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# Structural characteristics of the subtropical jet stream

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ABSTRACT. Characteristics of the subtropical jet-structure over India and Pakistan were studied with the help of longitudinal cross-sections. It was observed that the subtropical jet is a broad band of great latitudinal span located in the break between the middle and the tropical tropopauses. Generally the jet-core has two Layers of Maximum Wind (LMW) attached to it. But it is replaced by separate cores with no LMWs when the branching of the jet stream takes place. Connected to each core and located beneath it is found a layer of frontal type discontinuity which may be called the "Subtropical Front". The present knowledge about the westerly jet streams over India and Pakistan has been discussed in the light of above findings.

## 1. Introduction

Recent studies of the westerly jet stream complex have brought to light a number of novel features in the structure of the subtropical jet stream. Defant and Taba (1957,1958) emphasized the close connection between the core of the subtropical jet and what they called the subtropical breakline in the tropopause. According to them at the core of the subtropical jet also there is an abrupt break in the tropopause as in the case of the polar-front jet. To its north lies the middle tropopause and to the south the subtropical. Newton and Persson (1962) confirmed this finding of Defant and Taba but noted that the subtropical tropopause unlike the principal tropopauses, *i.e.*, polar, middle and the tropical, is sometimes quite attenuated, especially on its equatorward side. Serebreny *et al.* (1962), however, neglected the subtropical tropopause which they called merely a temperature discontinuity below the tropical tropopause. Hence they noted that "the subtropical jet stream in general is located to the south of the middle tropopause but below the tropical tropopause".

Over Japan and vicinity Mohri (1953) noted the frequent existence of a prominent stable layer below the subtropical jet stream which he called the subtropical front. It was suspected (Newton *et al.* 1958) that this phenomenon may be confined to this particular geographical region. But the later study by Newton and Persson (1962) showed that these upper tropospheric stable layers are generally connected to the subtropical jet over North America also. They agreed with the findings of Mohri (1958) that the base of the subtropical front is generally identifiable with the southward extension of the middle tropopause which may sometimes be traceable upto 500-mb level. Serebreny *et al.* (1962) also noted the intimate connection of this layer to the subtropical jet. They called it a layer of subsidence and stated that "the northern edge of this jet stream actually lies over the southern portion of the middle tropopause where middle tropopause is identified by a subsidence layer rather than a single break in lapse rate".

As regards the wind structure at the core of the subtropical jet stream, Newton and Persson (1962) observed that—

(*a*) In general two cores of strongest wind are found, one lying in the break between the middle and the subtropical tropopauses and the other often lying above the subtropical tropopause. And attached to both the cores are the Layers of Maximum Wind (LMW);

(*b*) The layer of maximum wind connected to the upper core extends to the south above the subtropical tropopause;

