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Doppler Radar Observations on the Structure and Characteristics of Tropical Clouds during the TOGA-COARE IOP in Manus, Papua New Guinea: Meso-γ Scale Structures of Stratiform Region in Tropical Cloud Cluster

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Abstract

We attempted to investigate the structure of a stratiform region of a tropical cloud cluster on Manus Island during the Intensive Observation Period (IOP) of the Tropical Ocean-Global Atmosphere program, a Coupled Ocean-Atmosphere Response Experiment (TOGA-COARE). Time series of Velocity Azimuth Display (VAD) and Extended VAD (EVAD) analyses for the two X-band radars were used to obtain horizontal wind profiles and convergence profiles for comparison with time series of the Integrated Sounding System (ISS) horizontal wind profiles. Two types of stratiform clouds on Manus Island were analyzed.

In Case A, northerly winds dominated at high level and northwesterly winds dominated the low and middle level throughout the period analyzed. The height of vertical shear between northerly winds and northwesterly winds gradually descended from 3.5 km to 1.5 km. A sudden ascent and descent of the vertical shear was

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associated with convergence and divergence in the middle level within the analysis area of the X-band radar. This rapid change of the height of the vertical shear corresponded to southeastward passage of a convective part. The convection contributed to initiating precipitation (10 mm/h) over Manus Island in the dissipating cloud cluster. This temporal change of the wind profiles may have caused by a southeastward wave in the boundary between the two layers. In Case B, a variation in the divergence profiles was associated with the interaction between convective cloud lines. When two linear echoes merged and changed to a stratiform echo, divergence was analyzed above 2 km. Convergence in the lower level then ascended with northeasterly winds and divergence developed in the lower level.

Case A was caused by development and passage of a convective part in the stratiform region. Case B was caused by merger of linear convection and transition to stratiform echoes. Similar divergence profile patterns with the dissipating stratiform regions were observed in both cases. These patterns were also similar to that of the anvil region of a squall line. However the scale, process to the stratiform precipitation and detailed structures of these cases were quite different from those of the anvil region.

1. Introduction

There have been many studies about tropical cloud clusters, and convective and stratiform clouds packed in a cloud cluster. Long-lived tropical squall lines and stratiform regions, which are referred to as the trailing anvil regions, were often studied by Zipser (1977), Houze (1977), and others. The classification of the convective regions and stratiform regions in a tropical cloud cluster has been actively discussed until now. In the Global Atmosphere Research Program's Tropical Experiment (GATE), there were few detailed analyses of the stratiform clouds compared with analyses of the convective clouds, though the difference of characteristics between the stratiform and convective regions were pointed out. Since the stratiform regions which last a long time bring much precipitation, information on stratiform regions is quite important for clarifying the structure and maintenance of the tropical cloud cluster. For this purpose, observations on wind fields in cloud cluster are essential.

In order to investigate the equatorial cloud clusters, observations with two X-band Doppler radars were carried out on Manus Island (2°S, 147°E) Papua New Guinea, for two and a half months beginning 12 November 1992 during the Intensive Observation Period (IOP) of the Tropical Ocean-Global Atmosphere program, a Coupled Ocean-Atmosphere Response Experiment (TOGA-COARE) (Uyeda et al., 1995). In this paper, we focus our analysis on wind fields and the temporal change in the stratiform region of a cloud cluster using the radars and the Integrated Sounding System (ISS) wind profiler. We analyzed two cases to reveal the fine structures of tropical cloud cluster. The Velocity Azimuth

Display (VAD) and Extended VAD (EVAD) analyses with a single-Doppler radar gave the time series of the vertical distribution of the horizontal velocities and divergences. Three-dimensional wind fields were evaluated by the two Doppler radars with dual-Doppler analysis. These methods will be reported in Section 2, and the results of the two cases in Section 3. We will discuss the detailed structure in association with the convection in Section 4.

2. Methods

In order to investigate the kinematic features and rainfall structures of a stratiform region of a tropical cloud cluster in detail, we analyzed two X-band Doppler radars and the wind profiler of a NOAA's Integrated Sounding System (ISS). The observation sites are shown in Fig. 1. We utilized the 915 MHz wind profiler data of the ISS, the specifications of which are shown in Table 1. The time resolution was about 15 minutes and the range resolution of the beam

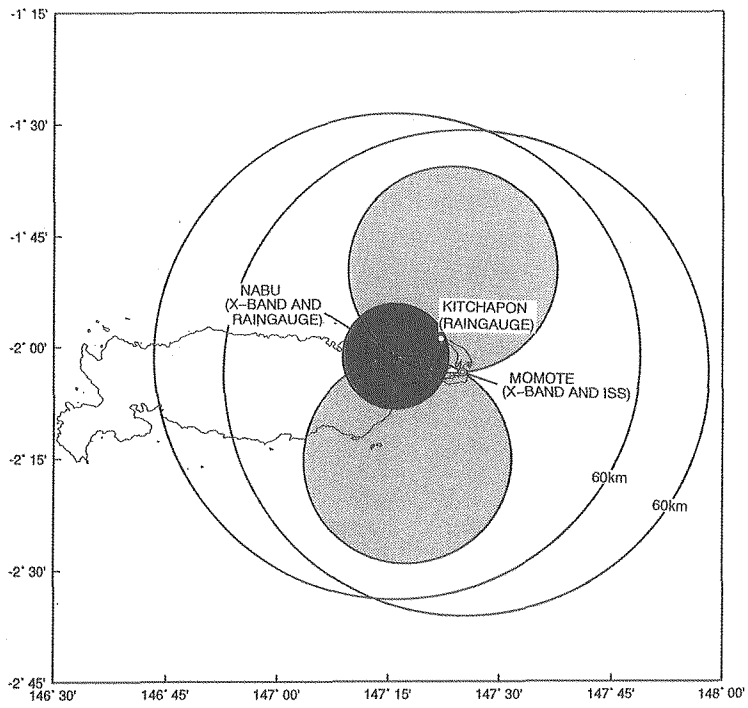


Fig. 1. Locations of an ISS, two X-band Doppler radars and two raingauges. The area analyzed by dual Doppler radar is lightly hatched. VAD and EVAD analysis ranges at an altitude of 5 km is shown by a dark circle.

Table 1. Typical parameter of the ISS wind profiler.

Frequency	915 MHz
Wavelength	32.8 cm
Peak Power	500 Watts
Resolution	60, 100, 250, 500 meters
Antenna type	Microstrip phased-array
Antenna size	1.8×1.8 or 2.7×2.7 m
Beam (2-way)	6.4 or 4.3 degrees
Range samples	50 to 200
Spectral points	64 to 2,048

direction was 250 meters. The profiler can measure horizontal and vertical winds above the radar site when it is not raining. Since the profiler data is affected by the fall velocity of the raindrops, we evaluate the horizontal winds by removing the fall velocity of the raindrops using the vertical velocity data.

