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Satellite imagery in the prediction of aviation hazards

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सार — हाल के वर्षों में उपग्रह से प्राप्त मौसम की सूचनाएं विमानन प्रचालनों में अद्वितीय साधन के रूप में उपलब्ध हुई हैं। विमानन प्रचालनों के लिए मौसम सम्बन्धी सूचनाएं देने के लिए यद्यपि समूचे विश्व में लगभग 12000 स्थानों पर दिन में कई बार सतह पर सिनॉप्टिक प्रेक्षण किये जा रहे हैं और लगभग 1200 स्थानों पर दिन में दो बार उपरितन पवन और रेडियोसोन्दे प्रेक्षण किए जा रहे हैं। फिर भी भूमण्डल पर बहुत से क्षेत्र ऐसे हैं जहां से आंकड़े दुस्प्राप्य हैं, जैसे बड़े-बड़े मरुस्थल, पहुँच से बाहर के पर्वतीय शिखर और समुद्री क्षेत्र। प्रथम अमरीकी मौसम उपग्रह टाइरस 1 अप्रैल 1960 में छोड़े जाने से दृश्य और अवरक्त चित्रों के द्वारा समूचे भूमंडल की अद्यतन सूचनाएं पहली बार प्राप्त होना सम्भव हो सका। दृश्य और अवरक्त दोनों चैनलों में ध्रुवीय कक्षा में चक्कर लगा रहे उपग्रहों से जो श्रेयस्कर चित्र प्राप्त होते हैं वे हालके वर्षों में भारतीय उपमहाद्वीप में विमानन सम्बन्धी पूर्वानुमान करने वालों के लिए बहुत ही सहायक सिद्ध हुए हैं। प्रस्तुत शोध पत्र में विमानन के लिए संकटपूर्ण मौसम की परिघटनाओं की सार्थकता से संबंद्ध अनेक मेघ अभिलक्षणों जैसे उष्णकटिबंधीय चक्रवात जेट प्रवाह, अल्प कालिक झंझा रेखाएं, टोरनेडो (बवंडर), कोहरा इत्यादि का वर्णन विमानों की सुरक्षा को ध्यान में रखते हुए किया गया है।

ABSTRACT. Satellite meteorological informations in recent years have proved to be a unique tool in aeronautical operations. Although about 12000 stations throughout the world are taking surface synoptic observations several times a day and about 1200 stations upper wind and radiosonde observations twice daily to provide meteorologial informations for aeronautical operations, still there are vast data sparse regions over the globe such as big deserts, inaccessible mountain ranges and oceanic areas. With the launch of first U.S. weather satellite TIROS-1 in April 1960, it was possible for the first time to get up-to-date information over the entire globe through visible and infrared imagery. The better quality pictures from polar orbiting satellites received in both visible and infrared channels have been very helpful to an aviation forecaster in recent years over Indian sub-continent. In the present paper, various cloud characteristics associated with potentially hazardous weather phenomena for aviation such as tropical cyclones, jet-streams, squall lines, tornadoes, fogs etc have been discussed with the special emphasis on the safety of the aircraft.

1. Introduction

Various meteorological parameters such as poor visibility, turbulence, thunderstorm, icing etc, affect the smooth operation of aircraft and also sometimes lead to aircraft accidents. Weather phenomena which are associated with these parameters are fog, jet streams, tropical cyclones, squall lines, tornadoes, mountain waves etc. The interpretation of the satellite imagery pertaining to such hazardous weather events is of vast potential utility to air navigators. In this paper, attempt has been made to describe cloud features of various weather systems with particular reference to their effect on flying conditions. Relevant synoptic observational evidences have also been discussed in the interpretation of the imagery and its significance to make clear the nature of the phenomena.

2. Phenomena causing aviation hazards

2.1. *Fog*

Fog is a great aviation hazard which generally hinders the normal functioning of the aviation services and leads to many diversions of aircraft as well as delays in take off. The poor visibility due to fog may sometimes lead to crash of an aircraft at the time of landing.

In north India, the weather in winter is generally dry but occasionally due to the incursion of moist easterlies in the lower levels or due to the rain caused by the passage of western disturbances, the air becomes humid leading to the occurrence of widespread fog during the late hours of night and early morning when the sky is practically clear and calm conditions prevail.

Recognition of fog in satellite photograph is very important from aviation point of view because of its large areal coverage and resolution, particularly it is very useful in data-sparse regions. The characteristic features of radiation fog observed in the visible imagery are flat texture and frequent sharp edges. In visible pictures tone, it is found to vary from light grey when fog is shallow to white when fog is comparatively thick and uniformity in the tone is observed. The brightness variation in the foggy patches are mainly due to the differences in the thickness of the fog.

An unusually long spell of synoptic-scale fog over north India occurred during the period 18 to 30 December 1973. The scanning radiometer picture of NOAA-2, USA Weather Satellite, recorded in the visible channel during 18 to 26 December 1973 is shown in Fig 1. In addition to the characteristics of fog mentioned above some more significant features observed in the satellite imagery during 18-30 December 1973 are described below :

(*i*) The visible imagery on all the days shows that the northern periphery of radiation fog runs parallel to the main Himalayan range at a distance of about 100 km. The fog-free belt along the Himalayan range may be attributed to the preponderance of the vegetation cover and uneven terrain leading to turbulence which dominates over the effect of radiative cooling. According to Roach *et al.* (1976), balance between the radiative cooling and turbulence plays a significant role in the development of radiation fog.

(*ii*) The fog coverage in the satellite imagery is found to be in conformity with the ground-based observations except in the peripheral areas where synoptic fog observations are available even outside the foggy areas seen in the satellite imagery. This may be attributed to the time difference between the ground and satellite observations ; the satellite imagery has always been recorded later than the synoptic hour of observations (03 GMT). The fog tends to dissipate at the outer edges and shrinks inward due to the differential surface heating by the sun around the fog boundary. Since the sun heats the ground beyond the fog more than beneath the fog, the cooler air within the fog boundary sinks and spreads out to replace the rising air at the periphery, setting up the circulation with consequent erosion of the fog at the outer edges (Gurka 1974).

