2. Cloud Type Identification via Meteorological Satellite Observation

2.1. Via Satellite Imagery

Clouds identified from satellite observation are referred to here as "cloud types," and those determined from surface observation are "cloud forms."

In contrast to ground-surface cloud observation with the human eye, satellites observe cloud tops from space. Visibility at the resolution of meteorological satellite sensors (approx. 0.5 – 1 km in visible/near-infrared and 2 km in infrared for Himawari-8/9) is coarser than seen with the human eye from the ground, and does not allow cloud type identification with as much detail as surface observation. Accordingly, satellite-based cloud identification is essentially different. For convenience, the terminology for cloud types classified via satellite imagery is based on that of clouds similar in origin and structure in surface observation.

2.2. Cloud Type Classification

In satellite-based identification, clouds may be classified as high-level (Ci), mid-level (Cm), stratus/fog (St), cumulonimbus (Cb), cumulus congestus (Cg), cumulus (Cu) or stratocumulus (Sc) (Table 2-2-1). As above, this differs from surface observation-based classification.

Clouds can be divided into stratiform (Ci, Cm, St) and convective (Cb, Cg, Cu) types, with Sc combining the characteristics of both.

The extent of stratiform clouds is much more horizontal than vertical, with coherent forms, smooth surfaces and uniform top heights. Convective clouds are thicker and smaller, with readily recognizable discrete cellular forms and uneven surfaces.

Clouds are also categorized as high-, mid- or low-level. It should be noted that satellite-based identification is based on top height, unlike surface observation, which relies on base height. Generally, top heights above 400 hPa are high-level, 400 to 600 hPa are mid-level, and below 600 hPa are low-level. As detailed in the previous chapter, top heights are estimated using brightness temperature in infrared imagery and vertical temperature profiling based on objective analysis and numerical weather prediction. Cg and Cb are generally not included in such classification because they develop vertically and belong to multiple altitude classes.

Table 2-2-1. Satellite imagery-based cloud type classification

<table>
<tr><th>Cloud type</th><th colspan="2">Classification</th></tr>
<tr><td>High-level clouds Ci</td><td rowspan="3">Stratiform clouds</td><td>High-level clouds</td></tr>
<tr><td>Middle-level clouds Cm</td><td>Middle-level clouds</td></tr>
<tr><td>Stratus/fog St</td><td rowspan="3">Low-level clouds</td></tr>
<tr><td>Stratocumulus Sc</td><td>----</td></tr>
<tr><td>Cumulus Cu</td><td rowspan="3">Convective clouds</td></tr>
<tr><td>Cumulus congestus Cg</td><td rowspan="2">----</td></tr>
<tr><td>Cumulonimbus Cb</td></tr>
</table>

2.3. Principles of Subjective Identification

Conventional subjective cloud type identification with the human eye is based on visible and infrared imagery supported by meteorological expertise. Although the development of meteorological satellites has facilitated computerized objective identification with imagery highlighting near-infrared, water vapor and infrared differences, precise determination of weather conditions remains challenging. This section describes the principles of subjective cloud type identification.

2.3.1. Visible and Infrared Imagery

In visible imagery, clouds with high water content and thick clouds show high solar reflectance. Convective clouds appear brighter than stratiform clouds because they are thicker and contain more droplets, and higher development equates to higher reflectance. Cb is generally brighter than Cg, which in turn is brighter than Cu. Low-level clouds tend to be brighter than high-level clouds (e.g., St is brighter than Ci).

As lower-temperature areas appear brighter in infrared imagery, clouds with higher tops are more pronounced. Ci is generally the brightest stratiform cloud, followed by Cm and St. However, radiation from below thin clouds is added to radiation from the clouds themselves, which can lead to underestimation of cloud top heights. For instance, Ci is often a thin cloud type that can be mistaken as Cm in infrared imagery. Meanwhile, very thick Ci has a cloud top temperature similar to that of Cb, making them harder to distinguish. For St with lower top heights, the temperature difference between the top and the ground is smaller than for other cloud types, making identification harder from infrared imagery. The development stage in convective clouds can be categorized by top height, with Cb being the highest in convective clouds followed by Cg and Cu.

Figure 2-3-1 shows qualitative relationships in cloud type identification based on visible and infrared imagery.

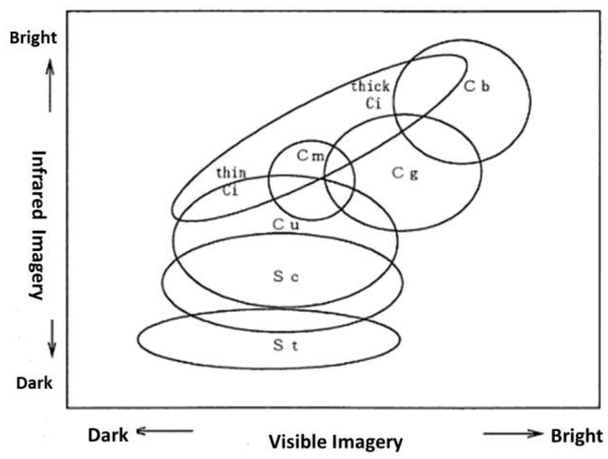

Fig. 2-3-1 Cloud type identification

2.3.2. Identification via Form

Stratiform clouds tend to have uniform top heights and expansive areas. The edge of St in contact with mountains often follows topography contours. Ci shows characteristic shapes, such as streaks, feather-like blowing from Cb (e.g., anvil cirrus) and fiber-like structures perpendicular to the subtropical jet axis (e.g., transverse lines).

