Some Characteristic Features of Cloud Lines Seen in GMS Imageries

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Abstract

Cloud lines consisting of cumulonimbi (Cb lines) are frequently observed in GMS imageries, especially in regions south of the main baroclinic zone. Such Cb lines are studied in the northwestern Pacific Ocean with respect to the morphological and analytical aspects.

It is revealed that the frequency of the occurrence of Cb lines is maximum in summer and minimum in winter. Spatial distribution of the occurrence of them is broader in autumn than in any other season. All the Cb lines in GMS imageries for three years are classified into seven categories. Two different types of Cb lines are selected and analysed herein. According to the results of the analysis, it is clearly pointed out that a stable layer exists between 800 and 900 mb and a potentially unstable layer is observed under the stable layer on the eastern side of Cb lines. Such the unstable layer extends vertically up to 600 mb in just front of the cloud lines. This provides preferable condition to the development of convective clouds. In the rear of Cb lines, dry and stable and/or neutral condition is observed at lower and middle levels of the troposphere.

1. Introduction

Cloud lines consisting of cumulonimbi (called Cb lines or cloud lines for simplicity hereafter) are frequently observed within the coverage, of GMS especially in regions south of the main baroclinic zone. Once such Cb lines appearing, they last usually for about 12-18 hours and extend for several hundred kilometres. The authers tried to reveal some characteristic features of those cloud lines seen in GMS imageries with respect to the morphological and analytical aspects within a limited area shown in Fig. 1. Cb lines in this paper are defined as that length, width and life time are more than several hundred kilometres, less than 150 kilometres in the mature stage and more than 6 hours, respectively. The period for the study is set up for three years from October 1979 to September 1981 and the data used in this study are composed of the GMS imageries taken at three hours intervals in the routine works at Meteorological Satellite Centre (MSC) and other conventional meteorological data which are easily obtainable at MSC for meteorological analyses.

Cb lines are also detectable by radar observation net works and many studies have been achieved on this kind of subject by rader observation data combined with conventional data (e. g. R. Tatehira, 1971 ; K. Ninomiya and T. Akiyama, 1974 ; K. A. Browning and T. W. Harrold, 1970). Fine structures of Cb lines and mechanisms of the development of such cloud lines have been revealed by those researches.

The main purpose in this paper is placed on revealing gross features of Cb lines by classifying all the Cb lines observed for the three years, analysing the seasonal change of the spatial distribution of the occurrence of Cb lines and achieving some case studies for typical examples within a certain degree of tolerance.

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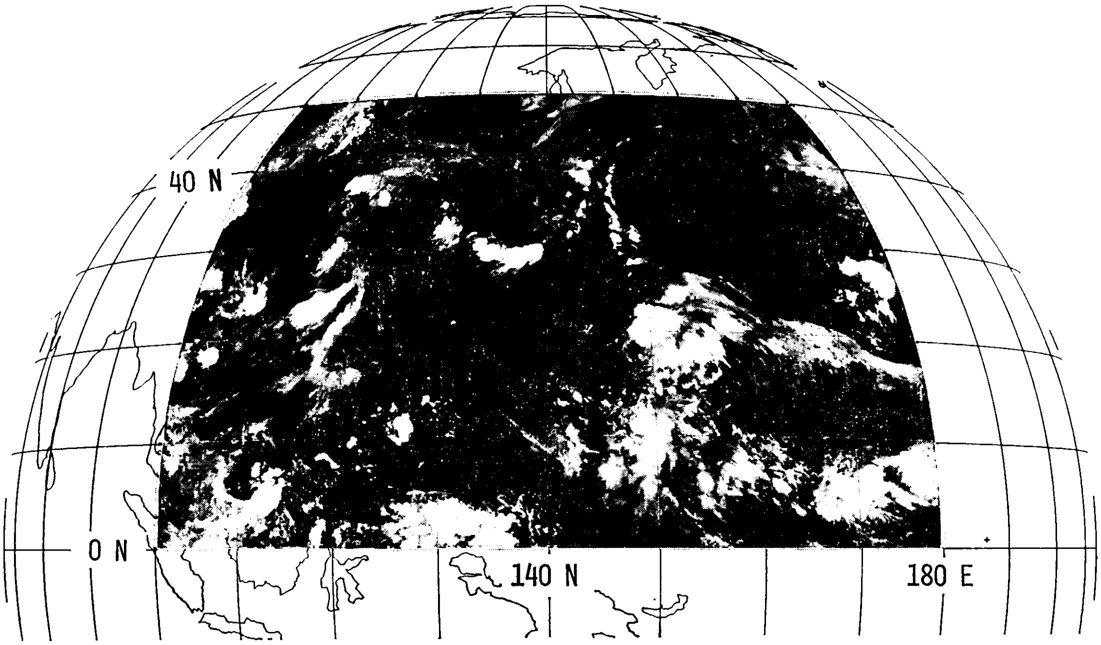


Fig. 1 Target area in this paper.

2. Classification of Cb lines

Cb lines in GMS imageries appear in various patterns. Fig. 2 shows typical patterns of them which are commonly observed in the target area (Fig. 1). Some explanations for Fig. 2 will be given below.

(a) Cb lines along the front edge of cloud bands associated with cyclonic disturbances.

A cloud band stretches southwestward from the cloud area (marked by C in Fig. 2 (a)) associated with a cyclonic disturbance. A Cb line forms along the front edge of the cloud band. In this case, the cloud line seems to be the representation of a cold front in the Norwegian frontal wave model. The tip of southwestern part of the cloud line often becomes slowly or stationary in spite of steady eastward movement of the low pressure system which is accompanying the cloud band (line). This type of cloud lines stretches sometimes along a whole cloud band which is connecting two consecutive low pressure systems in the westerly zone.

(b) Cb lines just ahead of cold frontal cloud bands.

A cold frontal cloud band often accompanies a Cb line just ahead of the band. This type is parallel to the cloud band and is observed most frequently by GMS within the target area than any other types.

(c) Cb lines along the front of cold air advection.

