Cloud frequency in eastern Mongolia and its relation to the orography

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I Introduction

Inhomogeneity of surface condition often affects the climate over land (*e.g.* vegetation, soil moisture, urban buildings). Kanae *et al*. (2001) has shown the influence of deforestation on the climate over Indochina Peninsula. Sen *et al*. (2004) investigated the modification of atmospheric circulation after the re-greening the degraded land in China. Inoue and Kimura (2004) revealed the effect of urban area to cause the shallow cloud formation. On the other hand, in general, mountain plays an important role to drive mountain and valley circulation. The circulations modify the distribution of atmospheric water vapor, and finally the static stability around the mountain (Sato and Kimura, 2003), which strongly affects the cloud formation and precipitation near mountain.

Characteristic land cover variation is found in northeastern Asia. In northern China, there is one of the largest desert areas, the Gobi desert, around the border between Mongolia and China. The vegetation of grassland becomes gradually dense to the northward in Mongolia, and forest distributes in the northern mountainous area of Mongolia, which is almost consistent with the annual precipitation distribution in this region. Sato (2004) has investigated the importance of terrain slopes to give relatively large amount of precipitation in this region, because Mongolian territory is also covered with complex terrain.

II Data analysis

Thirty seconds resolution topography data provided by U. S. Geological Survey (USGS) is used (Fig. 1). The Normalized Difference Vegetation Index (NDVI) Twenty-year Global 4-minute AVHRR NDVI Dataset by CEReS (Center for environmental Remote Sensing, Chiba University) is used as vegetation distribution in eastern Mongolia. The NDVI in August is averaged during 1981 and 2000 (Fig. 2).

The visible channel data of Satellite Geostationary Meteorological Satellite (GMS) provided by Kochi University is mainly analyzed in current study as information of the cloud cover. The resolution of the GMS visible data is 0.05 degree. The period of the analysis is 4 years from 1998 to 2001 in August, that is, 120 days in maximum. The frequency of cloud appearance is calculated for each pixel in 08, 10, 12, 14, and 16 Local Time (LT). The difference of visible band reflectance induced by solar zenith angle is corrected by a trigonometric function. If the surface albedo of each GMS grid exceeds criteria of 0.5, the grid is assumed to be covered with clouds. The frequency of the cloud cover is shown as a percentage of days by divided with total days of observation. Precipitation data provided by Institute of Meteorology and Hydrology, Mongolia (IMH) is used to compare the precipitation and cloud frequency.

III Result

Fig. 3 illustrates a cloud frequency in August over

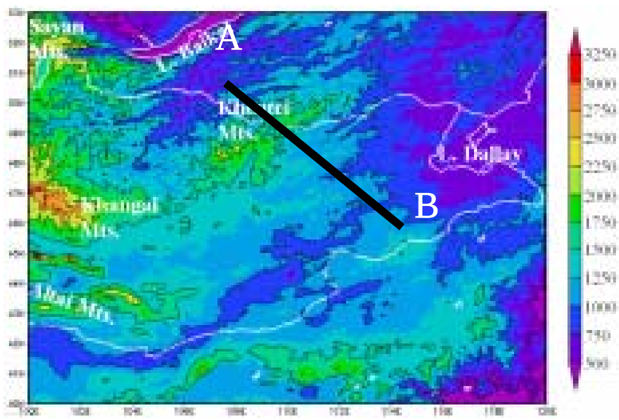


Fig. 1 Topography over the analyzed domain. A line between A and B indicates the section shown in Fig. 4.