Convective clouds are usually relatively small, increasing in thickness with development, combining and appearing larger in satellite imagery. Cloud size generally follows the order of Cb, Cg and Cu from largest to smallest. Convective clouds often form characteristic patterns (carrot-shaped/cellular) and lines.

The edges of convective and low-level clouds are clear in satellite imagery, while high-level clouds are influenced by strong winds and tend to exhibit vague feathery forms.

2.3.3. Identification via Texture

The relatively high spatial resolution of visible imagery reveals fine cloud-surface textures. The surface of stratiform clouds is smooth and uniform, while that of convective clouds is rough and uneven. Cloud surface conditions can be determined from the unevenness of shadows appearing when illuminated by the sun from a steep angle.

2.3.4. Identification via Movement

The relatively strong winds generally observed in the upper atmosphere cause Ci clouds to move faster than low-level types such as St, Sc and Cu. Tall clouds such as Cb and Cg move more slowly than Ci due to the influence of faster winds at cloud tops and slower winds at cloud bottoms.

2.3.5. Identification via Temporal Evolution

Convective clouds have a relatively short lifespan, with rapidly changing shapes and top heights. As such changes are more subtle in stratiform clouds, Cb and Ci can be distinguished using these characteristics.

2.4. Examples

2.4.1. Identification from Visible and Infrared Imagery

Figures 2-4-1 and 2-4-2 show examples of cloud type identification. **A** to **G** below correspond to the symbols in the figures. **H** and **I** are outlined in Section 2.4.3.

- A bright cloud area **A** appears between northern Hokkaido and the Sea of Okhotsk in the infrared image along the wind direction in the upper layer, with an underlying lower cloud area through it in the visible image. Hence, A is identified as thin Ci.
- The cloud area **B** over the sea southeast of Okinawa is Cm. This has a uniform surface and appears light grey in the infrared image because of its higher temperature as compared to **A**. It appears white in the visible image and stretches along the wind direction in the middle layer.
- The cloud area **C** at around 150 degrees east longitude to the east of Japan is St. This appears darker than surrounding cloud in the infrared image and is approximately the same temperature as the sea surface, making it difficult to identify. It appears light grey with a smooth surface in the visible image.
- The cloud area **D** over the East China Sea off the southwestern coast of Kyushu is Sc. It appears dark grey in the infrared image and light grey with a distinct border in the visible image.
- The partially streaky cloud area **E** between the Yellow Sea and the East China Sea is Cu. In the infrared image, it appears brighter than the Sc in area **D**. In the visible image, it appears white with clusters featuring distinct edges.
- The cloud area **F** (arrow marking) over the sea near the Ogasawara Islands is Cb. Its rim to the west is clear in the infrared image but obscure to the east under the influence of upper-level winds. It has a clustered appearance in the visible image with a relatively white form.
- The belt-shaped latitudinal cloud area **G** over the Yellow Sea is associated with a cold-air mass, as per **E**. However, it contains Cb and Cg, and is more developed than the Cu of **E** and brighter in both the infrared and visible images.

