Simultaneous Measurements of a Stratiform Cloud by Multipoint Videosonde Launchings

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Abstract

Multipoint videosonde launchings into the same stratiform cloud system were carried out in Okinawa during the Baiu rainy season for the first time. Six minutes after the first videosonde launching from Cape Zanpa (26.44°N, 127.71°E), the second videosonde was launched from Onna (26.50°N, 127.84°E), which is located 15km northeast of Cape Zanpa. Microphysical features observed by simultaneous videosonde soundings revealed the well-known horizontal homogeneity of the stratiform cloud, but local differences in cloud microphysics were found in the cloud, which are expected to be related to the developing/dissipating processes of the stratiform cloud. This new observation technique using the videosonde will be useful in investigating three-dimensional microphysical structures that change over a short period of time, such as short periods of intensive heavy rain.

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1. Introduction

Balloon-borne special radiosonde, which can acquire precipitation particle images using a video camera, is one of useful tools for directly evaluating cloud microphysics. The videosonde (Takahashi 1990) and hydrometeor videosonde (HYVIS) (Murakami and Matsuo 1990; Orikasa and Murakami 1997), which were developed in late 1980s, have contributed to the understanding of cloud microphysics. Videosonde observations can provide high-resolution vertical profiles of precipitation particles that are similar to those provided by aircraft observations, but at lower cost. Furthermore, videosondes can be launched into severe disturbances into which aircraft cannot fly.

In previous studies, Murakami et al. (1994) deployed 31 HYVISs and eight hydrometeor video dropsondes (HYDROSs) into short-lived convective snow clouds during four winter seasons and clarified the evolution of microphysical structures based on a composite of separate snow clouds at various stages. Takahashi et al. (1999) conducted videosonde observations of winter monsoon snow clouds along the coast of the Japan Sea. They classified their videosonde soundings into different stages of cloud life based on the updraft in the clouds and discussed the electrical structures at each stage. Suzuki et al. (2014) classified videosonde soundings of Okinawa Baiu monsoon rain in four cloud types based on radar reflectivity distributions and quantitatively evaluated the shape of graupel in different stages of development. Watanabe et al. (2014) launched 15 videosondes over a period of three days into snow clouds associated with the cold air outbreak in early winter and investigated the evolution of the microphysical structures. Their videosonde launches were one-off and discontinuous, and they merely discussed the evolution of microphysical structures in clouds by compositing various videosonde soundings using indicators such radar reflectivity. More than two videosondes were not launched simultaneously (or over a short time interval) into the same rain cloud.

In these previous studies, videosondes were not launched continuously at short intervals due to cost and technical constraints. After launching a videosonde, it is necessary to wait for one hour before launching another videosonde. As such, videosondes could not be launched into the same rain system, and videosonde observation could not be used to evaluate the entire life cycle of a cloud system due to the propagation speed and short lifetime. Therefore, they could not but argue about the development stages of the rain system and the microphysical structures, by the composite of the data obtained from videosondes that launched into the different rain system, using the assumed ascent rate of the videosonde and a remote sensing technique such radar reflectivity distributions. For the better understanding of entire life cycle of a cloud system, simultaneous measurement by multipoint videosondes is needed.

Suzuki et al. (2012) developed a new videosonde observation system that consists of a low-cost receiver combined with an existing radiosonde system and use a Global Positioning System (GPS) slave method that simplifies the control of the directional antenna. Multiple receivers enable videosondes with different radio frequencies to be launched simultaneously and continually at short intervals, which was not previously possible.