A cloud band suggesting a boundary of strong cold air advection is often observed in northeast to souahwest flanks to a well defined cold vortex aloft which causes considerable development of a low pressure system at surface (SFC) in the east of Japan in winter season. The cloud band stretches sometimes for a few thousand kilometres and its width becomes narrower gradually as the cloud band moves towards east and south. After that, a Cb line forms upon occasion just ahead of and along this kind of cloud bands. This suggests that this type of Cb lines occurs along boundaries between the subtropical air mass and the polar air mass.

(d) Cb lines in the warm sector of low pressure systems.

A Cb line appears in front of a cloud band which stretches to southwest from a cloud area which is associated with a low pressure system. This type of cloud lines is rather apart from the cloud band within a warm sector when it appears first and the

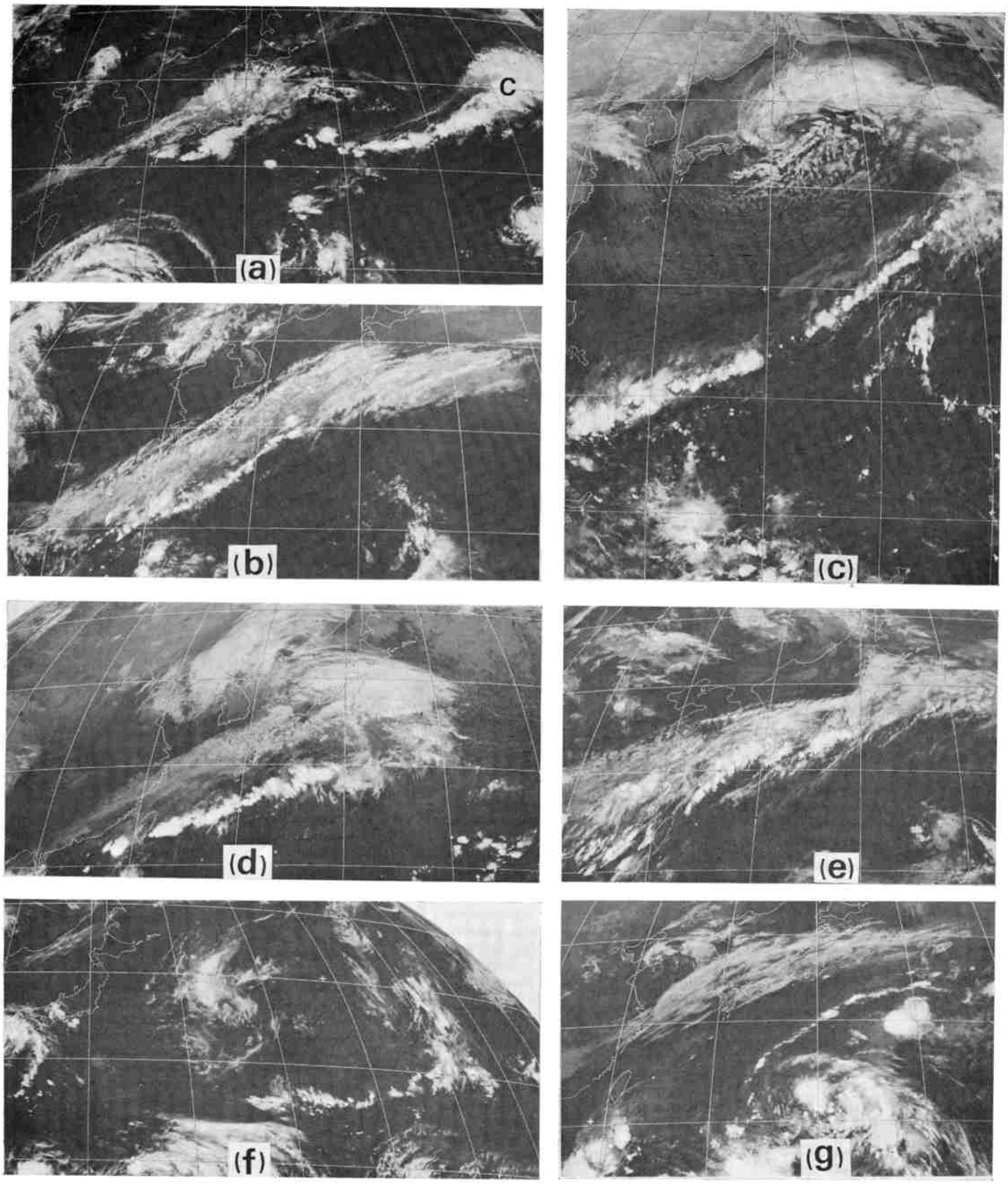


Fig. 2 Various patterns of Cb lines as seen in GMS imageries. See text for details.

band approaches to the Cb line gradually.

(e) Cb lines in the periphery of subtropical high pressure systems.

Cloud lines appear in cloudless areas in periphery of subtropical high pressure system just south of a cloud band which is associated with a baroclinic zone along the southernmost portion in the westerly zone. This type of Cb lines usually crosses the cloud band mentioned above with a certain angle and two or three cloud lines appear simultaneously.

(f) Cb lines in the periphery of upper cold lows.

In the warmer seasons, a blocking pattern appears in the northwestern part of the Pacific Ocean. A cut-off low travels to south and a Cb line forms in the south to southwest periphery of the low.

(g) Cb lines in the outer regions of tropical cyclones.

In an outer region of a tropical cyclone, a well developed Cb line appears sometimes and often reaches to a cloud area which is associated with the tropical cyclone. This type of cloud lines is observed in the north to northeast quadrant of the cyclone centre. Southernmost of the cloud line sometimes consists of a part of a cloud area which is associated with the cyclone and indicates lower level circulation of the cyclone.