Two X-band radars, Hokkaido University, Meteorological Laboratory (HUML) and Institute of Low Temperature Science (ILTS) (see Uyeda et al., 1995), were placed at Nabu and Momote. We must note that HUML radar tend to have weaker reflectivity than ILTS radar. The VAD winds were calculated for each Doppler radar using the PPI velocity data at elevation angles of 20° or 21° in order to evaluate the horizontal wind profiles above the radar site. The winds were compared with the wind data of the ISS. We also used the simplified EVAD method (Srivastava et al., 1986) to evaluate horizontal divergence profiles. For the EVAD analysis, we used the data from two elevation angles; 20° (or 21°) and 12° (or 13°). The VAD and EVAD analyses were performed on the radar data collected at 15-minute interval. Rawinsondes launched every 6 hours from the Momote site were available for analysis. We also utilized the hourly brightness temperature data (0.1°×0.1° mesh data) of Geostationary Meteorological Satellite-Infrared (GMS-IR). In addition, horizontal wind fields were analyzed with dual-Doppler radar data.

In this paper we will use the terms, 'stratiform' and 'convective' cloud or echo to classify the rainfall states. This classification has been used frequently, but here we will adopt the following qualitative definition of stratiform echoes:

- A bright band must exist around the 0°C level in reflectivity data of vertical cross section and the time-height cross section of the profiles of the X-band Doppler radar.
- It has a large echo area, the reflectivity value is not so strong, and the horizontal gradient is small.

Further, we defined a convective echo as follows:

- It has a small, strong (more than 35 dBZ) core, and the gradient of the edge of the core is very sharp.
- There is no horizontally uniform pattern in the radar echo map.

3. Results

In order to determine the fine structures of the stratiform regions of tropical cloud clusters, we analyzed two cases in which stratiform echoes were observed by the X-band Doppler radars. In one case, there is southwestward propagation of stratiform clouds from the outside of the radar analysis area on 14-15 December 1992 (Case A). In the other case, there is an abrupt change from convective echo to stratiform echo in the analysis area on 18-19 January 1993 (Case B). In this section, we will describe the results of analyses for the two cases in detail.

3.1 Propagation of stratiform cloud (Case A)

3.1.1 Long-term changes

At first, we will describe the overall characteristics and the changes of this case. We use the local standard time (LST=UT+10) of Papua New Guinea hereafter. Figure 2 shows the brightness temperatures (T_{BB}) of a GMS from 1400 LST on 14 December to 0400 LST on 15 December 1992. During the day time, the eastern edge of a cloud cluster covered Manus Island (Fig. 2a). At 1800 LST the cluster went away to the west, and a new cluster arose on the east side of Manus (Fig. 2b). The cluster developed and broadened out to the west. At 2100 LST it entered the mature stage of the cluster since it had the lowest T_{BB} (184 K) in this period. Its western edge reached Manus Island at 2200 LST. At 0000 LST and 0200 LST, the cluster covered the whole Manus Island, but the low T_{BB} (less than 220 K) area became small. At 0400 LST, the cluster dissipated as shown in Fig. 2f. Rainfall was recorded between 2200 LST and 0300 LST (Fig. 3a). The phenomena during the rainfall period will be analyzed in detail in the next subsection.

Figure 4a and 4b show the vertical profiles of potential temperature θ, equivalent potential temperature θ_e, and saturated potential temperature θ_e* that were derived from soundings launched from Manus Island They were observed before and after the rainfall event in this case. At 1600 LST the condition was moist and convectively unstable except around 2 km and 3 km that had shallow stable layers. It seemed that these stable layers compressed

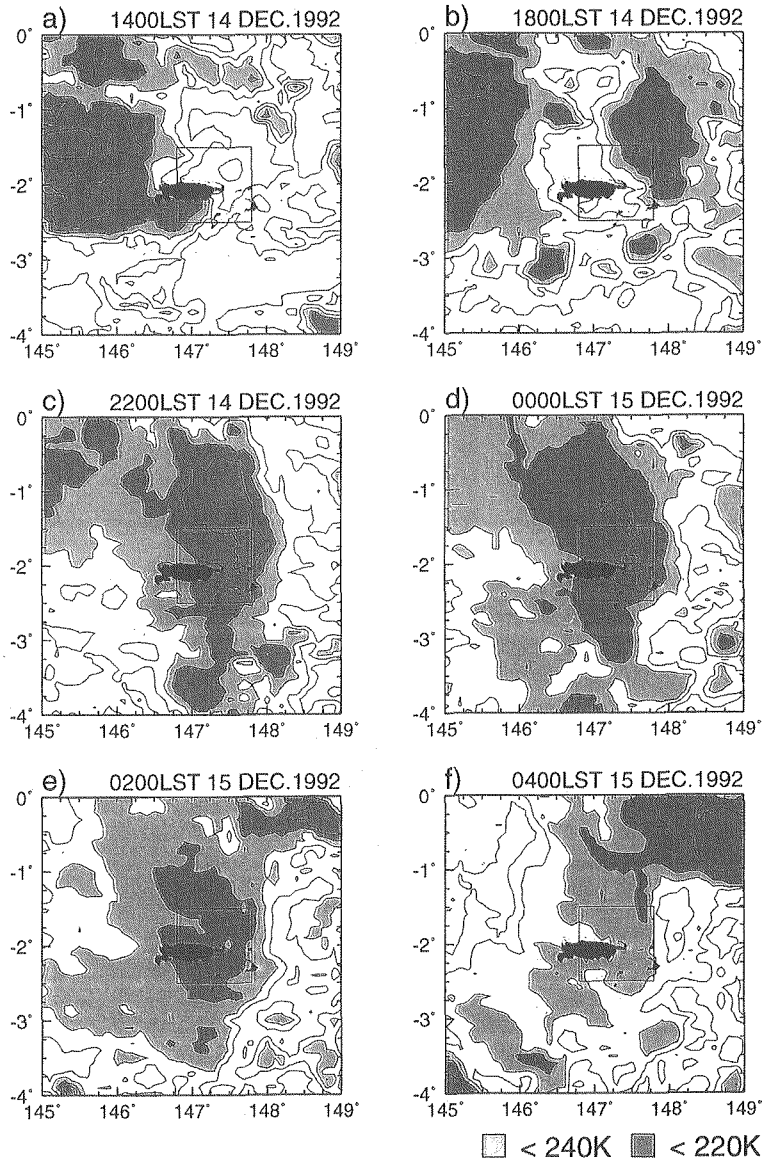


Fig. 2. The brightness temperature of the GMS-IR (at the interval 20 K) from 1400 LST 14 December to 0400 LST 15 December 1992. The black area shows Manus Island, and the shaded areas show T_{BB} less than 220 K. The rectangle represents the area in the X-band radar analysis of Fig. 6.

