# Detection of High Probable Areas of Turbulence on Satellite Imageries*

**Takashi Tsuchiya****

**Abstract**

It is feasible that high probable areas of turbulence are detectable on satellite imageries by careful examination to characteristic cloud features which are closely related to certain meteorological phenomena listed below:

(1) Jet streams.
(2) Cyclonic disturbances.
(3) Convective activities.
(4) Orographic effects.

The auther shows that the relationship between the characteristic cloud features appeared on GMS imageries and turbulences reported by aircrafts mainly near Japan within the limited period from April to July, 1978. This relationship would be extended to other areas besides the limited areas shown in this article, especially to data sparse areas as oceans, deserts, polar regions and so forth.

## I Introduction

All the bumpy conditions affecting all the vehicles such as aeroplanes, rockets, VSTOLs and others are called turbulence. Turbulence is ascribable to some critical conditions in the atmosphere, that is, discontinuities of meteorological quantities and the lack of uniformity of the other environment. How the turbulence affects vehicles depends on various factors, e. g. degrees of the discontinuities and the uniformity just mentioned above, aeronautical factors considered when vehicles were designed, flying techniques and so on. Hence, one cause of turbulence is not necessary to affect the other vehicles in the same way. In spite of such complexities of turbulences as discribed above, many ovservational facts have been made clear and a number of researches have been achieved with respect to the safe navigation. Those results have revealed some characteristic features of turbulence. On the other hand, the invent of the meteorological satellite has offered a new tool to observe meteorological phenomena and has made us approach in different ways to study atmospheric structures with a lot of data including satellite imageries. Researchers working for the use of satellite data have proved that some characteristic cloud features indicate the existence of meteorological disturbances and critical conditions which are closely related to causes of turbulence. Therefore, satellite imageries

* This is a lecture note on "Turbulence as seen in Satellite Imageries" at a long term training course organized by JICA and held at MSC during December 1978 to January 1979. Although plenty of imageries of GMS showing turbulent areas were displayed and detailed explanations were made in the lecture, only the outline of the lecture is described and the typical imageries are reprinted in this article due to the limitation of the space.

** Meteorological Satellite Center.

are useful to detect high probable areas of turbulence.

## II Detection of High Probable Areas of Turbulence on Satellite Imageries

Turbulent areas can be detectable with a certain degree of tolerance by characteristic clouds which indicate disturbaces and critical meteorological conditions being considered as the causes of turbulence.

Clouds listed below are notified for the detection of turbulent areas:

(1) Jet cirrus clouds.
(2) Major cloud systems.
(3) Convective clouds.
(4) Wave clouds.

Those clouds correspond to the following meteorological phenomena:

(1) Jet streams.
(2) Large scale cyclonic disturbances.
(3) Convective activities.
(4) Orographic effects.

## III The Relationship between Caracteristic Cloud Features and Turbulence

### 1. Jet Cirrus Clouds

Jet atream axes are indicated by streaky and/or line shaped Ci clouds, sharp edge of a Ci shield with anticyclonic curvature and their shadows casted on the lower level clouds on the opposite side of the sun. They exist within 1-3 degrees latitude to the polar side of those Ci cloud edges. Turbulence is encountered very often near jet stream with light to heavy intensity, but areal extent is rather small.

Characteristics of turbulence near Jet Ci are as follows:

(1) Turbulences with moderate to greater intensity occur above 30,000 feet on both side of Jet Ci edges or lines of the shadows casted on and are generally confined to the area within 3 degrees latitudes of those edges.
(2) Higher probability of moderate to heavy turbulence exists within a dense over Jet Ci than in a thin, broken or scattered Jet Ci.
(3) Higher risk of severe or extreme turbulence is expected in areas where transverse lines appear than in other areas where they are not present.

### 2. Major Cloud Systems

Turbulences occur within and near well organised disturbances such as low pressure systems, frontal zones and tropical cyclones. The exsistence of those disturbances is easily identifiable in satellite imageries by characteristic cloud features as major cloud systems. Those are exemplified as cloud vortices, long stretching cloud bands and so forth. Therefore, the high probability of turbulence caused by those disturbances is detectable in satellite imageries.

Major cloud systems have large areal extent and usually comprise such various causes of turbulence as convection, orographic effects and jet streams. Therefore, all the influential areas of large scale disturbances are considered to be high probable areas of turbulences with light to moderate intensities, vertically and horizontally.

### 3. Convective Clouds

Convective activities are identifiable by the existence of cumuliform clouds who appear white and lumpy in visible imageries and grey to white in infrared ones. They are, in some cases, embeded in major cloud systems and are, in other cases, organised into large Cb clusters. They also exist as isolated cumuliform clouds, appearing white dots in both visible and infared pictures when they have developed in some vertical extent.

Characteristics of turbulence in and adjecent to convective clouds are as follows:

(1) Cu clouds are causes of light to moderate turbulence.

(2) Individual Cb cells and Cb clusters produce moderate to heavy turbulence.

(3) In the areas where developed open cellular clouds exist, vehicles encounter light to modelate turbulences. These clouds are generally associated with the maximum positive vorticity advection.

(4) Turbulences caused by convective activities are not restricted within cloud areas but also in other areas immediately surroundings of such convective clouds.

(5) Significant turbulences frequently occur at higher levels, even 5,000 feet above tops of developing cumuliform clouds due to strong ascent motion.

(6) The degree of turbulence depends on the developing stage of cumuliform clouds and the location of the vehicles relative to those clouds.

### 4. Wave Clouds

Turbulences with light to severe intensities are caused by roughness of the earth's surface, especially the mountains. Clouds, affected by orographic effects, are detectable by wave clouds on the lee side of the mountains.

Characteristic features of turbulences caused by orographic effects are as follows:

(1) Turbulences associated with the orographic effects occur at lower levels below 20,000 feet as well as at higher altitude up to the lower stratosphere.

(2) Moderate to severe turbulences are encountered at immediately higher levels to mountain tops on the just lee side of the mountain and at the higher altitudes more than 30,000 feet above regions where wave clouds exist at lower levels.

## IV Examples

Typical GMS pictures are exemplified in this paper within the period from April to July, 1978. Moderate ( Λ ) and severe turbulence ( $\hat{\Lambda}$ ), heavy icing ( Ψ ) and thunderstorm ( R ) are taken up among all the turbulences and other severe weather reported by aircrafts during Apr. to Jul., 1978. Height and time of the occurrence are also shown on the right side of those symbols in hundreds of feet and in GMT, respectively. All the data other than cloud imageries are employed from "Daily Weather Maps" which is issued by the Japan Meteorological Agency and includes analysis charts at SFC (00z and 12z), 850mb (12z), 700mb (12z), and 500 mb (12 z) and observation data (00 and 12 z). If there is no corresponding analysis charts in the Daily Weather Maps, suitable charts are selected from those maps and data sets in the Daily Weather Maps to compare such pictures as illustrated in this paper with other meteorological data.