In this classification, there exist some difficulties in assigning a proper type to a given Cb line among types (a), (b), and (c) in Fig. 2 in some case. This suggests that Cb lines in those types occur under close synoptic situations. Scales of Cb lines and the developing stage of the disturbances accompanying those types of Cb lines, however, seem to be different each other. In the case of (a), a disturbance is distinct and in the early developing stage when the cloud line appears. On the other hand, the disturbance is not clearly defined in the case of (b). The extension of the cloud lines in both cases of (a) and (b) are usully for several hundred kilometres and up to one thousand kilometre. On the contrary, a well defined and long stretching Cb lines appear in the case of (c) for a few thousand kilometres under such conditions as fully developed low pressure systems existing and strong cold air outbreak extending broadly to the subtropical regions. In this case, no Cb lines are observed in any early developing stage of the low pressure system which causes the cold air advection.

3. Seasonal variation of the occurrence of Cb lines

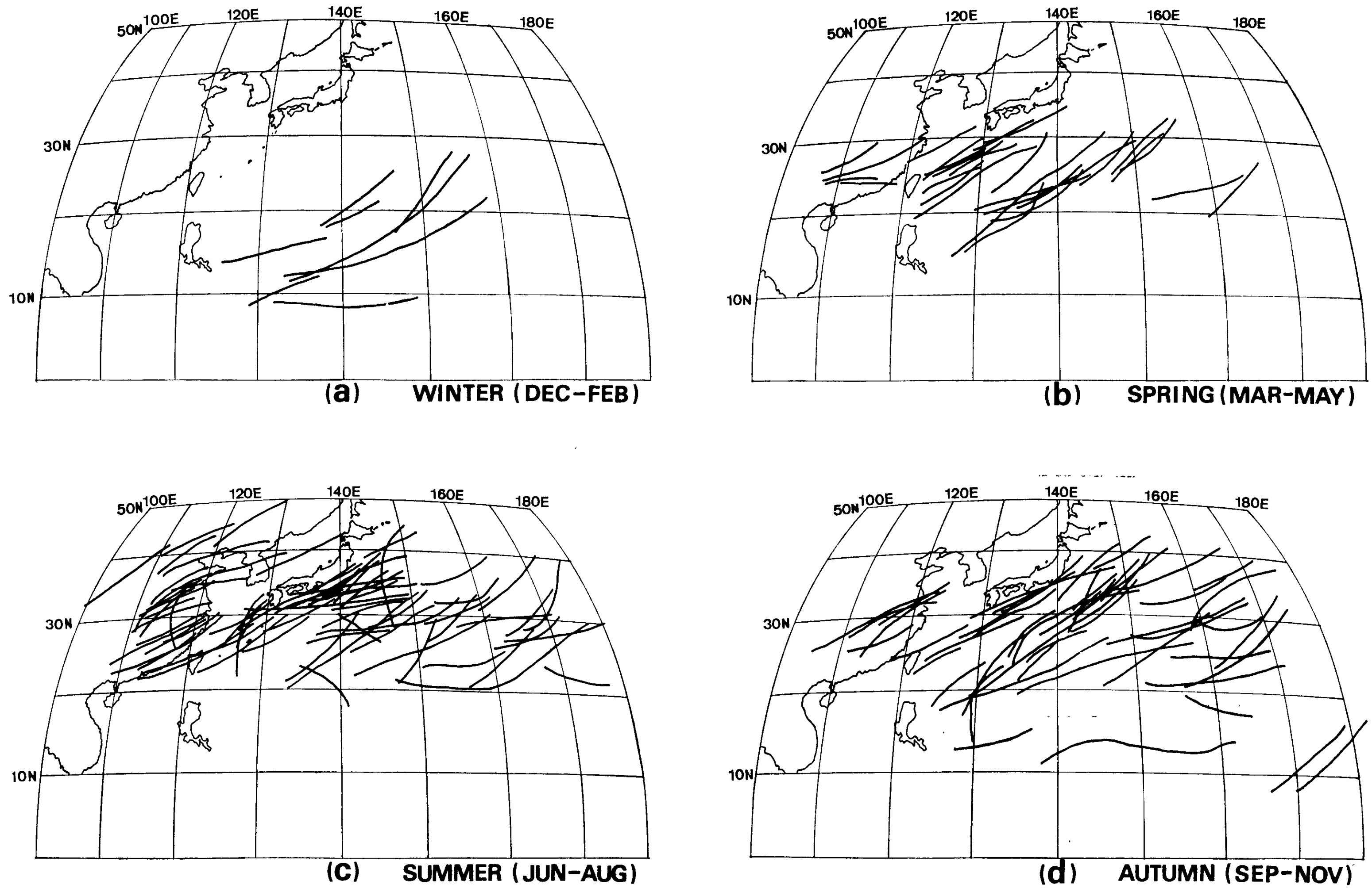
Areal extent of the occurrence of Cb lines varies season to season. Fig. 3 shows such seasonal variation for each season in the target area.

In winter, several cloud lines are only observed and locations of them are in limited range of 10–30°N and 125–155°E in both north-south and east-west directions, respectively, as seen in Fig. 3 (a). Cb lines appear more frequently in spring than in winter (Fig. 3 (b)). The occurrence of the cloud lines is spread out in east-west direction (105–170°E) and less extention is observed in north-south direction (15–35°N). A few cloud lines concaving to northwest and southeast appear in this season. Fig. 3 (c) indicates that Cb lines are observed most frequently in summer and the areal extent of the occurrence of Cb lines is broadened in both east-west (110–180°E) and north-south directions (20–50°N) compared to that in spring. No cloud lines appear in the southern region below 20°N. Cloud lines with convex shape towards south, southeast, northwest and north form in this season, suggesting the occurrence of various types of cloud lines mentioned in the previous section. Further widely spreaded region of occurrence of Cb lines is indicated by Fig. 3 (d) in both directions in autumn. The region of the occurrence in autumn is bigger than in any other season. The range is from 110 to 180°E and from 10 to 40°N. Various types of cloud lines are also observed in this season as in summer.

Such variation of the occurrence of Cb lines would be closely related to the seasonal change of the synoptic situation in this region investigated.