A campaign observation using a C-band polarimetric radar (COBRA; Nakagawa et al. 2003) synchronized with the videosonde was carried out at the National Institute of Information and Communications Technology (NICT) Okinawa Electromagnetic Technology Center from 2007 in order to obtain a better understanding of the microphysical structures in Baiu monsoon clouds. Nakakita et al. (2009) developed a hydrometeor classification technique using precipitation particle data obtained from videosonde soundings. Takahashi and Suzuki (2010) revealed the electrical structures of Baiu monsoon stratiform clouds using videosondes. Suzuki et al. (2014) showed the graupel formation process in the different developing stages of convective clouds. In this study, during this campaign, videosonde observations by two receivers were conducted at Okinawa during the Baiu monsoon rainy season of 2013 in order to investigate three-dimensional microphysical structures of precipitating clouds. On May 17, we launched two videosondes from NICT and Cape Zanpa into the same stratiform cloud. The present paper concentrates on describing the microphysical features of the stratiform cloud revealed by the new videosonde observation technique.

2. Videosonde launchings into a stratiform cloud on May 17, 2013

During the Baiu monsoon rainy season in 2013, we launched 17 videosondes into Baiu monsoon rain clouds from the Okinawa NICT Electromagnetic Technology Center. Okinawa has a subtropical oceanic climate. At the beginning of May, the Baiu stationary front begins to influence Okinawa Island. The Baiu rainy season ends around the middle of June. On May 17, simultaneous measurements by two videosondes launched from multipoint observation sites were carried out for the first time. A rainband associated with the Baiu stationary front was located to the south of Okinawa Island, and stratiform regions extended to the north (Fig. 1a). The rainfall amount from 14 to 15 JST (Japan Standard Time = UTC + 9 h) was 5.5 mm at Yomitan-son near Cape Zanpa. The
maximum 10-minute rain was 1.5 mm (14:30–14:40 JST), and rain stopped once at 15:20 JST. Thereafter, weak rain continued intermittently, and the total precipitation from the beginning was 14.5 mm (13:30–17:00 JST).

A videosonde is a balloon-borne radiosonde that acquires images of precipitation particles via a charge-coupled device (CCD) camera. The videosonde was designed by Takahashi (1990) and has been further developed by Suzuki et al. (2012). The videosonde system uses stroboscopic illumination. Interruption of the infrared beam by a particle triggers the strobe, and a particle image is then captured by the CCD camera. Particle images are transmitted to the receiving system at the surface before being displayed and recorded onto videotapes. Recorded precipitation particles are classified as raindrops, frozen drops (hail), graupel, ice crystals, or snowflakes based on transparency and shape, as described by Takahashi and Keenan (2004). Information concerning atmospheric pressure, temperature, humidity, and wind was obtained from a Meisei RS-06G radiosonde that was attached to the videosonde. A videosonde was launched by using a 600 g balloon with helium gas having a buoyancy of approximately 3 kgf.

Two videosondes were launched from Cape Zanpa (26.44°N, 127.71°E) and Onna (NICT; 26.50°N, 127.84°E), respectively. Figure 1b shows their trajectories along with the locations of Cape Zanpa, NICT (Onna), and the COBRA radar site, respectively.

Two videosonde receivers were mounted on the roof of NICT at Onna (approximately 18 m above sea level). The frequencies of the videosondes were 1673 MHz and 1680 MHz, whereas those for the Meisei RS-06G radiosonde were 403.8 MHz and 404.1 MHz. Videosonde #1 was transported from the Onna observation site to Cape Zanpa. Just after the launch at Cape Zanpa, the signal from videosonde #1 was captured by the receiving antenna at Onna.

3. Results and discussion

After the launch of videosonde #1, the range-height indicator (RHI) scan of the COBRA radar was operated at six-minute intervals at an azimuth of 245°, the direction of which is toward Cape Zanpa and Onna from the COBRA radar site, which is located approximately 24 km northeast of the Onna observation site. Figure 2 shows the RHI images from 14:59 to 15:41 JST. Note that the X axis in Fig. 2h is inverted, which means that videosondes were located northeast of the COBRA radar at that time. The RHI images show an obvious bright band characterizing a stratiform cloud. Videosonde #1 climbed to the bright band at 15:11 JST, followed by videosonde #2 at 15:17 JST. The radar echo more than 10 dBZ reached 9 to 10 km. After 15:23 JST, the bright band signature in radar reflectivity gradually weakened, and the stratiform cloud began to dissipate. Temperatures (relative humidity) at the time of launch at Zanpa and Onna were 22.6°C (78.3%) and 22.8°C (81.0%), respectively. The 0°C altitudes observed by videosondes #1 and #2 were 4.33 km and 4.56 km, respectively, which is a slight difference.