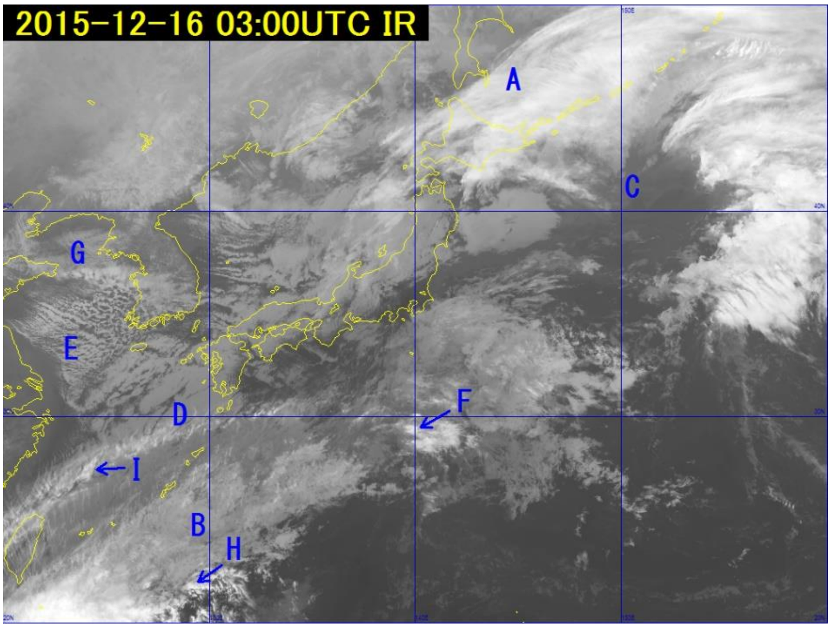

Fig. 2-4-1 B13 infrared image for 03:00 UTC on 16 December 2015

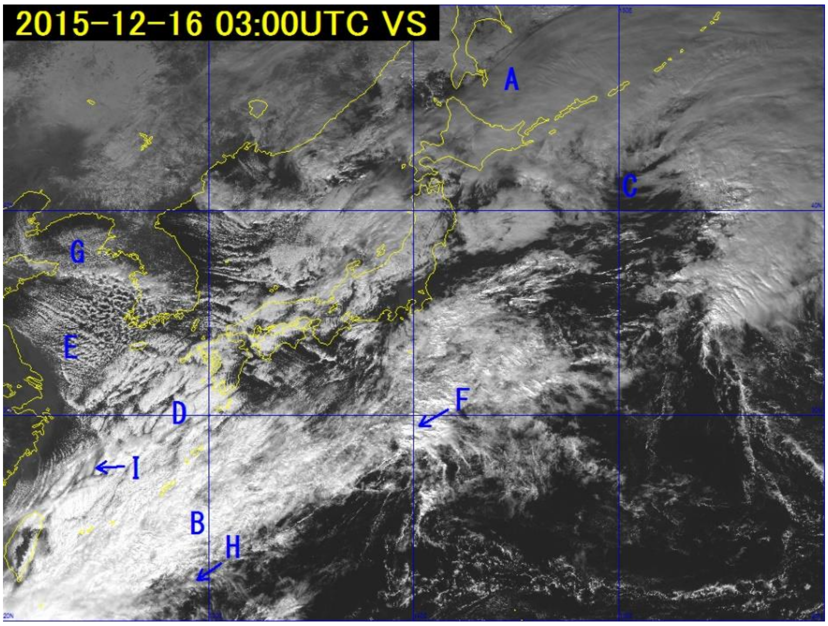

Fig. 2-4-2 B03 visible image for 03:00 UTC on 16 December 2015

2.4.2. Cb and Cg Examples

Cb and Cg examples are shown in Figs. 2-4-3 and 2-4-4.

- The cloud area **K** (arrow marking) to the south of Japan is Cb. In the visible image, it appears clustered in white. To the west, the cloud line **J** (arrow marking) with Cg is seen. In the infrared image, low-temperature areas corresponding to the Cg clouds show a line form with particular intervals. In the visible image, this formation appears as spaced white clusters with convective cloud lines.
- The cloud areas **L** and **M** incorporate both Cb and Ci. The unclear Cb boundaries can be estimated by comparing the brightness and texture of Cb itself with the surrounding areas

in infrared and visible imagery.

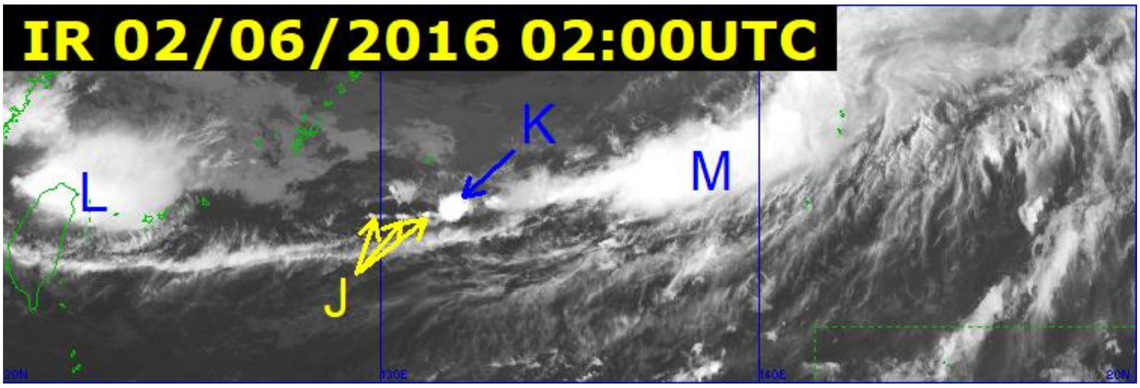

Fig. 2-4-3 B13 infrared image for 02:00 UTC on 2 June 2016

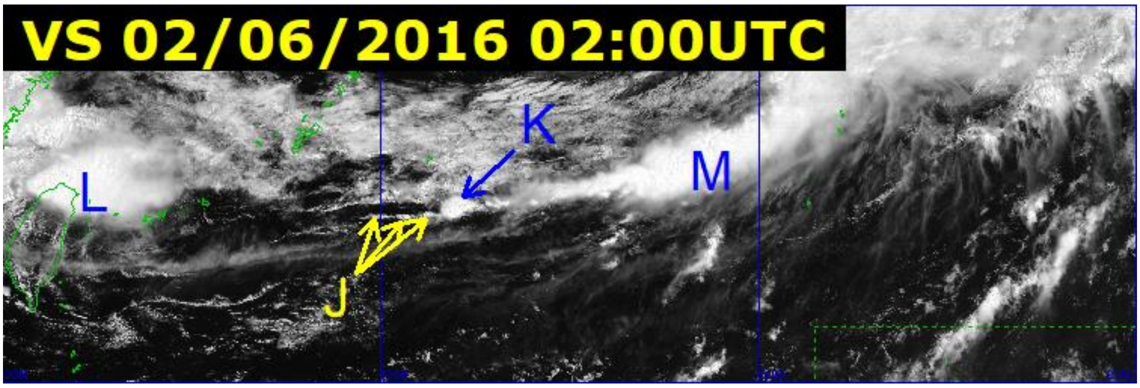

Fig.2-4-4 B03 visible image for 02:00 UTC on 2 June 2016

2.4.3. Ci and Cb Examples

The distinction between Ci and Cb is based on the shapes of each cloud described above in consideration of differences in movement speed and synoptics.

