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Some case studies of cirriform clouds over India during the winter period

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ABSTRACT. A few cases of extensive formations of upper tropospheric clouds over north and central India during the winter of 1969-70 were studied utilizing satellite pictures in conjunction with synoptic and upper air charts as well as aircraft reports and hourly observations from airport stations. The ground-observed cloud reports are compared with satellite pictures. The clouds were found to be associated with the jet stream and formed when large amplitude troughs extended into India and neighbourhood. The clouds were also organised in transverse as well as parallel modes; prevailing lapse rates and vertical wind shears have been found to be different in the two modes of organizations.

1. Introduction

Satellite pictures have shown extensive quasi-organised patterns of upper tropospheric clouds in association with jet streams. These cloud formations are believed to be closely related to the horizontal and vertical air motions that occur in the vicinity of the jet streams. Four types of jet-associated cloud organisations have been noticed in the satellite pictures—long shadow lines, sharp-edged large cirrus sheets, longitudinal bands or streams and transverse bands (Anderson *et al.* 1969). Satellite observed high clouds are usually thick *Ci* or *Cs*, cirrus spissatus and possibly *Ci* fiblatus; thin *Ci* and small cloud elements such as *Ci* uncinus cannot be seen in satellite pictures. Cirrus spissatus and fiblatus occur in dense globular form and may create the impression of *Cb* to persons not quite familiar with the satellite picture interpretation.

Satellite observed jet stream clouds have been studied by Oliver *et al.* (1964) Whiteny *et al.* (1966) and Viezee *et al.* (1967) mostly over North American areas. So far no study has been made over Indian area.

Extensive formations of high and medium clouds sometimes occur over large parts of north and central India during the winter months; they have been found to be associated with the sub-tropical jet stream. A few cases of such clouding during December 1969–January 1970 over Indian area were studied using satellite pictures and the results are presented in this paper. The cases studied refer to the following dates: 3, 4, and 5 December 1969, 10-11 January 1970 and 17 January 1970. They cover the types of commonly observed cloud organisations over the Indian area associated with jet streams.

2. Case Studies

Case I : 3-5 December 1969

The satellite pictures for these days are shown in Figs. 1-3; the ground observed clouds at 0300 GMT of 4 December 1969 are shown in Fig. 4, as a typical example during the period.

3 December — The picture for 3rd shows the cirrus clouds originating from the Arabian Sea (north of Lat. 15°N) to the east of Arabia coast and extending northeastwards to Gujarat State, south Rajasthan and Sind. The clouds are arranged in nearly parallel lines running from southwest to northeast. Many of these lines are noticed to be composed of small thick individual globules. The shadows cast by these clouds towards the north are seen as dark lines on the pictures. The surface map on this day (at 0300 GMT) showed that ground observers reported cloudy to overcast skies over Sind, Gujarat State, Rajasthan and adjoining areas, the cloud types being cirriform with some stations reporting altocumulus as well.

4 December — The clouds have extended northeastwards towards Western Himalayas. Over north Gujarat State they have thickened. The clouds are still oriented southwest to northeast in parallel lines. The ground reports at 0300 GMT were again cirriform and altocumulus clouds. Over Gujarat State where the clouds had thickened the reports of *Ac* were more in number and in amount.

5 December — The clouds have extended further eastwards to Eastern Tibet. The parallel streaks of clouds were more prominent in the north—from Sind and south Rajasthan to Tibet. Over Gujarat State and north Madhya Pradesh, the clouds are

