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The Study of Mesoscale Phenomena, Winter Monsoon Clouds and Snow Area*

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ABSTRACT

The clouds under a moderate winter monsoon situation taken with S190A camera reveal existence of clouds with band structure of various wave lengths. The wave length ranges from 0.4 to 3.5 kms. There is a good relationship between the longitudinal cloud band and vertical wind shear. There is a distinct difference in size of clouds between the Japan Sea side or upwind side and the Pacific Ocean side or downwind side of Japanese Mainland. Large solid cumulus clusters have the size of 20x35 km^2 over the Japan Sea off the coast of Hokuriku District.

It is found that S190 A aerial color pictures showing shadows of fair weather cumuli over the sea can be successfully used in estimating cloud height while S190A Station I picture is more useful over the land since it can more clearly distinguish shadow from vegetation. The height of fair weather cumuli estimated from shadows agree with the lifted condensation level. It is also found that S190A pictures are effectively used in delineating snow cover area.

S192 data, especially IR channel is found to be effective in finding topography of nimbostratus.

I. Introduction

During the SKYLAB EREP experiment observations were made twice, i.e. Sep. 18 1973 and Jan. 11 1974. On Sep. 18 1973 Japan was under frontal clouds while on Jan. 11, 1974 Japan was under the influence of a moderate winter monsoon.

The track of Jan. 11 1974 is shown in Fig. 1 together with topography and aerological stations. The track of Sep. 18 was approximately two degrees of longitude east of the track in Fig. 1. In the figure approximate coverage of the pictures used in the study of wintermonsoon clouds and snow cover area are shown in broken lines.

Located to the east of the largest continent of Eurasia between the Japan Sea and

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* NASA Headquarters Proposal Registration No. 022

the Pacific Ocean, Japan is under the influence of monsoon during winter. Cold air from the Asiatic continent is heated from below and abundant water vapor is supplied over the Japan Sea thus active formation of convective cloud takes place. These clouds bring heavy snowfall once in a while to the areas facing the Japan Sea. Since the social and economical effects of heavy snowfall is so large that many investigations on the mechanism of a heavy snowfall as well as snow cloud have been made in Japan.

Asai (1954, 1966) made analyses of clouds over the Japan Sea off the coast of Hokuriku while present author made detailed studies on the clouds appearing in meteorological satellite pictures (1967, 1969, 1974). Meteorological satellite pictures can show a synoptic scale cloud distribution well, however due to the limitation of resolution mesoscale cloud structure could not be resolved.

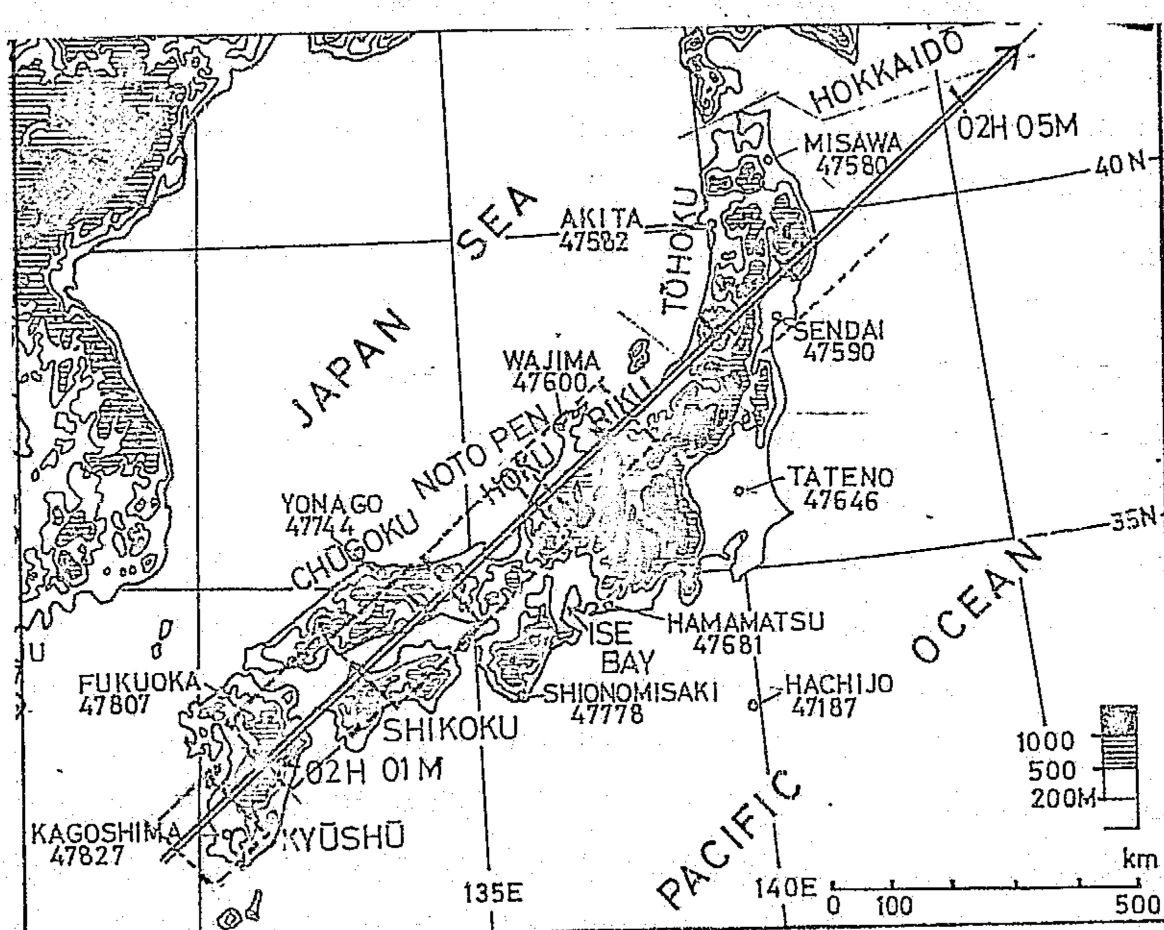

Fig. 1 The track of SKYLAB on 11 Jan. 1974 over Japan. The location of SKYLAB and time are shown. Locations and international station numbers of aerological stations are also shown.