- In Figs. 2-4-1 and 2-4-2, the cloud area **F** (arrow marking) over the sea east of Japan is Cb (as previously described), which moves more slowly than surrounding cloud areas because it is affected by wind in the upper, middle and lower layers, but its shape changes faster than that of Ci. The cloud area **I** (similar to **F**; arrow marking) over the East China Sea is Ci, as determined by its rapid movement. The cloud area **H** (arrow marking) south of Okinawa in the infrared image is also Ci. Both Ci instances may be easily mistaken as Cb based on their shapes and top temperatures. Ci can be identified by its slow evolution in both infrared and visible imagery.

2.5. Differences Between Cloud Types Identified via Meteorological Satellites and Cloud Forms in Surface Observation

2.5.1. Introduction

This section describes cloud types identified via meteorological satellites and cloud forms identified via surface observation in comparison. Surface observation produces 10 cloud form categories depending on base heights and textures (World Meteorological Organization, 2017). In contrast, as meteorological satellite observation is conducted from above the Earth, cloud types are determined from 1. top temperatures and textures in infrared imagery, and 2. sunlight reflectance and cloud textures in visible imagery. However, it is difficult to distinguish cirrostratus, cirrus, altostratus and nimbostratus in satellite imagery due to limited spatial resolution.

In satellite imagery, upper- and mid-level clouds are each classified as single types. Cloud masses overall are classified as stratiform, convective, or both, resulting in seven classifications in total. Stratiform clouds are categorized as upper (Ci), mid (Cm) or stratus/fog (St) in order from the highest top, while convective clouds are categorized as cumulonimbus (Cb), cumulus congestus (Cg) or cumulus (Cu) in order from the tallest. Cg appears only in satellite cloud classification with development to an intermediate extent between Cb and Cu. Stratocumulus (Sc) has intermediate characteristics between stratiform and convective. Table 2-5-1 compares related characteristics.

Table 2-5-1 Cloud types identified via meteorological satellites and cloud forms in surface observation

Identification via meteorological satellites

Type	Abbreviation
Upper-level clouds	Ci
Mid-level clouds	Cm
Stratocumulus	Sc
Stratus/Fog	St
Cumulus	Cu
Cumulus congestus	Cg
Cumulonimbus	Cb

Identification via surface observation

Level	Type	Abbreviation
High	Cirrus	Ci
	Cirrocumulus	Cc
	Cirrostratus	Cs
Mid	Altocumulus	Ac
	Altostratus	As
	Nimbostratus	Ns
Low	Stratocumulus	Sc
	Stratus	St
	Cumulus	Cu
	Cumulonimbus	Cb

Below are comparisons between cloud photographs taken on the ground and satellite images (infrared and visible) at corresponding times. Unless otherwise stated, the cloud type abbreviations here refer to satellite-based cloud classification.

2.5.2. Case Studies

2.5.2.1. Case 1: Ci Only

In both the infrared image (Fig. 2-5-1) and the visible image (Fig. 2-5-2), hardly any cloud is seen over the Kanto Plain except for a latitudinal band extending from the vicinity of Mt. Fuji to the area south of the Meteorological Satellite Center (MSC) in Kiyose, Tokyo. This cloud area appears relatively bright in the infrared image but grey in the visible image, and land can be seen through it. Hence, it can be identified as Ci. In a photograph taken from the ground (Fig. 2-5-3), the sky above the MSC is clear and the upper-level cloud stretches from west to south. In this example, it can be identified as an upper-level cloud area both from the ground and from the satellite.

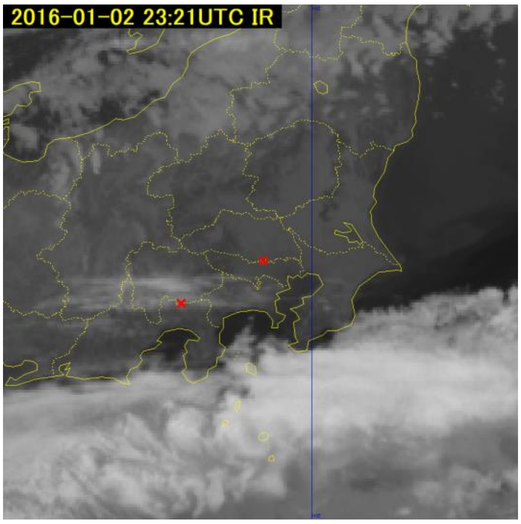

Fig. 2-5-1 B13 infrared image for 23:21 UTC on 2 January 2016; red crosses: Mt. Fuji (left) and MSC (right)

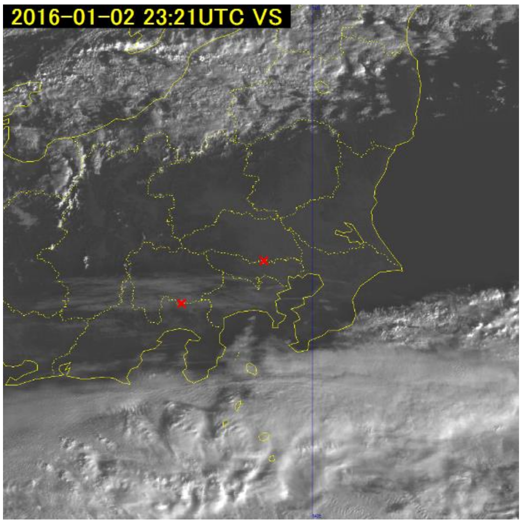

Fig. 2-5-2 B03 visible image for 23:21 UTC on 2 January 2016; red crosses: Mt. Fuji (left) and MSC (right)