3. Case Study

Two case studies were carried out in order to analyse structures of Cb lines and synoptic situations around the cloud lines. Those cases are selected among all the cloud lines which passed through an observation network in the Ryukyus, the Kyushu island and the Korean peninsula. Fig. 4 shows the observation network employed for meteorological



Fis. 3 Seasonal variation of appearance of Cb lines within the target area for three years (Oct. 1979-Sep. 1981).

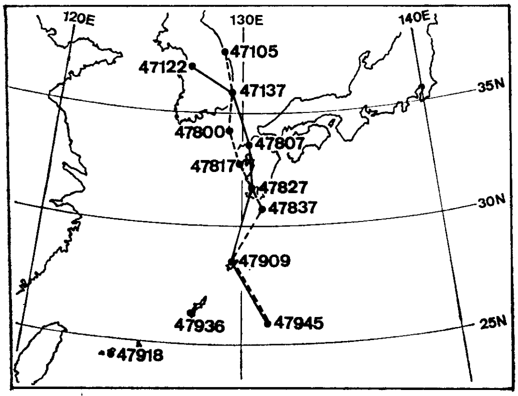


Fig. 4 Stations used in meteorological analyses. A thick line denotes the location for time sequence at various levels exceptfor the surface (SFC). A broken line represents stations for time sequence at SFC.

analyses of time-space cross sections at various levels and thermal structures. The cross sections at upper levels and SFC are achieved along the thick lines and the broken lines in Fig. 4, respectively. All the stations are mentioned by station numbers in 5-digit which are orthorized by WMO communication code.

3.1 Case 1 : 28-29 March 1980

A cloud area marked by C in Fig. 5 corresponds to a low pressure system. Initial development was indicated by immature cumuliform clouds in line at 281800 Z (not shown) and the cloud line denoted by A and B developed gradually as shown Fig. 5 (a), (b) and (c). Remarkable development is seen at about 291200 Z (Fig. 5 (d)) 18 hours after the initial formation of the cloud line. The extension of the cloud line in mature stage is for about 1500 km long and 100 km wide. The cloud line moved southeastward by about 50 knots and passed through near stations of 47909, 47918, 47936 and 47945 at 290300 Z, 290900 Z, 290900 Z and 291500 Z, respectively. The Cb line began weakening after 291200 Z as seen in Fig. 5 (d) and (e). Active convective clouds are still seen in the southwesternmost of the cloud line at 291800 Z.

Time-space cross sections at various levels are shown in Fig. 6. Those figures in Fig. 6 indicate that a remarkable cyclonic disturbance has passed this region and the trough line inclined to the west vertically. At SFC, the centre of the low pressure system passed through 47817 at about 290600 Z with changes of wind, temperature, dew point depression (not shown) and weather. Wind direction changes from easterly-southerly to northerly-westerly and continuous rain with moderate to strong intensity is altered to shower along a cold trough stretching to SSW. This indicates the typical characteristic features when a cold front accompanied by a distinct low pressure system is passing in a westerly zone.

There is a well-defined cyclonic circulation with maximum southerly wind of 65 knots to the east of the centre at 850 mb in Fig. 6 (b). Wet air is observed within the cyclonic circulation and to the southeast of the low pressure system. In the middle (500 mb) and the upper (300 mb) troposphere, a distinct trough is outlined by Fig. 6 (c) and (d). Wet areas locate just ahead of the trough in northern portion of the analysis domain and around the northeastern tip of the Cb line at 500 mb level where active convective clouds intrude into this level. Other areas are dry even in areas where the cloud line exists because of the lack of appropriate data when the line has passed through a station 47945 between 291200 Z and 291800 Z as mentioned earlier.

Fig. 7 indicates the time change of wind, equivalent potential temperature (θ_e) and saturated equivalent potential temperature (θ_e*) at 47936 and 47945. Warm and wet air intrudes mainly into lower levels below 800 mb with rather strong southerly winds at both stations before the passage of the Cb line as seen in Fig. 7. Potentially unstable layers below 800 mb may partly be caused by the advected air and the thickness of the potetially unstable layers increases at both stations at 290000 Z than at 281200 Z, A stable layer between 800 and 900 mb suppresses the development of convective clouds within this potentially unstable layer. Thermal structure at 47945 shows that a wet and unstable layer extends rapidly to 600 mb at 291200 Z immediately before the passage of the cloud line. This provide the preferable areas to develop convective clouds in the vicinity of the Cb line.