Examples shown here are as follows:

| | | | | |
|---|---|---|---|---|
| 1. | Jet streams | | | |
| | 00 z | 21 | May | 1978 |
| | 06 z | 4 | May | 1978 |
| 2. | Major cloud systems. | | | |
| | 00 z | 21 | Apr. | 1978 |
| | 06 z | 19 | Jun. | 1978 |
| 3. | Convective clouds | | | |
| | 16 z | 3 | Jul. | 1978 |
| | 12 z | 12 | Jul. | 1978 |
| 4. | Orographic effects | | | |
| | 00 z | 31 | May | 1978 |

## V Concluding Remarks

It is briefly shown that high probable areas of

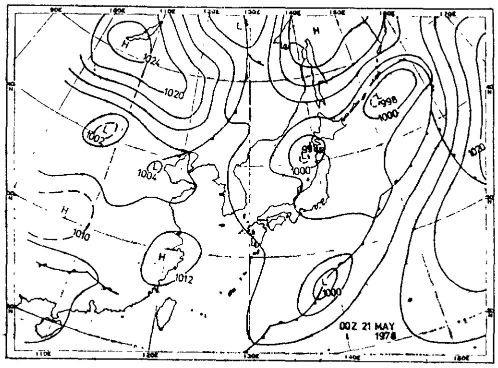


**Fig. 1a.** SF Cchart.

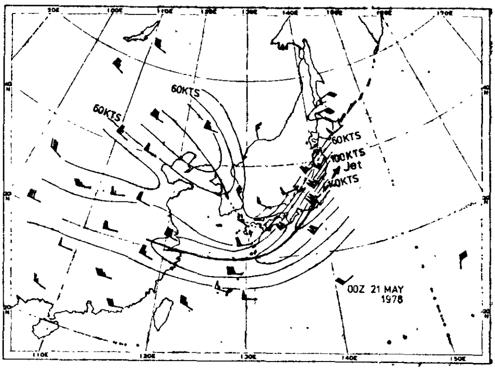


**Fig. 1b.** One of jet stream axes and winds at 250 mb

**Example 1. Jet stream** (0000 z 21 May 1978).

A very deep through has just passedthrough Japan at SFC and a frontal system runs in SW-NE direction as shown in Fig. 1a. A cold vortex west of the frontal system is analysed in the eastern part of the Sea of Japan.

Those features are seen in Fig. 1c, that is, a SW-NE oriented cloud band suggesting a frontal system and a dark grey cloud mass indicates existence of a cold votex aloft centred at about 41N 138E. A distinct Ci streak is seen just inside and along the northern edge of the cloud band. A jet stream axis runs along 30N from the east coast of the China continent to the south of Kyushu island of Japan, then changes its direction to northeast with maximum velocity of 150 kts or more as seen in Fig. 1b. Ci streaks runs along the jet axis and to the south of the axis with reference to vertical section analysis (not shown).

Turbulence was reported near the Ci streak as seen in Fig. 1c but the height of the Ci must be higher than that of the occurrence of the turbulence with respect to white appearance of the Ci streak indicating the level higher than 9600m(below −30°C).

