HORIZONTAL ROLLS AND PLUMES DETECTED BY A 3D-SCANNING COHERENT DOPPLER LIDAR

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ABSTRACT

Using 3D-scanning coherent Doppler lidar, we detected various kinds of atmospheric phenomena. In this paper, we will show some characteristics of horizontal rolls and plumes.

1. INTRODUCTION

Aerosol indirect forcing results from the interactions of aerosols and clouds. However, the aerosol-cloud interaction is not enough to evaluate aerosol indirect effect. Air-motion is the key factor that connects aerosols and clouds especially in the atmospheric boundary layer. Although Doppler sodar and wind profiler measure vertical profile of winds, 3D-scanning coherent Doppler lidar (3D-CDL) is the only tool that can measure 3D distribution of aerosols, winds and clouds. We deployed a 3D-CDL on May of 2004 at Sapporo, Japan, to progress the Cloud Science (Fig. 1). Its wavelength is 1.54 μm (eye-safe). The maximum detection range, the minimum range resolution and scanning speed are 20 km, 25 m and 1rpm, respectively.

Using the 3D-CDL, we detected such various kinds of atmospheric phenomena as plume, horizontal roll, fog, smoke, fire-work, fine-weather cumulus, low-level stratus, local front, down- burst, wake of buildings, mid-level clouds, clear-air turbu- lence and cirrus cloud etc. In this paper, we will show detailed struc- tures of plumes and hori- zontal rolls that are most pre- dominant and im- portant airflows in the boundary layer.

Fig. 1 Outlook of 3D-CDL

2. HORIZONTAL ROLLS

Figure 2 shows an example of horizontal distribution of Doppler velocity horizontal rolls, that appeared when surface wind speed exceeded 5 m/s. Table 1 is the summary of characteristics of observed horizontal rolls below the level of 100 m. The wave- length of observed horizontal rolls is one order smaller than that reported before. The direction of rolls is parallel with shear-vector. The area of updraft is suggested to be much smaller than that of downdraft. S/N in the updraft region was smaller than that in the downdraft region. This fact suggests that updraft transports dry and small aerosol particles from the ground surface to the upper level and downdraft transports wet and large aerosol particles from above to lower level.

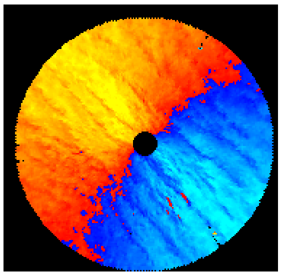

Fig.2 Horizontal distribution of Doppler velocity of horizontal rolls.

Table 1 Characteristics of observed horizontal rolls

Wavelength	200 – 750 m
Depth	250 – 900 m
Aspect ratio	0.6 — 2.0

The most interesting features of horizontal rolls revealed by the 3D-CDL is their finite structure both in time and space. Linear theories assume the infinity and steady state of horizontal rolls. In nature, of course, this assumption cannot be supported. Figure 3 clearly shows that the distance between rolls is not uniform, but horizontal rolls sometimes merge and split.

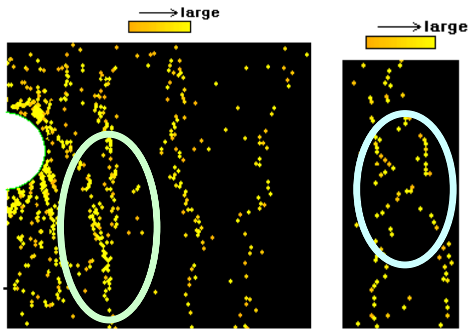

Fig.3 Horizontal distribution of convergence area associated with horizontal rolls. These figures clearly show that horizontal rolls have finite structure both in time and space.

3. PLUMES

3.1 Wet and dry plumes

We found two types of plumes, that is, wet plume and dry plume. Wet plume develops when the ground surface is wet, and contains wet and large aerosols (Fig.4a). Wet plumes transport both latent and sensible heat from the ground surface to the upper level, and moisten the boundary layer. Fair weather cumulus are formed when some of wet plumes reach the condensation level. Dry plume develops when the ground surface is dry, and contains dry and small aerosols (Fig. 4b). Dry plumes transport mainly sensible heat from the ground surface to the upper level and dry-up the boundary layer.