Taking advantage of high resolving power with responsivity in different spectra in the data of SKYLAB attempts are made to clarify the detailed structure of winter monsoon clo uds as well as other mesoscale feature of clouds and snow cover area.

2. The meteorological situation at the time of picture taking on Jan. 11 1974

The surface weather maps at 00 and 03 GMT 11 Jan. 1974 showing the weather of Japan approximately 2 and 1 hours before and after the SKYLAB pass are shown in Fig. 2 (a) and (b) respectively. The pressure pattern is a typical one during winter in Japan with strong eastward pressure gradient accompanied by cold north-westerly wind. In the area facing the Japan Sea the prevailing weather is snow while in the areas in the Pacific Ocean side weather in general is fair.

Comparing two sccessive weather maps no remarkable change of weather is recognized except at a few stations in western Japan. In the stations marked with letters A, B and D, cloud amount decreased rather rapidly while at station C snow stopped.

In order to see a large scale trend of weather system at the time of SKYLAB pass over Japan, the variation of temperature, winds and height of 500-mb level during the period between 9th and 15th of January at Yonago (47744) are plotted and shown in Fig. 3. Yonago is located on the coast of the Japan Sea. The average values of air temperature and height of 500-mb level in Jan. at Yonago are also indicated in the figure in a solid line. From the figure it can be seen that it was in the time of cold advection and in advance of pressure trough on the day of the pass.

Both air temperature and height of 500-mb level are lower than the average value which together with winds indicate that Japan was under a moderate winter monsoon situation at picture taking time.

The upper air charts at 850-, 700-, 500- and 250-mb levels are shown in Fig. 4 which show the upper air condition 2 hours before SKYLAB pass. In the figure contours are drawn every 30 meters (geopotential meter in strict definition) in 850- and 700-mb charts, while every 60 and 100 meters in 500- and 250- mb levels respectively.

Iso-relative humidity lines are also drawn in broken lines. In 850-mb chart a sharp contrast in relative humidity distribution is seen between the Japan Sea side and the Pacific Ocean side. In 500-mb level chart a weak trough is seen to the upstream of Japan, or to the west of Japan. The high relative humidity above 700-mb level is partly due to the effect of synoptic scale diturbance. In 250-mb chart a strong jet stream is found in the southern Japan in zonal direction. At Hachijojima (47678) the observed highest wind speed is as high as 94 m/s at 219-mb level.