Figure 3 shows size-height diagrams of the precipitation particles obtained from the videosonde #1 and #2 soundings. Around the −5°C level in videosonde #2, there were no data because of unexpected transmission trouble. Major particle images transmitted from videosondes show raindrops, snowflakes, and ice crystals. Snowflakes and melting particles around the freezing level indicated a typical stratiform cloud. In the case of videosonde #1, ice crystals were detected up to 11 km in altitude. On the other hand, no ice crystals were found above 9 km in altitude in the case of videosonde #2. The maximum snowflake diameter was approximately 4 mm, which is larger than in the case of videosonde #2. Graupel-like particles were detected above the freezing level. The particles were distinguished from the snowflakes formed by the aggregation growth because they were not flake-form. However, it is impossible to conclude whether these are general graupel formed by the riming growth because our videosonde observation cannot clarify the existence of the updraft and the supercooled drops in this stratiform cloud. Further microphysical observation using a microscopic camera, such as HYVIS (Murakami and Matsuo 1990), will be needed. Moreover, melting particles were observed by videosondes just below the melting layer, which corresponds to the altitude of the bright band detected by the COBRA radar (Figs. 2c, d). Here, we should avoid comparing the number of melting particles observed by videosondes #1 and #2, because our videosonde, with an ascent rate of approximately 5 m s⁻¹, cannot obtain a sufficient number of samples in order to discuss the melting processes in the bright band having a depth of several hundred meters.

Figure 4 shows the differences in temperature, relative humidity, wind direction, and wind speed for 100 m increments of altitude between the two videosonde soundings. Negative values indicate that the values obtained by videosonde #1 were smaller than those obtained by videosonde #2. The mean differences were −0.12°C for temperature, −3.71% for relative humidity, and 0.62 m s⁻¹ for horizontal wind. The standard deviations for differences in temperature, relative humidity, and horizontal wind were 0.53°C, 2.88%, and 1.61 m s⁻¹, respectively. As such, the soundings of the two videosondes were similar. Partially in altitude, however, there were some differences. Around 3 km ASL, the relative humidity of videosonde #2 was higher than that of videosonde #1, and the southwesterly was dominant in videosonde #1, whereas the westerly was dominant in videosonde #2. Figure 5a is a scatter diagram representing 5°C-mean particle diameters.
Fig. 2. COBRA RHI images. Circles indicate the locations of videosondes #1 (red) and #2 (blue). The red and blue arrows indicate the locations of Cape Zanpa and Onna, respectively. (a) 14:59 JST, (b) 15:05 JST, (c) 15:11 JST, (d) 15:17 JST, (e) 15:23 JST, (f) 15:29 JST, (g) 15:35 JST, and (h) 15:41 JST. AZ indicates the azimuth of COBRA radar RHI scan. The X axis in (h) is inverted.

Fig. 3. Size-height diagrams of the precipitation particles observed by (a) videosonde #1 and (b) videosonde #2. Open circles, solid circles, triangles, crosses, and squares indicate raindrops, melting drops, graupel-like drops, ice crystals and snowflakes, respectively. Data around the −5°C level in Fig. 4(b) are not provided due to some transmission problems.
obtained from videosondes #1 and #2, in which only particles of greater than 0.5 mm in diameter are plotted due to the limited measurement accuracy of the infra-red sensor installed in the videosonde. The mean particle diameters were similar, but with large raindrops observed by videosonde #1 at the lowest level and large snowflakes observed by videosonde #2 around the freezing level as shown in Fig. 3. Figure 5b is a scatter diagram representing the 5°C-mean number concentrations of all particles (without classification) calculated every 5°C obtained from videosondes #1 and #2. This figure indicates the similarity of the number concentrations between videosondes #1 and #2 except near the surface (below the 20°C level) and the cloud top (above the −15°C level). Figure 5c is a scatter diagram of the 5°C-mean flattening of all particles. Flattening is an index that quantitatively indicates the shape of the particle. If the flattening is 0, the particle is circular. Note that our videosonde has only a camera and can only provide two-dimensional particle images, so the circular image is herein assumed to represent a globular shape. Figure 5c shows two distributions with 5°C as a border, and the data are distributed approximately linearly without particles observed at colder than −25°C.