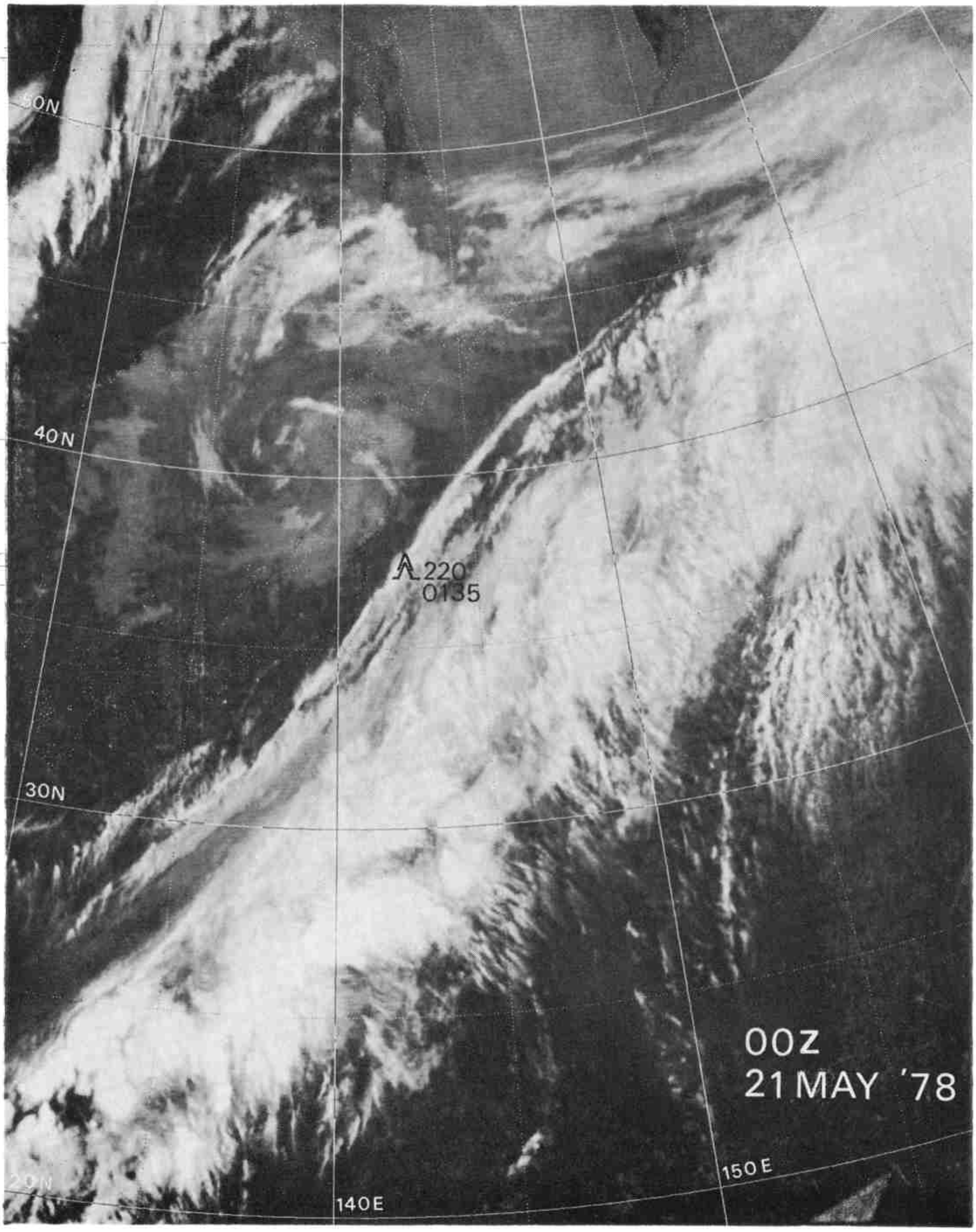


**Fig. 1c.** Relationship between characteristic cloud features and a turbulence encountered.

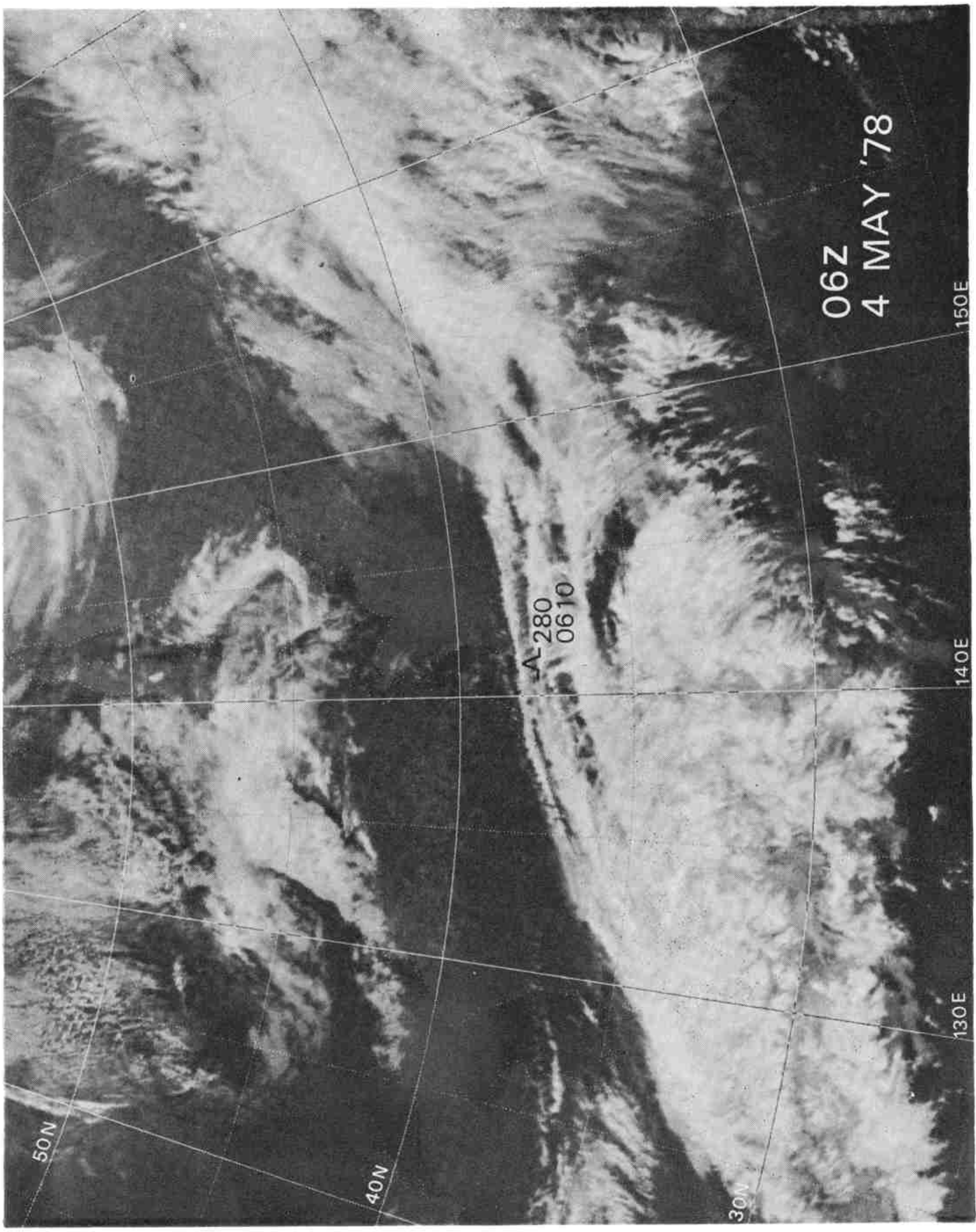


**Fig. 2c.** Relationship between characteristic cloud features and a turbulence encountered.

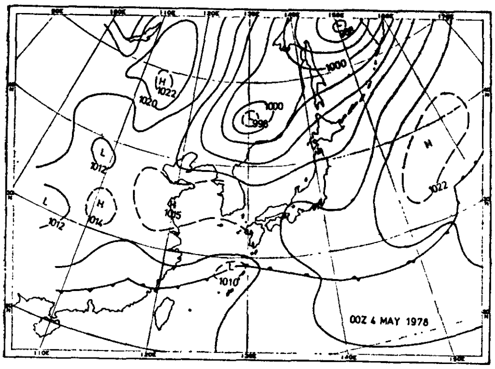


**Fig. 2a.** SFC chart.

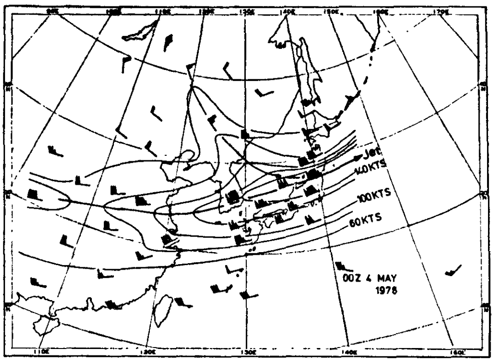


**Fig. 2b.** One of jet stream axes and winds at 250mb.

**Example 2. Jet stream** (0600Z 4 May 1978).

A deep trough aloft is suggested by developed lows at the Okhotsk Sea and the Siberia. A high pressure system over the northwestern Pacific Ocean is predominating and covers most of Japan as seen in Fig. 2a. On the other hand, a clearly defined jet stream is observed to the southeast flank of the deep trough with the maximum wind speed exceeding 150 kts in Fig. 2b. Vertical cross section analysis along 140E at 040000Z (not shown) indicates that one of jet axes is locating at about 38N along 140E and the corresponding jet axis is stretching WSW-ward as seen in Fig. 2b. Ci streaks in Fig. 2c change its location from 36N at 040000Z to 38N at 040900Z. Distance between the Ci streaks and the jet axis was about one degree in latitude at 040000Z. Considering the coincidence of time changes of the Ci streaks along 140E with those of the jet stream axis, we can conclude that the axis was located also at just north of the Ci streaks when the picture was taken. Moderate turbulence occurred within the area where Ci streaks were observed.

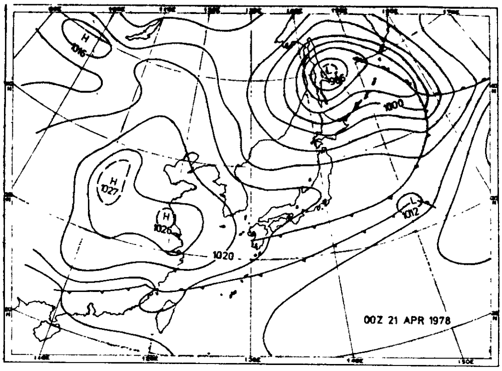


**Fig. 3a.** SFC chart.

**Example 3. Front** (0000Z 21 Apr. 1978)

A well developed low is located in the Okhotsk Sca and high pressure system is analysed in the China and the Siberia at SFC chart in Fig 3a. This pressure pattern is closely resemble to that of NW-ly winter monsoon near Japan. One of cold frontal systems is running from an occluded point south of the Kamchatka Peninsula and another one is stretching from a low pressure system far east of Japan main island. Those frontal systems reach to the sea south of Japan. Fig. 3b represents a frontal cloud band which corresponds to those frontal systems and covers Japan islands north of 25N except for the Hokkaido island. Moderate to heavy turbulences are observed whithin the cloud band at 050~110 hundred feet. This indicates that aeroplanes encountered those turbulences below middle level cloud layers in the inclined frontal systems.