(*iii*) The examination of the upper wind field indicates a very remarkable change in the wind strength from non-foggy days to foggy days. It is clear from the morning rawin data of New Delhi and Lucknow that the wind strength undergoes considerable reduction from 18 December onward upto 30 December and this decrease is noticed at all levels right up to the top of the troposphere. This may be due to a large-scale subsidence over northern part of India, associated with large-scale intense convective activity over Bay of Bengal in Inter Tropical Convergence Zone (ITCZ) seen in the pictures and to the north of India due to frequent passage of western disturbances. Advection of moisture due to easterly perturbations over foggy area may also be one of the causes for long persistence of fog.

2.2. *Jet stream*

Jet stream is one of the weather phenomena with which potential turbulence is associated. The turbulent air motions near the jet core cause buffeting effect on the aircraft causing discomforts to the passenger and sometimes leading to the structural damages. After the launch of first weather satellite in 1960, satellite pictures have been very useful in locating the jet stream or maximum wind zone with certain identifiable cloud features in the vicinity of the jet.

Two types of jet streams, trooical easterly and sub-tropical westerly, are seen over India. Tropical easterly jet stream is seen during southwest monsoon season while sub-tropical westerly jet stream is seen during rest of the seasons. The jet-stream being phenomena of the upper troposhpere have dominant appearance in the cirrus cloud field. The distribution of cirrus clouds in the vicinity of the jets depends upon the vertical and horizontal motions in their vicinity. The cloud features associated with jet streams are long shadow lines, large cirrus shields with sharp boundaries, long cirrus bands, cirrus streaks and transverse bands within cirrus cloud formations. These cloud features have been illustrated in Figs. (2)-(5).

During pre-monsoon, post monsoon and winter months, large amplitude upper air troughs occasionally move from west to east across Indian sub-continent. They pick up moisture from Arabian Sea and Bay of Bengal and often result in long cirrus shields. These shields look very bright in the visible imagery due to the underlying convective clouds and in the infra-red imagery due to the cold cirriform clouds. The sharp poleward edge of the cirrus shield may be due to the subsidence of the air in the zone immediately poleward of the jet stream. Studies in this field (Endlich and McLean 1965) show an average downward motion of 40 cm per second in the close poleward vicinity of the jet stream.

NOAA-5 satellite pictures recorded in the visible channel on the morning of 23 and 24 April 1977 (Fig. 2) show a well-defined jet stream clouds emanating from Arabian Sea in association with a large amplitude deep westerly trough. Fig. 2(a) shows jet clouds originating from southwest Arabian Sea (north of Lat. 8°N) extending northeastwards to central parts of the India across north Maharashtra coast. Transverse bands are clearly seen over central Arabian Sea.

The movement of the jet may be seen by comparing the cloud imagery of 23 and 24 April. The entire cloudiness in the Arabian Sea on 23 April is observed to have moved eastwards by about 5-6° longitudes in 24 hours. Also the jet clouds which extended upto Maharashtra and Gujarat State on 23rd morning, extended more northeastwards and penetrated into Assam and adjoining States on 24th morning. Transverse bands over Maharashtra coast and adjoining east central Arabian Sea, just southwest of Bombay, can be seen in Fig. 2(b). The clouds in the visible and IR pictures have been observed to appear equally bright indicating the presence of convective clouds along with cirriform clouds. Transverse bands are generally found to appear over the are having wind speed of 80 kt or more (Anderson *et al.* 1974) and large vertical wind shear. Bombay, situated in the vicinity of the area having transverse bands, reported wind speed of 85 kt at 250 mb at 00 GMT on 24 April. The corresponding vertical wind shear between 250 and 300 mb was found to be 58 kmph/km . This type of cloudiness over data sparse regions is of great help in locating areas of severe turbulence for aircraft warning. In the corresponding IR picture of 24 April, a sharp boundary is seen on the poleward edge, which is one of the important characteristics to identify jet stream cloudiness. Strong convective clouds are seen over southwest Arabian Sea and Indian Peninsula which lie in the right entrance sector of the jet, an area prone to heavy precipitation activity.

The scanning radiometer pictures received in the visible channel of NOAA-5 satellite on the morning of 21 and 22 October 1977 are shown in Fig. 3. In both the pictures, cirrus shields associated with sub-tropical westerly jet stream extending from Bay of Bengal to China have well-defined sharp poleward edges. These shields look very bright in visible imagery due to underlying convective clouds and are seen to emanate from ITCZ. The northern end of the cirrus shield in Fig. 3 (a) is observed to cast shadow on the lower cloud deck seen as a dark line over Bangla Desh and Assam area. The intense convective clouds seen over southern Peninsula, Sri Lanka and south Bay of Bengal may be due to expected high level divergence caused by the advection of positive vorticity in the right entrance sector of the jet.

The tropical easterly jet stream (TEJ) in the cloud field normally appears in association with the perturbations in the upper tropospheric easterly currents in the Bay of Bengal and Arabian Sea (Singh and Hem Raj 1982). Since this jet is found at about 15 km above sea level, some agency is required to transport requisite amount of moisture near the level of the jet. Although tropical easterly jet is found on the upper tropospheric charts almost daily from mid-June to September but it is observed in satellite imagery only when perturbations extend upto upper tropospheric levels.

When active monsoon conditions prevail over the Indian sub-continent, the dominance of low and medium clouds over sea and land areas hinders the detection of TEJ which predominantly consists of cirriform clouds. But in weak monsoon conditions, TEJ can be clearly identified in the thermal infrared imagery as extended mass of cirrus clouds mostly in long cirrus bands along the jet axis. Well-marked jet clouds extending from Karnataka coast to Somali coast is displayed in the visible and IR pictures of NOAA-4 satellite recorded on the morning of 29 July 1975 (Fig. 4). On this day, weak monsoon conditions prevailed over Arabian Sea. Closed cellular clouds of small vertical extent are seen over north Arabian Sea (Fig. 4 a). Low and medium clouds are practically absent over south Arabian Sea where cirrus banded jet clouds can be well distinguished by its straight smooth appearance and its extensive length (Fig. 4 b). Since cirriform cloud have less albedo than convective clouds (*Cu* and *Cb*) jet clouds in the visible imagery (Fig. 4a) do not appear as bright as in the thermal infrared imagery (Fig. 4b) because colder clouds appear brighter in IR imagery.