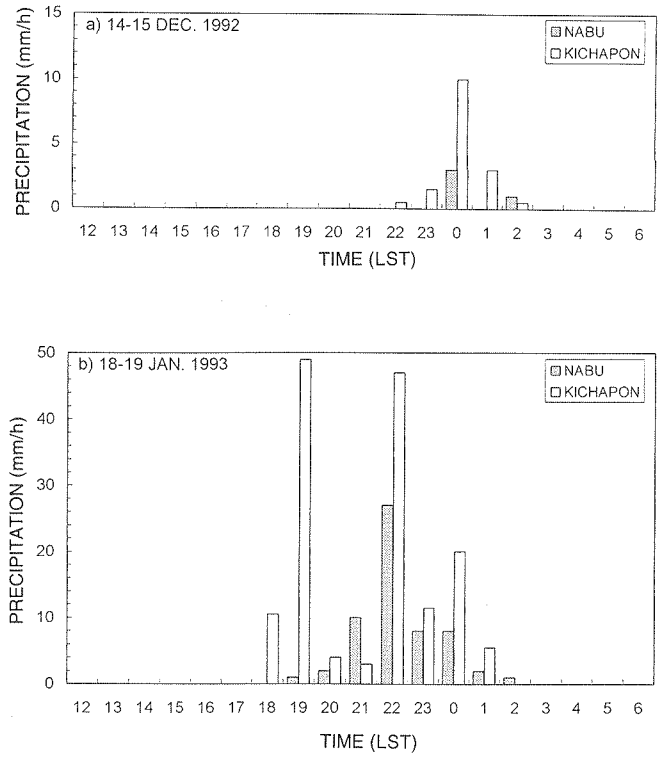


Fig. 3. The time series of precipitation at Nabu and Kichapon, (a) from 1200 LST 14 December to 0600 LST 15 December 1992 and (b) from 1200 LST 18 January to 0600 LST 19 January 1993.

the strong convection and strong rainfall. At 0400 LST the moist air mostly disappeared after the rainfall.

Figure 5 shows the time-height cross section of the horizontal wind profiles measured by the ISS between 1200 LST 14 December to 0600 LST 15 December. The profiles changed frequently before 1800 LST, that is during the day time, by approaches and passages of convective echoes. A northwesterly wind dominated in the lower layer and a northerly wind dominated in the higher layer after 1800 LST, that is during the night time. Their boundary is shown by a solid line. The dashed line means that the shear was weak. It suddenly ascended from 2.0 km to 3.5 km at 1900 LST. The boundary then gradually descended to 1.5 km from 1900 LST 14 December to 0400 LST 15 December. After 2200 LST, when the rainfall began and higher cloud area ($T_{BB}<220$ K) covered Manus Island (Fig. 2), the northwesterly wind suddenly strengthened and the top of the

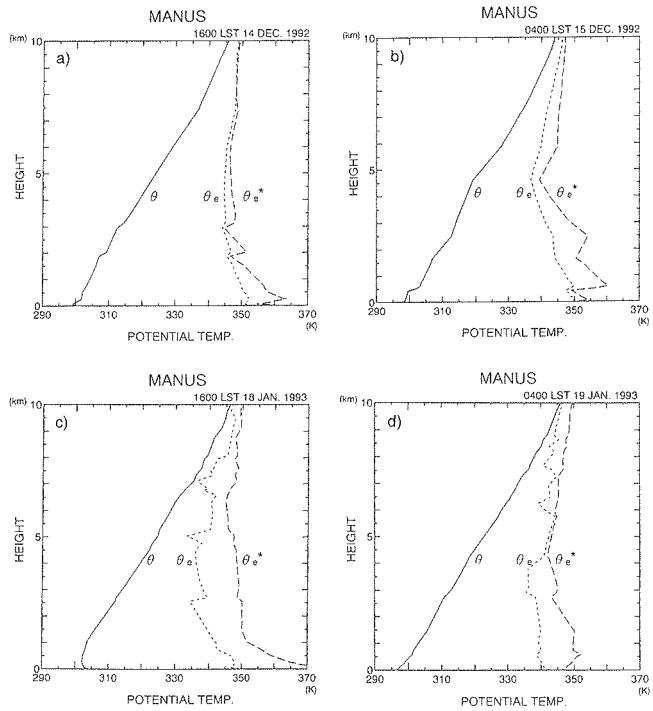


Fig. 4. Soundings at Momote, Manus Island, (a) 1600 LST 14 December 1992, (b) 0400 LST 15 December 1992, (c) 1600 LST 18 January 1993 and (d) 0400 LST 19 January 1993, showing the vertical profiles of potential temperature θ_e, equivalent potential temperature θ, and saturated potential temperature $\theta_e{}^*$.

layer rose to 3.5 km. From 0100 LST to 0230 LST it rose higher to 5.5 km, then immediately descended to 2.0 km. This suggested that another smaller system was coming to Manus Island in the period from 2200 LST 14 December to 0230 LST 15 December. Therefore, in the next subsection we will describe the results of the analyses for the period in detail.

3.1.2 Period of stratiform echo

Figure 6 shows the hourly change of the reflectivity image of the X-band Doppler radar at Nabu from 2200 LST December to 0200 LST 15 December 1992. A weak, broad echo appeared to the northeast of Manus Island at 2200 LST. It approached, and covered Nabu at 0000 LST and 0100 LST, then suddenly dissipated. The change of the radar echo corresponded to that of the low-temperature area (<220 K). However, some small, strong regions were packed in the broad echo, and these cannot be found on the satellite map (Fig. 2).

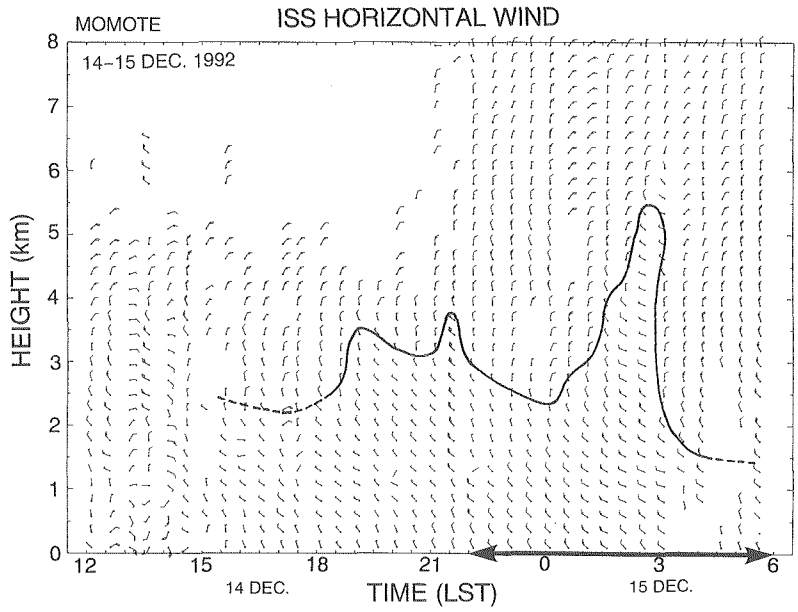


Fig. 5. The time-height cross section of horizontal wind profiles of the ISS radar at Momote from 1200 LST 14 December 1992 to 0600 LST 15 December 1992 (flag, 20 m/s; full barb, 5 m/s; and half barb, 2.5 m/s, respectively). The solid (dashed) lines show large (small) vertical shear of the horizontal wind. A solid line with arrows from 2200 LST 14 December to 0600 LST 15 December 1992 indicates the period of VAD and EVAD analyses with two X-band Doppler radars (see Fig. 7 and 8).

