Monitoring of atmospheric turbidity and cloud above Tokyo using ground based network cameras

Daiki Hashikita[1], Ryoko Oda[2], Hirofumi Sugawara[3], Naoko Seino[4]

[1] *Chiba Institute of Technology, Tsudanuma 2-17-1, Narashino, Chiba, Japan, s1023197WT@s.chibakoudai.jp*

[2] *Chiba Institute of Technology, Tsudanuma 2-17-1, Narashino, Chiba, Japan, ryoko.oda@it-chiba.ac.jp*

[3] *National Defense Academy, Hashirimizu 1-10-20, Yokosuka, Kanagawa, Japan, hiros@nda.ac.jp*

[4] *Meteorological Research Institute, Nagamine-1-1, Tsukuba, Ibaraki, Japan, nseino@mri-jma.go.jp*

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1. Introduction

Local heavily rain and pollutant emission are important issues in summer of Tokyo. Several mega-cities in the world, including Tokyo, are faced to open seas, in which atmospheric conditions are considerably affected by sea/land breeze circulation. Therefore, monitoring of atmospheric conditions above both sea and city are important to evaluate the atmospheric environment in cities under sea/land-breeze circulations. We installed network cameras in a rim of Tokyo-Bay to monitor the visible atmospheric conditions, e.g. cloud development and atmospheric turbidity, above the Tokyo-Bay and the city areas of Tokyo.

2. The abstract

2.1 Estimation of the horizontal position of cumulous clouds

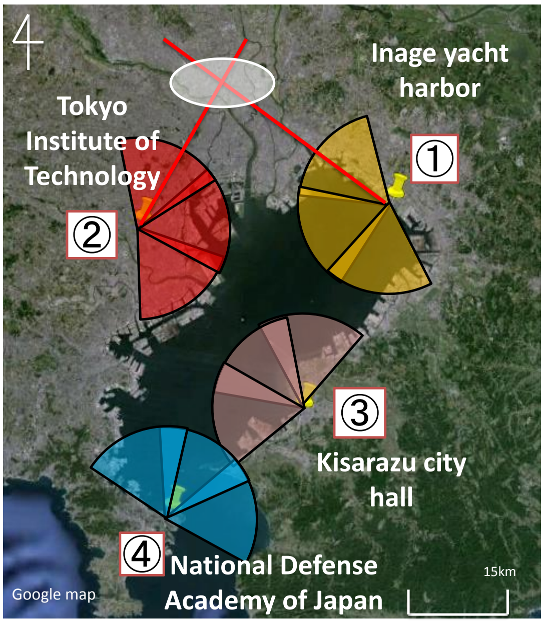
From the camera image, a direction from the camera to an object in the picture is known. If an object is taken from two separated locations, the horizontal location of the object is identified as a cross point of two lines from the object to the respective cameras. Based on this strategy, the horizontal locations of cumulous clouds are detected.

2.2 Estimation of the height of cumulous clouds

The height of bottom and top of cumulous clouds can be estimated based on the stereo image. Firstly, the information of horizontal position of the clouds is obtained as in section 2.1. Then, the height of the cloud in the image is calculated as,

$$h = d \tan\theta. \qquad (1)$$

Where, h is height from the ground, d is the horizontal distance from the camera to the object, θ is an angle between the ground and the object as estimated as pixel level × 0.10625(degree).



	latitude	longitude
①Inage yacht harbor	N 35° 37′26.20″	E 140° 3′21.58″
②Tokyo Institute of Technology	N 35° 36′4.35″	E 140° 41′6.32″
③Kisarazu city hall	N 35° 22′33.98″	E 140° 54′59.95″
④National Defense Academy of Japan	N 35° 15′23.73″	E 140° 43′15.35″

Fig. 1 Locations of network cameras.