A unique TEJ cloudiness extending from Goa, Karnataka coast to Somali coast is shown in the IR picture of NOAA-2 satellite recorded at 0418 GMT of 29 August 1974 (Fig. 5 b). This jet cloudiness also appeared when weak monsoon conditions prevailed over the country and adjoining sea areas except northeast India. In this case, the cirriform clouds associated with TEJ are so shallow to reflect the solar radiation that it is hardly seen in the visible picture (Fig. 5 a) whereas they are very distinct in IR imagery as an extensive cirrus band with fairly sharp equatorward boundary.

At present, wind informations upto 12 km are routinely required for commercial aviation in India. With the introduction of supersonic transport, winds upto 18 km will be needed for aeronautical operations. The detection of the easterly jet stream over remote oceanic areas will provide useful information in the preparation of the flight plans for supersonic jet operations. This may also serve the purpose of meteorological briefing for long distance flights especially for the long oceanic routes, *e.g.*, Bombay-Nairobi, Bombay-Mauritius, Madras-Singapore etc.

2.3. *Tropical storms*

One of the most disastrous weather phenomena which is of vital interest to aircraft operations is tropical storm. Tropical storms are associated with intense convective activity which results in vigorous thunderstorms mostly in the eye-wall. Their frequency is more during pre-and post monsoon months than in southwest monsoon season. Meteorological satellites are uniquely suited to the task of tracking of the tropical cyclones. Satellite imagery has provided immense benefits in determining their characteristics. Dvorak (1975) has developed a fairly reliable technique for the analysis and forecasting of tropical cyclone intensity. Though this technique was developed using pictures of the tropical cyclones of Atlantic and Pacific Oceans but the studies by Mishra and Hem Raj (1975) and Gupta *et al.* (1977) on tropical cyclones of Bay of Bengal and Arabian Sea indicate minor difference from Atlantic and Pacific experience.

Tropical cyclones undergo changes in their cloud patterns in time and space. From these variations, one can estimate the wind speed and central pressure of the system and make some judgement about its development and movement. These estimates are based on the organisation, size and banding of the tropical storms.

Although the tropical cyclones viewed in satellite pictures appear in great variety of patterns ; most can be described as having a comma or a rotated comma configuration. The cloud features related to cyclone intensity are central features (CF) and outer banding features (BF). The central features are those which appear within the broad curve of the comma band and either surround or cover the cloud system centre. The outer banding features refer to only that part of the comma cloud band that is overcast and curves evenly around the central features. These two parameters, the CF and BF, and an implied cloud depth parameter taken together, comprise the T-number description of the cyclone.

The technique presently used in India in the analysis and forecasting of tropical cyclone intensities from satellite pictures is the same as used by U.S.A. (Dvorak 1975). T-numbers between 1 and 8 are assigned to tropical storms, with larger number corresponding roughly to greater intensities.

In Dvorak's technique, a code is available for summarising information on any tropical storm. There are only six groups in the code and normally no more than 19 spaces are required to convey a great deal of information, for example, the storm's T-number, its current intensity; whether it has weakened, strengthened or remained the same in the past 24 hours; and what its present tendency is. The general form of the code is :

$$T\ (\alpha)/(\beta)\ \left\{\begin{array}{l}\text{PLUS}\\ \text{MINUS}\\ \text{(Blank)}\end{array}\right\} \Big/ \left\{\begin{array}{l}\text{D}\\ \text{S}\\ \text{W}\end{array}\right\} (\gamma)/(\delta)$$

Here,

α is the today's T-number

β the current intensity number

γ the amount of change during the indicated number δ

δ hours since the previous observation

D is used if development is taking place;

W in case the weakening, and

S if no change has occurred.

'PLUS' and 'MINUS' refer to ongoing change, *i.e.*, change indicated at the time of the current observation.

(i) The East Pakistan (now Bangla Desh) cyclone of November 1970

An ITOS-1 picture of the East Pakistan cyclone of 11 November 1970 recorded in visible channel is shown in Fig. 6. This cyclone was a natural calamity of great magnitude which took a toll of about half a million human lives. The storm wave generated by the cyclone completely washed away 15 off-shore islands of East Pakistan and many more islands were seriously affected. The intensity analyses done by Mishra and Hem Raj (1975) reveals that the storm was most severe on 11 November 1970 and had intensity T-7. According to Dvorak (1975) a storm with T-7 as intensity has maximum wind speed of 140 kt and minimum sea level pressure of 915 mb. This storm hit East Pakistan coast with intensity T-6.5 (maximum wind speed 127 kt; minimum sea level pressure 929 mb) late on the evening of 12th.

(ii) The Porbandar cyclone of October 1975

Fig. 7 is scanning radiometer picture of NOAA-4 satellite recorded in visible and infrared channel on the morning of 22 October 1975. A severe cyclonic storm which crossed north Gujarat coast near Porbandar at 1000 GMT on 22 October 1975 is seen in the figure. This is the first time since the year 1877 that a severe cyclonic storm crossed Gujarat coast in the month of October. The development of the storm was very rapid. It intensified from a low pressure area to severe cyclonic storm with a core of hurricane winds and reached its peak intensity within a period of less than three days. Usually a cyclonic storm weakens rapidly after crossing the coast, but this cyclone lay over land close to Porbandar after landfall throughout the evening of 22 October 1975 without showing signs of any significant weakening.