Figure 7 is the time-height cross section of the wind profiles measured by the wind profiler at Momote (Fig. 7a) and analyzed with the VAD method at Nabu (Fig. 7b) from 2200 LST 14 to 0600 LST 15 December. The time resolution is 15 minutes. The northerly winds in the higher layer and the northwesterly winds in the lower layer dominated through this period. Their boundary is shown by solid line in Fig. 7. The two lines are similar, but exhibit a time lag. The peak time of the height and rapidly descending time at Momote were delayed by about 45 minutes from the times at Nabu. Figure 8 shows the time-height cross section of vertical profiles of divergence in the analysis area of the Nabu X-band radar with the EVAD method. When the vertical shear was ascending, the convergence strengthened more than $2\times10^{-4}s^{-1}$ between 2 km to 4 km around 0015 LST December, and there was a divergence layer above the convergence layer. After 0215 LST, a divergence dominated below 3 km and there was a convergence above the divergence.

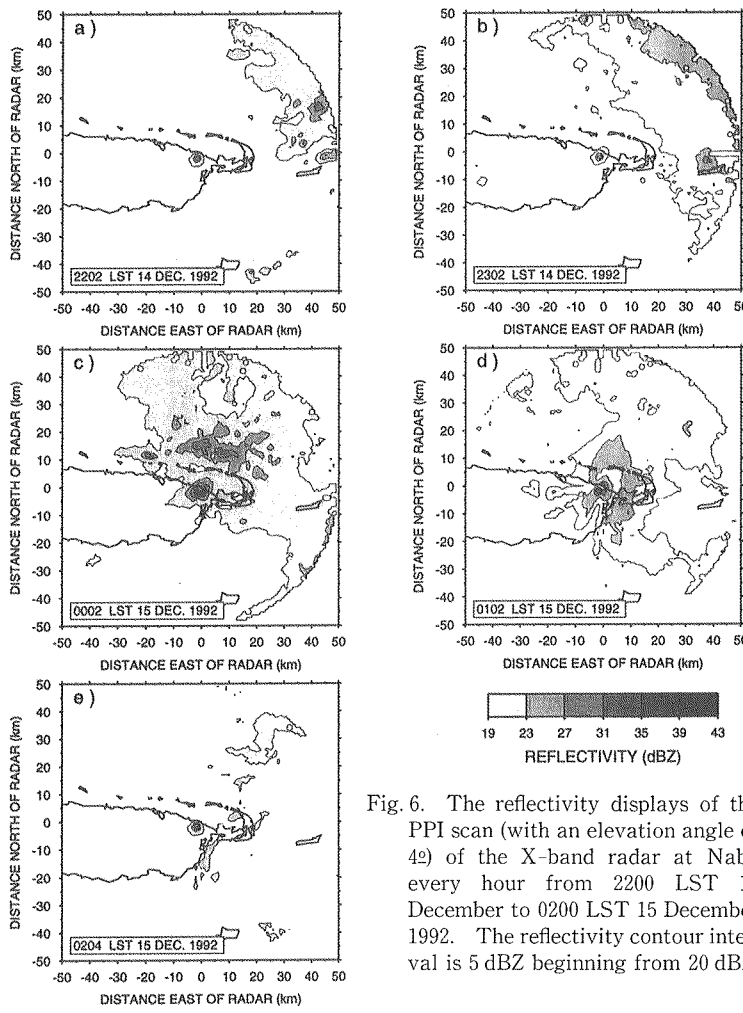


Fig. 6. The reflectivity displays of the PPI scan (with an elevation angle of 4°) of the X-band radar at Nabu every hour from 2200 LST 14 December to 0200 LST 15 December 1992. The reflectivity contour interval is 5 dBZ beginning from 20 dBZ.

Figure 9 shows the reflectivity at Momote and the horizontal winds from the dual Doppler analysis at 0000 LST and 0030 LST 15 December at heights of 1.0 km and 3.0 km. A radar echo exceeding 10 dBZ covered this analysis area during both times. A linear, strong echo, that had about 50 km long and extended from west-southwest to east-northeast, was located in it north of the radar sites. This strong echo was also seen on the radar echo map at Nabu (Fig. 6). At 0000 LST, northwesterly winds dominated at 1.0 km all over this area. Northerly winds generally dominated at 3.0 km, and the wind field