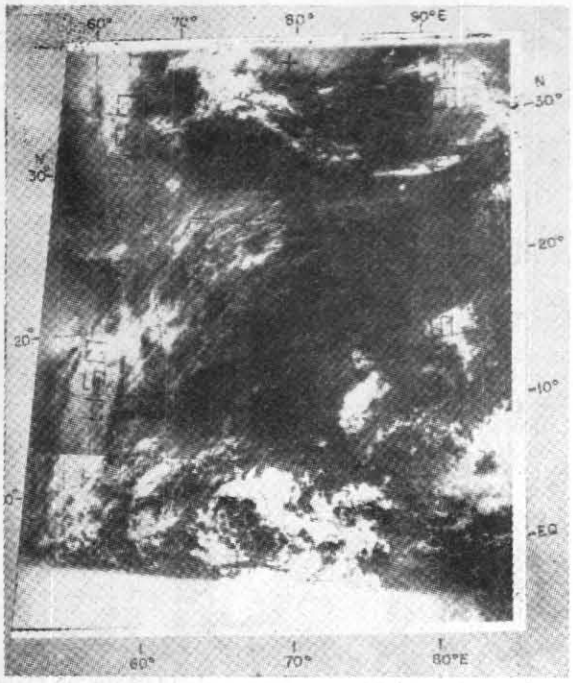

Fig. 1. 3 Dec 1969
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4125 (0924 IST)

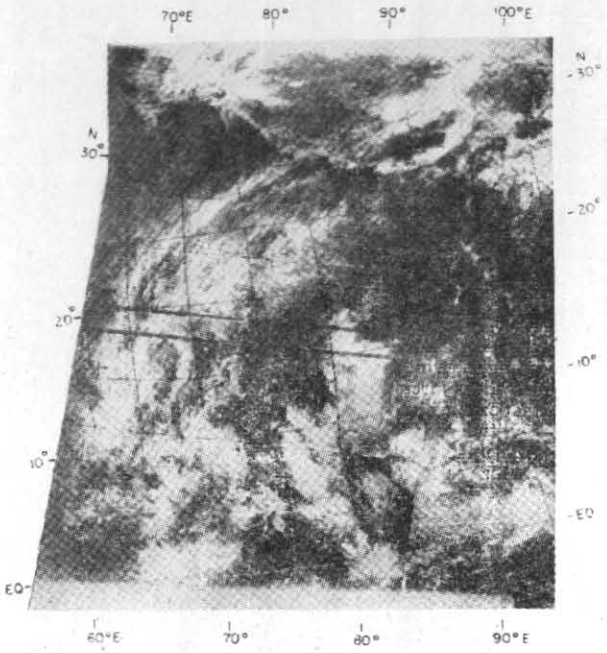

Fig. 3. 5 Dec 1969
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4450 (0941 IST)

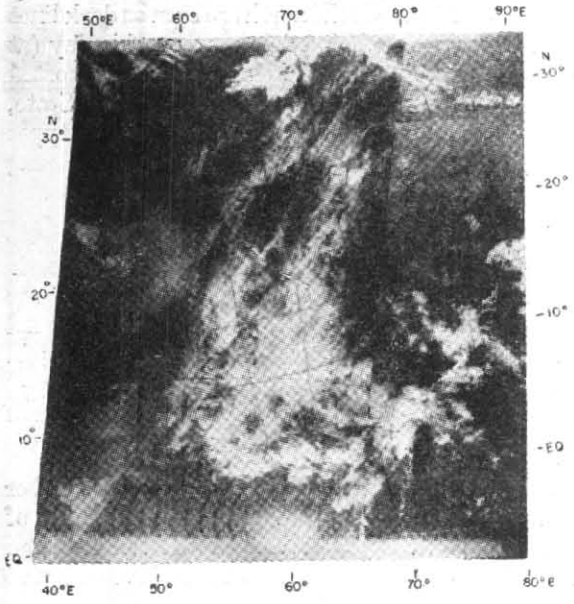

Fig. 2. 4 Dec 1969
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4438 (1016 IST)