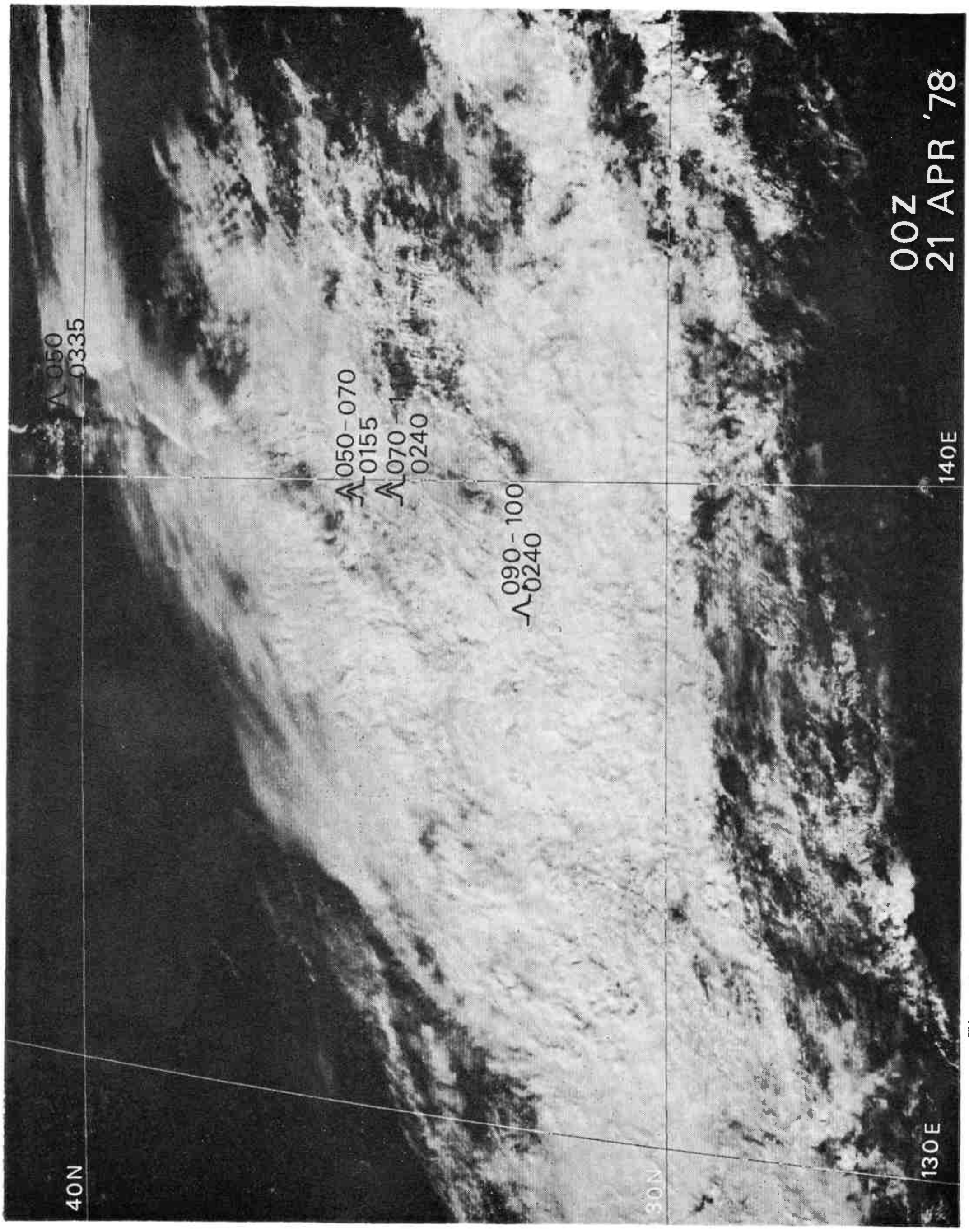


**Fig. 3b.** Relationship between characteristic cloud features and turbulences encountered.

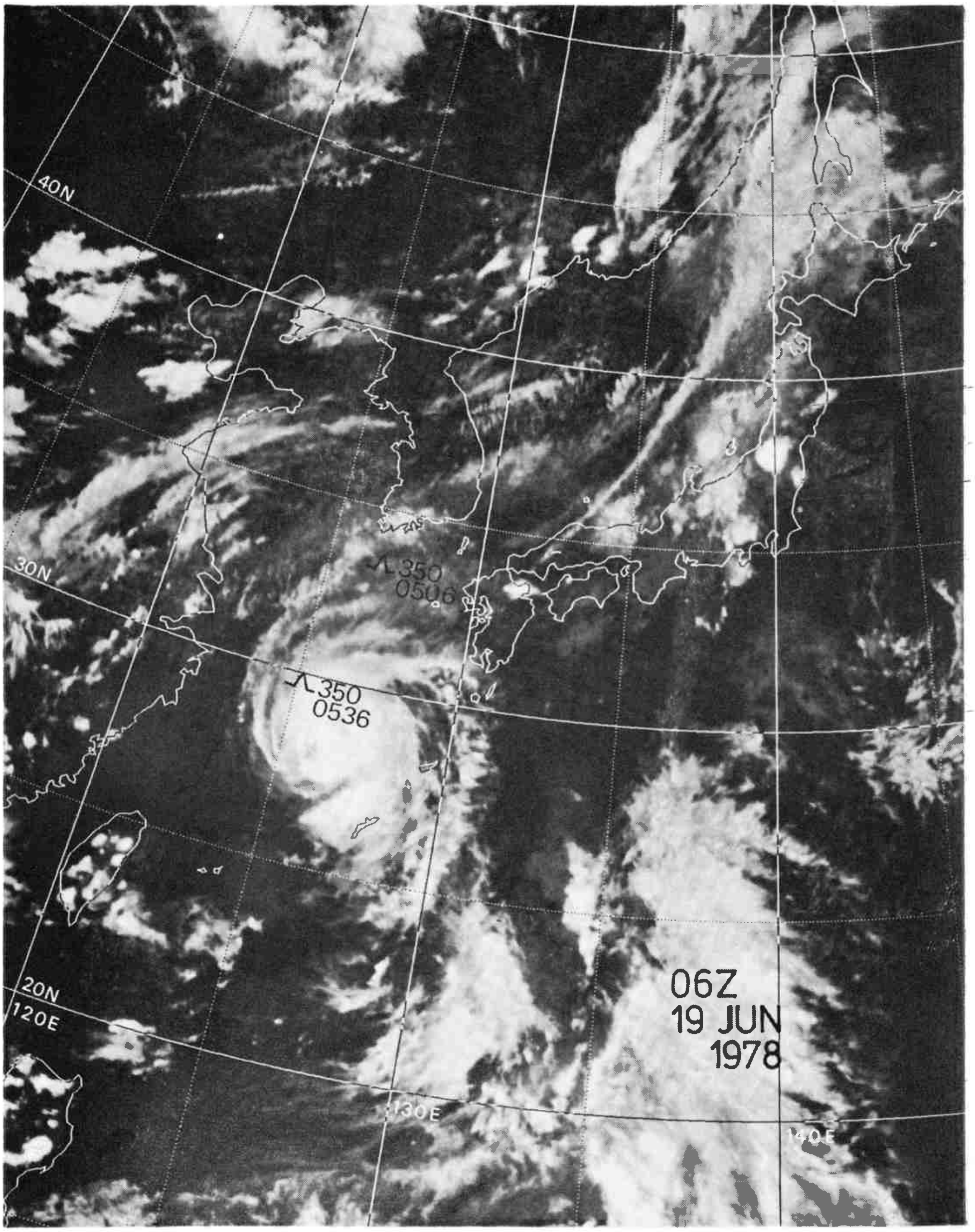


**Fig. 4b.** Relationship between characteritic cloud features and turbulence encoutered.

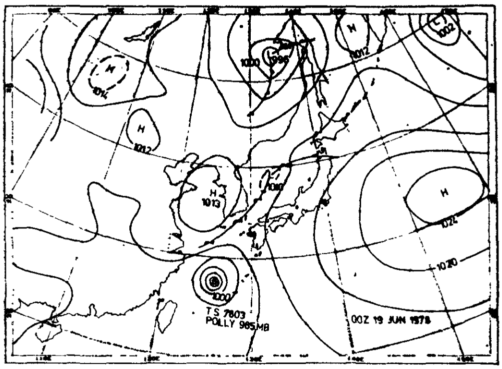


Fig. 4a. SFC chart.

**Example 4. Thphoon** (0600Z 19 Jun. 1978).

Typhoon Polly was moving northward in the East China Sea. Predominant subtropical high pressure system extends SE-ward and forms a part of warm sector over Japan ahead of a front in the Sea of Japan as seen in Fig. 4a. Cumulonimbi appear in the warm sector, especially in Honshu and Kyushu islands of Japan. A cloud system associated with the tropical storm accompanies anticyclonically curved Ci streaks to the west and the north of the cloud system centre as seen Fig. 4b. Such Ci streaks indicate outflows from the cloud system at higher levels. Moderate turbulences occur in areas where Ci streaks are observed.

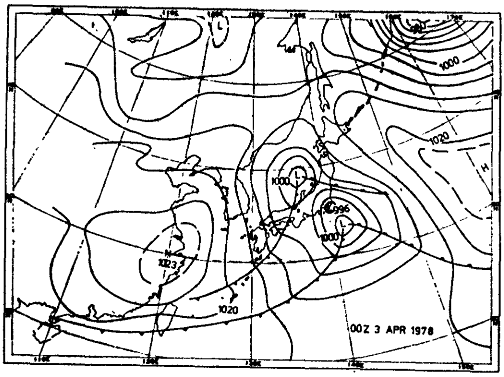


**Fig. 5a.** SFC chart.

**Example 5. Cold vortex** (0600Z 3 Apr. 1978).

A cold front stretches from a low pressure system in the Sea of Japan passing through western Japan and the sea surroundings of that part of Japan at 0300Z as indicated by SFC chart, Fig. 5a. Cold air outbreak progressed towards east behind the front. Western half of Japan is covered by the cold airmass 6 hours later since the analysis in Fig. 5a was made. Well developed cumulonimbi are observed whithin the cold airmass. Cu lines are also seen in the Sea of Japan at that time as seen in Fig. 5b. Temperature at 500mb was recorded by −30°C at a coastal station at 0312000Z.

Aircrafts encountered moderate to heavy turbulences, icing and thunderstorm at rather lower levels. Such situation seems to be common when cold air outbreaks occur and cumulonimbi develop within the cold airmasses.