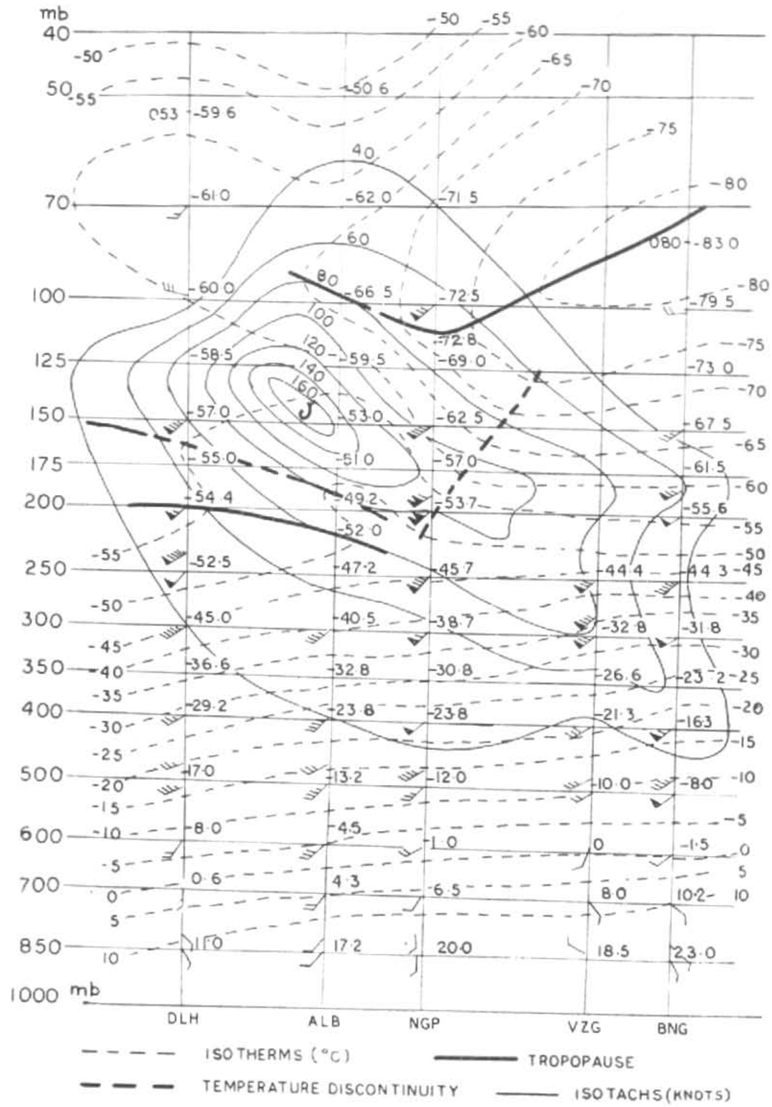


**Fig. 1. Vertical cross-section along Long. 80°E on 17 February 1962 (1200 GMT)**

(*c*) The LMW connected to the lower core slopes upward towards north on the cyclonic flank of the jet and often identifiable as a discrete wind maximum several kilometres above the polar front jet stream. On the anticyclonic flank the LMW slopes down towards south and is sometimes stronger than the higher level LMW;

(*d*) Sometimes there is only one core of the jet lying in the break between the tropopauses and two LMW's connected to it on the southern side and one to the north ;

(*e*) Sometimes shallow filaments of strong wind are found in the lower stratosphere above the tropospheric jet stream:

(*f*) When winds are strong there is a reasonable conservation of isentrope 345° K along the level of the lower LMW to the south. Along the LMW higher up also there appears to be a quasi-conservative potential isotherm along the flow.

(*g*) The LMW north of the subtropical jet lies just above the layer of the highest stratospheric temperature.

Bannon (1954) also in a study of winds at Habbania and Bahrein noted that "the level of maximum wind falls southward through the strong wind belt" and that "the stream is found to be broad and without strong horizontal gradients". Serebreny *et al.* (1962), however, state that the subtropical jet is not a broad band of strong winds but consists of more than one wind maximum. According to them the main core is located above an isotherm of —15° at 500-mb level. Sometimes another core is found to the south above the isotherm of —11° (at 500 mb) and occasionally even a third one above —6° C isotherm (500 mb). They do not note any layer of maximum wind as found by Newton and Persson or Bannon though they stress that the "subtropical jet stream complex may cover a great latitudinal span".

**2. Study**

An attempt has been made in this paper to look into these aspects of the subtropical jet stream over India and Pakistan. Though the situations presented are for a limited period (17 to 22 February 1962) the cases examined were extensive. The presentable vertical cross-sections could, however, be made during this period only. As such the results seem to be fairly representative of the general characteristics of the subtropical jet stream over the subcontinent,

*Case I*

During the period 15 to 25 February 1963, it was observed that in a deepening wave-trough in the upper tropospheric westerlies, the middle tropopause moved south to Delhi and to still lower latitudes on a number of days. On a few such occasions it was also possible to construct longitudinal cross-sections based on fairly reliable and more or less sufficient data. Cases presented here, therefore, belong to this period only.

Fig. 1 shows a vertical cross-section along longitude 80°E on 17 February 1962 (12 GMT) on which are projected upper air observations of Delhi, Allahabad, Nagpur, Visakhapatnam and Bangalore. Madras could not be included because of doubtful temperatures. The stations being very much scattered along the longitude (80°E) the projection has been made parallel to the contours at 300-mb level considering that these (contours) are fairly representative of the conditions prevailing in the jet stream region.