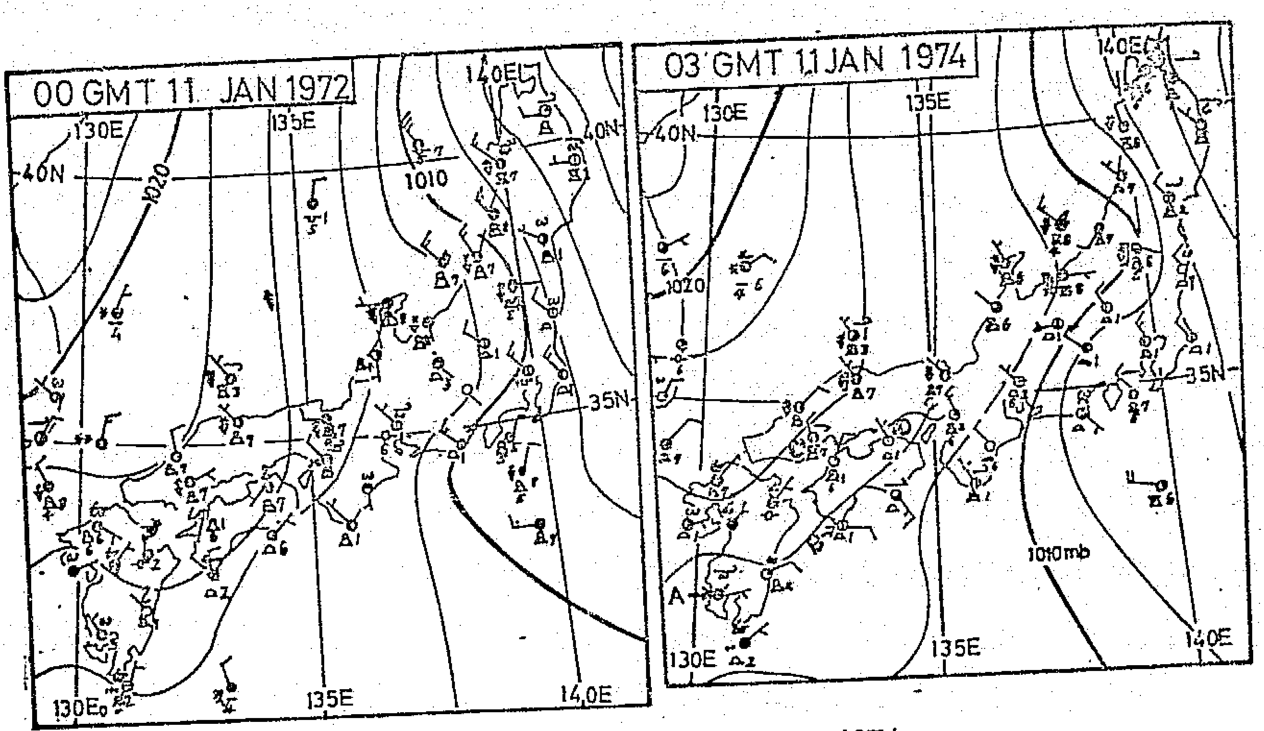

Fig. 2 Surface weather maps at 00 and 03 GMT 11 Jan. 1974

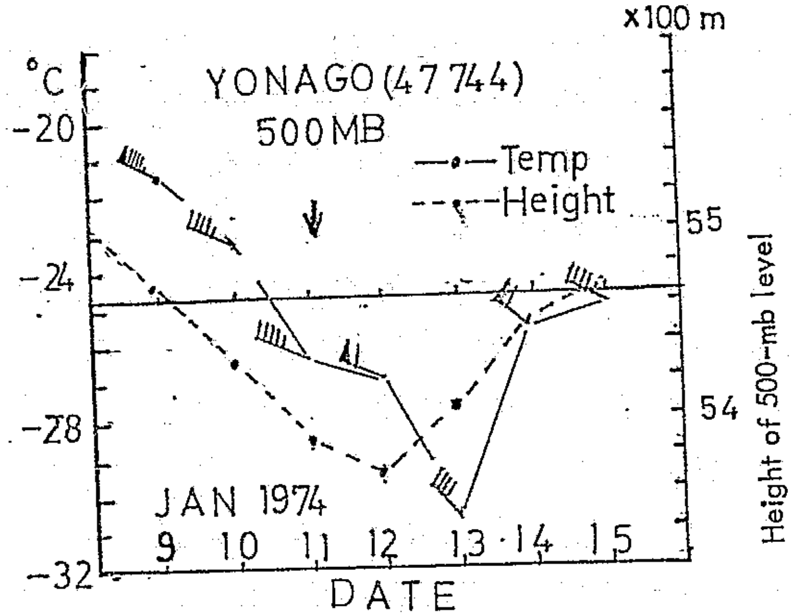

Fig. 3 Variation of temperature, height and winds of 500-mb level

3. Winter monsoon cloud over and around Japan observed from space

Over-all cloud distribution observed by meteorological satellite ESSA 8 is shown in Fig. 5 which is a mosaic of two pictures taken in successive orbits. The western half was taken at 02h 18m 08s on Jan. 11 1974 while the eastern half was taken 114 minutes 42 seconds earlier. Since the mosaic was made operationally at Japan Meteorological Agency, the location of western half is a little off and should be moved about half a degree southward. Since the time difference of the pictures between ESSA8 8 and SKYLAB is about 17 minutes it can be considered almost simultaneous. In the picture taken from meteorological satellite a pronounced effect of Japanese islands on the cloud distribution is seen however no detail is recognized. It is almost impossible to distiguish cloud type. The detail of clouds will be shown in the following section in the order of picture taking time, i. e. from south-west to north-eastward.

Fig. 6 is the copy of S190A aerial color picture taken above Kyushu, south western island and one of the four main islands consisting Japan. As to the location refer to Fig.1. The surface observation indicates the cloud type observed from the surface at Kagoshima is cirrus and altocumulus.

Outstanding feature is the several streaks with a sharp edge. The location of the edge approximately corresponds to that of jet stream axis. The spacing of cloud streaks is in average 3.1 kms. Imbedded in the streaks is wave structured clouds of extremely short wave length nearly perpendicular to the streaks. The wave length of the imbedded clouds ranges from 0.4 km for an extremely fine one appearing like a finger prints in the picture to 2.3 kms which look like cumulus and the prevailing value of spacing is approximately 1 km.

The vertical structure of the air above Kagoshima is shown in Fig. 7 which is a radio sounding data plotted on an Emagram. In the figure air temperature and relative humidity are shown in solid and broken lines respectively. The symbols of winds are those used internationaly in meteorological services. The distribution of relative humidity indicates two layers of high humidity which agrees with the surface observation of double layers of clouds of high and middle clouds ; cirrus and alto-cumulus. It is interesting to notice that the cloud cover as observed from the surface at Kagoshima is 5/8. It is considered that the cloud cover as seen from the surface will be a little larger than that observed from space due to viewing angle effect which is very important fact for the interpretation of space data.

The condition further north-east along the track of SKYLAB is indicated in Fig. 8, which covers north-eastern Kyushu, western Shikoku and a part of Chugoku District The picture is a mosaic of two successive pictures.

A sharp fish bone like wave clouds are seen in the lower left with an average wave length of 2.3 kms. Since these clouds are over the mountainous areas it looks these clouds are formed by vertical motion induced by orographical effects although a