Fig. 7 shows a typical comma pattern with tight circular banding. In the visible picture, there are indications of inner banding inside the Central Dense Overcast (CDO). The sharp round eye of the cyclone is approximately 60 km in diameter. It is centred near 20.5° N, 69° E. The CDO is surrounded by a well-organised convective band

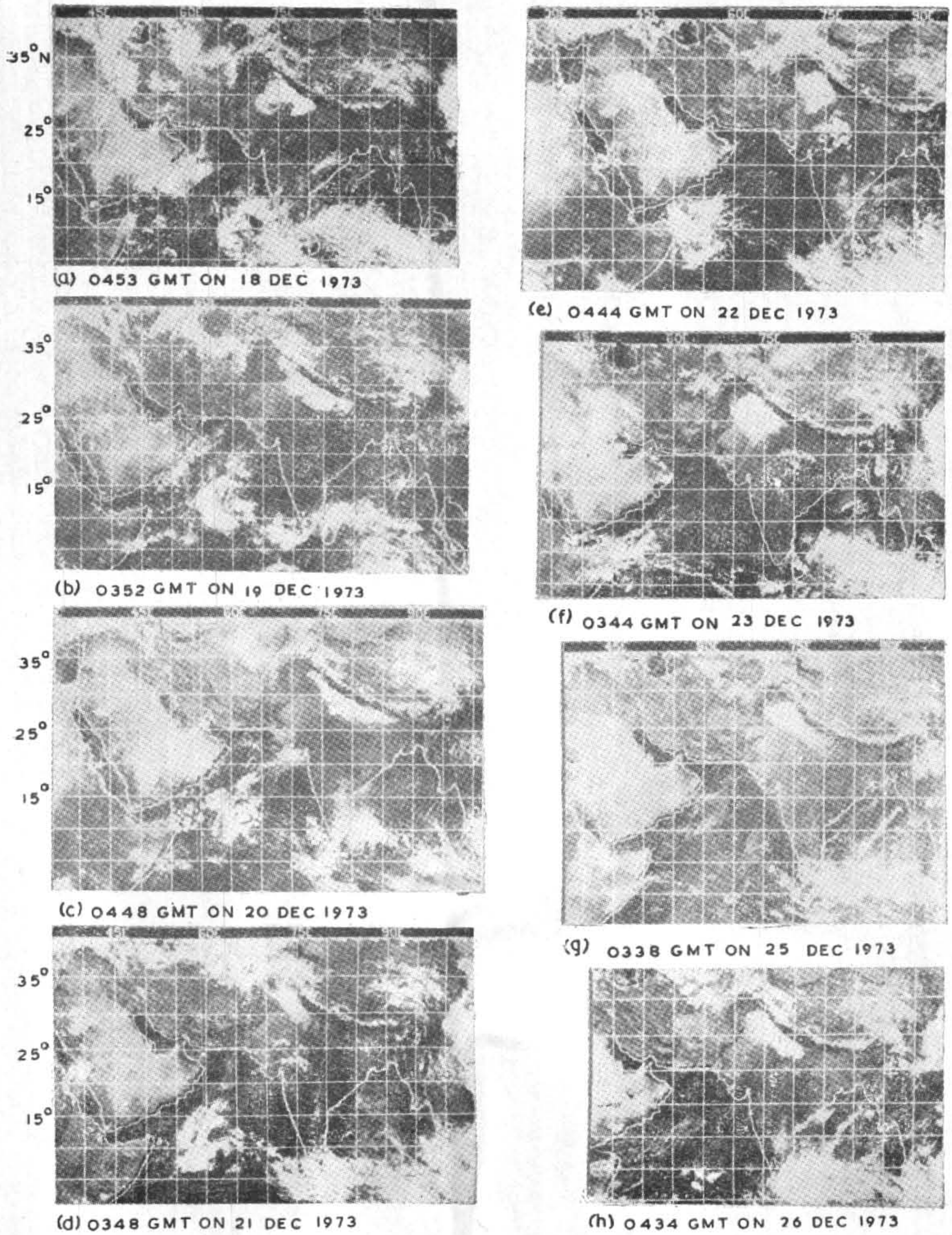
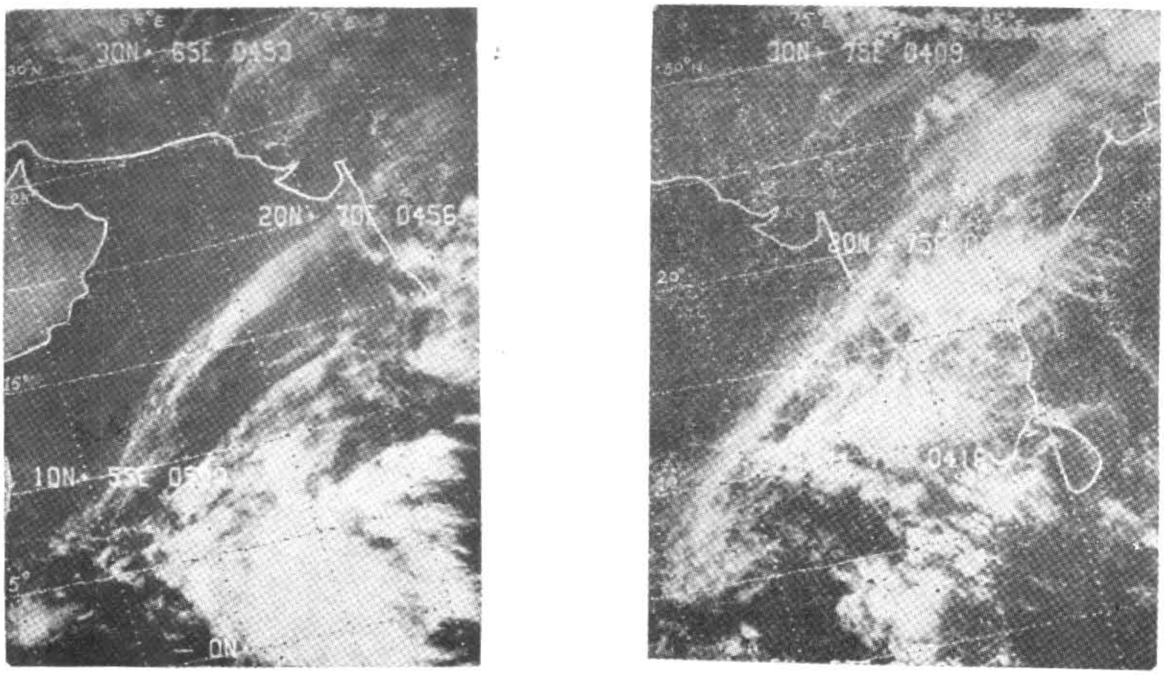
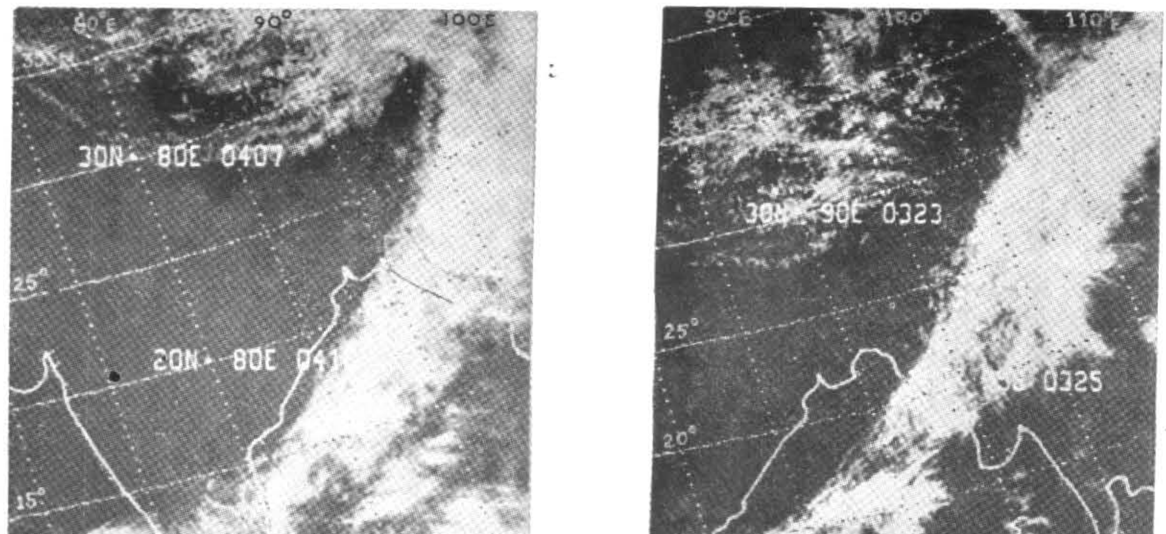