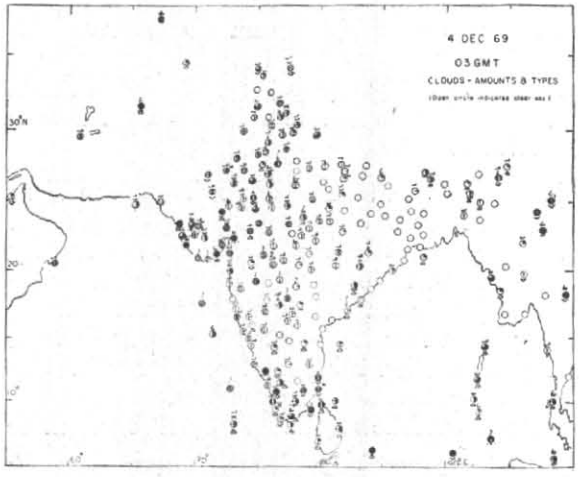

Fig. 4

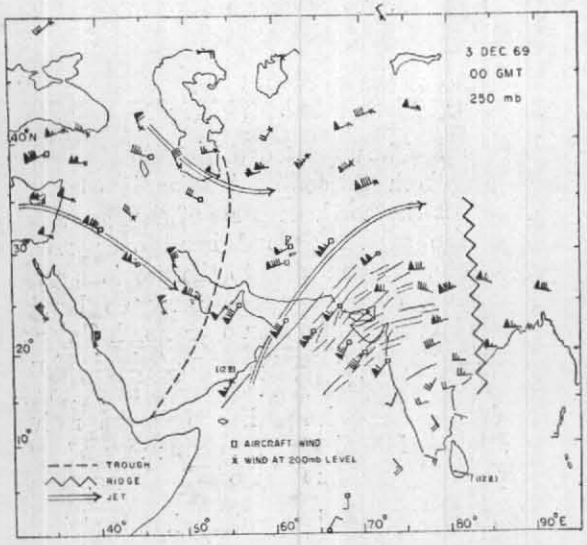

Fig. 5

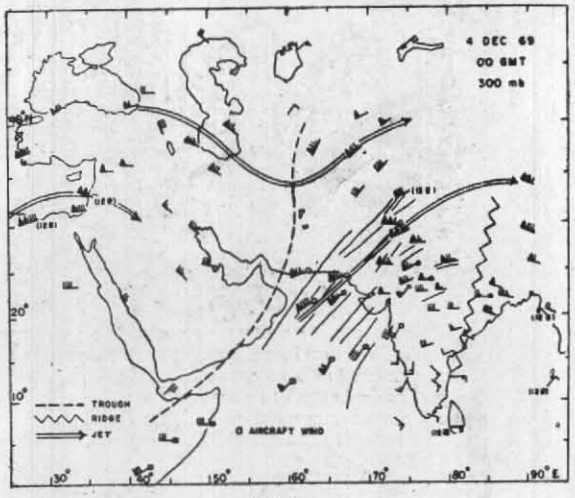

Fig. 6

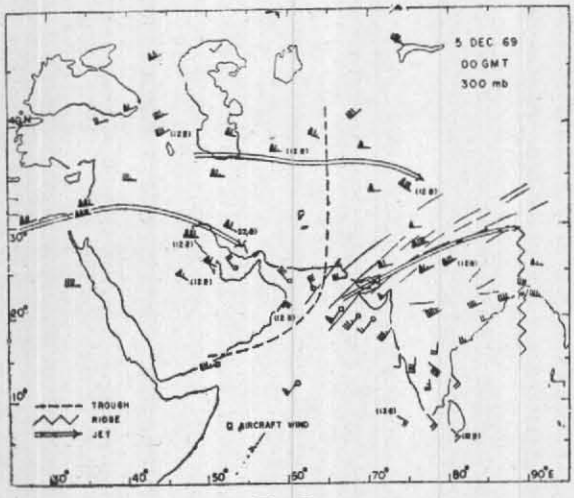

Fig. 7

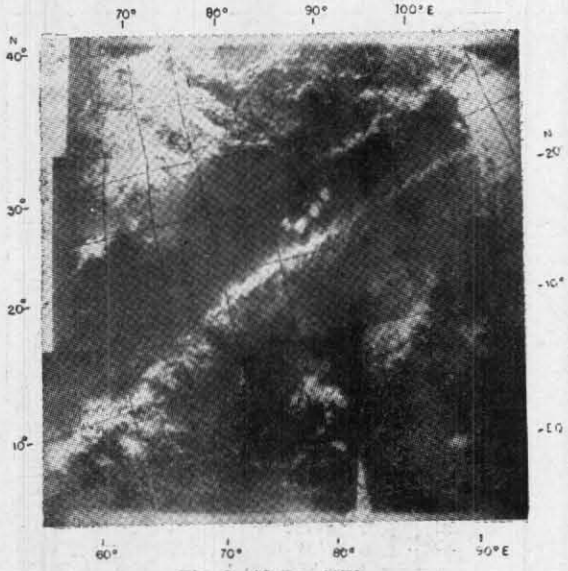

Fig. 8. 10 Jan 1970
ORBIT No. 4901 (0723 IST)
4902 (0918 IST)

disorganised and appear in large masses. On this day also the surface observatories reported cirriform and altoclouds. Over the area of massive clouds in Gujarat State reports of heavier *Ac* clouds were noted.