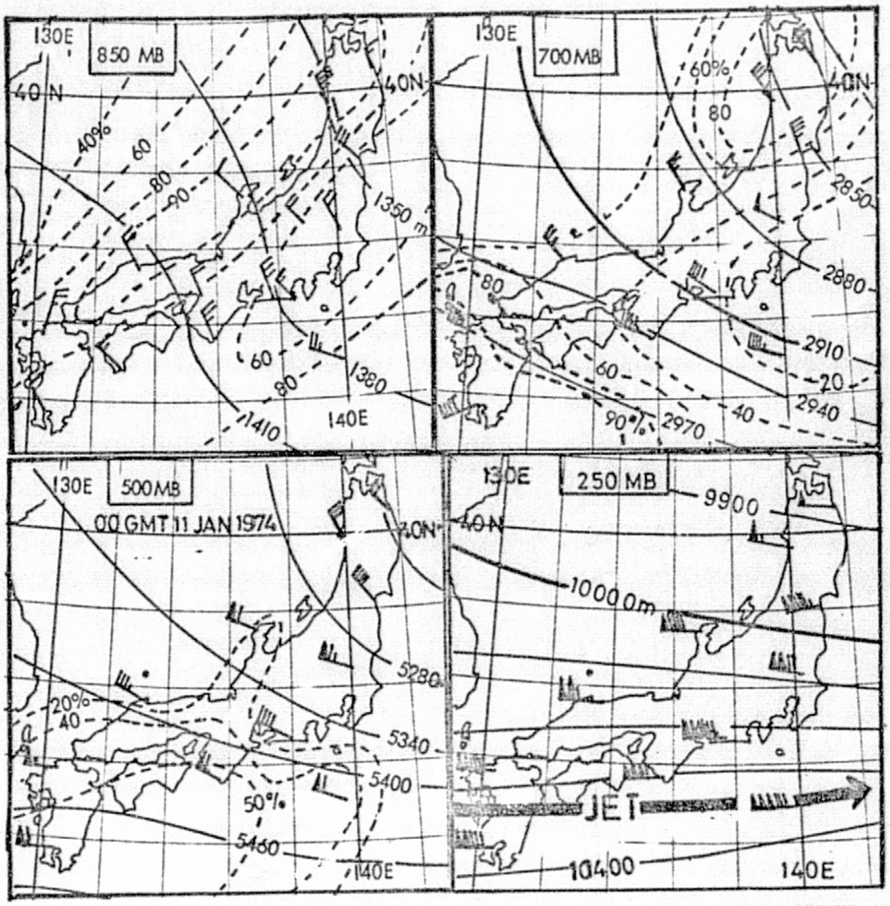

Fig. 4 Upper air chart at 00 GMT 11 Jan. 1974

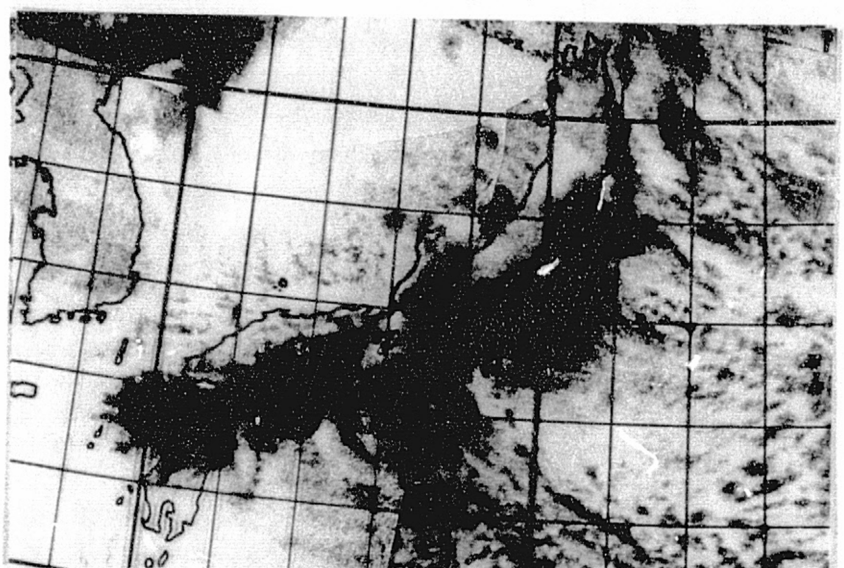

Fig. 5 ESSA 8 APT mosaic made at Japan Meteorological Agency. Western half was taken at 02h 18m GMT 11 Jan. 1974.

wave length is much shorter than the ordinary mountain waves.

The vertical structure of the air above Fukuoka (47807) located north-west of the wave cloud area is indicated in Fig. 9. In the figure the letters RH, T, D and V are relative humidity, air temperature, wind direction and wind speed respectively. The figure indicates that it is fairly humid throughout the layer. A weak temperature inversion is found at 750-mb level. The wind direction backs upward and above the inversion layer the wind is persistently westerly throughout the layer.

Another interesting feature found in Fig. 8 picture is several rows of cumuli over the strait between Kyushu and Shikoku. These cloud look just like a thin cloud band in the meteorological satellite picture of Fig. 5. The height of the cumuli estimated from the ;shadows in the picture is in average 1.3 kms ranging from 1.0 to 1.5 kms. There may be cumuli of lower level when they are small, however the shadow of too small cumuli are hard to recognize by eyes.

The vertical wind shear defined by dv/dz where v and z are wind speed and height respectively is 9×10^{-3}/sec in this case which satisfies the criterion for longitudinal or along the wind direction orientation of convective clouds proposed by present author (1967, 1974). The ratio of width of spacing of cloud rows to the cloud height ranges from 3.1 to 3.5 kms in average which has a good agreement with the result obtained over a tropical region during BOMEX Experiment (Kuettner, 1971).

Fig. 10 indicates orographical effects on cloud distribution. The monsoon clouds after having crossed the mountain range suddenly disappears at the coast of the inland sea. This is mainly due to downslope motion but it is also due to the effect of divergence. Over the inland sea small cumuli begin to form. The height of the cumuli estimated from the shadows ranges from 0.9 to 1.5 kms.

The vertical structure of the air above Shionomisaki (47778) located further south of the area is indicated in Fig. 11 which shows that the lifted condensation level is approximately 1300 meters. In the original color pictures estimation of cumuli height from shadow is made for the clouds with the size larger than a few kms. It is found that the correspondence between the lifted condensation level and the height of cumuli.

A good example of orographical effect is seen in the abundance of small cumuli over islands and land. The cloud in the south of Shikoku shown in Fig. 12 is a high level cloud. The height estimated from the shadow is about 5.5 kms which corresponds to high relative humidity at Shionomisaki.

Monsoon clouds over the Japan Sea and her coastal areas under moderate winter monsoon are shown in Fig. 13 (a) and (b). The clouds seen in these picture are different from those previously shown. Large cloud clusters are seen over the sea. Careful analyses reveal that each large cluster is composed of several large cumuli. The clusters coalesce into a larger cluster over a mountainous slope when they are carried into the inland.

Fig. 6 SI90A Aerial color.
02h 01m II Jan. '74.

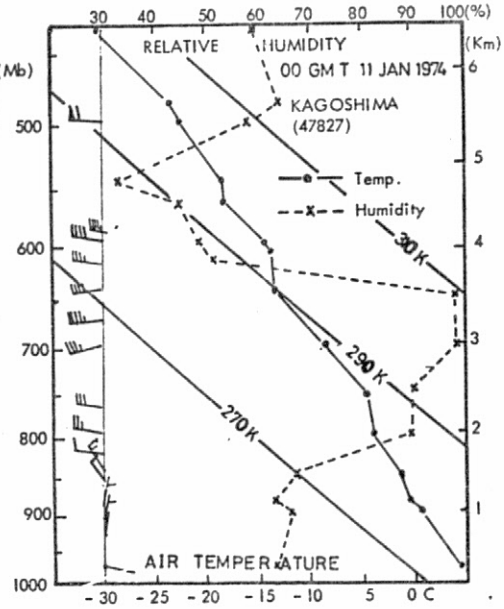

Fig. 7 Radiosounding at Kagoshima.
00 GMT II Jan. "74/.