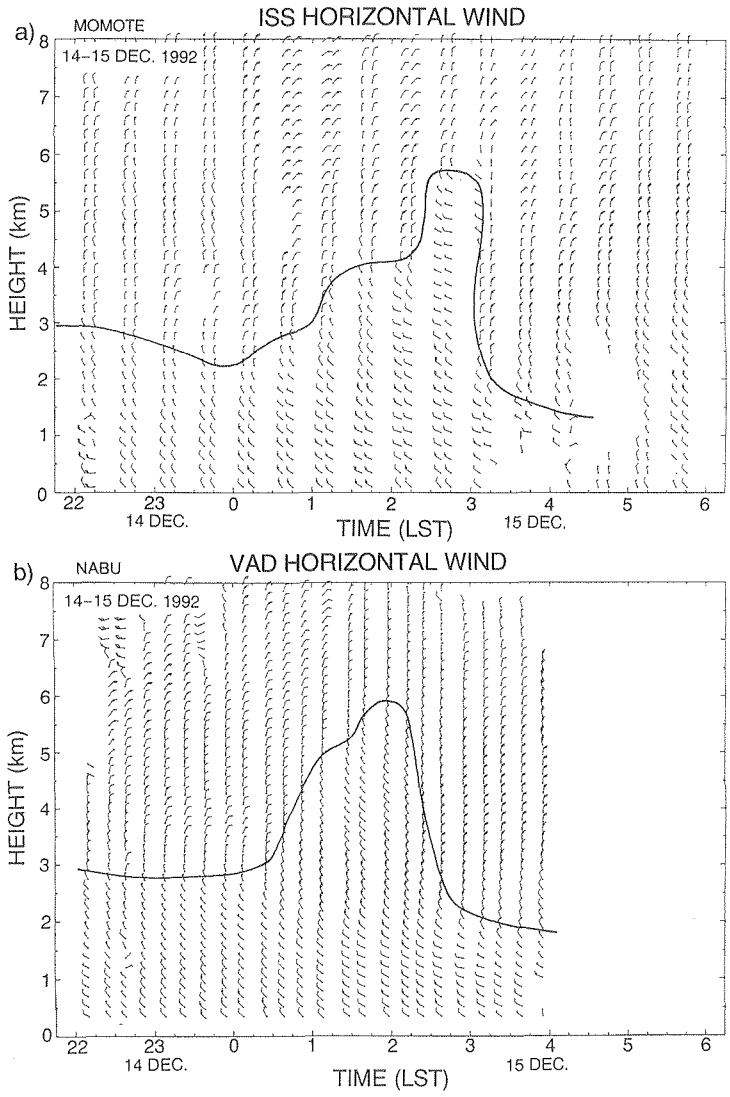


Fig. 7. The time-height cross section of the horizontal wind profiles of (a) ISS radar at Momote and (b) X-band Doppler radar at Nabu from 2200 LST 14 December to 0600 LST 15 December 1992. The flag and barbs represent the same values as in Fig. 5. The solid lines show a boundary between northwesterly wind and northerly wind.

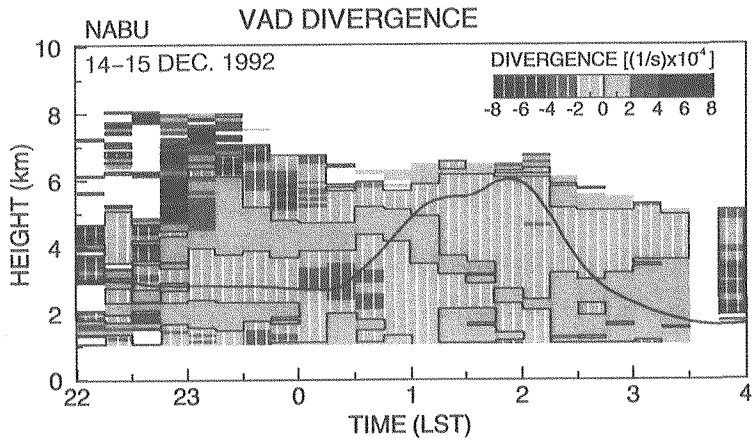


Fig. 8. The time-height cross section of the divergence profiles of the X-band Doppler radar at Nabu analyzed with the EVAD method from 2200 LST 14 December to 0400 LST 15 December 1992. The solid line shows the same boundary as in Fig. 7b.

fluctuated on the linear echo. This indicated the existence of a 'convective part' in a larger stratiform echo. Northwesterly winds existed north of the linear echo at 3.0 km. At 0030 LST the convective part moved southeastward according as southeasterly approaching of northwesterly winds and reached Nabu at this time. These wind fields change corresponded to the profiles of the ISS wind profiler.

Figure 10 shows north-south cross sections of reflectivity along line A-A′ in Fig. 9 ; the volume scan data of the radar at Momote every 20 minutes from 0000 LST to 0100 LST 15 December is utilized. At 0000 LST, strong, narrow echo existed 15km north of Nabu. This echo corresponded to the convective part as a linear echo band in Fig. 9. The strongest reflectivity existed above 3.0 km. It propagated southward to 15 km south of Nabu at 0100 LST. This corresponded to the linear echo that passed over Nabu from north to south at 0300 LST (Fig. 9).

3.2 Abrupt change from convective to stratiform (Case B)

In this subsection, we will describe the structure and the temporal changes of cloud systems on Manus Island on 18-19 January 1993 (Case B). Satoh et al. (1995) analyzed this case in detail and described the three-dimensional kinematic structures of mesoscale convective systems with dual Doppler radar analysis. In this case, much heavier rainfalls were observed than those of Case A (Fig. 3).

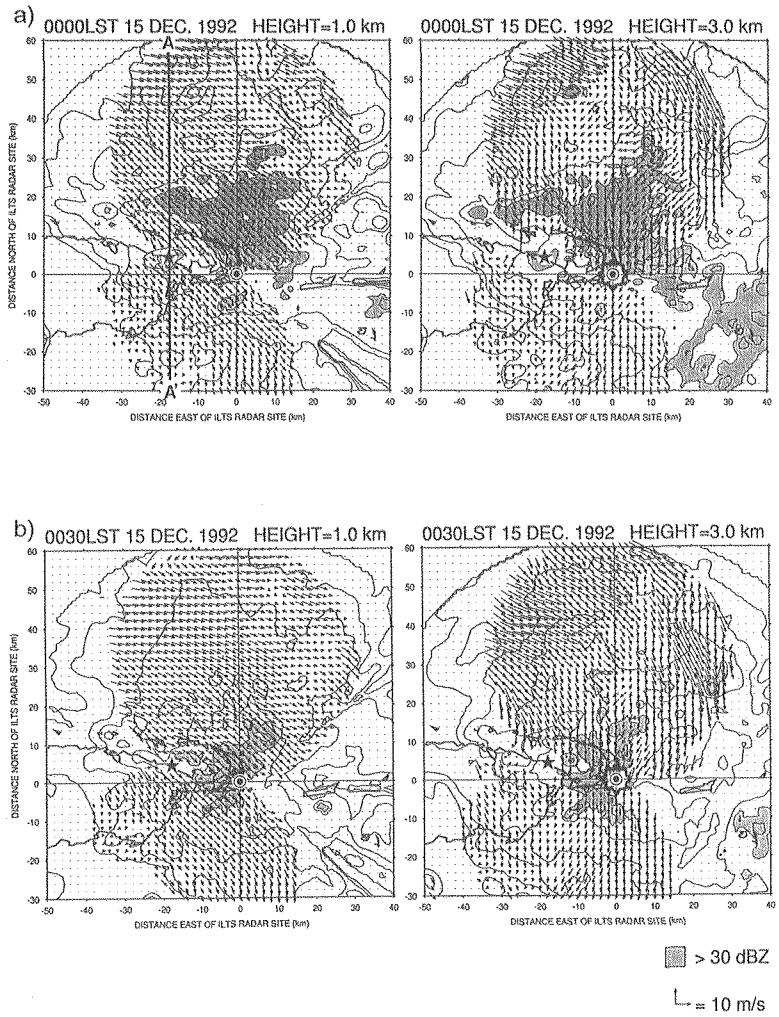


Fig. 9. The reflectivity of the X-band radar at Momote and the horizontal wind from the dual Doppler radar analysis at (a) 0000 LST and (b) 0030 LST 15 December 1992. The horizontal cross sections at 1.0 km (left) and 3.0 km (right) are shown. The reflectivity contour interval is 5 dBZ from 10 to 45 dBZ. The hatched area is greater than 30 dBZ. The double circles indicate Momote; the black star, Nabu.