Fig. 1. NOAA-2 scanning radiometer visible imagery showing widespread fog over north India during December 1973 recorded at (a) 0453 GMT on 18th, (b) 0352 GMT on 19th, (c) 0448 GMT on 20th, (d) 0348 GMT on 21st, (e) 0444 GMT on 22nd, (f) 0344 GMT on 23rd, (g) 0338 GMT on 25th and (h) 0434 GMT on 26 Dec 1973



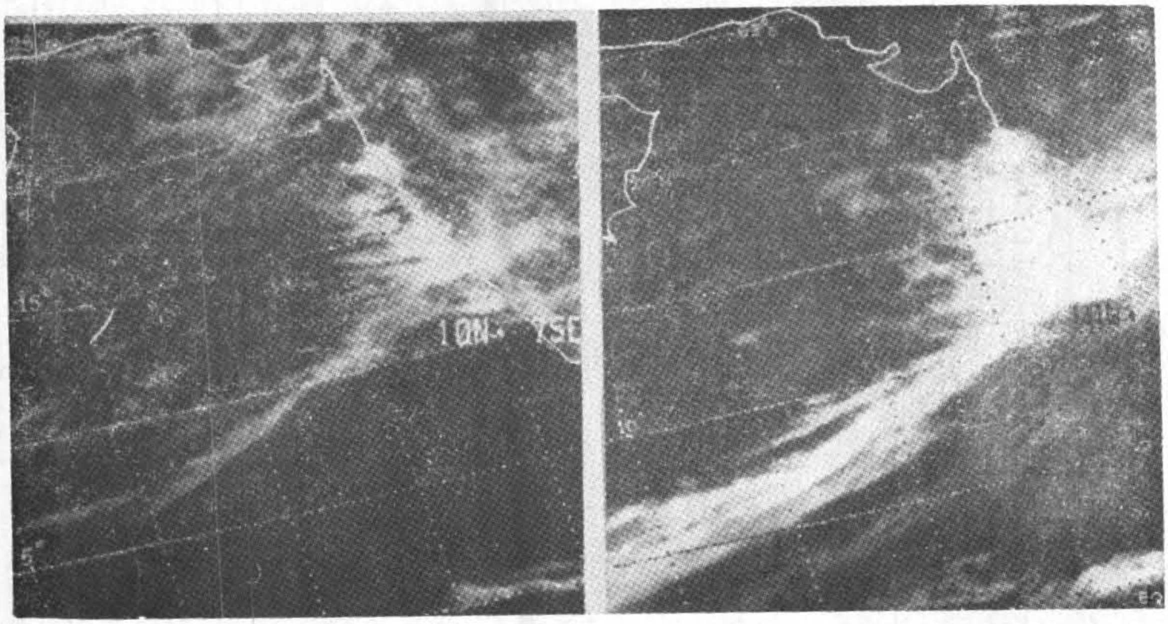
(a) 0458 GMT on 23 April 1977 (b) 0412 GMT on 24 April 1977

Fig. 2. Scanning radiometer pictures of NOAA-5 recorded in the visible channel showing (a) Jet clouds over the Arabian Sea moving towards central India and (b) Jet stream clouds extending from central Arabian Sea to Assam and adjoining areas