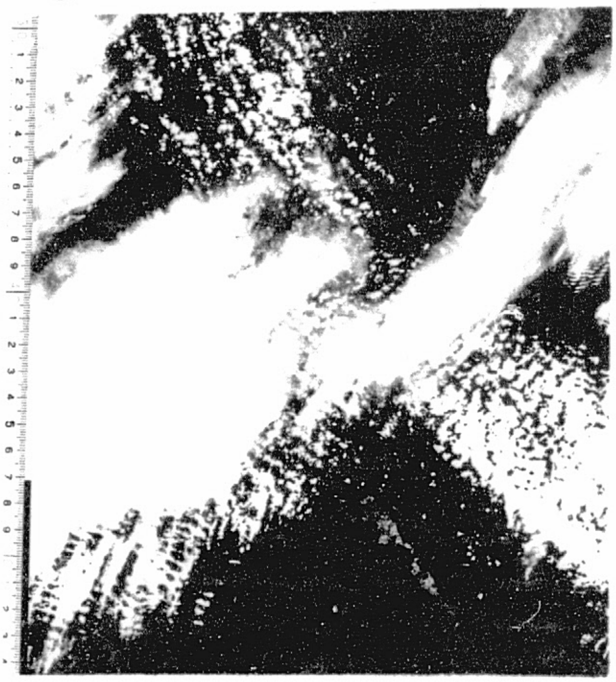

Fig. 8 Copy of SI90A aerial color.

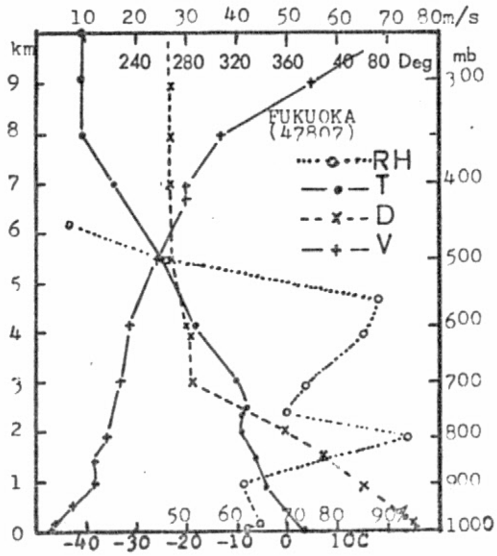

Fig. 9 Upper air condition at Fukuoka. 00 GMT II Jan. 1974. RH, T, D and V are relative humidity, temperature, wind direction and speed.

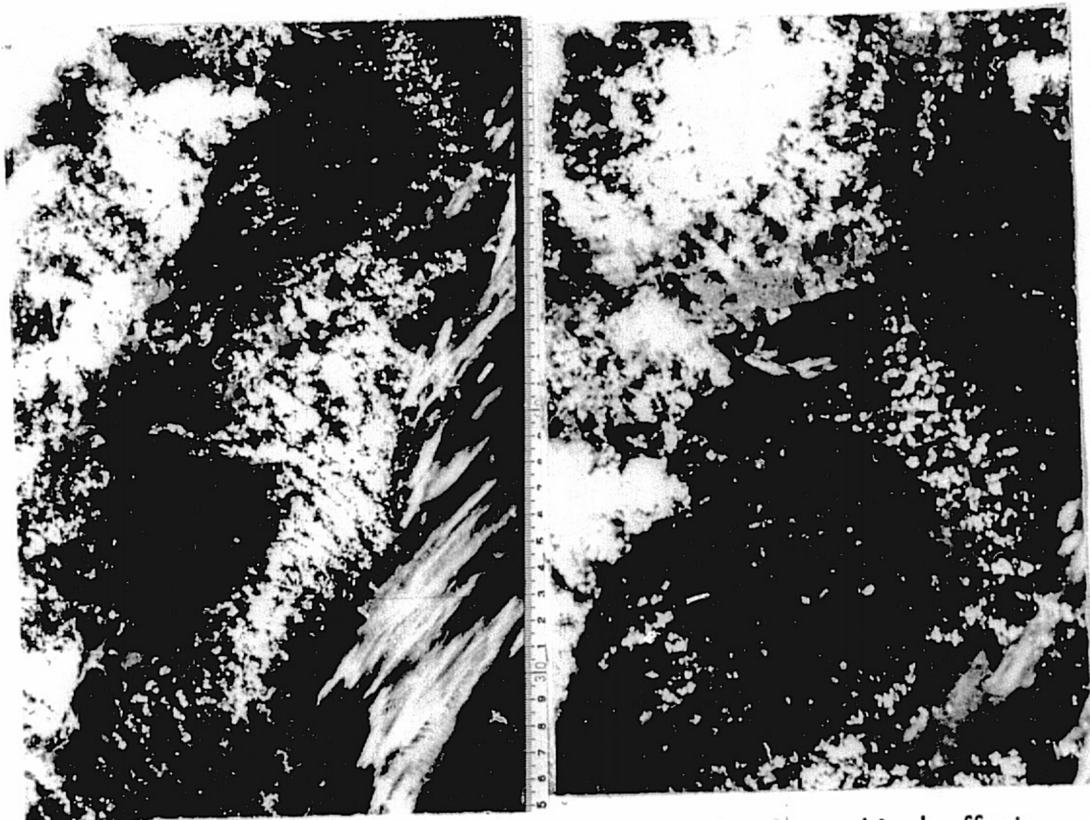

Fig. 10 S190A pictures showing shadows of cumuli, orographical effects on the formation of clouds. Color picture is an enlarged one. One mm corresponds to 708 meters which applies to all other pictures with scale. The location is the coastal region of Seto Inland Sea.