The upper tropospheric flow patterns on these three days are shown in Figs, 5 to 7. For each day one level (either 250 or 300 mb, depending on the availability of data) has been presented. Aircraft reports and off-time reports are also plotted on the charts. The axis of the jet stream is shown by a double line. The winds at the other levels and the temperature distribution were also taken into account to locate the jet axis. The positions of the *Ci*-bands observed by the satellite are indicated by thin lines. During this period a well-marked deep trough moved from Iran, Persian Gulf and Saudi Arabia to West Pakistan and north Arabian Sea. The hemispherical charts showed that it was a period of low index circulation, with deep troughs and ridges. There was a cut-off low near Aral Sea area with a cut-off high further north over

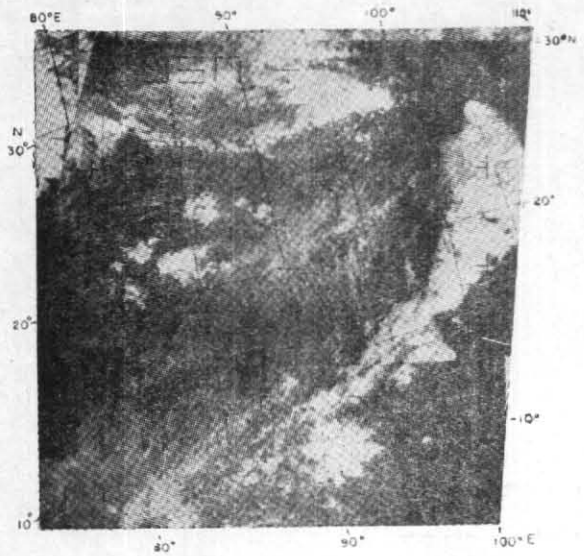

Fig. 9. 11 Jan 1970
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4915 (1009 IST)

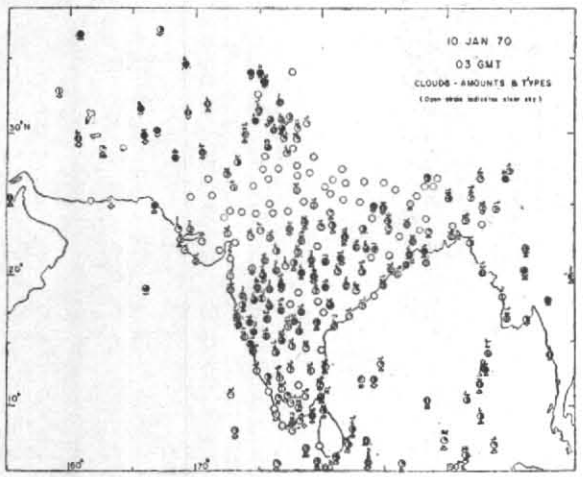


Fig. 10

Central USSR. These charts (Figs. 5 – 7) bring out the following points regarding the location of the cirrus clouds in relation to the upper tropospheric flow pattern—

(*i*) The clouds are in the region between the trough and the ridge and located in the area of strong winds (>50 kt). The ridge and trough lines sharply demarcate the eastern and western limits of the clouds.

(*ii*) The bands or streaks are oriented closely parallel to the wind flow or at small crossing angles.

(*iii*) The clouds are entirely to the south of the jet axis in the initial stage (on 3rd) and gradually they move across the jet axis to the north during the subsequent two days.

Case II : 10-11 January 1970

The satellite pictures for these days are shown in Figs. 8 and 9 and the corresponding ground-observed clouds for 10th may be seen in Fig. 10.