Fig. 2-5-3 View of upper-level clouds looking southwest from the MSC, 23:21 UTC, 2 January

2.5.2.2. Case 2: Ci Cloud Area Only

In the infrared image (Fig. 2-5-4), a straight cloud line extends from the area west of the MSC toward the prefectures of Chiba and Ibaraki. In the visible image (Fig. 2-5-5), the cloud area around the MSC appears white, but the further east it goes, the thinner and more transparent it becomes. The area around the MSC exhibits relatively thick upper-level cloud, and the area eastward shows thin upper-level cloud with an almost static western end that appears to be the origin. A photograph taken at the MSC (Fig. 2-5-6) shows the edge of the area, which can be identified as upper-level cloud both from the ground and from the satellite.

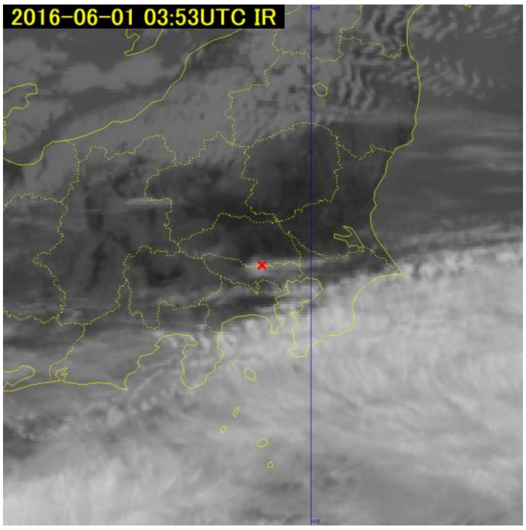

Fig. 2-5-4 B13 infrared image for 12:53 JST on 1 June 2016; red cross: MSC

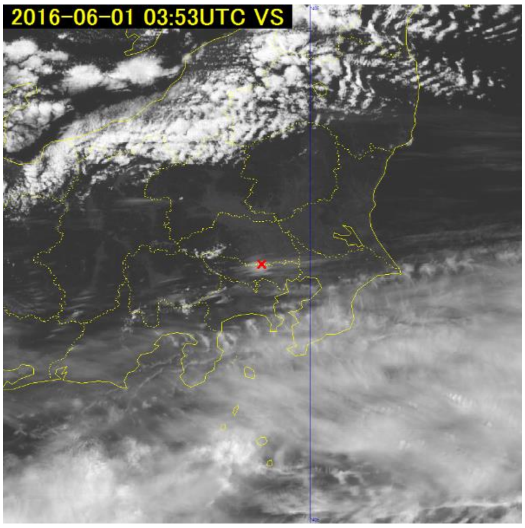

Fig. 2-5-5 B03 visible image for 12:53 JST on 1 June 2016; red cross: MSC

Fig. 2-5-6 View west from MSC for 12:53 JST on 1 June 2016. Upper-level clouds were observed from the ground.

2.5.2.3. Case 3: Ci Cloud Area Only

In the infrared image (Fig. 2-5-7), a white belt-form cloud area is observed from the west of Jogashima (Miura, Kanagawa). In the visible image (Fig. 2-5-8), this appears grey, and the ground can be seen through it. Accordingly, it can be judged as upper-level cloud. The thin cloud area spreading northward (Fig. 2-5-9) corresponds to the thin upper-level cloud area or its edge, as also seen in satellite imagery. The undeveloped Cu in the center of the photograph is not recognized in satellite imagery because its is too small for the satellite's spatial resolution.