There was a strongly unstable condition below 1 km at 1600 LST before this event because of sunshine in the daytime (Fig. 4c). A convectively unstable layer existed between this height and 5 km. The air was much drier than that of Case A (Fig. 4a and 4b). Dry, convectively neutral air existed below 4km,

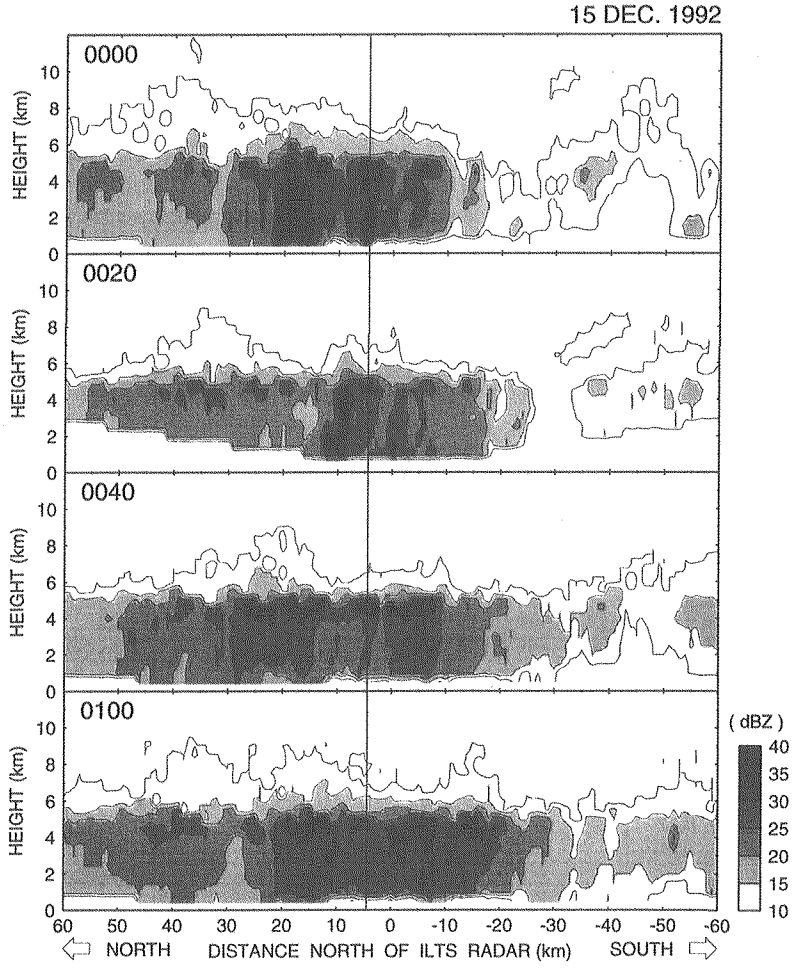


Fig. 10. Vertical cross sections of the reflectivity displays of X-band radar at Momote every 20 minutes from 0000 to 0100 LST 15 December 1992. The reflectivity contour interval is 5 dBZ beginning at 15 dBZ. Locations of these sections are indicated by the line A-A' in Fig. 9.

and saturated air existed above 4 km at 0400 LST 19 after the event (Fig. 4d). This suggested the existence of anvil clouds above 4 km and downdrafts below 4 km.

Figure 11 shows the time series of horizontal wind profiles using the VAD method at Nabu from 2100 LST 18 January to 0500 LST 19 January 1993. The horizontal winds were basically northerly at all levels, but they fluctuated before 0000 LST 19 January. At 0000 LST 19 January a northeasterly wind layer

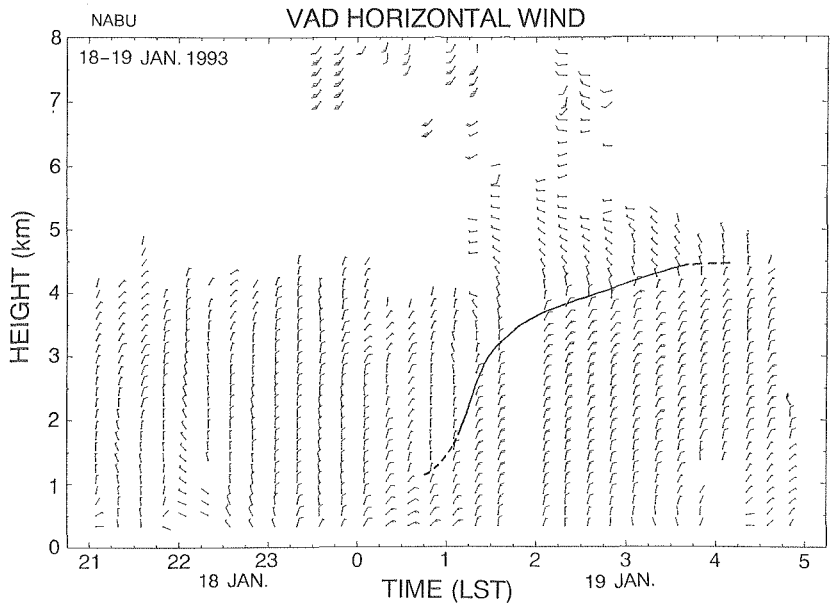


Fig. 11. As in Fig. 7b, except for the period from 2100 LST 18 January 1993 to 0500 LST 19 January 1993.

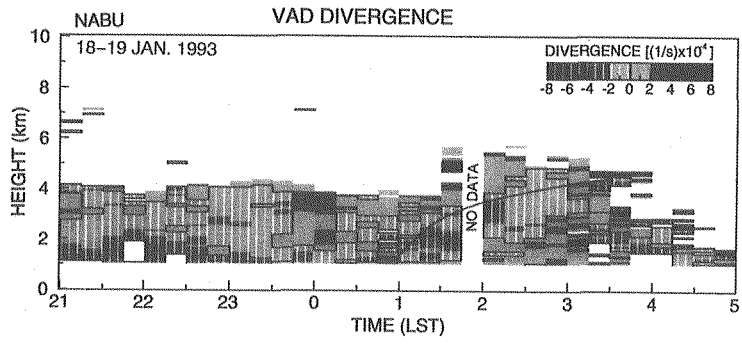


Fig. 12. As in Fig. 8 except for the period from 2100 LST 18 January 1993 to 0500 LST 19 January 1993.

appeared in the lower level. The solid line indicates the boundary between the northerly wind layer and the northeasterly wind layer. The northeasterly wind layer rapidly thickened, and the top reached 4km at 0200 LST. The wind speed in the layer became more than 10 m/s.

Figure 12 shows the time series of divergence profiles using the EVAD method at Nabu from 2100 LST 18 January to 0500 LST 19 January 1993.