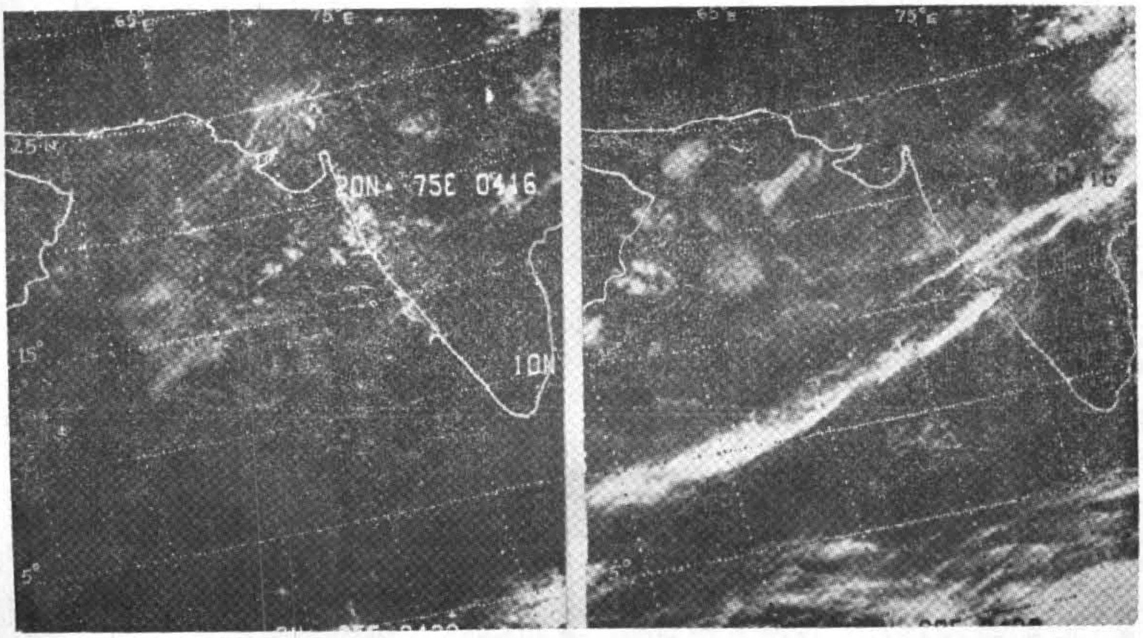
(a) 0410 GMT on 21 October 1977 (b) 0325 GMT on 22 October 1977

Fig. 3. Visible imagery of NOAA-5 satellite showing well defined sub-tropical jet stream clouds over Bay of Bengal with sharp poleward boundary and emerging from ITCZ



(a) Visible channel (b) Infra-red channel

Fig. 4. Scanning radiometer pictures of NOAA-4 satellite recorded at 0445 GMT on 29 July 1975 showing tropical easterly jet stream clouds extending from Karnataka coast to Somali coast



(a) Visible imagery (b) Infra-red imagery

Fig. 5. Tropical easterly jet stream clouds over Arabian Sea recorded by NOAA-2 satellite on the morning (0418 GMT) of 29 August 1974

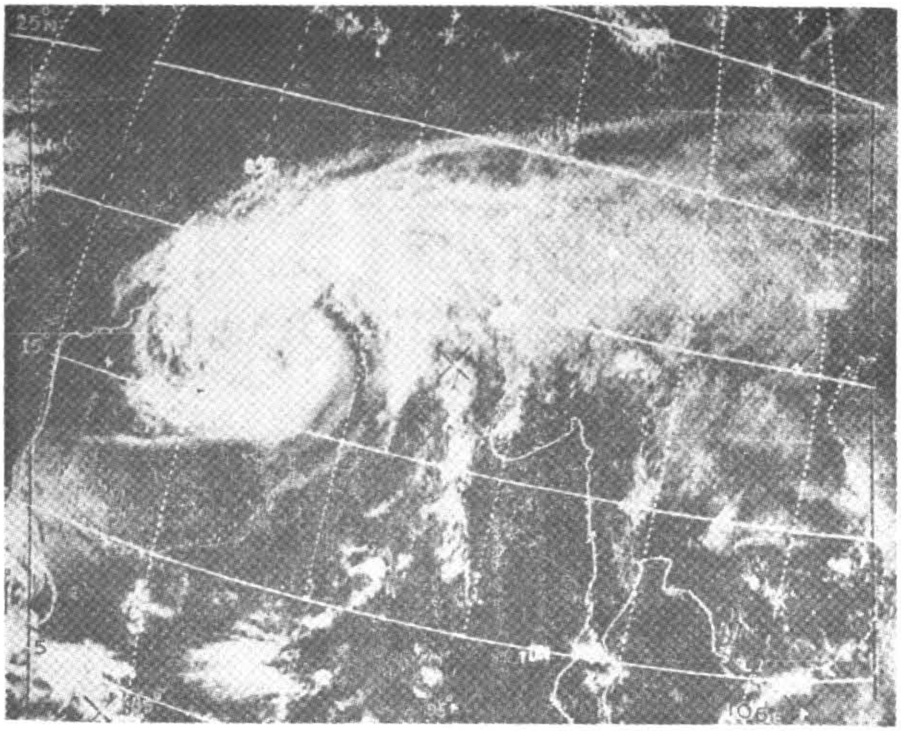
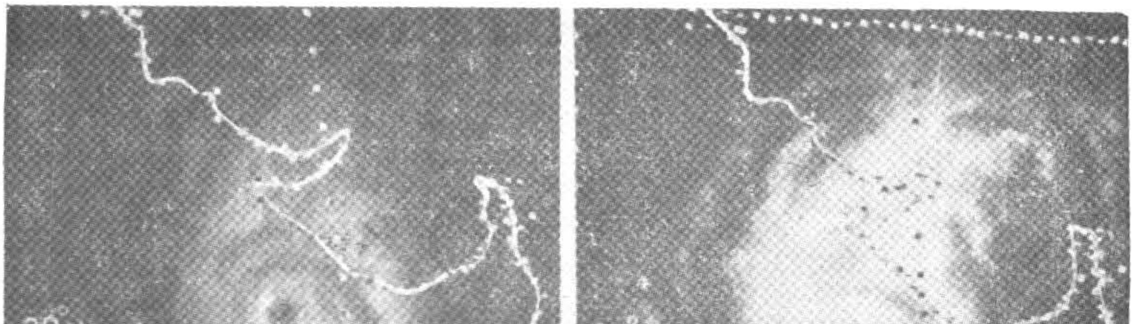
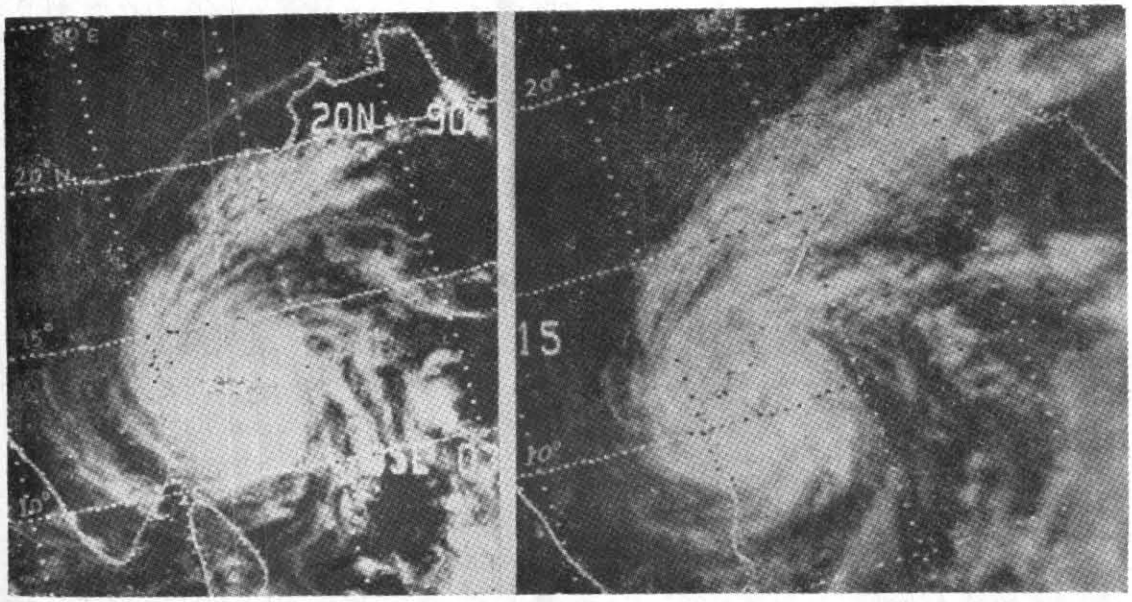