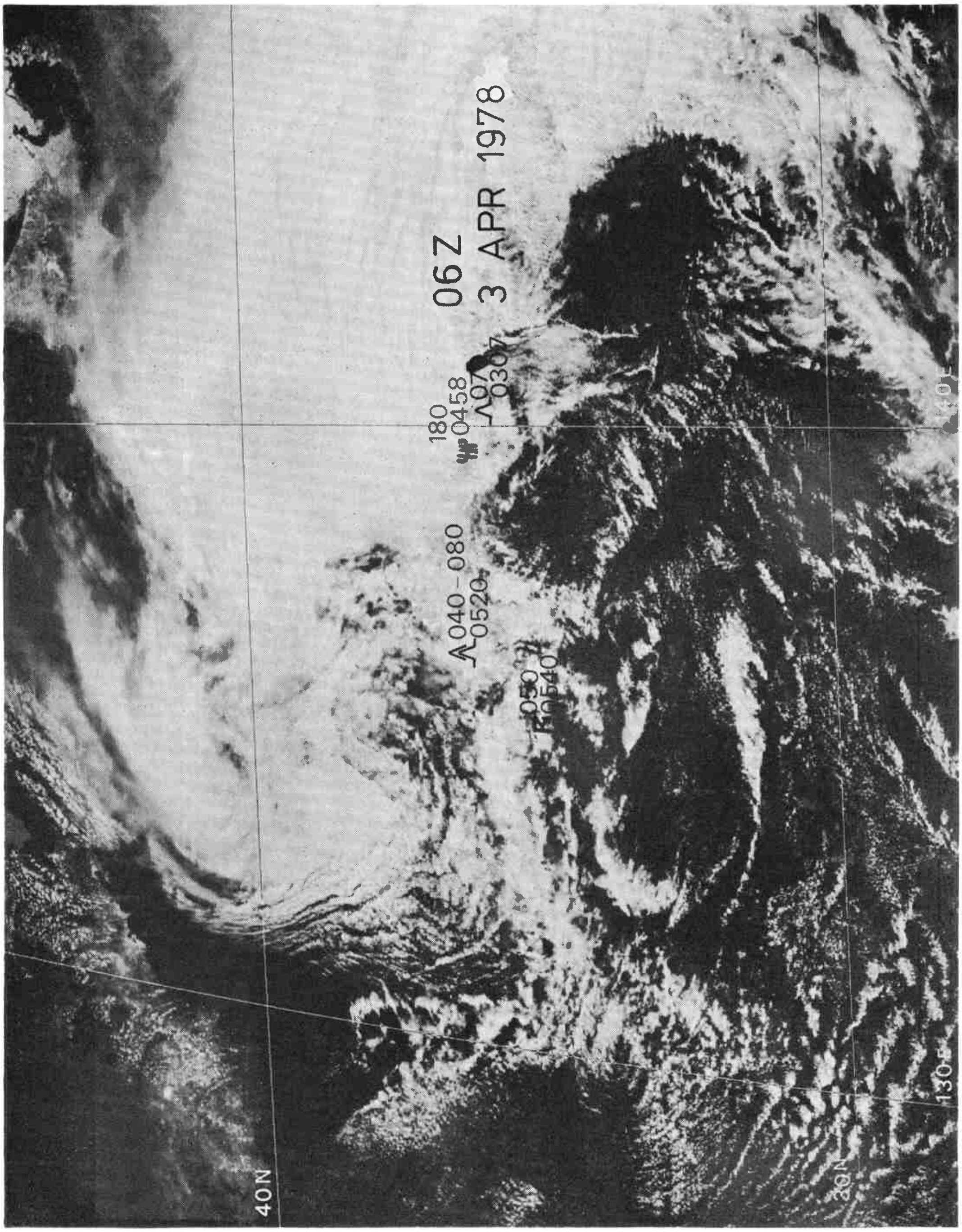


**Fig. 5b.** Relationship between characteristic cloud features and turbulences and other severe weather encountered.

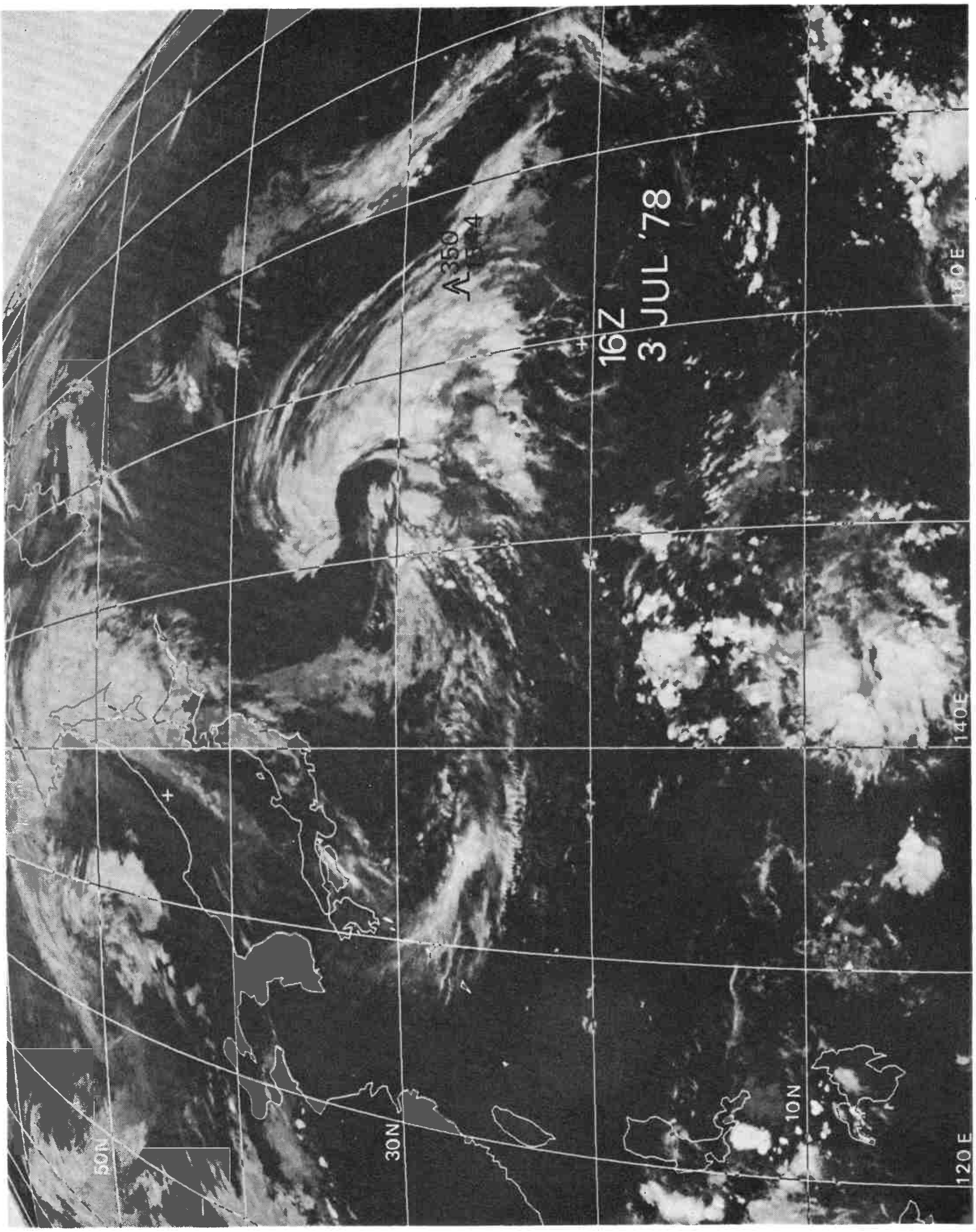


**Fig. 6c.** Relationship between characteristic cloud features and a turbulence encountered.

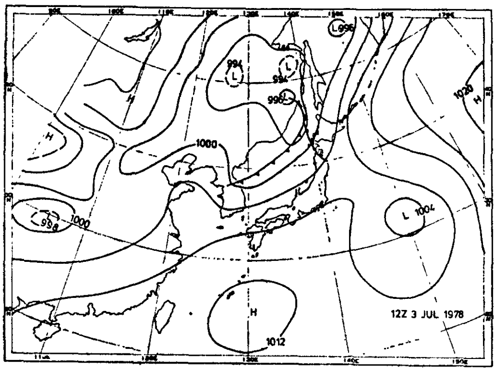


Fig. 6a. SFC chart.

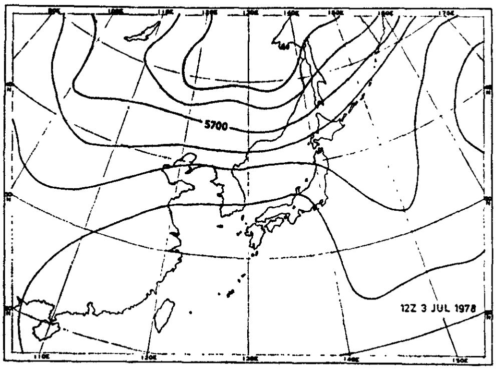


Fig. 6b. 500mb chart.

**Example 6. Cb clusters** (1600Z 3 Jun. 1978).

A large low pressure area is analysed in the southeast of Honshu island as seen in Fig. 6a. At 500mb, a deep trough intrude southward down to 20 N (Fig. 6b). This indicates that a number of active convective clouds exist within this area as seen in Fig. 6c.

An aeroplane observed a strong turbulence in a Cb cluster in the peripheral of the low pressure system in the SFC chart.