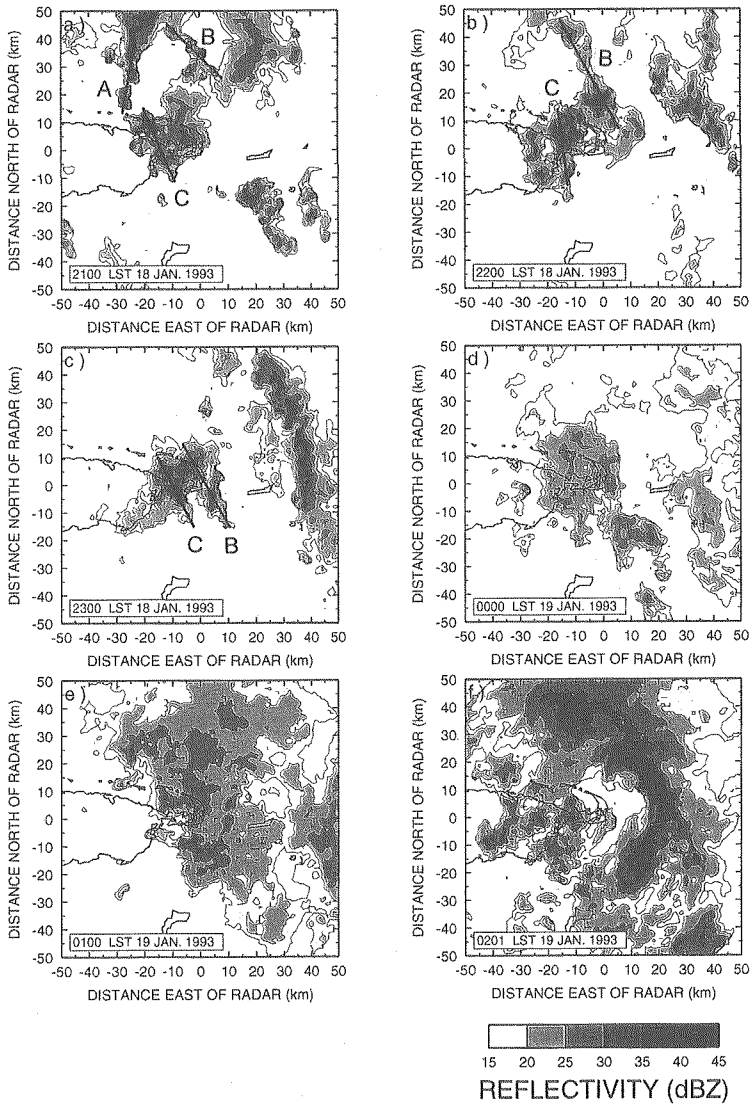


Fig. 13. Sequential horizontal cross sections of the reflectiyity displays at the height of 3 km from ILTS radar every 1 hour from 2100 LST 18 to 0200 LST 19 January 1993. The reflectivity contour interval is 5 dBZ beginning at 15 dBZ. Convective linear echoes are labeled by A, B and C.

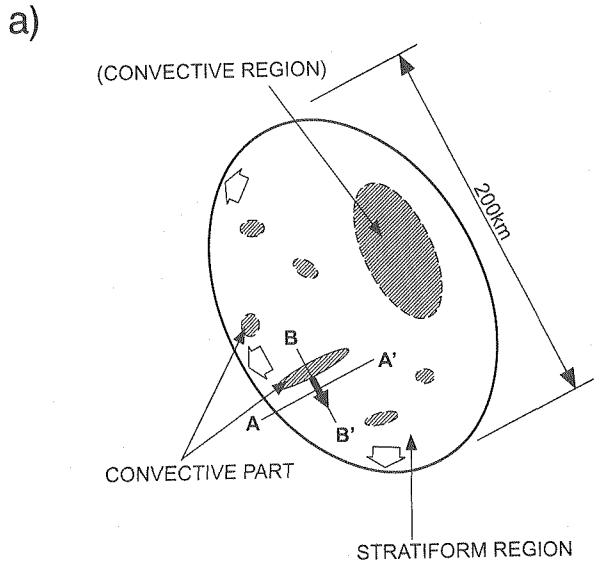
Before 2330 LST on 18 January, strong convergence dominated the whole level. After 2330 LST 18 January the pattern suddenly changed, that is, divergence dominated above the 1.5 km level. At that moment, two linear convective

echoes existed west and east of the radar site and moved slowly southwestward. At 0030 LST 19 January a convergence dominated above 1.5 km again. The convective echoes suddenly decayed or changed to stratiform clouds around 0100 LST. The pattern then rapidly became convergence again below 3 km. However, divergence appeared above 3 km. After 0200 LST, the convergence layer became high. Another divergence layer spread from the lower level, and the convergence layer ascended gradually. These pattern changes after 0100 LST are similar to the pattern of the latter half in Case A.

Figure 13 shows the time series of reflectivity of Momote radar at 3 km from 2100 LST 18 to 0200 LST 19 December 1993. At 2100 LST, three linear echoes existed around Manus Island (labeled A, B and C in Fig. 13a). The fluctuation of wind profile was caused by propagation and change of these echoes (Fig. 11). At 2200 LST, echo A diminished. Echo B moved southwestward and approached Manus, while echo C stayed over Nabu. These two echoes merged over Manus Island at 0000 LST 19, then rapidly broadened, became weak, and changed from convective to stratiform.

4. Discussion

In this section, we will discuss the detailed structures that brought precipitation over Manus Island from the temporal change of wind fields and divergence fields within the VAD analysis area of the radars. In Case A, the radar echoes during the observation period were almost stratiform. The wind pattern was the northwesterly in the low and middle levels and the northerly in the high level. The pattern basically continued from 1900 LST 14 to 0600 LST 15 December 1992. A conceptual model is shown in Fig. 14. The stratiform echo was made in a larger system than in the analysis area of the X-band radars. A cloud cluster occurred at 1400 LST on the east side of Manus and broadened out southwestward (Fig. 2a). This cloud cluster may have had some convective regions northeast of Manus Island because of a low T_{BB} area in Fig. 2b-2d. At 1900 LST, the edge of the cloud cluster covered Manus Island and the pattern of the wind profiles changed. Northwesterly wind in the lower layer and northerly wind in the upper layer dominated, and a strong vertical shear existed between them in the cloud cluster. At 2200 LST a stratiform echo entered in the observation range of the radars. The cluster and the stratiform echo then gradually weakened according as decaying of the low T_{BB} area. Horizontal shear between northwesterly and northerly wind may have occurred and propagated to Manus Island. At 0000 LST 15 December, it entered the VAD