In Fig. 2 are shown the individual soundings used in this cross-section. It can be seen that at Delhi a more or less isothermal tropopause with a slight inversion in the beginning occurs at 195-mb at a temperature of —55°C. This isothermal condition continues upto the end of the flight (53 mb). According to definition of Defant and Taba (1957, 1958) this tropopause is of the middle latitude type. The tropical tropopause has not been reached in Delhi ascent. It may also be noted that the overall tropospheric and lower stratospheric temperatures of Delhi are much lower than those of Allahabad and other southern stations. Apparently Delhi was under the influence of middle latitude troposphere whereas others under the subtropical-tropical. Allahabad shows two tropopauses. The lower one beginning at 220 mb (—52°C) is of the middle latitude type (*see* Fig. 1 also) which extends upto 150 mb above which a break in lapse-rate occurs. At 100 mb tropical tropopause begins. This characteristic of double tropopause with break in-between is typical of the subtropical jet soundings as defined by Defant and Taba. Nagpur and other southern stations show the characteristics

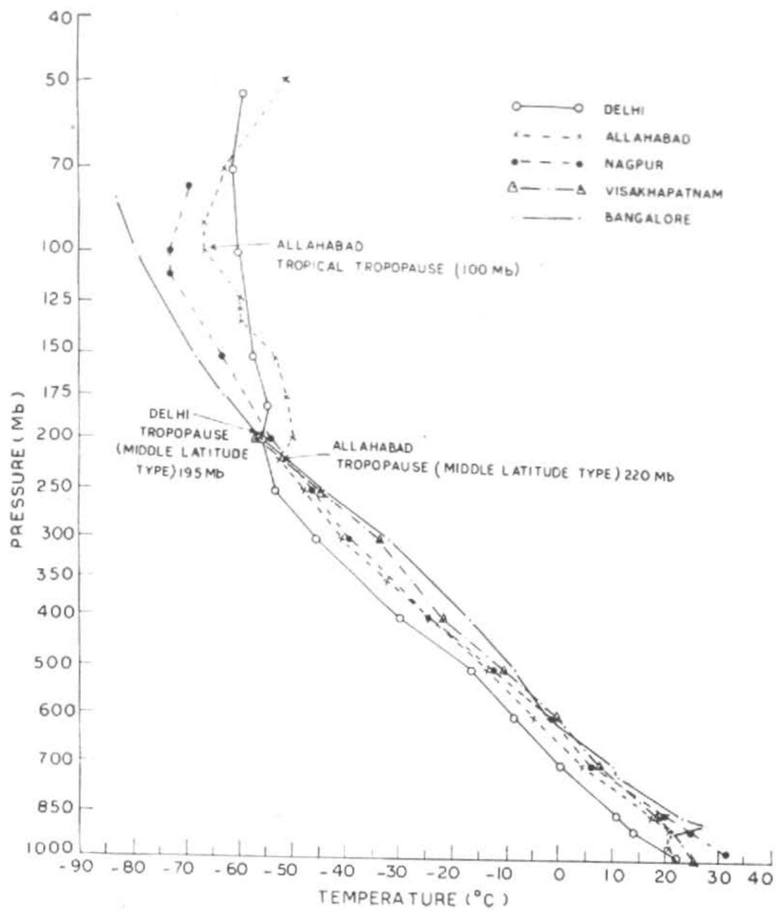


**Fig. 2. Upper air temperatures on 17 February 1962 (1200 GMT)**

of tropical atmosphere. From the strong temperature gradient existing between Delhi and Allahabad right upto 150-mb level and the subtropical jet characteristics of the Allahabad sounding, it is easy to infer that the jet-core would be situated between these two stations at 150-mb level close to the north of Allahabad.

Coming to Fig. 1 now, it can be seen that the middle tropopause slopes down from Delhi to Allahabad south of which it cannot be traced. The layer of inversion above it which may be identified with the subtropical front of Mohri or layer of subsidence of Serebreny *et al.* is quite clear. The jet-core is situated above it and below the tropical tropopause. There is no subtropical tropopause in this case. A temperature discontinuity, however, is discernible south of Nagpur above 200-mb level.