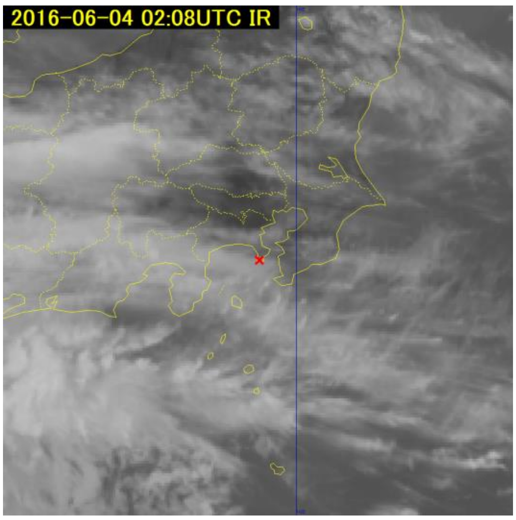

Fig. 2-5-7 B13 infrared image for 02:08 UTC on 4 June 2016; red cross: Jogashima

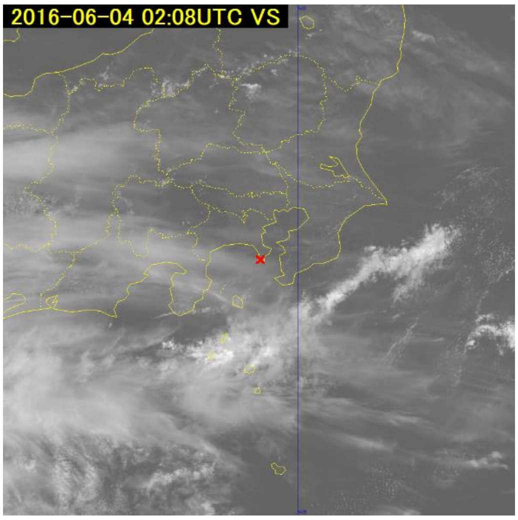

Fig. 2-5-8 B03 visible image for 02:08 UTC on 4 June 2016; red cross: Jogashima

Fig. 2-5-9 View north from Jogashima for 02:07 UTC on 4 June 2016. Upper- and lower-level clouds were observed from the ground.

2.5.2.4. Ci and Cm Overlap

In the infrared image (Fig. 2-5-10), a large thick cloud mass approached from the sea south of Honshu. The clouds in the sky above the MSC were broken and thin. As land can be seen around the MSC in the visible image (Fig. 2-5-11), this can be judged as a thin upper-level cloud area. Although it is difficult to distinguish these clouds from single-shot images, video shows different speeds of movement, indicating an overlay of upper- and mid-level clouds. These can be distinguished here both via surface observation and satellite imagery, but the thin mid-level clouds appear dominant in photography (Fig. 2-5-12). Since infrared radiation is transmitted from lower-level clouds, their observation brightness temperature in infrared imagery is higher than the actual value. Accordingly, it is difficult to estimate cloud top height from brightness temperature alone.

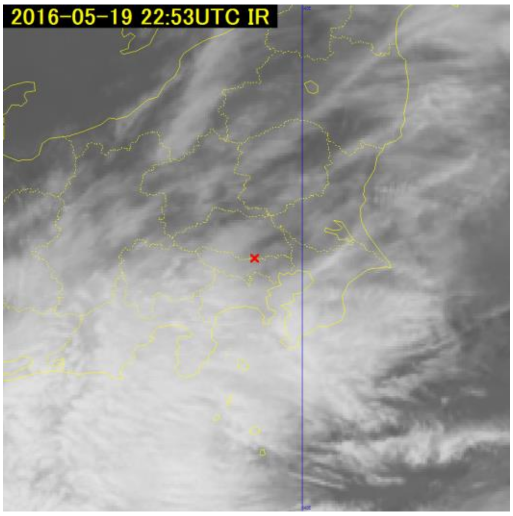

Fig. 2-5-10 B13 infrared image for 22:53 UTC on 19 May 2016; red cross: MSC

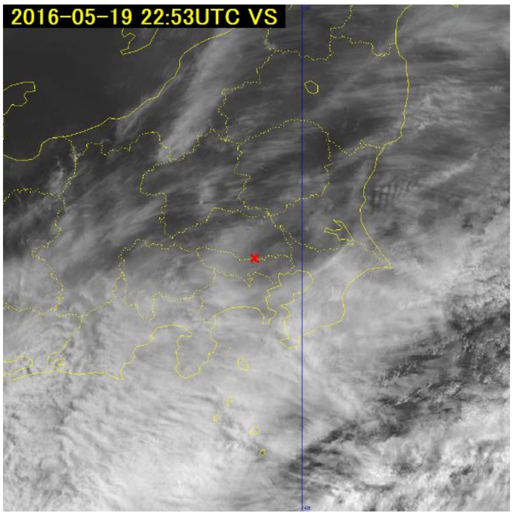

Fig. 2-5-11 B03 visible image for 22:53 UTC on 19 May 2016; red cross: MSC

Fig.2-5-12 View east-northeast from the park next to the MSC for 22:52 UTC on 19 May 2016. Upper- and mid-level clouds were observed from the ground.

2.5.2.5. Ci and Sc/Cu Overlap

In the infrared image (Fig. 2-5-13), a thin upper-level cloud area was observed from west-northwest to east-southeast. Lower-level cloud over the Kanto region is seen in grey, but this is difficult to distinguish from land in places where the temperature difference from the ground is small. In the visible image (Fig. 2-5-14), the cloud area and land surface are clearly distinguishable, and lower-level clouds are seen over the Kanto Plain. In this example, the presence of mid- and upper-level clouds cannot be judged via surface observation because lower-level clouds covered the entire sky (Fig. 2-5-15). However, both upper- and lower-level clouds are recognizable in satellite imagery. These are difficult to identify from such imagery when thick upper-level clouds are present.