10 January – The upper troposheric cloud pattern is extending from east central Arabian Sea to upper Burma across the northern parts of the Peninsula. There is also a minor cloud band over north Gujarat State. In contrast to the previous case, these clouds show pronounced transverse bands. Transverse bands are also seen over north Gujarat State. The ground observers reported cirriform clouds as well as *As* and *Ac* clouds. over north Maharashtra State where the clouds are rather thick in the satellite pictures, more number of stations reported larger amounts of altoclouds.

11 January—The satellite picture shows a striking pattern of transverse bands over the eastern half of India extending from Orrissa coast to Upper Burma. Ground stations reported mainly high clouds with some *Ac*. The upper tropospheric cloud pattern does not extend west of 86°E.

Figs. 11 and 12 show the upper tropospheric flow on these two days. This was also a period of low index circulation and a deep trough was extending from Iran to southeast Arabian Sea on 10th. The lower portion of the trough moved rather rapidly across India; on 11th it was extending from East Uttar Pradesh to off Ceylon. The sub-tropical jet stream over India was well to the south of the seasonal position on these two days. The satellite observed clouds were to the south of the jet axis and to the east of the trough line on both the days.

Case III : 17 January 1970

The satellite picture for the day is shown in Fig. 13 and the corresponding ground-observed clouds in Fig. 14. The clouds are extending from east central Arabian Sea to northeastwards across the Peninsula to Bihar Plateau and show transverse striations. The ground observers reported mostly cirriform clouds with some altoclouds.

The upper troposphere flow pattern on this day (Fig. 15) also showed a trough extending from West Iran to extreme west Arabian Sea and a ridge from Andaman Sea to East Tibet. The sub-tropical jet stream was to the south of the mean seasonal position. The clouds were mainly to the south of the jet stream and between the trough and ridge lines.

3. Discussion

These case studies show that extensive upper tropospheric clouds form over India and neighbourhood in association with jet streams, when

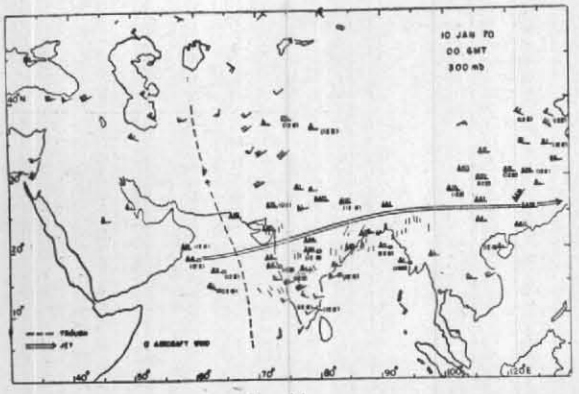


Fig. 11

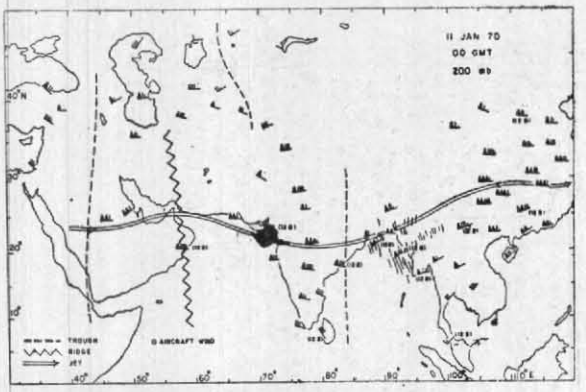


Fig. 12

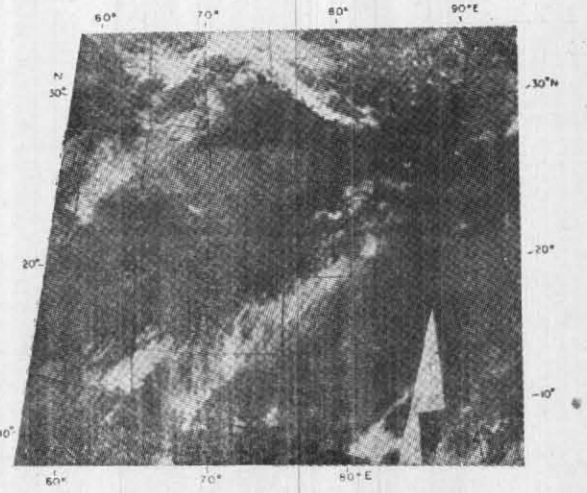


Fig. 13. 17 Jan 1970
ORBIT No. 4989 (0737 IST)
4990 (0932 IST)