The jet stream seems to have a single core in this case, which is quite broad latitudinally. There appears to be no indication of two or more cores either in the horizontal or vertical. As regards the layers of maximum wind (LMW) connected to the core, though nothing can be said about them on the cyclonic flank, it appears that there are two on the anticyclonic flank. The one sloping down to the south is very clear. It lowers down to 400 mb over Bangalore. The other one seems to be lying above it between 200 and 175-mb levels as a second maximum over Bangalore indicates. Unfortunately there are no observations over Visakhapatnam upto that level. But Fig. 3 shows that there was in all probability a second maximum at a height of about 12 km over that stations also, thus confirming the presence of a second LMW at a height of about 12 km. None of these LMWs follow any isentrope as found by Newton and Persson.

In the absence of sufficient observations the placing of isotachs in the jet-core region is in general arbitrary. No claim, therefore, is made of the accuracy of horizontal or vertical wind shears. The same is true for all the cases discussed in this note.

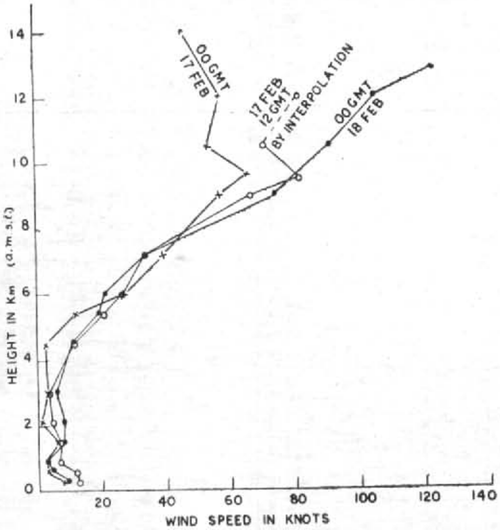


**Fig. 3. Graph showing wind-speed against height (Visakhapatnam) for 17 and 18 February 1962**

*Case II*

Fig. 4 shows a vertical cross-section along longitude 75° E on 21 February 1962 at 12 GMT. It extends from Khorog (37° 30′ N, 71° 30′ E) to Bangalore. The observations of Peshawar are for 00 GMT as there are no observations at 12 GMT at this station. For Ahmedabad too, temperatures have been taken from the morning ascent as the evening values were doubtful. The data so borrowed is only upto 125-mb where the tropical tropopause in the 12 GMT ascent of Ahmedabad appeared.

A study of the soundings used in this cross-section revealed that the ascent of Delhi and stations to its north showed characteristics of middle latitudes whereas those of Jodhpur and to its south of subtropical-tropical. The gradient of temperature was mainly concentrated between Delhi and Jodhpur indicating that the jet-core was likely between these two stations. On this day no station was having the characteristics of subtropical jet soundings.

It can be seen in Fig. 4 that the jet-core was located between Delhi and Jodhpur at about 200-mb level. The subtropical front below was quite extensive and very well defined. The middle tropopause which sloped down towards south from Khorog (247 mb, —54·8° C) to Delhi (310 mb, —43·7° C) formed the base of this subtropical front. There was no trace of subtropical tropopause in this case. Tropical tropopause obviously lowered down from Bangalore (100 mb) to Ahmedabad (125 mb in the 12 GMT ascent of 21st) north of which unfortunately it was not reached in any of the ascents.

The layers of maximum wind connected to the jet core on the anticyclonic side appear to be two as in the previous case. The lower one which sloped down towards south is quite clear and can be seen right upto Bangalore. The upper one also seems to be present though it cannot be very clearly indicated for want of observations. There does not seem to be any particular isentrope connected to either layers of the maximum wind.

*Case III*

In Fig. 5 is presented a case of bifurcated subtropical jet which could be located on the 12 GMT 300-mb chart of 22 February 1962. On this chart was seen a well developed ridge in the westerlies along longitude