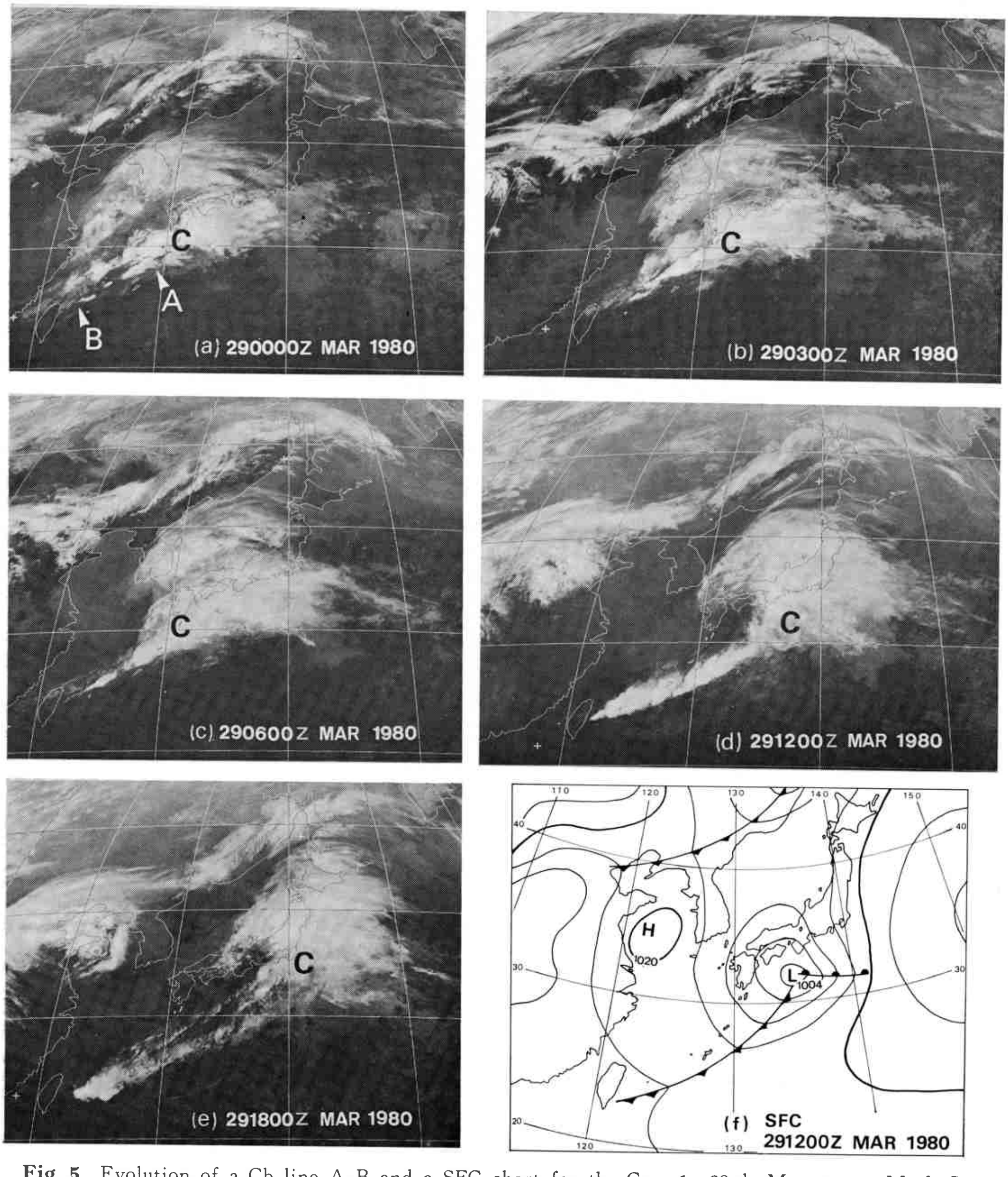


Fig. 5 Evolution of a Cb line A-B and a SFC chart for the Case 1, 29 th Mar. 1980. Mark C denotes a cloud area associated with a low pressure system.

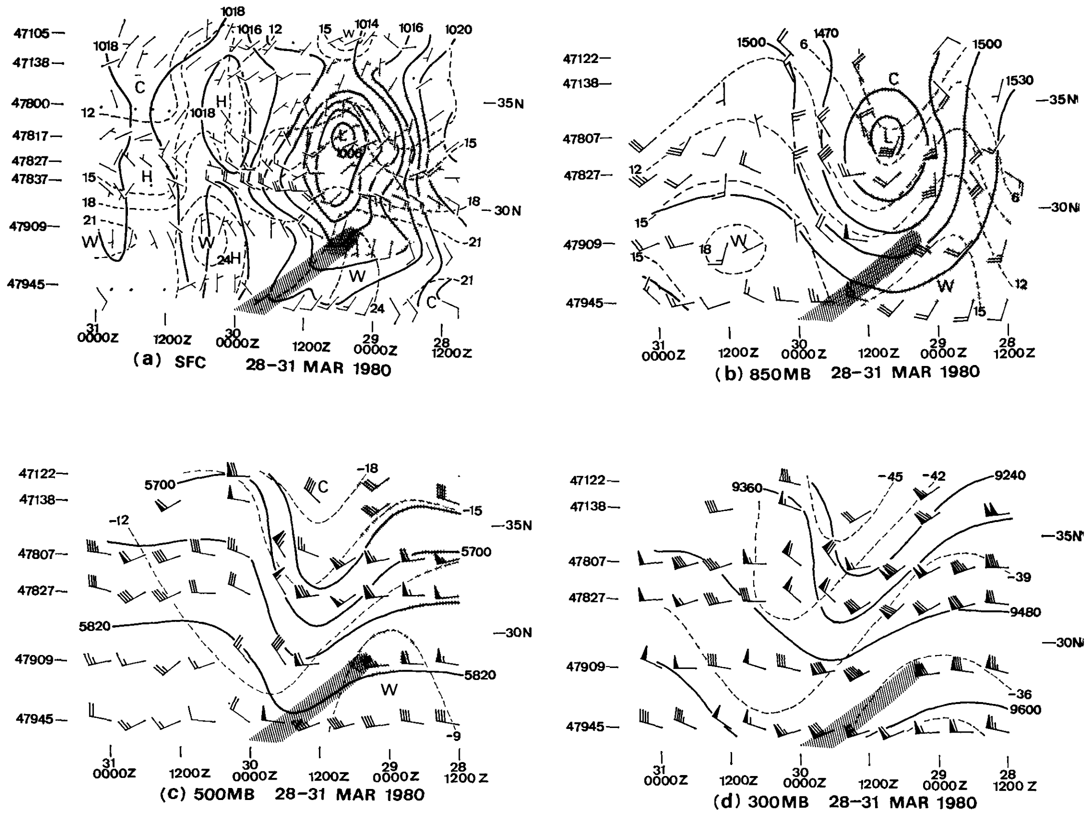


Fig. 6 Time sequence at SFC, 850, 500 and 300 mb. Thick lines, thin broken lines and stipple areas represent height contours (isobars at SFC), isotherms and wet areas, dew point depression less than 3 degrees (rainfall areas at SFC). Hacthed areas denote a Cb line concerned.