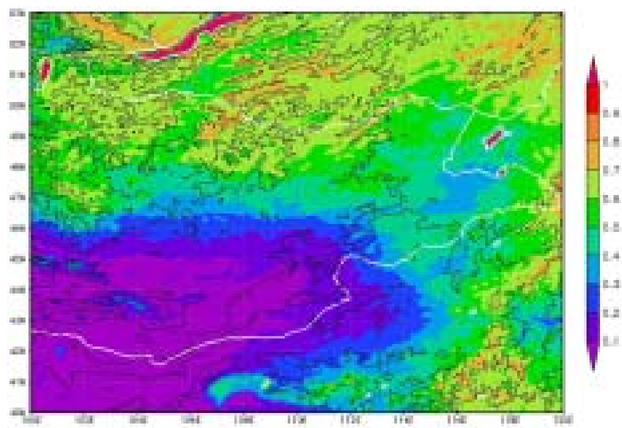
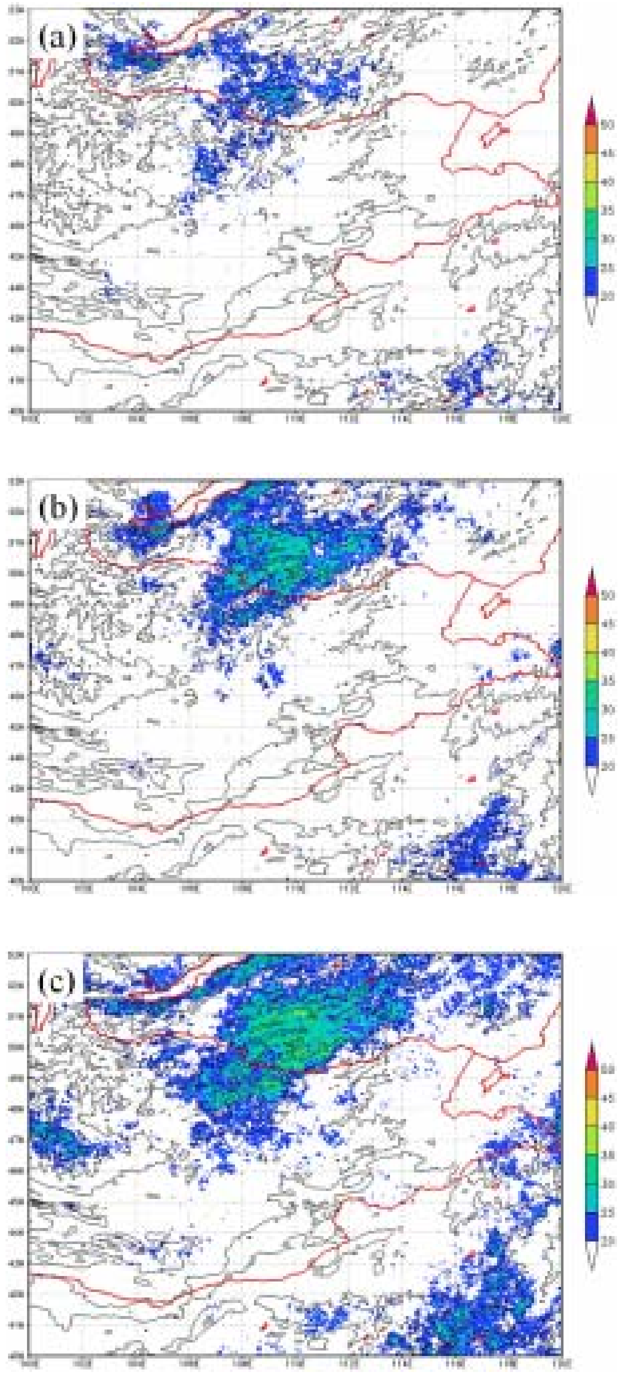


Fig. 2 Climatology NDVI distribution in middle July.

eastern Mongolia. In 08 LT most part of analyzed domain shows less than 10 percent except for the northern part of Mongolia and around the Lake of Baikal. The high frequency is found over southeastern region of the domain, eastern edge of the Altai Mountains, and the Khentei Mountain with 20-30 percent. The high frequency regions at 08 LT continuously keep high values in 10 LT; especially it exceeds 35 percent near top of the Khentei Mountain. The frequency increases close to 30 percent over east of the Khangai Mountain. The highest region of the cloud frequency is located in northwest of the Khentei Mountain over Russia. At 12 LT, the frequency retains 40 percent in many grids over the Khentei Mountain, which means that this region is covered by cloud around noon in 12 days of August. Over grassland, the frequency gradually increases up to 30 percent in maximum at 14 LT. However, the frequency is low in the relatively low altitude grassland around 115° E, 47° N or the semi-basin region surrounded by the mountain, *e.g.* 104° E, 45° N and 103° E, 49° N. In northern China around 107° E, 41° N, the cloud frequency is low over vegetated surface; on the other hand, relatively high frequency is found in the vicinity over less- or non-vegetated mountain. In 16 LT, the cloud frequency reaches its maximum in diurnal cycle in all over the analyzed domain. The highest regions distribute around the Khentei Mountain, the Khangai Mountain, and the Sayan Mountain exceeding 50 percent in maximum. On the other hand, the lowest frequency is found near the Taklimakan desert and the Lake of Dallay and the Lake of Baikal.