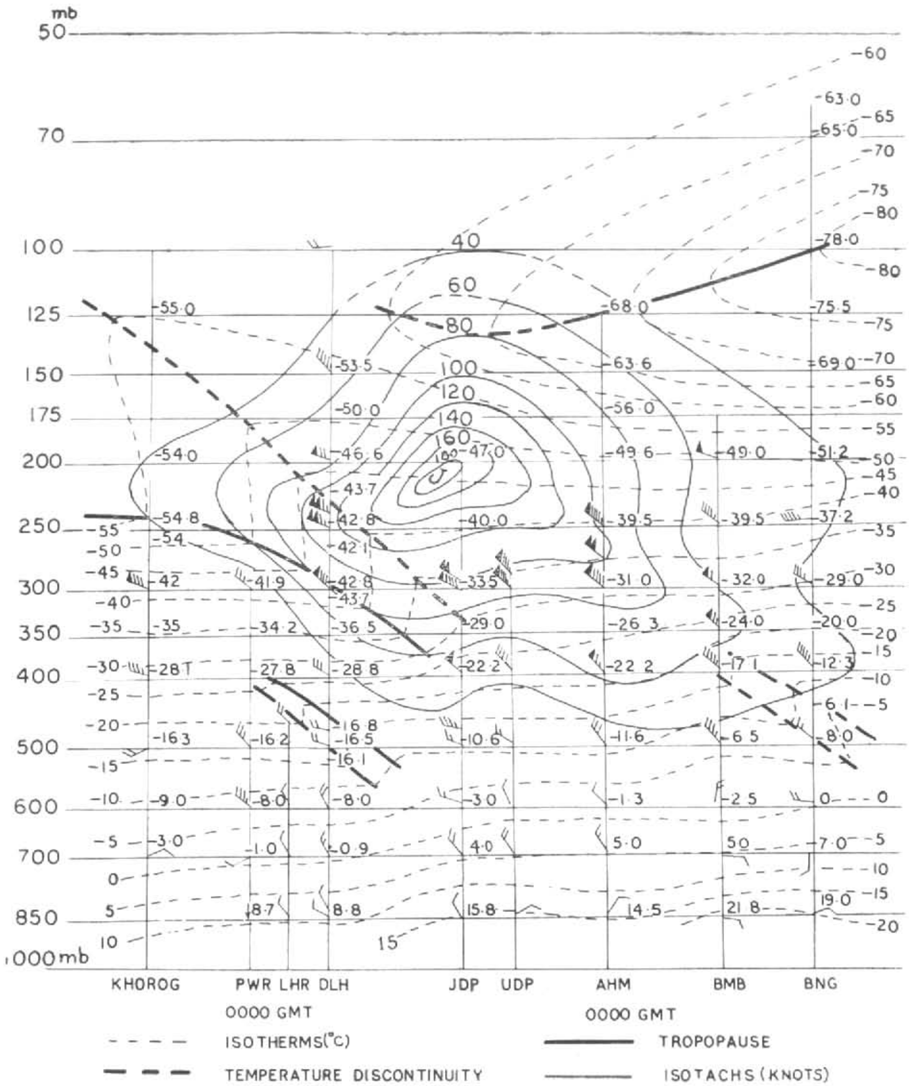


**Fig. 4. Vertical cross-section along Long. 75°E on 21 February 1962 (1200 GMT)**

70°E and passing through Peshawar. Due to the development of this ridge the subtropical jet from west was bifurcated; the southern branch passing over Karachi, Nagpur and Visakhapatnam and the northern one south of Khorog (37° 30′ N, 71° 30′ E).

The vertical cross-section shown in Fig. 5 is along longitude 73° E on which are projected latitudinally stations from Tashkent to Trivandrum. Observations of Peshawar and Lahore are for 00 GMT of 22nd. The data of Russian and Pakistan stations have been taken from the Mesran messages which, as is well known, leave out the details of temperature and wind-structure.

In this figure the two tropopauses, *i.e.*, middle and tropical, are quite apparent. Middle tropopause which extends from Tashkent to Khorog (37° 30′ N, 71° 30′ E)

