Temporal and spatial variation of urban cloud in various cities in Japan

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1. INTRODUCTION

Local clouds and their properties are important because they are initial stages of the rainfall processes. Lately, several studies have been carried out for the understanding of local cloud properties. Formation of cloud and its thickness highly effects the intensity of downward shortwave radiation at the surface level (Thapa Chhetri et al. (2017)[1]). The objective of the study is to see the temporal and spatial variation of urban cloud in various coastal cities in Japan, using satellite downward shortwave radiation dataset developed by Takenaka et. al (2011)[2]) .The diurnal variation of cloud was analysed by calculating the clear sky rate (CSR). Among the study area, Tokyo and Osaka are the first and third largest city in Japan with highly urbanised area near to the coastline, whereas Matsuyama is the smaller cities compared to Tokyo or Osaka with urbanised area far from the coastal area **(Fig. 1)**. Various studies have shown the effect of Urban Heat Island (UHI) in all these cities.

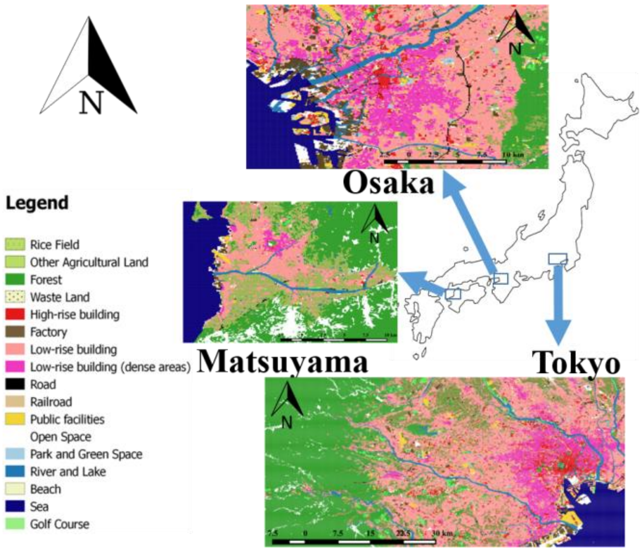

Fig: 1 Study areas and their land use pattern

2. METHODOLOGY

Solar radiation decreases when sky is covered by clouds. Thus in this study reduction of solar radiation was used as an index of cloud presence and thickness. Decrease of solar radiation due to the blockage of cloud was calculated using the following concept. An ideal time series dataset was created by selecting the maximum values of each time series for every month. The ideal time series data resembles solar radiation on a virtual clear sky condition. The averaged time series SW dataset of target days is normalized by respective SW in fair weather day to get Clear Sky Rate (CSR) also known as Relative short wave radiation (Allen et al. (1998) [3]).

$$CSR = \frac{\text{target day SW}}{\text{SW in virtual clear sky condition}} \quad (1)$$

CSR value ranges between zero to one (0-1). Lower the CSR, higher the cloud coverage and the cloud thickness, while higher the CSR, lower the cloud coverage and the cloud thickness. Diurnal spatial analysis of the cloud with the help of CSR was conducted in the study areas between June, July and August. Around 14-17 days with 50%-80% cloud coverage were selected as the representative days for this study.