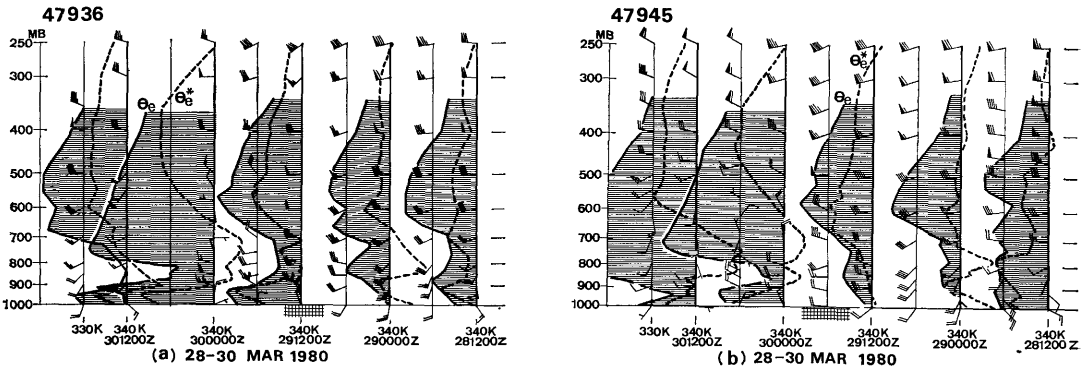


Fig. 7 Time change of vertical wind profile, equivalent potential temperature (θ_e) and saturated equivalent potential temperature (θ_e*) at 47909 and 47945. Striped areas represent negative deuiation of θ_e from 340 K at each obsevation time. Check stripes denote approximate time of the passage of the Cb line.

After the passage of the Cb line, the warm and wet air in the lowest layer is altered and the cold air appears at 47936 at 291200 Z and at 47945 just after 300000 Z. Remarkable stable layers are seen below 800 mb at 47936 after 291200 Z and no potentially unstable layers are observed at 47945 after 300000 Z. Above those stable layers, almost neutral or stable layers with very dry condition exist. Near the southwest end of the Cb line, vigorous convective clouds are still observed as seen in Fig. 5 (e), where potentially unstable condition does not change much (not shown) at the nearest station, 47918 at 300000 Z.

The cloud line in this case is one of typical Cb lines in the category of the type in Fig. 2 (a). The cloud line formed in front of a sharp trough with a cold air mass. Therefore, the passage of the Cb line causes the changes of some meteorological factors mentioned earier.

3.2 Case 2 : 24-25 Oct. 1980

Changes of cloud features in this case are shown in Fig. 8. A cloud area marked by C with a bulge of cirriform clouds (called Ci bulge) in Fig. 8 (a) suggests the existence of a cyclonic disturbance commonly in the southwest to the bulge. The cloud area C progressed to east-northeast following the movement of a low pressure system which is seen in Fig. 8 (f). A Cb line indicated by arrows A and B in Fig. 8 (a) developed first in the sea south of the Kyushu island at about 240300 Z and then, stretched towards southwest. This cloud line lasted for about 15 hours and another Cb line began to form just behind the first one which is denoted by arrows E and F in Fig. 7 (c). Those cloud lines moved southeastward by about 50 knots during the period of this study. The former one passed through 47909 and 47936 at about 240900 Z and 241200 Z. The latter one developed rapidly and reached to maximum intensity with about 2000 km long and 100 km wide at 241800 Z. This cloud line passed through two stations, 47909 and 47945, at about 241200 Z and 250000 Z. At 241800 Z, a frontal cloud band marked by G in Fig. 8 (d) merged with the middle and the southwestern portions of the Cb line which was in the maximum intensity. The Cb line decayed rapidly 6 hours after the merger.

Fig. 9 shows time sequences of certain meteorological elements at various levels. At SFC, a major low pressure system accompanied with a cold front suggested by the concentration of isotherms is passing in the northern part of the analysis region and rainy weather continues in front of and in rear of the low. In the southeastern part of the low, a small scale disturbance is indicated by isobars along the cloud line. Showers and thunderstorms and the descend of the temperature are observed. Clear sky appeared in the rear of the cloud line near 47909 at 241600 Z after the passage of the cloud line. On the other hand, rainy weather continues in the southern region owing to a cloud band which exists just behind and along the Cb line in that region (Fig. 8 (e)). A thermal concentration running in north-south direction and change of wind direction from southerly to northerly are detected at 850 mb in south and southeast region to the centre of the major low pressure system. This thermal pattern indicates that the cold air mass is advected to the south of the low pressure system from the west of the band. The Cb line appears in the warm sector whilst the cloud band forms in the thermal concentration as seen in Figs. 8 and 9. The change of winds seemes to coincide with the front of the thermal concentration in Fig. 9 (b) but it is too difficult to point out that the change of winds is attrbiutable only to thethermal concentration because the Cb line and the cloud band locate closely each other in this case.

There is a warm ridge at the middle (500 mb) and upper (300 mb) levels above the area where the cloud line exists, as seen in Figs. 9 (c) and (d). A wet area spreads in the ridge below the middle troposphere. Time change of vertical wind profile and thermal structure at 47909 and 47945 are displayed in Fig. 10. Although southerly winds above 700 mb change scarcely during the period of this study, easterly winds seen at 231200 Z below 850 mb change to southerly to northwesterly at both stations. This suggests that the predominant subtropical high pressure system has turned gradually to the low pressure system in this region.