large amplitude troughs extend to low latitudes. These clouds are seen over areas of strong upper tropospheric winds; horizontal shears are also large over these areas. The clouds are confined to the region down wind from the trough line upto the next ridge —a region favourable for upward motion. These results are consistent with earlier studies (Rao and Raman 1962). The clouds are mostly south of the jet stream, though their movement across the jet axis to the north is also noticed.

On 4 and 5 December 1969 when the crossing of the jet axis by the cloud system occurred, another jet stream was also seen further to the north across Iran, Afghanistan and Russian Turkistan. We are not going in greater details into this rather controversial point of the cloud system crossing the jet axis (Whitney *et al.* 1966 and Reiter and Whitney 1969). Surface observations have shown that the satellite observed jet stream clouds are mostly cirriform clouds with a fair amount of alto-clouds (mainly *Ac*) mixed up.

The examination of the hourly observations at the major airport stations during these days showed the following features—

(*i*) The clouds persist for most of the time of the day. They generally decrease considerably after midnight (during the late night hours) and they reappear again towards the morning.

(*ii*) Cirriform types of clouds are preponderant.

(*iii*) Sometimes there is alternate increase and decrease of cloud amounts, which may be attributable to the movement of the bands across the station.

These case studies also showed that the clouds organise themselves both in the longitudinal as well as transverse modes. A rough estimate of the spacing in between the bands (both latitudinal and longitudinal) was 40 to 70 km. The question that arose was whether there was any difference in the upper

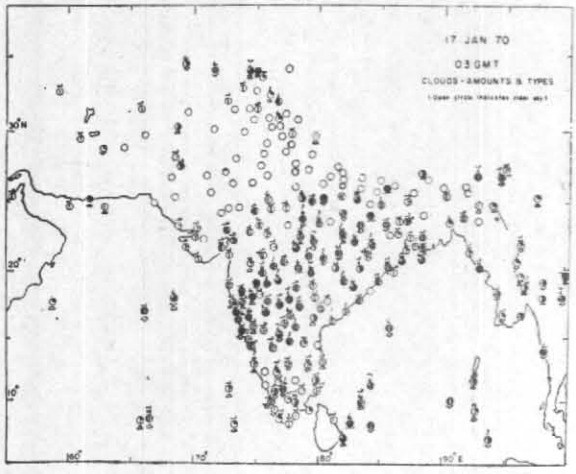


Fig. 14

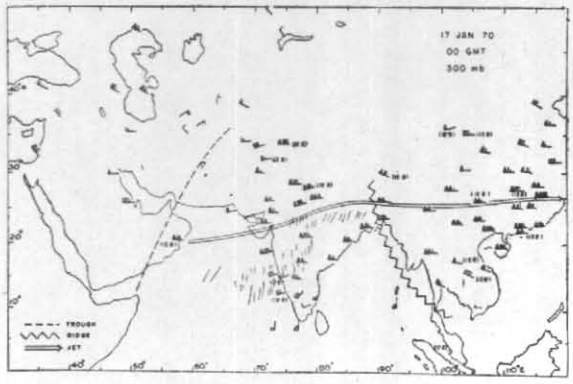


Fig. 15

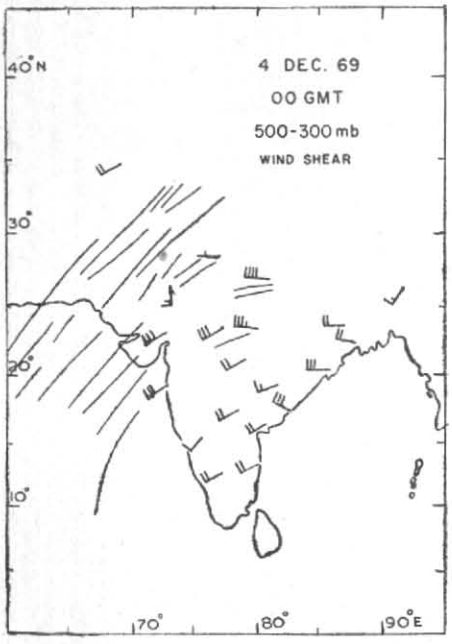


Fig. 16(a)