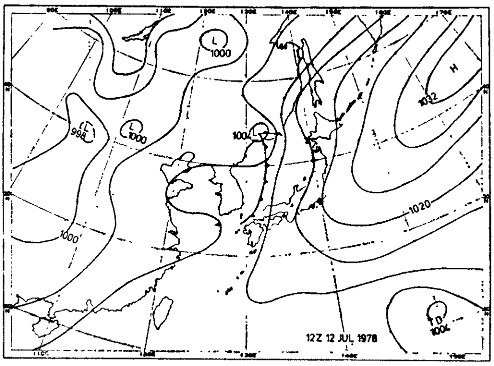


**Fig. 7a.** SFC chart.

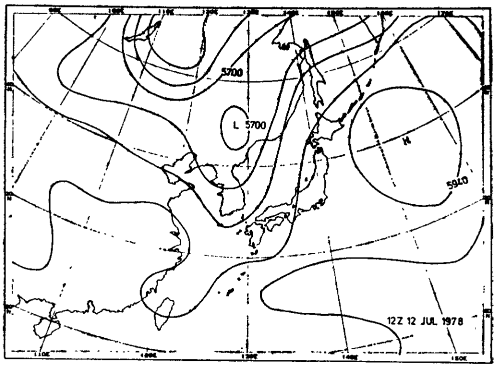


**Fig. 7b.** 500mb chart.

**Example 7. Cb clusters (1200Z 12 Jul. 1978).**

Predominant high pressure system covers widely seas around Japan. In a southern peripheral of the system, a weak tropical depression is observed as seen in Fig. 7a. In the Sea of Japan, there is a low accompanying a frontal system. Low pressure area extends towards west from the tropical deperession at 500mb shown in Fig. 7b. Several Cb-clusters aligned along the low pressure areas at 500mb are observed as seen in Fig. 7c.

An aeroplane encountered strong turbulence in a cloud cluster of Cb to the WSW of the tropical depression.