Wet but stable condition is seen further east to

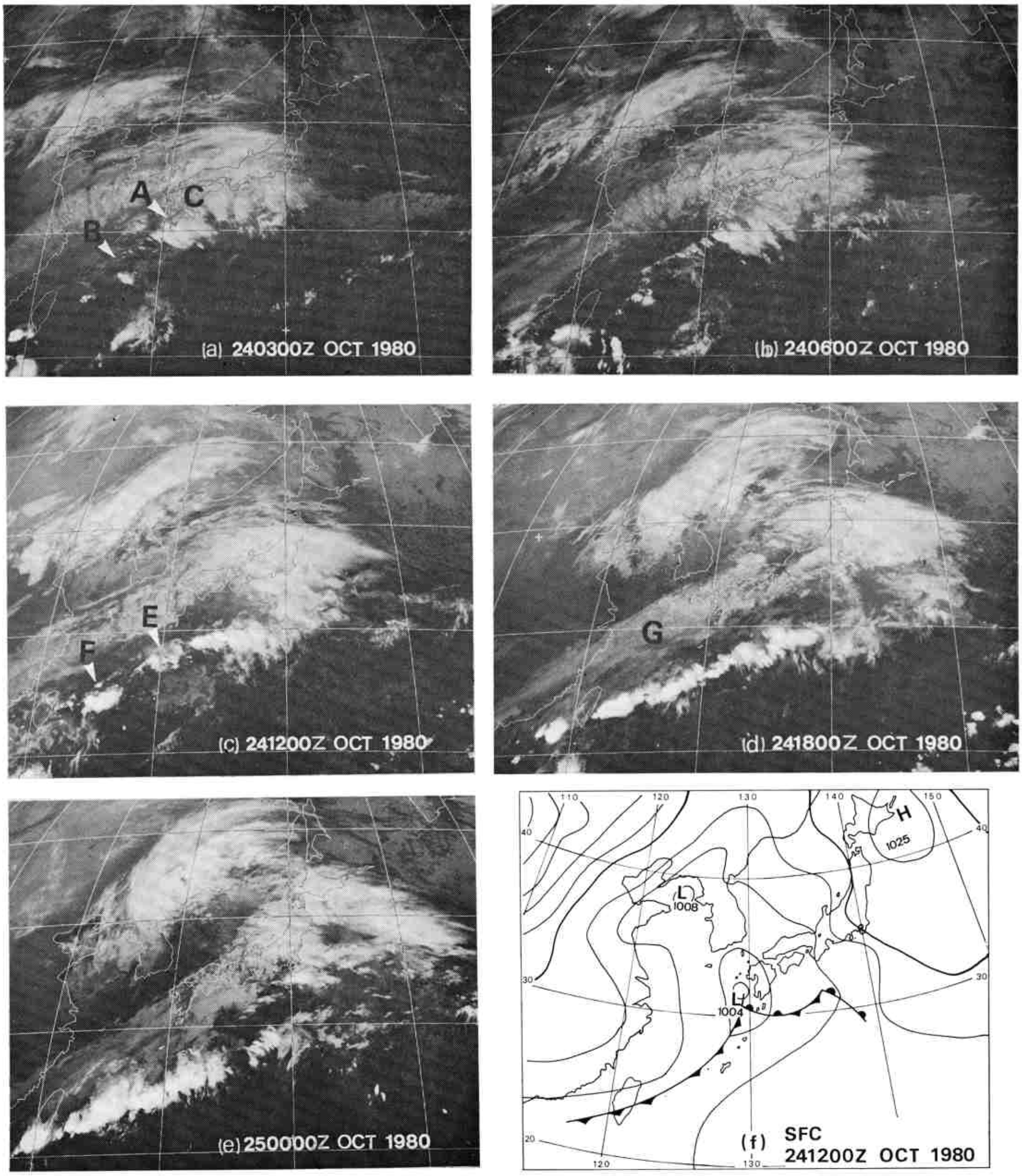


Fig. 8 Same as Fig. 5 but for 24 th Oct. 1980.

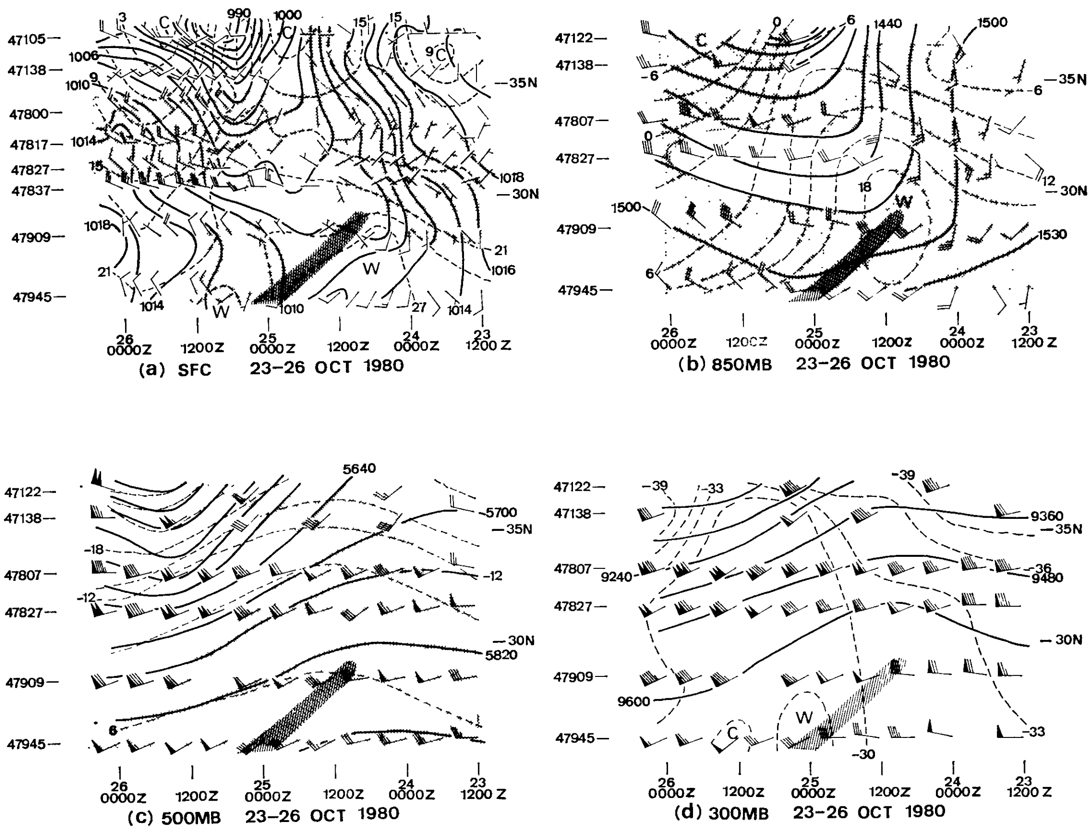


Fig. 9 Same as Fig. 6 but for 24 th Oct. 1980.