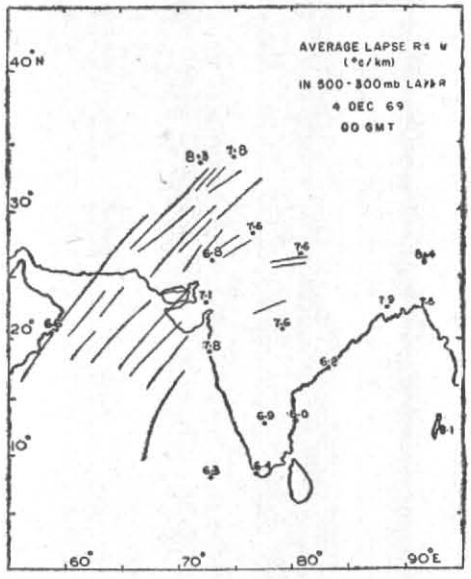


Fig. 16(b)

(a) wind shear and (b) average lapse rate (°C/km) in 500-300 mb on 4 Dec 1969

tropospheric conditions to distinguish the occasions of latitudinal bands from those of longitudinal bands.

The upper air charts presented earlier would at the first instance suggest that the transverse bands are associated with stronger winds. To examine the case a little further the wind shear and stability conditions in the layer 500-300 mb (in which these clouds were assumed to be embedded) were looked into. According to Yagi (1969), cirrus clouds form in the levels where wind shear exists. Taking into account the levels at which the strongest shears occurred as well as the heights of bases of clouds reported by aircraft and ground observers, it appeared that it was a fair assumption to take 500-300 mb layer as the main layer in which the jet associated clouds were present on these days. It was seen that transverse bands were associated with larger magnitude of wind shears and less mean lapse rate in the 500-300 mb layer and the longitudinal bands with relatively

less wind shear and greater lapse rates. The wind shear and lapse rate charts for 4 December 1969 and 17 January 1970 illustrating these points are given in Figs. 16 and 17.

A few studies have been made on *Ci* clouds using photographic and photogrammetric methods (Shaeffer 1953, Conover 1960, Reuss 1963, Yagi 1969). Yagi has tried to explain the formation of *Ci* uncinus, *Ci* spissatus and *Ci* fiblatus by utilising sterophotographic observations of clouds with simultaneous radiosonde and rawin ascents. He has concluded that *Ci* spissatus and fiblatus clouds form when there is a fairly deep layer in the upper troposphere with large lapse rates. *Ci*-spissatus and fiblatus are the types of clouds that are mostly noticed in satellite pictures. We have seen in the cases discussed, that transverse bands are associated with smaller lapse rates. In these cases even though the lapse rate is not thus quite favourable for the cloud formation, perhaps the vertical currents induced by some type of wave motion in the vicinity of the jet stream are responsible for the formation of spissatus type clouds.

Some of the radiosonde ascents examined in the present study also showed alternate stable and unstable layers and considerable increase of relative humidity in the upper tropospheric levels. However, these ascents could not be utilised for a more critical study, because the heights of base and top of clouds were not available to a sufficiently reliable degree of accuracy.