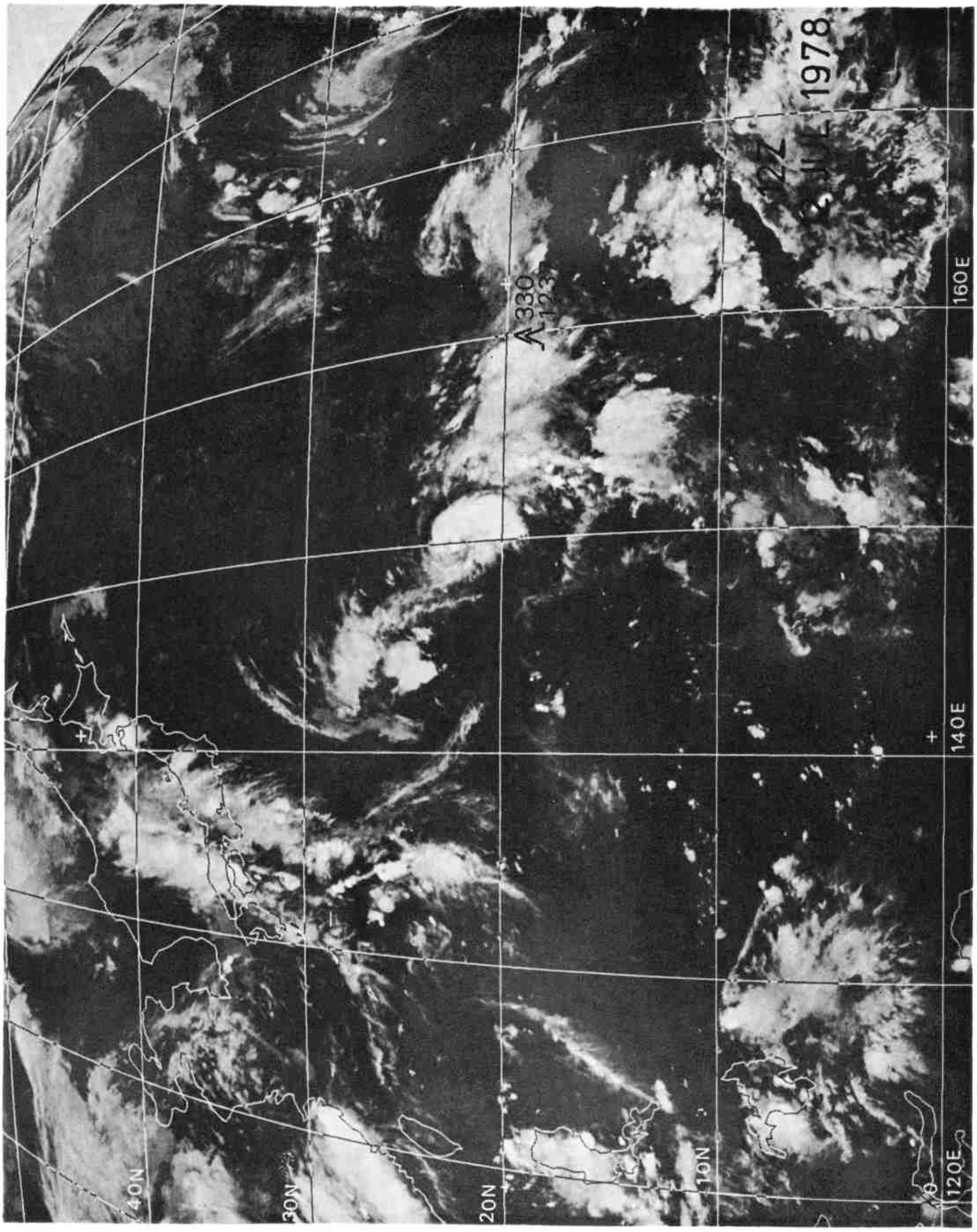


**Fig. 7c.** Relationship between characteristic cloud features and a turbulence encountered.

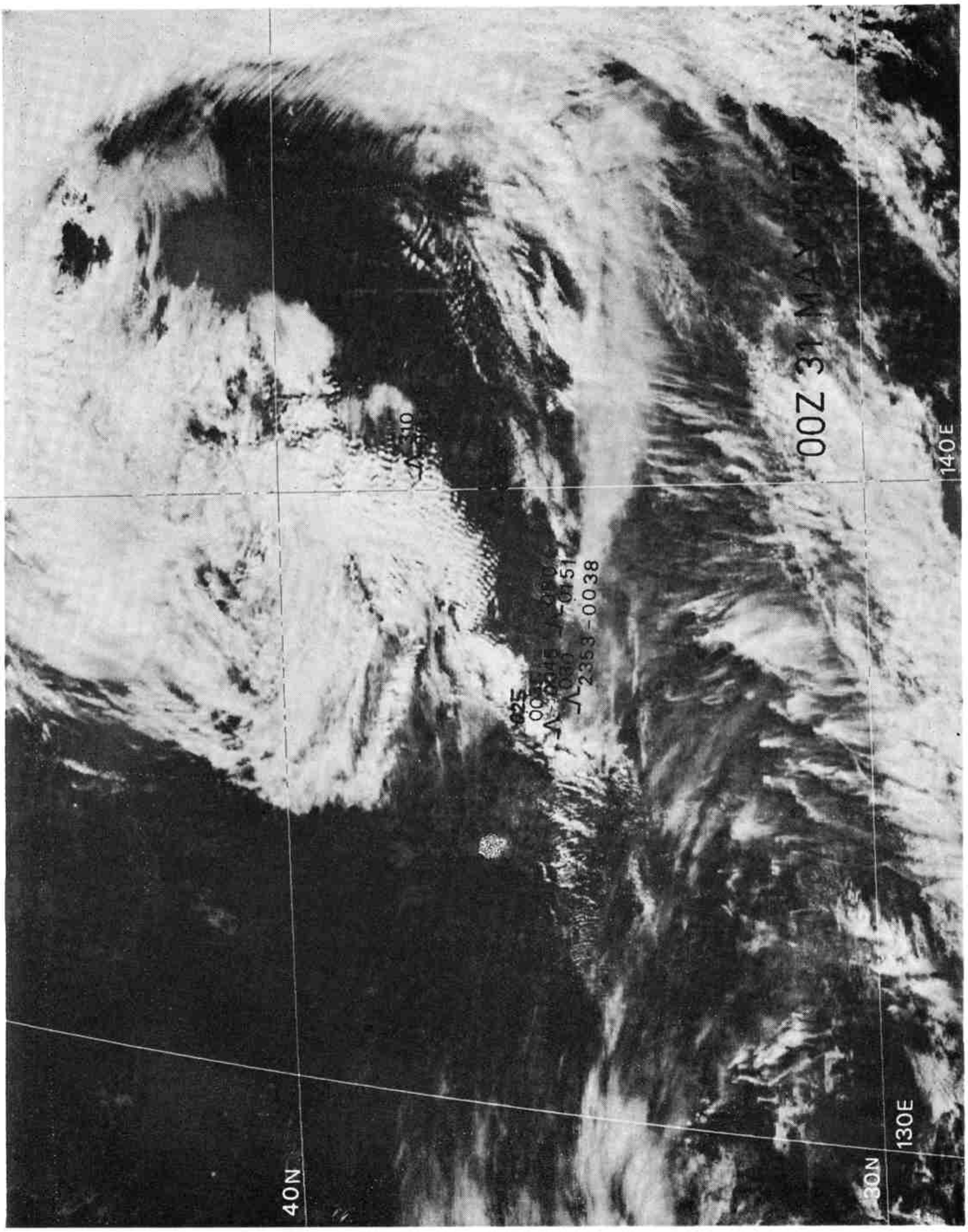


**Fig. 8b.** Relationship between characteristic cloud features and turbulences encountered.

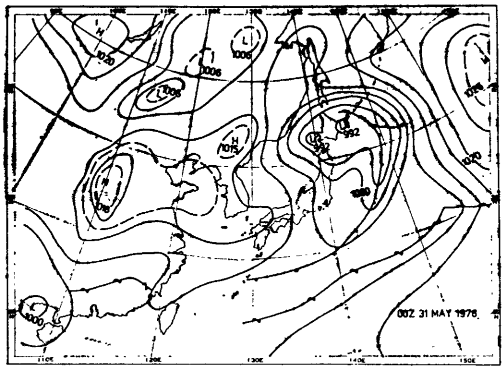

**Fig. 8a.** SFC chart.

**Example 8. Orographic effects** (0000Z 31 May 1978).

Well developed lows locate in Hokkaido island. High pressure systems are analysed in China, in the Yellow Sea and to the west of Vladivostok. This pressure pattern is shown in Fig. 8a. Isobars are concentrated in the peripherals of those low pressure systems. In the northern part of Honshu island, distances between adjecent isobars are rather short which suggests trong winds being prevailing in this district. In fact, westerly winds are observed with the speeds over 35kts at lower levels and over 110kts at higher levels in the northern Honshu island. Wind direction of those strong do not change much in vertical. Wavy clouds caused by the mountain ranges running through the central portion of Honshu island of Japan.

Aeroplanes reported several disturbances at lower levels and at higher level as well. Although it is not clear in this case how to relate the turbulence occurred at higher level to the orographic effects of the mountain range, there are observation and theoretical study with respect to such the relationship as just described above.

turbulences are detectable in satellite imageries by examining carefully the imageries in order to detect the characteristic cloud from which are closely related to turbulences as described in this paper. The most important thing to be mentioned is that the relationship between those cloud features and turbulences can be extended to such