The stratiform cloud is characterized by the layered microphysical structures with raindrops in the lower level, ice crystals in the upper level, and snowflakes around the melting layer, and the cloud exhibits horizontal homogeneity. The bright band and vertical distributions of precipitation particles observed by simultaneous videosonde soundings and COBRA RHI scans in the present study exhibited the typical stratiform cloud features. In addition, the horizontal homogeneity of particle number concentrations except near the surface and the cloud top (Fig. 5b) and the particle shape (Fig. 5c) was confirmed. However, the particle sizes shown in Fig. 5a were different in the horizontal distributions. Videosonde #2 observed larger snowflakes and raindrops around the 0°C level as compared those observed by videosonde #1 (Fig. 3). On the other hand, videosonde #1 observed larger raindrops near the ground. When videosonde #1 passed through the bright band, observing smaller snowflakes, it was supposed to have been in the dissipating stage. However, at that time, videosonde #2 was ascending through the stratiform cloud with active snowflake formation. The altitude of the 0°C level in the case of videosonde #2 was higher than that experienced by videosonde #1. This might indicate that there was a sufficient updraft to allow large snowflake to remain at the 0°C level. In addition, in the case of videosonde #1, the cloud top was higher than that in the case of videosonde #2. COBRA RHI images showed the stratiform cloud was in the dissipating stage after two videosondes rose through the 0°C layer (Fig. 2). The microphysical information obtained from two videosondes directly supported the developing/dissipating process revealed by the radar observation. Further simultaneous observation by multiple videosondes will be necessary for a more detailed discussion.

Takahashi and Suzuki (2010) revealed the electrical structures of Baiu monsoon stratiform clouds using videosondes. They compared three videosonde soundings of different rain cases. It means that these soundings were one shot, and they only discussed the electrical structure of a certain developing stage. Moreover, possibly, the developing stages in beginning and end of soundings might be different. It is well known that precipitation particles play important roles for the electrical structure, so it is essential to measure the spatial and temporal changes of the precipitation particle distributions densely. We will obtain much more important information by launching three videosonde into a same precipitating cloud rather than three launches into three different clouds.

4. Summary

We performed a simultaneous videosonde observation by multipoint videosonde launchings for the first time. This means that videosondes in the same precipitating cloud system can simultaneously measure the particle distribution at different altitudes and provide information on the evolution of microphysical structures for a short time. In the present study, we reconfirm the horizontally uniform structure of the Baiu monsoon stratiform cloud by two videosonde launches from Cape Zanpa and Onna in Okinawa. In addition, we can determine the change of the microphysical structure in the stratiform cloud in the developing/
dissipating stage through simultaneous videosonde observations synchronized with COBRA radar. In previous studies, we composed various separate cases in order to clarify the microphysical structures in clouds, but this new videosonde launching technique will make it possible to follow the entire development process of precipitating clouds and to reveal the evolutions of the microphysical structure in a short time in severe convective clouds, which changes continuously. Radio frequencies of 1673 MHz, 1680 MHz, and 1687 MHz are permitted for the videosonde observation in Japan. So, we can launch up to three videosondes at the same time. Or every 10-minute launchings of videosondes, assuming the ascent rate 5 m s$^{-1}$, could measure the particle distribution every 3 km in altitude. Using a transmitter on/off timer device, the continuous measurements by multiple videosondes would be possible. It is also expected that new knowledge will be provided by simultaneous observation with rapid scan remote sensing techniques, such as the use of phased array weather radar.

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