A cumulonimbus developed in July 8, 2013 at the cross section of two read lines

Fig. 2 Photo images of cumulonimbus observed at (a) Inage Yacht Harbor and (b) Tokyo Institute of Technology

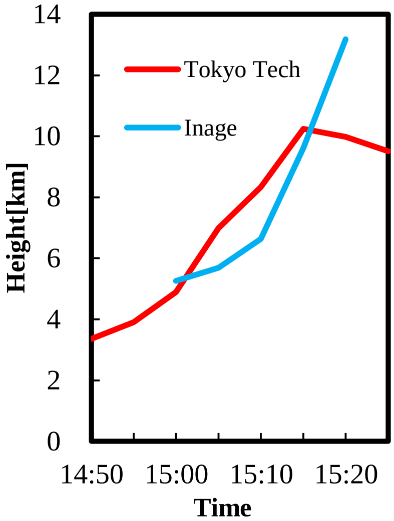


Fig. 3 Temporal evolution of the height of the cumulonimbus top estimated from the images obtained at two locations

3. Observations

3.1 Network camera

The network cameras were installed at 4 locations around Tokyo-Bay: Inage Yacht Harbor, Tokyo Institute of Technology, Kisarazu City Hall, National Defense Academy of Japan (see, Figure 1). All of four locations include 3 cameras looking different directions each other. Each camera records an image every 1 minute, and transfers it to a data server via internet. This system has been operated for 2 years.

3.2 SPM

SPM was measured by Atmospheric Environmental Regional Observation system (AEROS). This is used to compare with the atmospheric turbidity estimated by the photo images.

4. Results

4.1 Estimation of the horizontal position and temporal evolution of a cumulonimbus

Among all the observation period, the images obtained in July 8, 2013 were analyzed. In this day, a cumulonimbus was observed in two camera images from Inage Yacht Harbor and Tokyo Institute of Technology. The weather was fine until the noon on this day, and some cumulous clouds appeared in the afternoon. Temperature exceeded 30 degC in the Tokyo weather monitoring post.

Figure 2 shows the camera images obtained in (a) Inage Yacht Harbor and that in Tokyo Institute of Technology at 15:20. A cumulonimbus was seen in the both images. This cumulonimbus started to develop from about 15:00, and it caused a heavily rain at 16:40. From these two camera images, the horizontal position is detected as shown in Figure 1. This has also been observed in a satellite image.

The altitude of the cloud was also estimated based on the two images. Figure 3 shows the temporal evolution of the height of the cloud from 14:00 to 15:25. The top of the clouds was estimated to be at 5 km in beginning, and it reached up to 13 km in another 30 minutes.

Based on a radiosonde observation in Tateno, a sudden change of the direction of the wind and a stable stratification were seen at around 15 km from the ground. This height is considered to be the troposphere interface.

This supports the reliability of the estimation of the top of cumulonimbus After the full development of the cumulonimbus, it starts to rain and clear cloud image cannot be obtained.

4.1 Estimation of the horizontal position and temporal evolution of a cumulonimbus

Atmospheric turbidity was examined using the photo images obtained in daytime from January, 2013 to December, 2013. Visibility of landmark building (Kaihin Makuhari building at 3 km from the camera, and Tokyo Sky Tree at 25 km from the camera) is used as a measure of atmospheric turbidity. The strength of atmospheric turbidity is classified into 3 levels; (rank 5), Kaihin-Makuhari building cannot be seen, (rank 6-7) Kaihin-Makuhari building can be seen but Tokyo Sky Tree is not visible, (rank 8) Tokyo Sky Tree can be seen. These atmospheric turbidity levels were validated with the SPM density distribution measured by AEROS.

At visibility rank 5, SPM density was high in the metropolitan area reached about 45μg m^{-3}, when the coastal area of Tokyo Bay has especially large SPM density due probably to the many factories and car-places in this area. In this time, the general wind was strongly from south. This southern wind is expected to bring a high SPM density at the coast area to the in land. A salt particle in the sea breeze is also a possible factor to raise the atmosphere turbidity of the urban area.

At visibility rank 8, SPM density was low at about 10μg m^{-3}, in which the wind speed was weakly from northwest. In visibility rank 6-7, wind velocity and the direction of the wind are not constant.

5. Conclusions and future work

We installed network cameras around the Tokyo Bay to monitor the visible atmospheric conditions in center of Tokyo. Based on the stereo photo images, horizontal position, and height and depth of a cumulous cloud were quantitatively examined. This method has an advantage to monitor the cloud development in very fine time scale, and to provide a clear vertical view of the cloud (e.g. depth, altitude of cloud top and bottom). This has a possibility to predict the heavily rain before the rain fall starts.

The camera images are also utilized for the evaluation of atmospheric turbidity based on the visibility of a land mark of known distance from the camera. We confirmed a reasonable correlation of the visibility and the SPM density.

Now we have already installed a X-band radar in Chiba Institute of Technology to monitor rain droplet within clouds. This is also used to analyze the development of rainy cumulous clouds together with the camera images simultaneously monitored.

Acknowledgment

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