network established within the study area. The estimation of the global solar radiation for all the observation site was confirmed with high correlation. The study was verified using the whole sky images taken by a camera mounted with a fisheye lens installed on the rooftop of Engineering building at Ehime University to monitor the distribution of clouds. Here along the observation time period, the spatial distribution of the solar radiation and the distribution of cloud studied from the whole-sky photographs were in agreement with each other. Thus, the potential of using the estimated global solar radiation to monitor the distribution of the solar radiation and the cloud coverage was studied with high efficiency.

To monitor the efficiency of the PV system as a solar radiometer, comparison of the pyranometer observation and the PV observation was conducted. Considering this, the temporal and the spatial variation of the one-hour average time standard deviation of the CSR using the PV observation dataset was calculated. The diurnal and monthly variation of the CSR from the pyranometer observation and the PV observation was found to be in high correlation with each other. Thus, all the above result confirms the accuracy and the good performance of the proposed method for the ground-based monitoring of the solar radiation in Matsuyama plain.

As explained before, the classification of the cloud is of utmost importance to measure the radiation reaching the surface and precipitation. Thus, the one-hour time standard deviation of the CSR was taken into account to determine the type of clouds in the

study area. The CSR varied from 0 to 1 indicating the cloudy and clear sky condition, respectively. The cloud distribution and the sky condition over the study area was validated using the whole-sky camera installed at the Ehime University. The clear sky rate below 0.4 with smaller time standard deviation showed the cloud coverage to be larger with dominance of water bearing clouds such as stratus or cumulonimbus. The maximum and minimum time standard deviation within the clear sky rates between 0.4 to 0.8 shows the dominance of the cumulus clouds and high raised clouds such as cirrostratus to cirrus, respectively. Similar results were also explained by Duchon and O'Malley (1998) in their study for the estimation of the cloud type using the pyranometer observation. Both the pyranometer and PV observation showed similar cloud type and sky condition within different ranges of clear sky rates.

In conclusion, the local cloud coverage of the Matsuyama plain was studied efficiently using the ground-based measurement of the solar radiation. The potential of a PV system to be used as a radiometer for monitoring the temporal and the spatial distribution of the solar radiation and the cloud type was confirmed with high accuracy. This study is applicable for all the megacities and urbanizing areas with increasing number of PV system for monitoring the effects of urbanization. The estimation of the global solar radiation can be beneficial for understanding the local climate studies such as torrential rainfall. The dense photovoltaic monitoring of the solar radiation in order to cover the entire study area based on the land-use categories needs to incorporated to study the effect of urbanization on the local climate remains for the future work.