Fig. 6. ITOS-1 visible satellite picture recorded at 0858 GMT on 11 November 1970 showing well organ ised cloud feature associated with a severe cyclonic storm with a core of hurricane winds over north Bay of Bengal



(a) Visible channel (b) Infra-red channel

Fig. 7 . Scanning radiometer pictures of NOAA-4 satellite recorded at 0405 GMT on 22 October 1975 showing comma type cloud organisations over northeast Arabian Sea associated with a severe cyclonic storm with a core of hurricane winds



(a) 0304 GMT on 18 November 1977 over SW Bay

(b) 0416 GMT on 19 November 1977 over West Central Bay

Fig. 8. NOAA-5 visible imageries showing cloud organisation of fully developed severe cyclonic storm of hurricane intensity

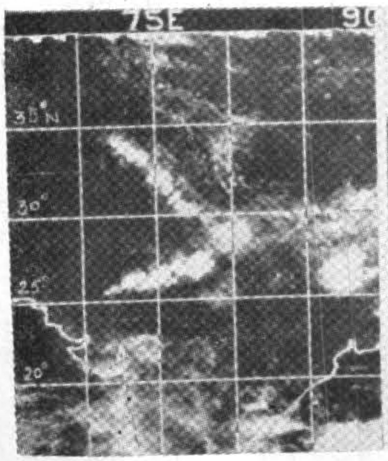
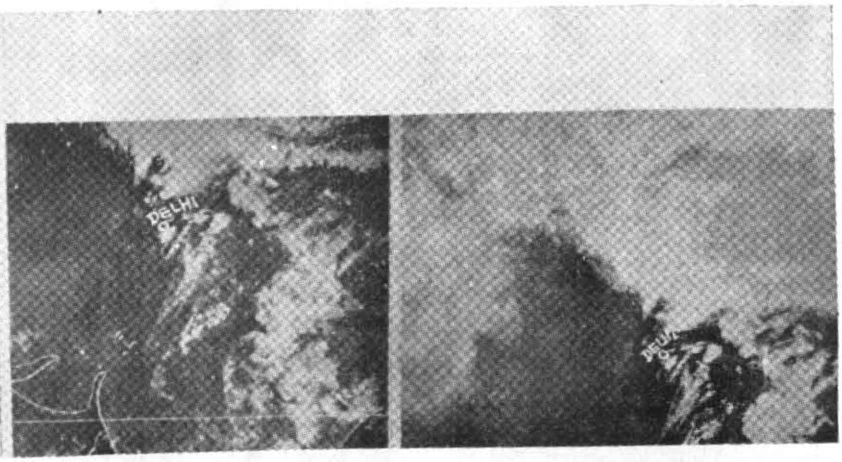


Fig. 9. Visible picture of NOAA-5 satellite *showing two distinct* squall lines converging over central U.P. on the morning of 22 July 1977



(a) 0.6–1.0 μ visible IR channel

(b) 8-13 μ infra-red channel

Fig. 10. Squall lines recorded near Delhi by U.S. Defense Met. Satellite imagery at 1504 GMT on 17 March 1978, the day tornado outbroke over north Delhi