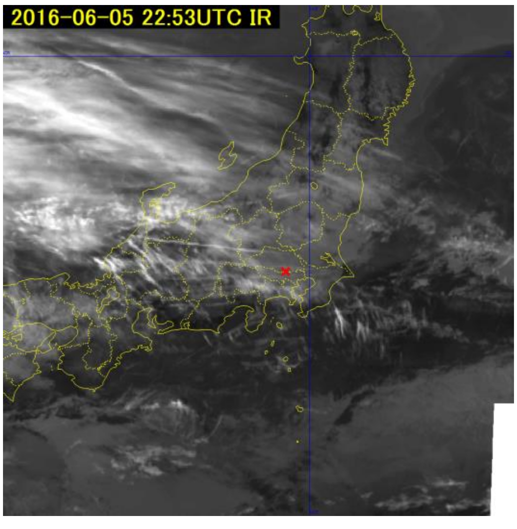

Fig. 2-5-13 B13 infrared image for 22:53 UTC on 5 June 2016; red cross: MSC

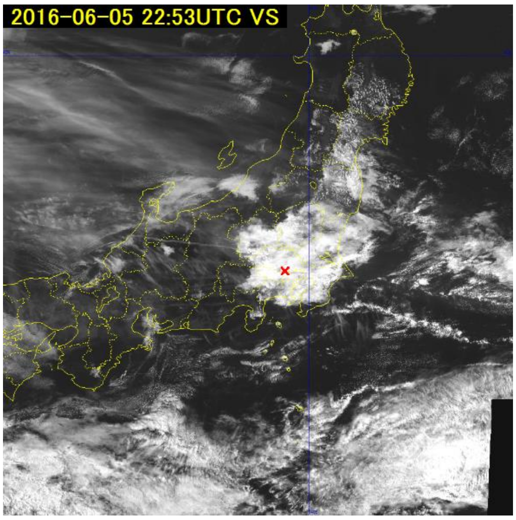

Fig. 2-5-14 B03 visible image for 22:53 UTC on 5 June 2016; red cross: MSC

Fig. 2-5-15 View southwest at the park next to MSC for 22:52 UTC on 5 June 2016. Lower-level clouds were observed from the ground.

2.5.2.6. Sc Only

In the infrared image (Fig. 2-5-16), grey clouds are observed around Tokyo. These appear slightly darker than clouds over the sea in the visible image (Fig. 2-5-17), but are still bright and show a wavy pattern. Accordingly, they can be identified as Sc. In this example, these can be identified as lower-level cloud from both surface observation and satellite imagery. However, the wavy pattern at the cloud top at intervals of 3 to 5 km in satellite imagery is not seen in surface observation, and the tiny gaps of several hundred meters between clouds seen in surface observation (Fig. 2-5-18) are not seen in satellite observation.

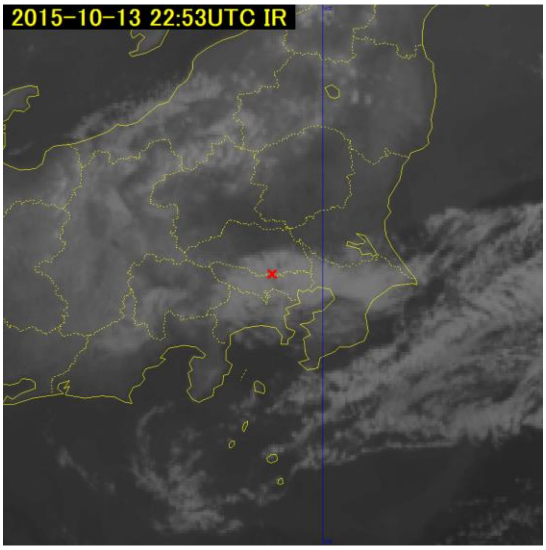

Fig. 2-5-16 B13 infrared image for 22:53 UTC on 13 October 2015; red cross: MSC

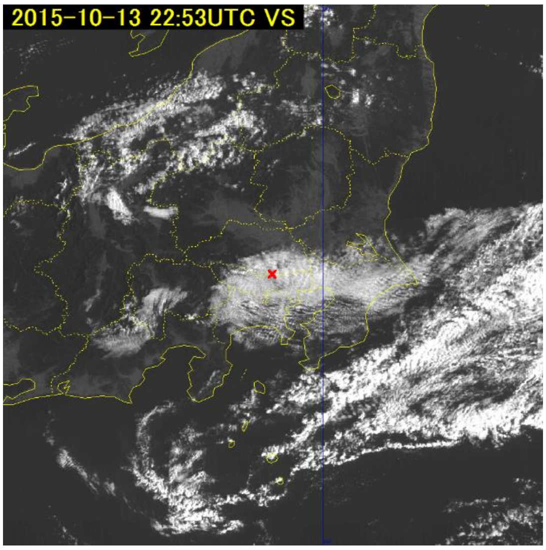

Fig. 2-5-17 B03 visible image for 22:53 UTC on 13 October 2015; red cross: MSC

Fig. 2-5-18 View southwest at the park next to MSC for 22:53 UTC on 13 October 2015. Lower-level clouds were observed from the ground.

2.5.2.7. Cb, Cg and Cu Co-presence

In the infrared image (Fig. 2-5-19), a remarkably bright cloud area is seen around the border of Tokyo and Saitama, along with a white area from the northern part of Ibaraki Prefecture to the northeast. In this example, the sun was shining from a westerly direction in the late afternoon. This cloud can be identified as an active convective type incorporating Cb because its western side appears bright in visible imagery (Fig. 2-5-20), which indicates vertical development. In a photograph taken near Kotesashi Station in Tokorozawa, Saitama Prefecture (Fig.2-5-21), anvil-shaped cirrus is seen around the top of the Cb, indicating significant cloud development. The minimum brightness temperature of the cloud area was –51.9°C, corresponding to an altitude of 196 hPa (41,577 ft, or approximately 12,700 m) when converted using JMA numerical weather prediction model (GSM: Global Spectral Model) data. The estimated distance from the shooting location to the cloud with the lowest brightness temperature was around 30 km.