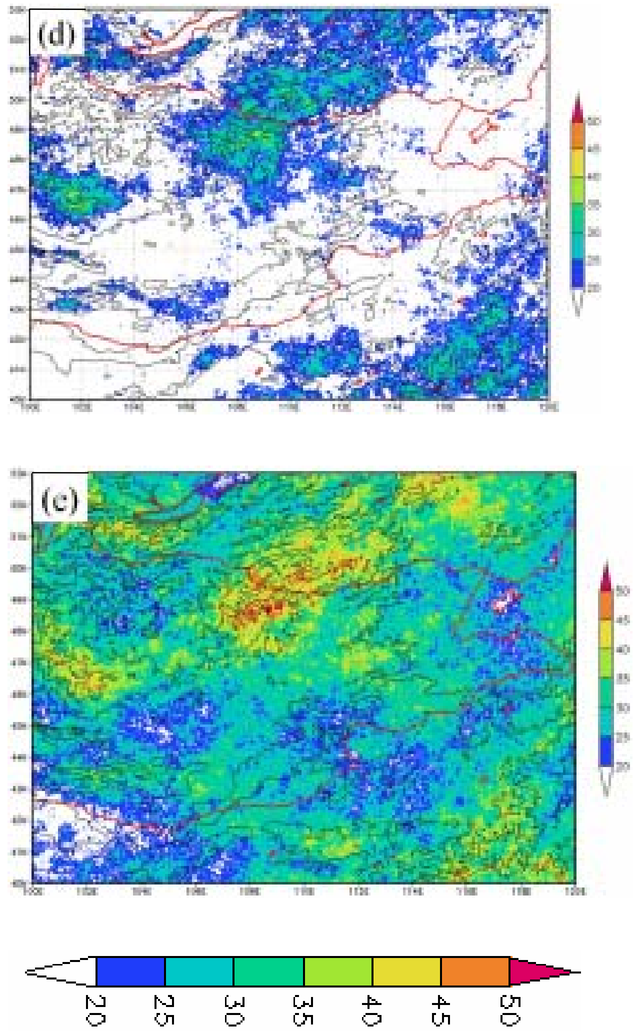


Fig. 3 Cloud frequency at (a) 8 LT, (b) 10 LT, (c) 12 LT, (d) 14 LT and (e) 16 LT.

IV Discussion

The surface cover of Mongolia can be roughly classified in desert, grassland, and forest regions. As it is shown in Fig. 3, cloud is likely to be observed over mountainous region, and is hardly observed over lake or humid land covers. Over vegetated or water surfaces, the latent heat flux tends to be larger due to the larger transpiration or evaporation than that over desert or sparse grassland. The horizontal contrast of water vapor content released to the atmosphere is strongly influenced by the inhomogeneous land cover. However, the humid surface hardly causes the cloud formation, although the water vapor is abundant in the atmosphere.

On the other hand, the mountain accumulates the water vapor as a result of mountain and valley circulation in clear daytime (Sato and Kimura, 2004). Additionally, the mountain slopes often act as a barrier of an environmental flow, causing a forced lifting of the air mass. Therefore, the cloud frequency is higher in the eastern edge of the Altai Mountain, where the climate is relatively dry near desert, than semi-basin area in north of the mountain. The frequency is lower in mountain foot around 104° E, 49° N in the Khangai Mountain although the evapotranspiration should be larger due to the existence of forest. By these reasons, the appearance of the cloud is less sensitive to the surface condition than that induced by terrain slope.

The difference of maximum frequency between the Khentei Mountain and the Khangai Mountain is evident, even though the difference of the altitude and the width of the mountain are considered to be almost same. It is caused by the topography around the mountain. The Khentei Mountain has a large open area in upwind against the prevailing synoptic scale wind. The precipitable water vapor in upwind of the Khentei Mountain is much larger than that in upwind of the Khangai Mountain, because it is strongly dependent with the ground altitude. In addition, the relatively low elevated area around the lake of Baikal is covered by the needle forest, taiga. These two differences maintain the easier cloud formation environment over the Khentei Mountain. Fig. 4 shows the cross section of cloud frequency and topography along with a line shown in Fig. 1. Cloud is often to be observed in northwest of the Khentei Mountain, and it rapidly decreases over lee of the mountain.

In general, the inhomogeneity of surface condition affects the atmospheric circulation and cloud formation (Inoue and Kimura, 2004). In this study, it is obvious that the water surface of lakes largely affects the modification of the cloud frequency. But the modification does not work to enhance the formation but to decrease the frequency in contrast. Therefore, the influence of topography on cloud formation is much larger than that induced by the vegetation contrast over the complex topography.

The climatology rainfall distribution is very similar with cloud frequency shown in Fig. 3(e). The rainfall distribution in Mongolia seems to be strongly affected by the terrain shape.

In southwest of the analyzed domain, the cloud

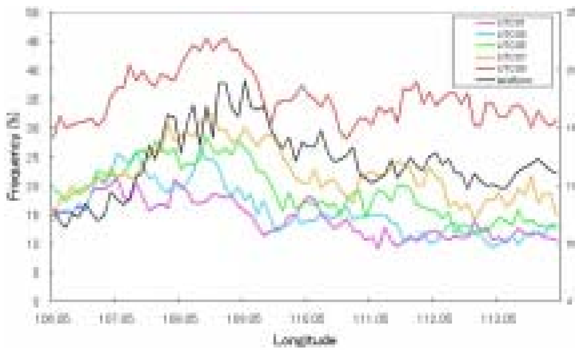


Fig. 4 Cross section of cloud frequency along line shown in Fig. 1. Black solid line indicates terrain shape.

frequency is considerably low even in the afternoon. Small evaporation from a semi-desert surface may contribute such a low cloud frequency in this region. However, the subsidence often prevails over the desert region in northern China. This can be another possibility why the cloud frequency is low in the desert region. Further investigations are needed to clarify the land surface process on the cloud formation in the arid region.

V Concluding remarks

The frequency of cloud appearance is investigated using a visible channel of Geostationary Meteorological Satellite. The frequency gradually increases in morning, and reaches maximum in 16 LT. Mongolia is located in characteristic rangeland of vegetation cover. But the distribution of cloud frequency is prominently larger over mountainous area than vegetation-covered area. The horizontal contrast of vegetation cover is known to affect the climate. However, the cloud formation is more likely to be affected by the topography rather than the vegetation contrast.

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