BILLOW CLOUDS OBSERVED AT THE MIZUHO PLATEAU, EAST ANTARCTICA

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Abstract: Billow clouds were photographed on the ice sheet of Mizuho Plateau, East Antarctica. Although aerological data at the time were not obtained, the general weather condition of constantly blowing katabatic wind was analyzed. The strong vertical wind shear and temperature inversion in the atmospheric boundary layer continue through the year except the few months of the summer season. This atmospheric structure is suitable for maintaining a Kelvin-Helmholtz instability. The observed billows are a result of this instability.

1. Introduction

Billow clouds are clouds shaped as waves and can be seen everywhere. Billows are often seen as parallel clouds but when seeing horizontally the clouds appear to roll up like sea waves.

Many reports with billows photographs have been issued and the causes are mentioned as lee waves, gravitational waves, and Kelvin-Helmholtz waves (LUDLAM, 1967; BURTON, 1979; COFFEY, 1980; MAROTZ, 1981). But billows in Antarctica have not yet been reported.

The billow cloud is one of the visualized wave motions in the atmosphere, and the wave motion is thought to be deeply related to the momentum transport in the atmosphere.

The author joined the 19th Japanese Antarctic Research Expedition (JARE-19) party and stayed at Syowa Station and Mizuho Station in 1978. Though special observations of clouds were not planned by the party, two photographs of billows were taken by chance at Mizuho Plateau, East Antarctica. Although meteorological data were not enough the vertical structure in the atmospheric boundary layer may be estimated by using the general condition of the katabatic wind. If so, it can be discussed whether this vertical structure is favorable for the formation of the billow clouds.

2. Observations of Billow Clouds

The films used to observe the billow clouds are of 35 mm color positive and 35 mm monochrome negative types, and the focal length of the lens used was 135 mm. Then dimensions of the picture on the film are about 15 degrees by 10

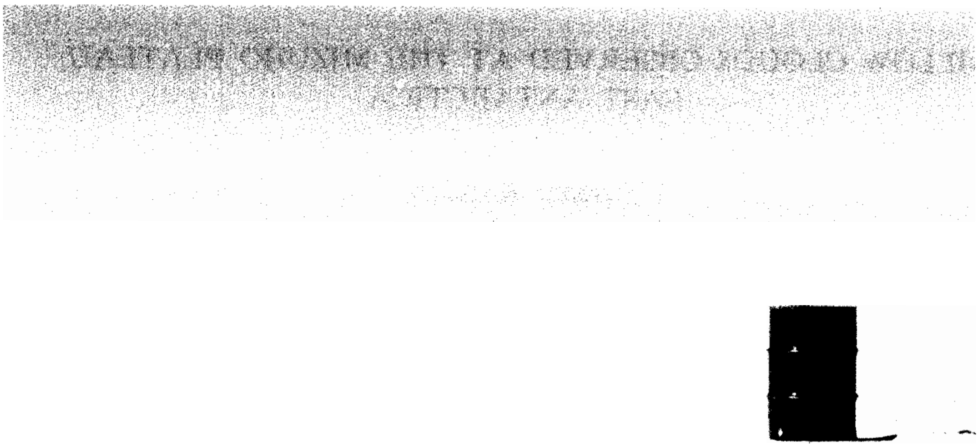

Fig. 1. Billow clouds in October 18, 1978.

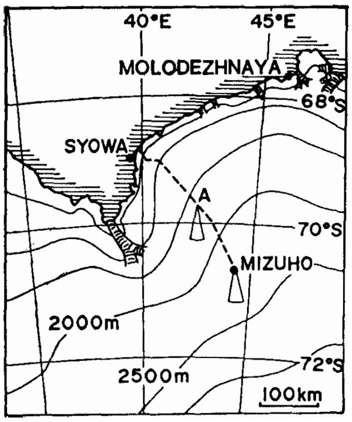

Fig. 2. Map of Mizuho Plateau.

Fig. 3. Billow clouds in December 17, 1978.

degrees. Using these photographs we can determine only the view angle, and not the absolute length or height of clouds.

Figure 1 shows billow clouds taken at point A of Fig. 2 on the route from Syowa Station to Mizuho Station at about 09 LT of October 18, 1978. The camera was directed to the south and the katabatic wind blew from left to right on the photograph.

Billows rise from lower stratiform clouds. Higher stratiform clouds are also seen. The bottoms of the billows are about 1.0 degree above the horizon. Billow amplitudes are about 0.4 degrees and the wave length is about 1.5 degrees. The shape of billows at the center seems like a sea wave rolling up but the top of it seems to be blown by the wind. The shape of the billows at the left seems to be not so well developed.

Figure 3 shows billow clouds taken at Mizuho Station at about 03 local time on December 17, 1978. The camera was pointed south and the wind condition is same as Fig. 1.