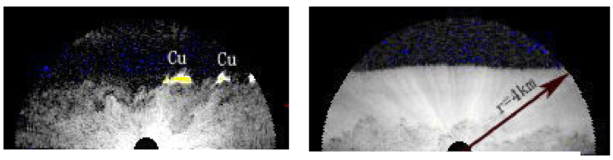

Fig. 4 (a) Wet plumes (b) Dry plumes

3.2 Temporal and spatial change of plume

Figure 5 shows temporal and spatial change of plumes from the very early developing stage to decaying stage. Their shape does not resemble air-bubble or jelly-fish, but volcanic ash cloud. The top boundary of plumes does not show round shape, but ragged, indicating strong mixing near the boundary. Usually, a pair of updraft and downdraft was found in a developing plume (Fig. 6). Updraft velocity sometimes attained nearly 10 m/s and strong downdraft existed just in front of the updraft region.

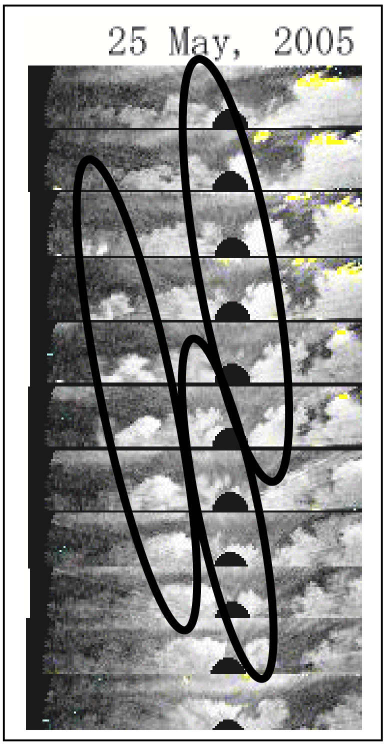

Fig. 5 Temporal and spatial change of plumes. Time interval of each figure is about 2-minutes.

3.3 Trigger of gravity wave

The turbulent boundary layer is often capped by temperature inversion layer. When such a turbulent air motion as plume in the boundary layer is strong enough to push up the upper stable layer, the gravity wave grows and propagates both horizontally and vertically. If the relative humidity in the stable layer is high, banded and/or wavy-type of clouds are formed in the updraft region of the gravity wave as shown in Fig. 7. Multi-layer structure of clouds is one of the most important factors affecting radiative heat budget of the earth surface and atmosphere. Our result clearly shows that plumes play an important role not only in the formation of low-level cumulus, but also in the formation of mid- and upper-level stratiform type of clouds.

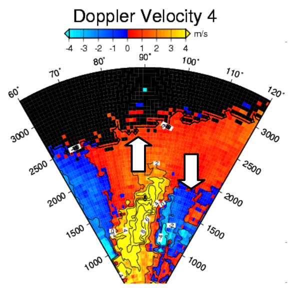

Fig. 6 A pair of updraft (～10 m/s) and downdraft(～5 m/s) in a developing plume.

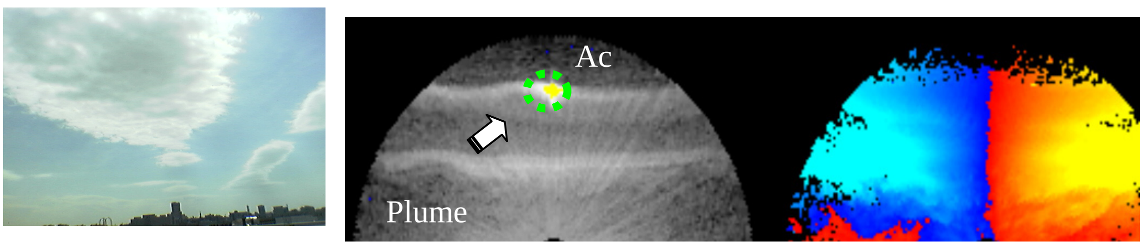

Fig. 7 (a) Altocumuls (Ac) (b) Developed plume and gravity waves (c) Doppler velocity