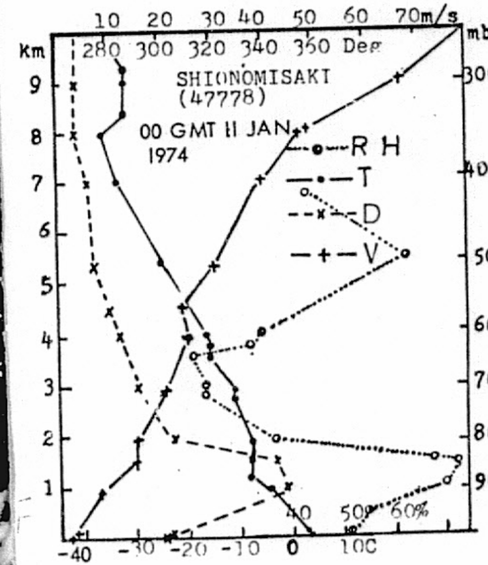

Fig. 11 Upper air condition at Shionomisaki. The letters represent same elemens as before. 00 GMT LL Jan. 1974.

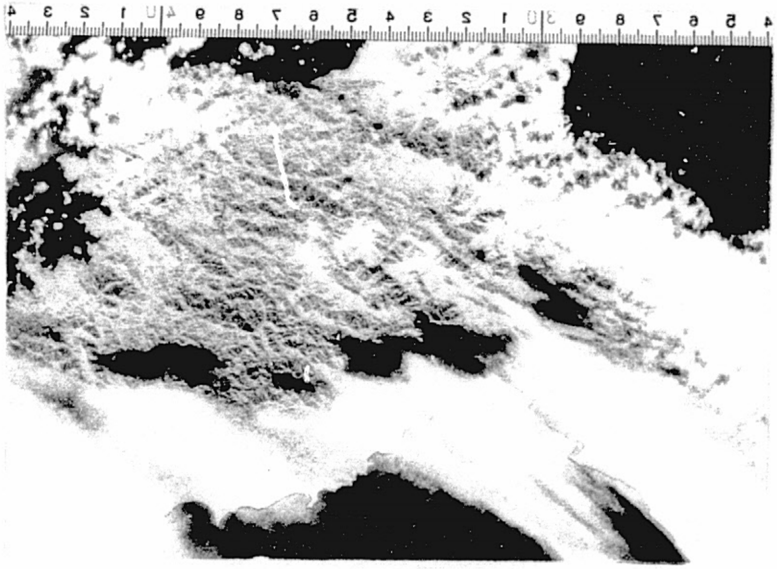

Fig.12 S190A Station I picture showing clear shadow of high clouds over densely vegetated area of Shikoku.

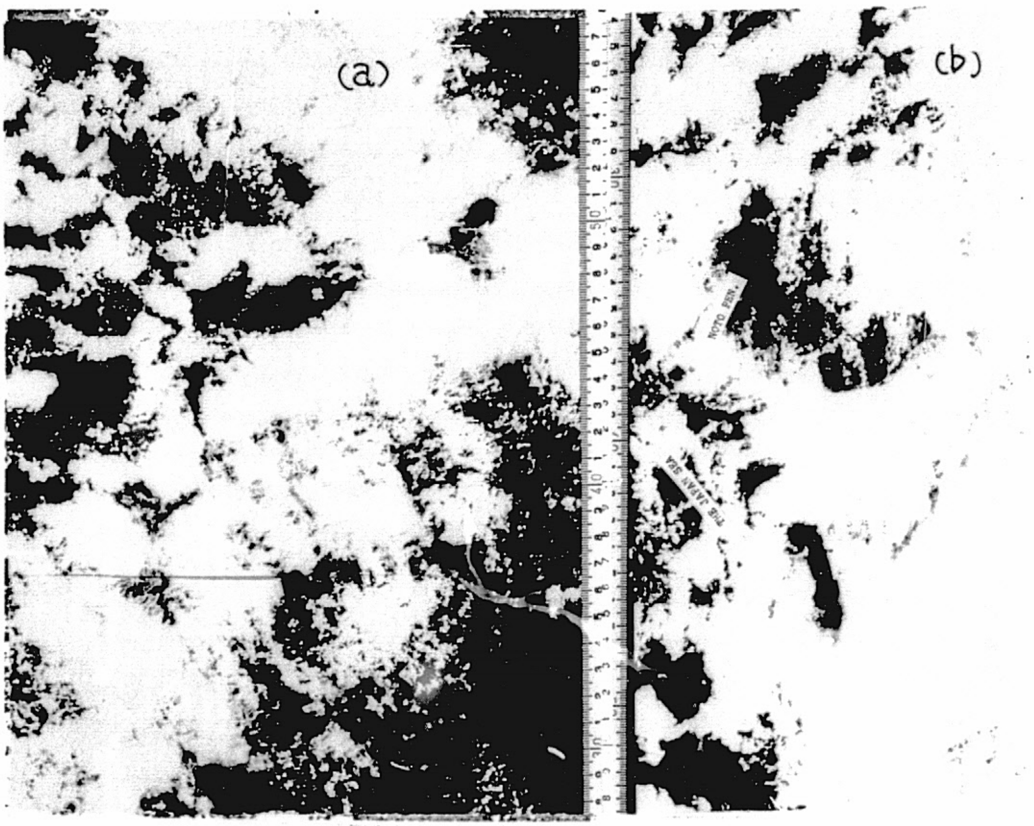

Fig.13 S190A picture showing large cumulus clusters over the Japan Sea and coastal region of Hokuriku District. Right hand side picture covers Noto Peninsula and the left hand side picture covers the area to the south-west of that of the right hand picture.

Since no shadow is recognized an attempt is made to find out the vertical extent of the cloud clusters through an analysis of radio sounding data. Fig. 14 indicates the radio sounding at Wajima located at the tip of Noto Peninsula and right under a large cloud cluster.

From the figure it can be seen that humid layer exists between 500 and 2200 meters. It is considereed that the value stated here may be the thickness of the clouds. Present author (1969) pointed out there is a good correspondence between the appearance in a meteorological satellite APT picture and snowfall and proposed three types of appearances in APT pictures corresponding to three types of snowfalls.

The daily snowfall chart made at Japan Meteorological Agency in an operational basis is shown in Fig. 15. The charts are made based upon the daily snowfall observed at 00 GMT at the reporting stations of Japan Meteorological Stations (JMA) Japan National Railway and hydroelectric power stations. Since daily snowfall is greatly influenced by orography, the actual distribution of snowfall will be different from the ;one shown here especially in the nountainous regions where no reporting stations exist. Although more data are necessary to get a conclusion it is considered that the cloud as shown in the previous figures bring heavy snowfall to localized area.