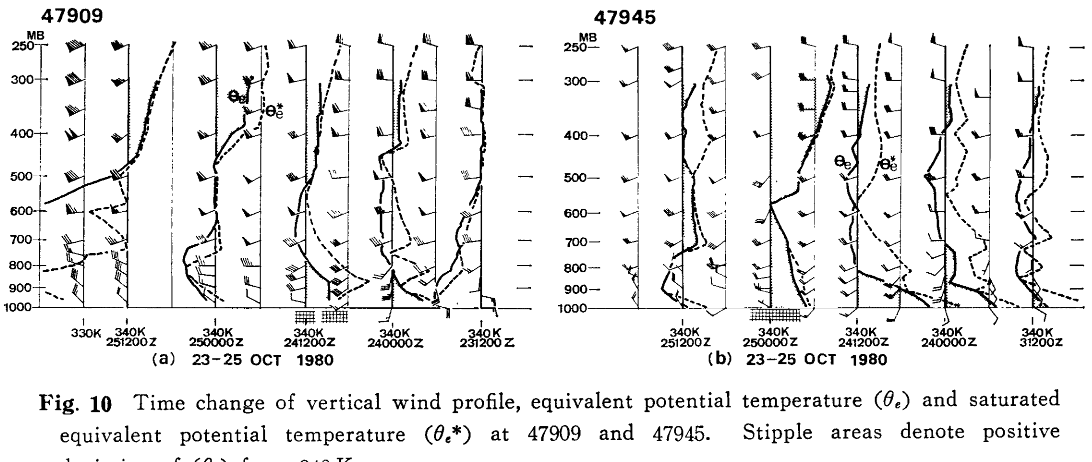


Fig. 10 Time change of vertical wind profile, equivalent potential temperature (θ_e) and saturated equivalent potential temperature (θ_e*) at 47909 and 47945. Stipple areas denote positive deviation of (θ_e) from 340 K.

the cloud line at 47909 at 231200 Z in Fig. 10 (a). Atmospheric condition near the cloud line becomes more unstable which is indicated by the warm and wet air intrusion in the lowest troposphere below 800 mb. Temperature below 500 mb also becomes warmer gradually before the passage of the Cb line through station of 47909 at 241200 Z (see Fig. 10 (a)). After the passage, the warm air is altered to cold air in the lowest levels where a stable layer exists above an unstable layer below 800 mb. Deep stable and/or neutral layers are observed above the stable layer.

On the eastern side of the Cb line, there is a potentially unstable layer below 900 mb as indicated by thermal structure at 47945 before 241200 Z in Fig. 10 (b). Warm and wet air is advected by southerly winds gradually into the east side of the Cb line. Such the air is in potentially unstable condition below 600 mb where no stable layer exists during the passage of the cloud line at 47945 at 250000 Z. Cold air is observed below 750 mb at 251200 Z and a stable layer forms again in the lowest troposphere with neutral layers aloft.

Changes of wind directions are observed from southwesterly to westerly approximately before and after the passage of the cloud line through 47909 and 47945 at about 241200 Z and 250000 Z, respectively.

The Cb line in this case was associated with a weak disturbance in the warm sector. The cloud line is categolised into type (d) in Fig. 2.

4. Concluding remarks

Cloud lines which consist of cumulonimbi are studied. The results are as follows :

All the Cb limes can be categolised into seven types with respect to the morphological point of view. The frequency and the spatial range of the occurrence of the Cb lines vary season to season. The frequency is maximum in summer and minimum in winter. Cloud lines are observed more often in autumn than in spring. The spatial range of the occurrence is broadest in both north-south and east-west directions in autumn. There are no observations of the Cb lines in the tropical regions south of 20°N in summer and in the temperate regions north of 30°N in winter. Such categories and the seasonal change would be closely related to causes of Cb lines and large scale changes of meteorological situations in the region studied in this paper. Unfortunately, those relationship has not been revealed yet.

Cb lines cause changes of wind directions, weather and the descend in temperature. In some cases where the Cb line locate very close to the cloud band associated with the thermal concentration, those changes just mentioned above are not clearly defined. Low pressure systems are closely related to the occurrences of the cloud lines, especially in the south and east flanks of the pressure system at SFC. Atmospheric condition in the vicinity of cloud lines is wet and potentially unstable with warmer air at lower levels up to about 600 mb. Such the unstable layer is altered to dry and deep neutral and/or stable layers in the cold air side of the Cb lines and convective activities are suppressed by those layers even if unstable layers exist in the lowest levels behind the Cb lines. In the warm air with some distance from Cb lines, atmospheric condition is potentially unstable at the lowest layers but a stable layer usually exists above the unstable layer between 800 and 900 mb.

Many problems have been left behind, e. g. to reveal the causes and fine structures of Cb lines, the relationship between types categolised in this paper and various causes considered and so forth. Further studies should be achieved on this subject successively and more precisely.

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気象衛星画像に見られる雲列の特徴

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気象衛星画像上には，積乱雲で構成される雲列が見られる。これらの雲列は短かいもので数百km，長いもので数千kmに及び，数時間から十数時間持続する。ここでは，これらの雲列の特徴を把握するために，3年間に北西太平洋域に出現した雲列について調査した。

雲列の出現度数や出現域は季節によって異なる。出現度数は冬に最も少なく，夏に最も多い。出現域は秋に最も広い。冬には日本の南海上の30°N以南にしか現われず，夏は20°N以北でのみ発生する。春は冬よりも頻度を増し，出現域も広がる。これらの雲列は衛星画像上で7つの型に分類することができる。

東シナ海で発生し南西諸島の観測網を通過した雲列の中から，異なる型に属する二例を選択して事例解析を行なった。

雲列の進行前面（東側）では，下層で南よりの風が卓越し暖湿気塊の移流によって対流不安定層が形成されていた。しかし800—900 mbには対流を抑圧する安定層があった。雲列のごく近傍ではこの安定層は消滅し，600 mbより下層では湿潤不安定となっていた。一方雲列の西側では700—800 mbより下層の気温が下がり，顕著な安定層が形成され，その上層では湿潤中立または乾燥した状態となっていた。