The billows in Fig. 3 are more complicated than those in Fig. 1 because the clouds are silhouetted. There is seen another higher cloud layer of cirrus. The bottoms of the billows are about 0.5 degrees above the horizon. The billows amplitude is about 0.3 degrees and the wave length is about 1.2 degrees.

3. General Structure of Atmospheric Boundary Layer on the Ice Sheet

Surface weather conditions at Mizuho Station on October 18 and December 16–17 are shown in Table 1 for reference (Fig. 1 of October 18 was not taken at Mizuho Station). These data suggest that the photographs were taken under conditions of moderate katabatic wind at Mizuho Station.

In JARE-19 party, instruments for aerological observation were not available at Mizuho Plateau, so the vertical structure at the times when the two photographs

Table 1. Surface meteorological data at Mizuho Station.

Date		Time (LT)	Temperature (°C)	Wind	(m/s)	Visibility (km)	Cloud (1/10)	Weather C_L	C_M	C_H	ww
October	18	03	-39.0	E	7.0						
		06	-38.8	E	7.5						
		09*	-35.3	E	6.5						
		12	-31.0	E	6.0						
		15	-29.8	E	6.0	10	2	0	0	2	01
December	16	21	-18.2	E	3.5	20	10-	0	3	X	03
		24	-19.8	E	4.5	20	10-	0	3	X	02
	17	03*	-23.6	ESE	8.0	20	1	0	3	1	01
		06	-20.0	ESE	8.0						
		09	-18.0	ESE	9.0	5	10	0	2	X	71

* Indicate the time when the photograph was taken.

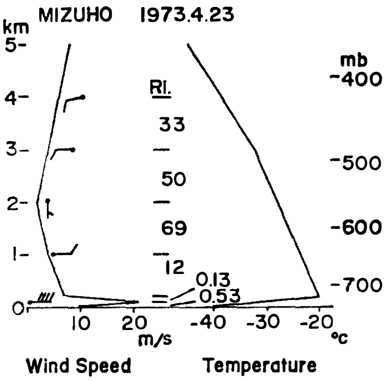

Fig. 4. Vertical profiles of temperature and wind speed at Mizuho Station in April 23, 1973 (KOBAYASHI and YOKOYAMA, 1976) and Richardson number (Ri).

were taken is unknown. But the Mizuho Plateau is classified climatically in the region of katabatic wind, and the atmospheric boundary layer on the ice sheet is generally characterized by strong temperature inversion and strong vertical wind shear. Figure 4 is one result of meteorological balloon soundings at Mizuho Station in 1973 (KOBAYASHI and YOKOYAMA, 1976). The intensity of temperature inversion is nearly 20°C and easterly wind over 20 m/s at 100 m height suddenly decreases to 7 m/s at 200 m height. For a convenient stability index, a gradient Richardson number, *Ri*, was calculated from the vertical air temperature gradient $\Delta\theta/\Delta Z$ and vertical wind velocity gradient $\Delta U/\Delta Z$:

$$Ri = \frac{g}{\bar{\theta}} \frac{(\Delta\theta/\Delta Z)}{(\Delta U/\Delta Z)^2},$$

where g is the acceleration of gravity and $\bar{\theta}$ is the mean absolute potential temperature of a layer. Values of the *Ri* number calculated from the above condition are also shown in Fig. 4. The *Ri* number is used to detect the Kelvin-Helmholtz instability; an *Ri* number less than 0.25 is required for the existence of the instability (DRAZIN, 1958).

4. Discussion

In Fig. 4 there is a suitable layer for K-H instability in the atmospheric boundary layer. Then we can expect instability and resulting wave motions in that layer. In Fig. 1 the shape of billows show that the easterly wind blown from left to right is stronger at the bottom than at the top. These two features point out that the billows are formed at the upper half of the inversion layer where the vertical wind shear is very large.

Two photographs tell only the view angle, but if the height of the inversion layer (*i.e.* the height of the billows) is assumed, absolute scales of the billows and a distance to the billows can be calculated geometrically. From 72 balloon soundings at Mizuho Station in 1980, the average height of the inversion layer is about 300 m (when the intensity of temperature inversion is larger than 5°C) (KAWAGUCHI *et al.*, 1982).

Table 2 shows calculated values of the billows based on the above assumption. The wave length is the same order as the value of BURTON (1979) but the ratio of

Table 2. Characteristic figures of billow clouds.

	Bottom's height	Amplitude	Wave length	Distance
October 18, 1978	220 m	80 m	320 m	12 km
December 17, 1978	190 m	110 m	450 m	21 km

wave length to amplitude is rather larger than the value of SCORER (1951). The estimated distances to the billows are 12 and 21 km; this seems reasonably consistent with the general scene shown in the photograph.

These wave motions in the atmosphere are thought to be not such a rare phenomenon because the structure of the atmospheric boundary layer on the ice sheet is generally suitable for maintaining the K-H instability. But whether the wave motion is to be seen or not is another problem of cloud physics.

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