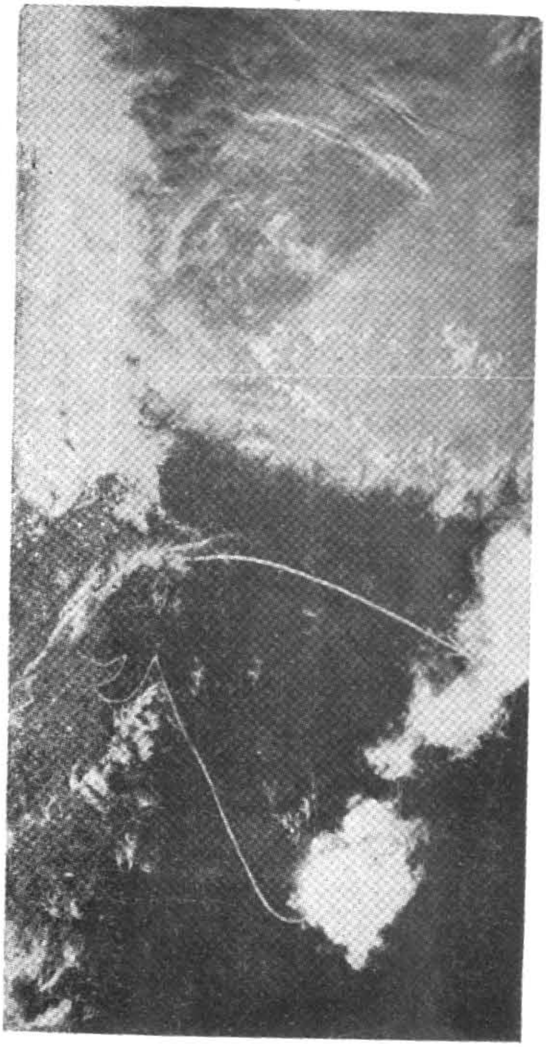


Fig. 11. U.S. Defense Met. Satellite imagery in infra-red channel at 1456 GMT on 16 April 1978 showing very active squall line over east coast of India and sub-tropical westerly jet stream clouds emanating from north Arabian Sea associated with large amplitude westerly trough

Fig. 12. Mountain wave clouds in the visible imagery of ITOS-1 satellite at 0824 GMT on 29 January 1971

about ½ degree in width which coils once round the CDO. According to the analysis done by Gupta *et al.* (1977) the storm intensity is T-6 (Maximum wind speed in the storm field is 115 kt and minimum sea level pressure 942 mb).

(*iii*) *The Chirala cyclone of November 1977*

A severe cyclonic storm with a core of hurricane winds struck south Andhra coast near Chirala on 19 November 1977 and caused considerable loss of life and property in the coastal areas. It was one of the greatest killer cyclones in Indian sub-continent during the past hundred years. The scanning radiometer picture of NOAA-5 satellite recorded in visible channel on the morning of 18 and 19 November 1977 is shown in Fig. 8. On 18 November, the storm is seen to be fully developed with a distinct sharp round edge. The analysis of the cloud system reveals that the storm has intensity T-7 (Maximum wind speed in the storm field about 140 kt and the minimum sea level pressure estimated about 920 mb) and is centred near 12.3°N, 82.8°E. On the morning of 19th, the storm had the same intensity (T-7). The storm crossed coast on 19th evening at about 1100 GMT more or less with the same intensity. Even a few hours before the landfall of the storm, eye is clearly visible.

2.4. *Squall lines and tornadoes*

There are specific atmospheric conditions which are responsible for the occurrence of severe weather such as squall lines and tornadoes. Satellite imagery in conjunction with the conventional meteorological data yield valuable information regarding the assessment of the behaviour of hazardous weather phenomena and help timely and accurate warnings.

The squall line appears in the satellite imagery as a line of cumulonimbus clusters. The *Cb* cells sometimes retain their separate entity along a line of convergence and sometimes merge together to form a bright band. Fig. 9 shows the NOAA-5 cloud imagery of 22 July 1977 received at 0440 GMT. Two distinct squall lines which are arranged in a V-shaped pattern converging over central Uttar Pradesh are seen in the picture. Jaipur and Jammu airports reported thunderstorms during the period of the occurrence of the squall lines. Dehra Dun, Mussoorie, Mainpuri, Sikar, Agra and Bareilly reported moderate to heavy showers at the same time.

Fig. 10 shows the cloud imagery of U. S. Defense Meteorological Satellite in infrared channel recorded at 1504 GMT on 17 March 1978. In the imagery, two active squall lines to the southeast of Delhi, running parallel in SW-NE direction and separated from each other by a distance of about 100 km are clearly seen. The sub-tropical westerly jet core at 1200 GMT of 17 March passed through just south of Delhi and intersected the squall lines. This synoptic situation led to the occurrence of tornado over Delhi on the evening of 17 March 1978. The severe weather outbreak in this tornado took place beneath the intersection of the sub-tropical jet stream with the squall lines and to the north of the jet axis. The environmental conditions in the tornado outbreak were characterised by deep surface moisture and large vertical wind shear in the mid and upper troposphere. The tornado was apparently triggered by a trough in the lower troposphere which moved from west to east across Delhi between 1200 and 1800 GMT on 17 March.

Fig. 11 shows cloud imagery of U. S. Defense Meteorological Satellite in infrared channel received at 1456 GMT on 16 April 1978. The satellite imagery clearly shows a well defined squall line sweeping along the entire east coast of India. The sub-tropical westerly jet stream is seen to cross the squall line near Bhubaneswar. The tornado outbreak took place in the five villages of Keonjhar district which is about 150 km north-northwest of Bhubaneswar. Thus, like north Delhi tornado, severe weather occurred beneath the intersection of the sub-tropical jet stream with the squall line and to the north of the jet axis. These synoptic scale observations as revealed by the satellite imagery will, therefore, be of immense utility to the forecasters in forecasting such severe weather phenomena over Indian subcontinent.

2.5. *Mountain waves*

Under favourable meteorological conditions, standing waves form in the airflow on the lee side of mountain barriers. Numerous aircraft accidents occur under the influence of these mountain waves which generate moderate to severe turbulence. The most severe turbulence is close to the mountains, lesser degrees of turbulence occur further downstream. The turbulence associated with the mountain waves are normally confined to altitudes below 6 km. The wave clouds seen in the satellite imagery are usually low or medium clouds. Wave clouds are shown in the visible imagery of ITOS-1 satellite recorded at 0824 GMT on 29 January 1971 (Fig. 12). Wave clouds are seen over the areas on the leeward side of the north-south running hill ranges of Mizoram and Manipur. Similarly lee wave pattern is also seen over the areas downwind of north Burma hills. The wave clouds in the satellite imagery identify the areas of high turbulence.

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