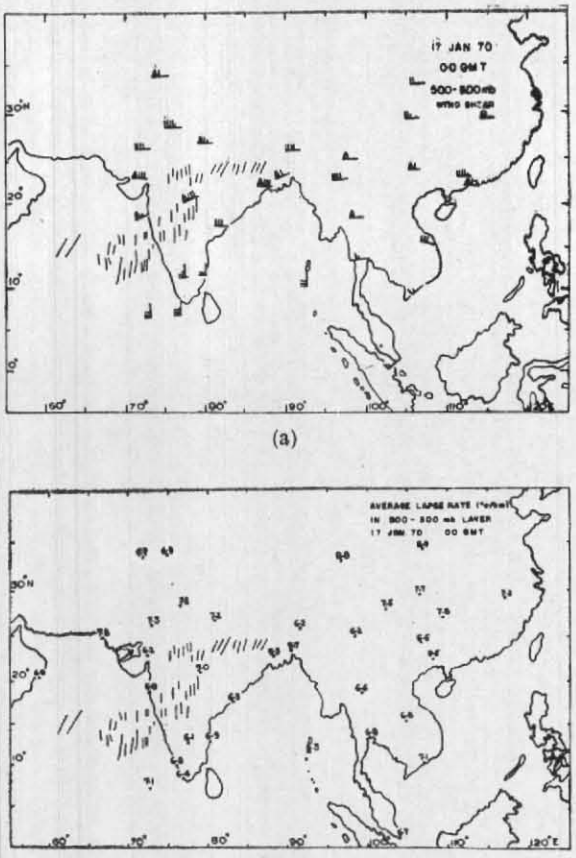
4. Conclusion

Using the satellite pictures and the concurrent upper tropospheric charts and ground-based cloud observations, the following conclusions have been arrived at—

(*i*) The jet associated upper tropospheric clouds are predominently high clouds with some mixture of alto-clouds.

(*ii*) The clouds form in the region of relatively strong winds and are organised either into longitudinal or transverse bands, depending on the wind shear and stability. Larger vertical wind shear and less lapse rate are associated with transverse bands, while smaller shear values and larger lapse rates are associated with longitudinal bands. These formations represent some types of wave motion in the vicinity of the jet stream. Though based only on a few cases, this point appears to be significant, and is being looked into further.

(*iii*) It has been noticed through examination of satellite pictures on a number of occasions that such banded *Ci*-structure appears to be more common over India and neighbourhood than the large *Ci* shields with or without shadow lines which appear to be more associated with the polar type jet.



(a) (b)

Fig. 17

(a) wind shear and (b) average lapse rate (°C/km) in 500-300mb on 17 Jan 1970

(*iv*) Although the sub-tropical jet stream is a quasi-permanent feature of the daily charts over India during the winter, still the clouds are not to be found everyday. They seem to form only with large amplitude troughs, when certain amount of advection of moist air at high level is possible over Indian area.

(*v*) Although these case studies refer to the winter period, such transverse bands are also noticed with easterly jet stream over India during the southwest monsoon period as well as in some cases of the outflowing *Ci* from the tropical storms.

Considerable co-ordinated work utilising satellite pictures, surface and upper air observations together with special aircraft observations

is necessary to understand the physical laws governing the formation of these clouds, their organization and their life history.

Acknowledgement — The author is grateful to Shri Y. P. Rao, who suggested the case studies and to the Meteorologists-in-charge of the MMOs Bombay, Calcutta and Palam, DMO Ahmedabad and IAF station, Jodhpur for readily supplying the current weather reports and aircraft weather reports required for this study. Thanks are also due to the members of the staff in the Forecasting Manual Unit for assistance in this study.

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DISCUSSION

DR. A.S. RAMANATHAN : Did you examine the horizontal shear also in the two types studied ?

SHRI V. SRINIVASAN : Not specifically. Horizontal shear is implied in the diagrams presented.

DR. P. KOTESWARAM : The first case presented by you seems to be one of wave formation. I would like you to examine the shears above 300 mb, say upto 100 mb.

DR. G.C. ASNANI : The study can be made more quantitative with the dimensionless parameter $f/\eta R_i$ where f=coriolis parameter, η=absolute vorticity and R_i=Richardson's number.

SHRI R.K. DATTA : Some portions of the pictures shown by you look similar to angels seen in radarscope. Could you detect any ?

SHRI SRINIVASAN : The jet stream associated clouds were over Indian mainland where enough surface observations are available. The clouds are predominently cirriform with altoclouds mixed up in some cases.