data sparse areas as oceans, deserts, mountaneous regions and so on. On the other hand, it is inevitable to say that we can not detect any high risk areas of turbulence where no clouds exsist or where the turbulent cloud forms are obscured by higher clouds or any other situations.

*Acknowledgement.* The auther acknowledges Mr. H. Mori at the New Tokyo International Aeronautical Meteorology Observatory, Narita, Chiba Pref. and Mr. R. Shoji at the Tokyo Aeronautical Meteorology Observatory, Haneda, Tokyo in collecting and offering those data to the auther.

## References

Anderson, R. K., J. P. Ashman, F. Bittner, G. R. Farr., E. W. Ferguson, V. J. Oliver and A. H. Smith, 1960: Application of Meteorological Satellite Data in Analysis and Forecasting. ESSA Technical Report NESC **51,** Washington D. C.

Anderson, R. K., J. P. Ashman, G. R. Farr, E. W. Ferguson, G. N. Isayeva, V. J. Oliver, F. C. Parmenter, T. P. Popova, R. E. Skidmore, A. H. Smith and N. F. Veltischev, 1973: The Use of Satellite Pictures in Weather Analysis and Forecasting. WMO Technical Note No. **124,** 276 pp., Geneva.

Finger, F. G. and R. M. McInturff, 1975: Application of Satellite Data to Aeronautical Meteorology. WMO Technical Note No. **142,** 93 pp., Geneva.

Lilly, D. J., 1971: Observation of Mountain-Induced Turbulence. Journal of Geophysical Research, Vol. **76,** No. 27, pp 6585-6588.

Nicholls, J. M., 1973: The Airflow over Mountains. WMO Technical Note No. **127,** 73 pp., Geneva.

---

## 気象衛星画像にみる乱気流域

土 屋　喬
気象衛星センター解析課

気象衛星画像にみられる特徴的な雲パターンから，乱気流発生の可能性が高い領域をある程度，限定することができる。その様な雲パターンの特徴は，

(1) ジェット気流
(2) 低気圧性擾乱
(3) 対流活動
(4) 地形効果

などと関連している。ここでは，これらの典型的な例を，1978年４月から７月までの４ケ月間のＧＭＳデータ(画像)から８例を選び出し，航空機などに依る乱気流の報告と対応づけて示した。この様な両者の対応は，一般の気象データが得られない海洋・砂漠・山岳地帯などでも，乱気流の発生し易い領域を気象衛星画像上で限定できることを示している。