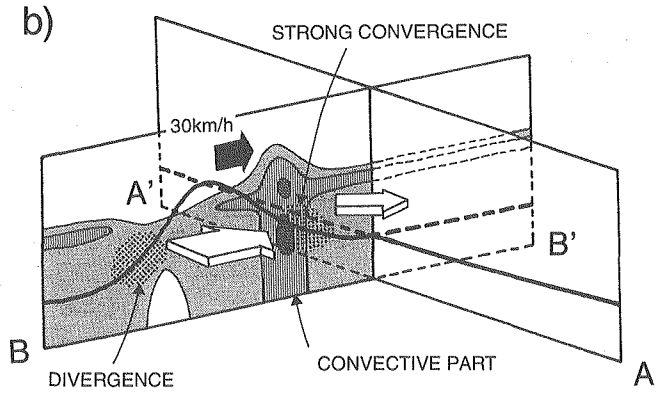


Fig. 14. The conceptual model of Case A. (a) The horizontal model of the cloud cluster. Shaded areas are observed (solid) and inferred (dashed) convective region. White arrows show growth of the cluster and the black arrow shows the direction of a convective echo that passed over Nabu. (b) Vertical model along A-A' and B-B' lines in Fig. 14a as a bird's-eye view from west in the observed area by the X-band radars. Shaded area is the radar echo, and the dotted area is the region of convergence and divergence. White arrows show the horizontal winds of the two layers and black arrow shows the direction of a convective echo and the wave.

analysis area of the radar. Convection occurred from the middle level because of the middle level convergence in the area (Fig. 10). There was moist air above 2 km in comparison with Case B (Fig. 4), and unstable air existed except for stable layers at 2 km and 3 km. The stable layers may have been broken by the convergence and updraft in the middle layer (Fig. 8) and the northwesterly wind layer thickened. Strong precipitation then occurred with passage of the convergence and linear convective echo. The southeastward propagation of northwesterly wind and horizontal shear line accounted for the time lag in the vertical profiles of winds between Nabu and Momote. After 0215 LST, the northwesterly wind layer suddenly became thin and divergence dominated in the middle level. The strong echo then disappeared from the analysis area in the stratiform echo. It seemed that this temporal change of the vertical profiles of horizontal wind was caused by a southeastward passage of a wave in the boundary between the northwesterly and northerly wind layers. The wave length of the wave was 60 km and the height was 3.5 km. Convergence and convection in the middle level developed in the front of the wave and divergence developed behind it.

In Case B, we analyzed the merger of the two linear convergence echo and the change to stratiform in the analysis area of the X-band Doppler radar. The horizontal scale of this system may have been smaller than that of Case A. At 0000 LST 19 January, divergence existed in the middle layer (Fig. 12). The echo in the VAD analysis area suddenly spread out and the reflectively at this time was weaker than prior periods in association with the divergence. This fact shows that the echo rapidly changed from convective to stratiform after merger of two convective echoes, labeled B and C. Therefore the reflectivity at this time was weaker than prior periods in association with the divergence. The echo then rapidly broadened, but kept the peak reflectivity because the field around Manus Island became convergent due to the inflow of northeasterly winds from the lower level (Fig. 11). The northeasterly wind and convergence layer then became higher, and divergence appeared at the lower level. This divergence profile agreed with the results of Gamache and Houze (1982).The pattern of divergence profiles after 0000 LST 15 December 1992 in Case A (Fig. 8) and after 0030 LST 18 January 1993 in Case B (Fig. 12) were similar. However, the structures and processes were quite different. The pattern of Case A was caused by the passage of a convective part in the stratiform region. In contrast, the pattern of Case B occurred during and after the change from convergence echo to stratiform echo. However, in both cases the divergence in the lower level and convergence in the higher level existed in the dissipating

stratiform region. These results suggest that the structures are common for stratiform regions in several types of tropical cloud clusters.

5. Concluding remarks

We attempted to investigate the structure of a stratiform region of a tropical cloud cluster on Manus Island during the TOGA-COARE IOP. Time series of VAD and EVAD analyses for the two X-band radars were used to obtain horizontal wind profiles and convergence profiles to compare with time series of an ISS horizontal wind profiles. Two types of stratiform clouds on Manus Island were analyzed. In one cases, a stratiform cloud that gradually approached in radar observation range from the northeast of Manus Island as analyzed (Case A : from 1200 LST 14 to 0600 LST 15 December 1992). This cloud developed at the western edge of a cloud cluster. In the another case, two linear convective clouds merged and changed to stratiform clouds (Case B : from 2100 LST 18 to 0500 LST 19 December 1993).

In Case A northerly winds dominated the high level and northeasterly winds dominated the low and middle levels throughout the period analyzed. The height of the vertical shear between the two layers gradually descended from 3.5 km to 1.5 km. During this period, a sudden ascent and descent of the shear in the middle layer, associated with convergence and divergence within the analysis area of the X-band radar, were identified. This rapid change of the height of the vertical shear between northerly and northwesterly winds corresponded to southeastward passage of a convective part. Convergence and convection found above 2 km in this stratiform cloud had a limited scale of about 50 km in length within the radar observation range. The convective part developed in the stratiform region at the edge of a cloud cluster and broke the stable layers. Consequently, this convection contributed to initiating precipitation (10 mm/h) over Manus Island in the dissipating cloud cluster. This temporal change of the wind profiles may have been caused by a southeastward wave in the boundary between the two layers. After the passage of the wave, convergence existed in the higher level, and divergence existed in the lower level. In Case B, the variation in the divergence profiles was associated with the interaction between convective cloud lines. When two linear echoes merged and changed to a stratiform echo, divergence was analyzed above 2 km. This may indicate that this divergence pattern is characteristic of convective echoes changing to stratiform. The convergence in the lower level then ascended with northeasterly winds, and divergence developed in the lower level. Case A was

caused by development and passage of a convective part in the stratiform region; Case B was caused by merger of linear convection and transition to stratiform echoes. The divergence profile pattern in the dissipating stratiform regions were similar to that of anvil region of a squall line.

We analyzed the detailed structures of a stratiform region of a cloud cluster with the VAD and EVAD method using two X-band Doppler radar, and the ISS wind profiler. We are certain that this type of study on tropical stratiform cloud could be helpful for the establishing convective and stratiform images of tropical cloud clusters, which is difficult to do using only GMS-IR data as discussed by Kikuchi and Uyeda (1996). We confirmed that the variations of meso-γ scale structures in stratiform regions of tropical cloud cluster. We believe that the dissipation process of the stratiform region of cloud clusters and convection from middle level in the stratiform clouds are important for understanding tropical cloud clusters. In these analyses, we could analyze a part of the whole stratiform region using X-band Doppler radars and the wind profiler. Therefore more quantitative studies and analyses, with remote sensing on the surface and from space which can observe larger areas, are needed. The Precipitation Radar (PR) of Tropical Rainfall Measuring Mission (TRMM), that was launched in November 1997, can observe the internal structure of a tropical cloud cluster in the whole area of tropical region. We believe that the systematic analyses across multi-scale can clarify the whole image of tropical cloud cluster.

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