4. Application of S190A picture to the study of snow cover area

Due to the great effect of orography, it es difficult to get an exact map of snow cover. An example of S190A picture showing ;snow cover area clearly is shown in Fig. 16. It is interesting to compare the picture with the snow cover chart made at Japan Meteorological Agency daily which is shown in Fig. 17. Since 0 cm line is not drawn in the snow cover chart no exact result is obtained however the picture suggests the distribution is much more complicated than than shown in Fig. 17. Even one S190 A picture may be able to improve the operationaly made snow cover chart enormously.

5. Cloud topography based on S192 data on September 18 1973

At the pass of SKYLAB on Sep. 18 1973 over Japan a weak depression of 1012 mb was at 31 N, 134 E and most of Japan was covered with cloud and in the western Japan rain was falling. In an attempt to study topography of cloud a color sliced imager is made using the data of Channel 13 of S192 MSS. and shown in Fig. 18. In the figure assignement of color is made as follows:

	-14	-11	-7.7	-4.8	-1.7	1.5	4.6 °C
W	M	R	Y	G	C	B	BL.

h where W, M,R,Y, G,C, B and BL represent White, Magenta, Red, Yellow, Green, Cyan, Blue and Black respectively.

The clouds observed at the surface are shown in Fig. 19 in which cloud type for low

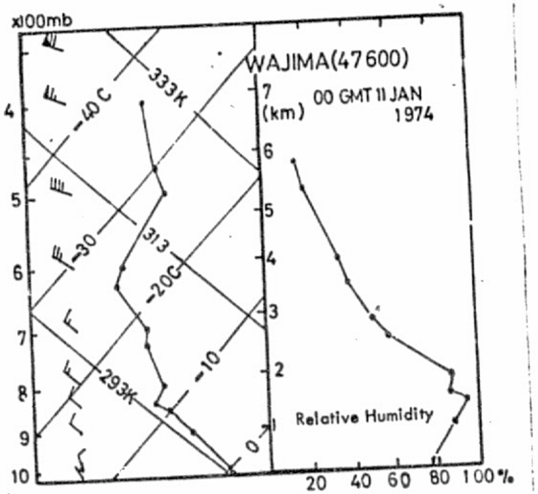

Fig. 14 Radiosounding at Wajima plotted on a skew-T diagram. 00 GMT 11 Jan "74.

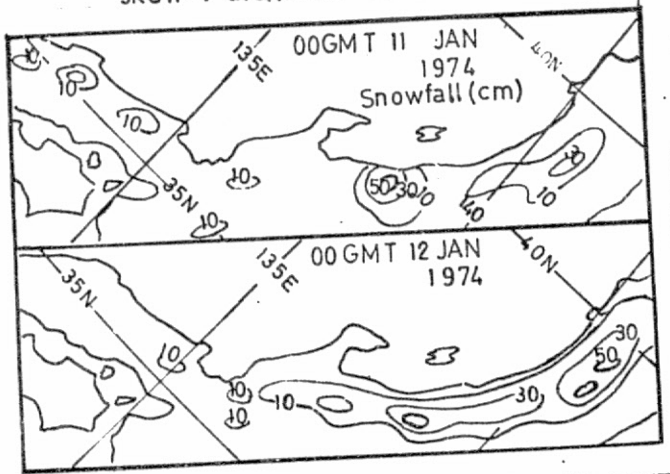

Fig. 15 Daily snowfall observed at 00 GMT.

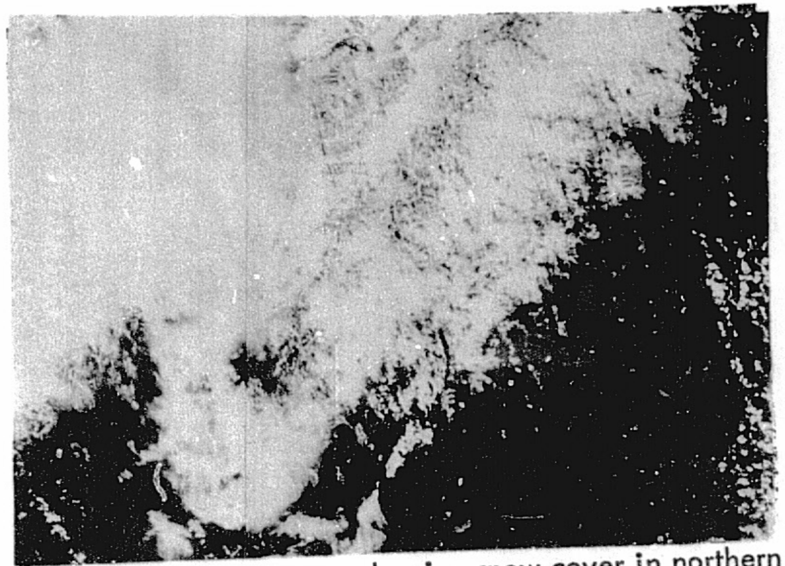

Fig. 16 S190 A picture showing snow cover in northern Japan.

Fig. 17 Snow cover chart made at Japan Meteorological Agency. 00 GMT Jan 11, 1974. Unit: cm.

middle and high cloud types and amount of coverage are ;indicated beside the station circles. The total cloud coverage in international code shows that all stations are overcast condition in the area. The area covered by S192 (Fig. 18) is shown in dotted line. The S 192 imagery show that there exists cold cloud or high cloud with smiregular spacing and lower temperature south-westwards.

The cloud as seen from the surface is shown in Fig. 20 which was taken at Kofu weather station simultaneously with the pass of SKYLAB. The base of cloud has rather uniform appearance with the sun very vaguely vibible.

The radio sounding at Hamamatsu and Tateno (250 kms north-east of Hamamatsu) is plotted in a skew-T diagram and is shown in Fig. 21. The vertical distribution of relative humidity is also indicated. The temperature distribution indicates that inversion or frontal surface exists at 600 and 400 mb levels at Hamamatsu and Tateno respectively. The relative humidity distribution indicates double layered humid layer or double layered clouds.