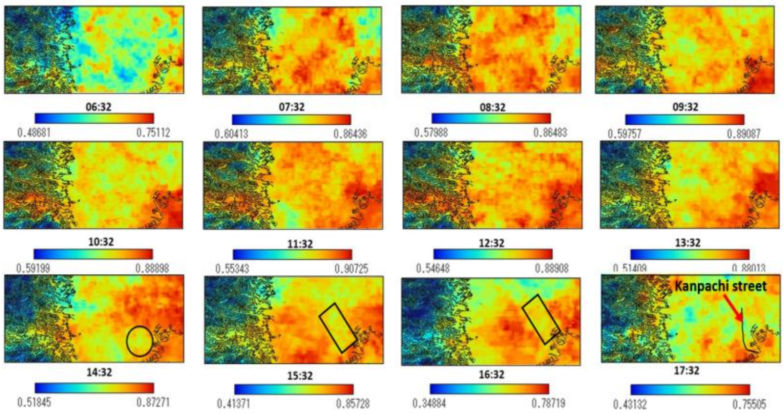

Fig.2 Temporal and spatial variation of CSR in Tokyo

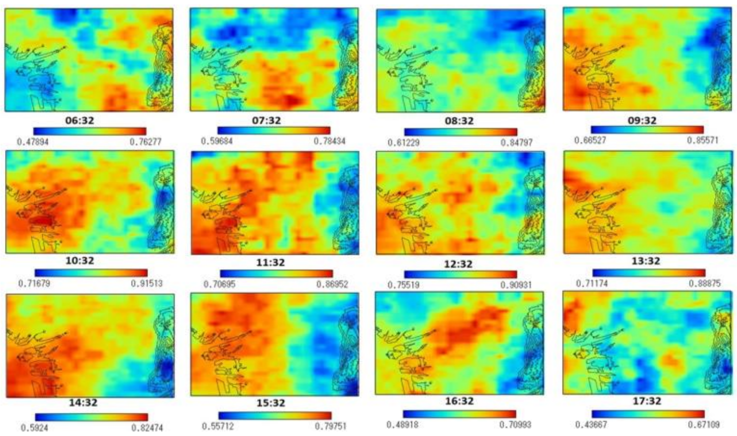

Fig.3 Temporal and spatial variation of CSR in Osaka

3. RESULTS AND DISCUSSION

a. Tokyo

The study shows that Tokyo plane is almost covered with cloud but no appreciable effect of urbanization (nearby the coastal area) on the cloud up to the mid-day is seen **(Fig. 2)**. The transportation of hot air from coastal area towards the plain may be one of the cause for the formation of cloud above the plane. The temperature and wind profile by Yamato et al. (2009)[5)] shows that the hot air is transported by the wind from the urban area near the coast, decreasing the temperature in order of the distance closer to the cost as the sea breeze penetrates in to the inland area. In the late afternoon, formation of clear clouds line can be seen in the urbanized area **(Fig. 2)**. The result agrees well with those observed by Kanda et al. (2001)[4)], which suggest that the formation of cloud in that particular place (Kanpachi street) is due to (i) the convergence of two sea breezes from Tokyo Bay and the Pacific Ocean, respectively, and (ii) additional heating due to an urban heat island.

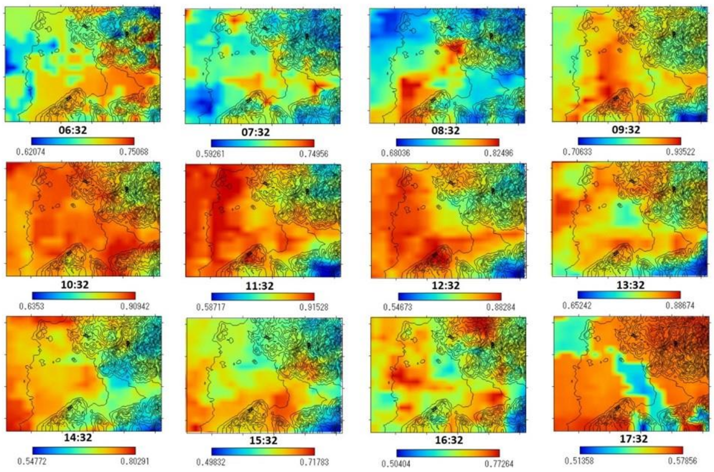

Fig.4 Temporal and spatial variation of CSR in Matsuyama

b. Osaka

The study suggest that at 13:32 pm, the cloud has formed above the urban area **(Fig. 3)**. It may be because of the UHI effect (which may not have been suppressed by the sea breeze at that particular area and time). In such condition, the unstable air parcel rises by convection, which eventually expands and cools adiabatically due to the decrease in temperature (altitude effect) resulting in the formation of cloud. Except at 13:32 pm, the cloud does not seem to have formed above the highly urbanized area. Instead, almost all the clouds area accumulated above the mountains on the eastern side of the mountains. It may be because of the active sea breeze present in the Osaka plane. Matsumoto (2009)[6)] have shown that the exhaust heat due to UHI is moved from the center area (highly urbanized area) of the Osaka plane to the east (mountains). The moving hot air mass may have been orographically lifted due to the blockage of the mountain present at the east (as shown in the Fig.4), forming the cloud adiabatically on the top of the mountain.

c. Matsuyama

The result suggest that urban clouds tends to be thicker than rural clouds in the afternoon around 12:32 **(Fig. 4)**. Morimoto et al. (2013)[7)] reported that the formation of clouds over urban area in Matsuyama was noticed after the mixing layer reached the LCL around 12:00 and it continued until evening, whereas in rural sites no noticeable development was seen. Average temperatures in urban areas in Matsuyama city are higher than its surrounding rural environment due to the heat island effect (ThapaChhetri et al., 2016[3)]). Increased temperatures may provide a source of unstable air. The warmer air parcel at the surface will rise under the influence of convection. As the parcel rises, it will adiabatically expand and cool due to the decrease in temperature (the altitude effect) resulting in the formation of clouds. It also suggest that the presence and thickness of cloud is higher the mountain areas **(Fig. 4)**.

Conclusion

The formation and distribution of cloud is highly affected by the wind speed and its direction. Due to the active sea breeze in the coastal areas, the presence of cloud in the coastal urban area is low compared to the urban areas far from the coastal areas and the mountaintops. The influence of urbanization on clouds highly depends on its location within the coastal plane. Closer the city towards the coastal line, lower will be the thickness of cloud. With reference to other urban heat island studies in these study areas, it shows that the cloud formation is likely to be higher in areas having higher temperature. The areas experiencing UHI with low intensity of wind or the places having wind convergence line generally leads to the formation of cloud above them.

Acknowlegement

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