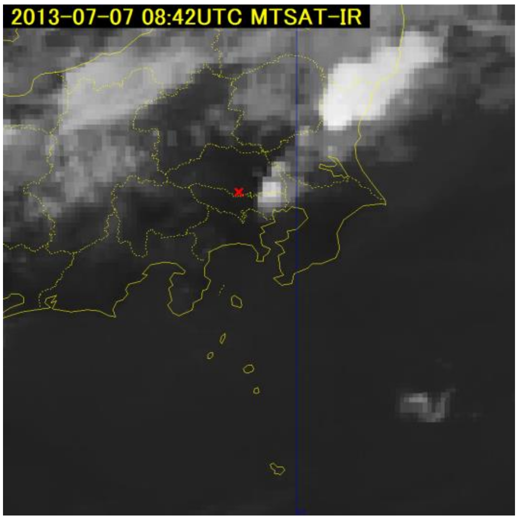

Fig. 2-5-19 Infrared image for 08:42 UTC on 7 July 2013; red cross: Kotesashi Station

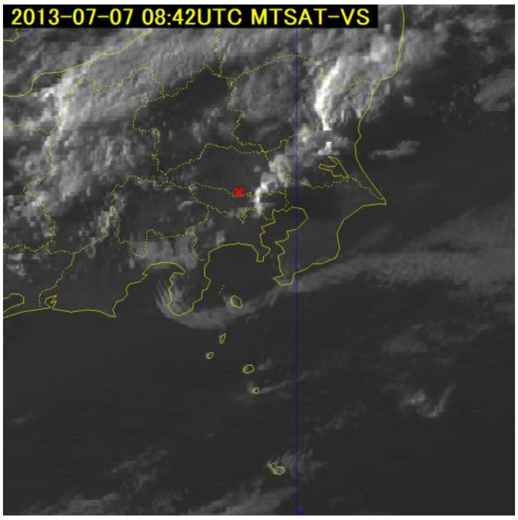

Fig. 2-5-20 Visible image for 08:42 UTC, 7 July 2013; red cross: Kotesashi Station

Fig. 2-5-21 Near Kotesashi Station, 08:42 UTC on 7 July 2013. Lower-level clouds were observed from the ground.

2.5.2.8. Cu and Cg Co-presence

In the infrared image (Fig. 2-5-22), a white cloud area is seen at the border of Saitama and Chiba. Vertically developed convective clouds are seen in visible imagery (Fig. 2-5-23) as in the previous case. No anvil-shaped cirrus is seen in a photograph taken near Kotesashi Station (Fig. 2-5-24), but a developed cloud area and cumulus congestus (or cumulonimbus calvus) are observed. The minimum brightness temperature of this cloud area was –37.0°C, corresponding to an altitude of 340 hPa (27,574 ft, or approximately 8,400 m) when converted using GSM data. The distance was estimated to be around 40 km from the shooting location to the cloud with the lowest brightness temperature.

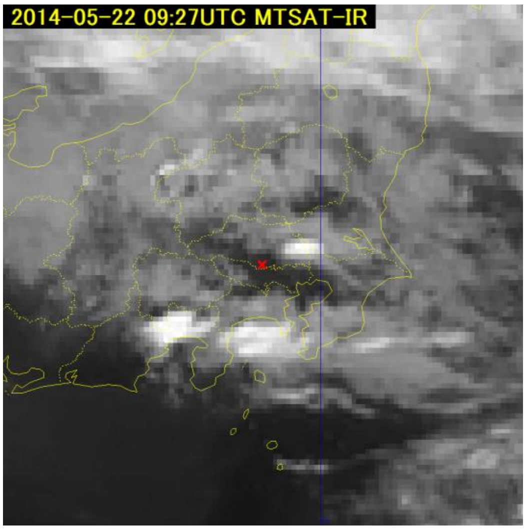

Fig. 2-5-22 Infrared image for 09:27 UTC on 22 May 2014; red cross: Kotesashi Station

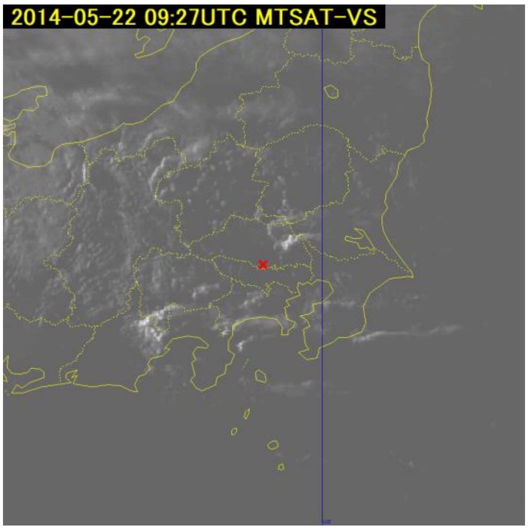

Fig. 2-5-23 Visible image for 09:27 UTC on 22 May 2014; red cross: Kotesashi Station

Fig. 2-5-24 View from the area near Kotesashi station for 09:28 UTC on 22 May 2014. Lower-level clouds were observed from the ground.

References:

- World Meteorological Organization (2017) International Cloud Atlas: Manual on the Observation of Clouds and Other Meteors (WMO-No. 407). https://cloudatlas.wmo.int/en/home.html