Comparing the temperature distribution in S192 imagery and radio sounding it is found there is a good correspondence. The spacing of red colored cloud is approximately 8 to 6 kms which suggests the existency of convective activity in the cloud layer.

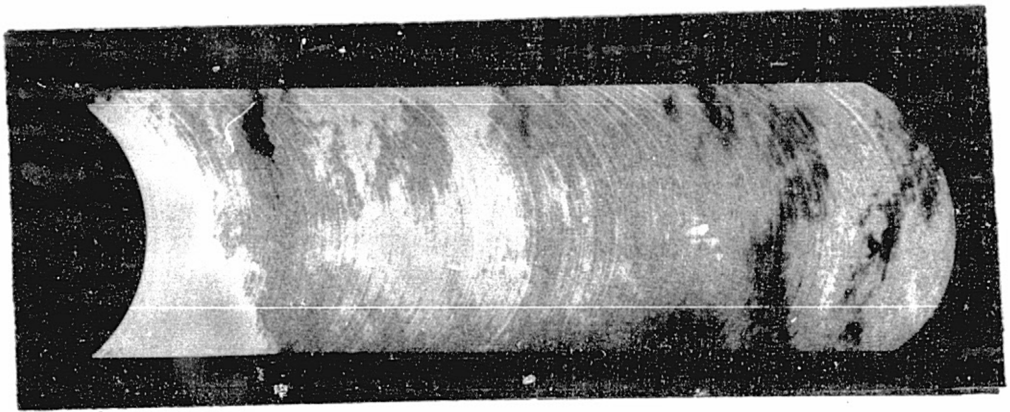

Fig. 18 Color sliced imagery of S192. The area is shown in the following figure.

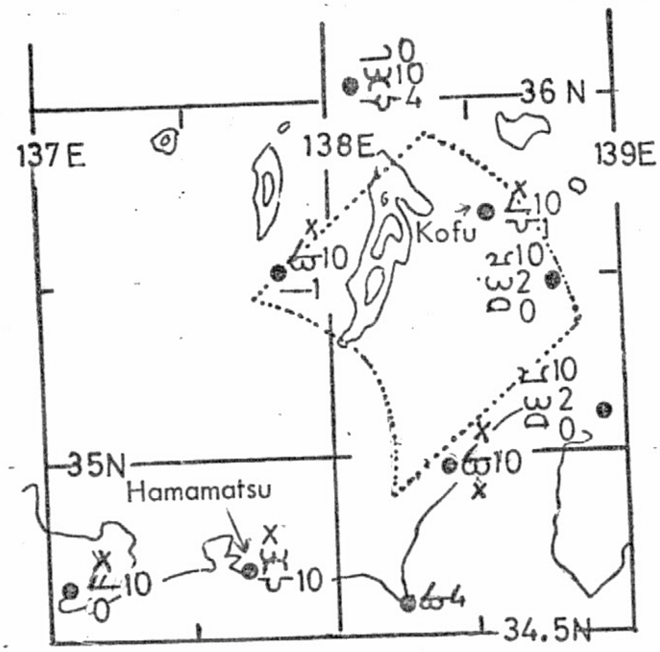

Fig. 19 The cloud type and cloud coverage as observed at the surface. The area covered by the color sliced imagery is indicated in dotted line. Surface observation at 00 GMT 18 Sep. 1973.

Fig. 20 The cloud as seen from the ;surface at Kofu.
The picture was taken simultaneously with the pass of SKYLAB. Courtesy by Mr. Shigemi Fujiwara.

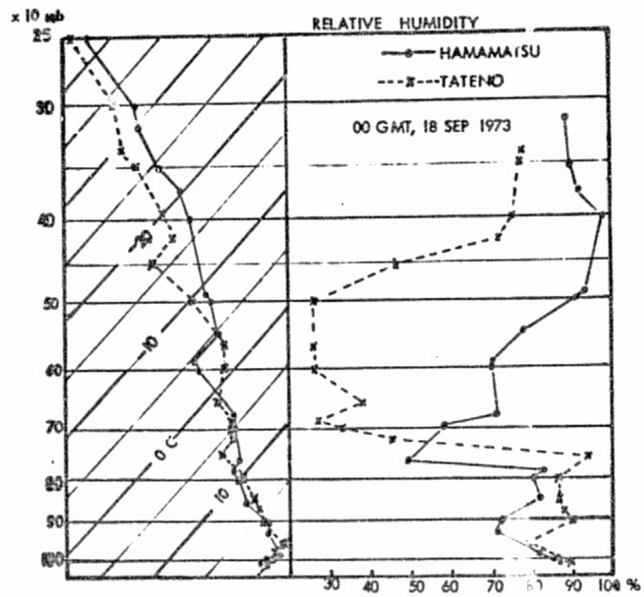

Fig. 21 Radiosounding at Hamamatsu and Tateno plotted in a skew-T diagram. 00 GMT L18 Sep. 1973

Concluding remarks

The foregoing analysis leads to the following conclusions. SKYLAB data with high resolving power as well as different spectral responsibity are extremely useful for the study of mesoscale structure of the clouds. In the nature there are unexpectedly many band-structured clouds of various wave lengths.

The fact that there exists various wave motions of different wave lengths as is revealed in this case over a comparatively narrow area suggests the complexties of atmospheric structure and motion. In order to understand behaviour of the atmosphere further accumulation of the data as well as theoretical study will be required.

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Attachment

List of the ID of the S190A pictures used in this report

Figure No. in the Report	ID
Fig. 6	205 RL 64 FEB 74
Fig. 8	208 ditto
Fig. 10 Left	212 ditto
Right	213 ditto
Fig. 12	210 RL 61 Feb 74
Fig. 13 (a)	215 and 216, RL 64 FEB 74
(b)	Mosaic of 215 and 216 RL 64 FEB 74
Fig. 16	Mosai cof 224 and 225 RL 64 FEB 74