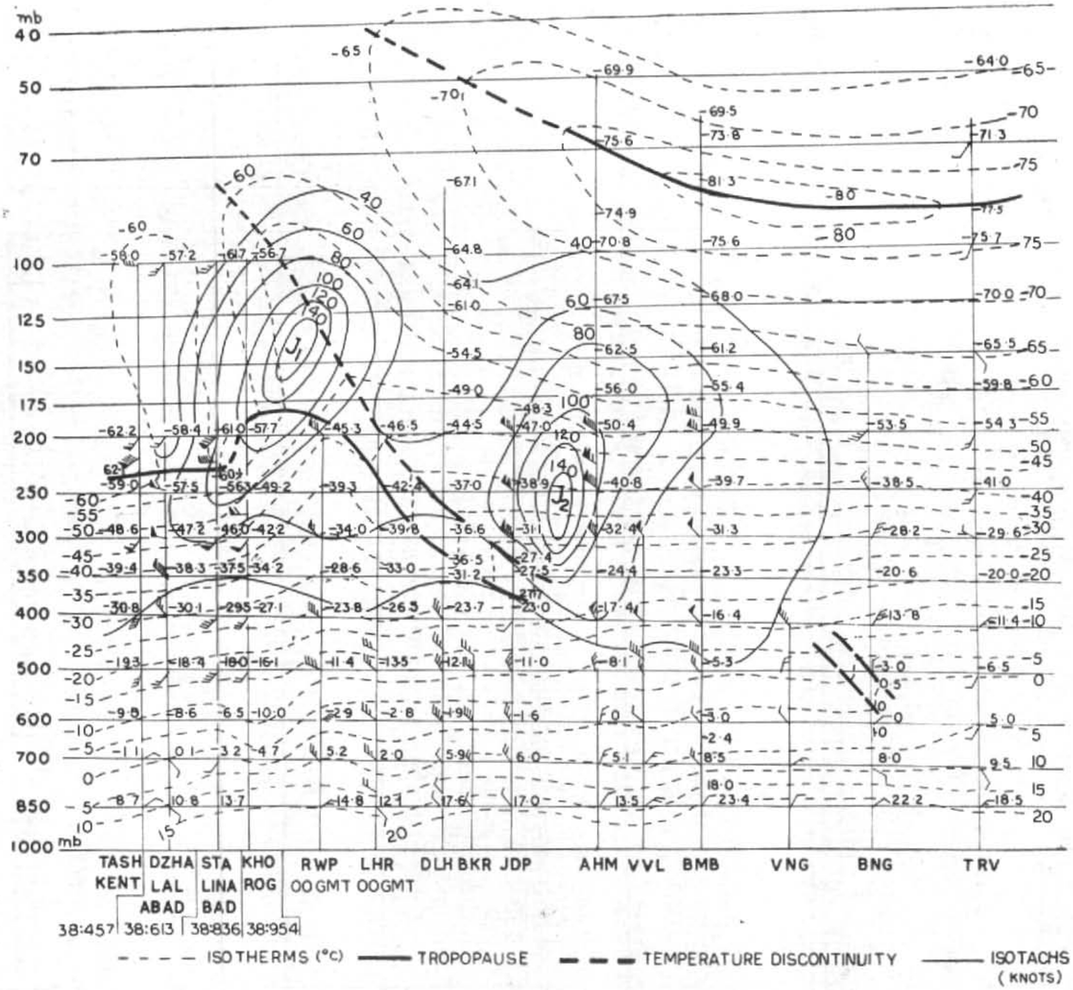


Fig. 5. Vertical cross-section along Long. 73° E on 22 February 1962 (1200 GMT)

lowers down to the south as the base of a temperature discontinuity. The tropical tropopause to the south seems to be extending upto Delhi. In the breakline between these two tropopauses is situated the core of the northern branch of the jet between 150 and 125-mb levels south of Khorog. The subtropical front below the core is well marked and extends upto Ahmedabad. It can be seen that the core is situated above a strong baroclinic zone which seems to be the result of the incursion of the subsiding middle stratospheric air to the south from below the jet-core (Koteswaram 1954). The detailed structure of this core could not be drawn with any degree of precision due to lack of observations. It does not seem likely, however, that it had any LMWs attached to it.

The southern branch of the jet which is located between Jodhpur and Ahmedabad below 250-mb has apparently no LMWs attached to it. It lies above the southern end of the subtropical front well below the tropical tropopause.

### 3. Conclusion

From the above study it may be inferred that—

1. The subtropical jet is a broad band of great latitudinal span and has layers of maximum wind (LMW) attached to its core. The breadth of the region of strong winds in the cases studied is roughly 800 km as noted by Bannon (1954) also.

2. On the anticyclonic flank of the core there are two LMWs; one sloping down to the south and the other above it located near about 200-mb level. The lower LMW is commonly more prominent and slopes at an angle of roughly 20° to 50° from the axis of the jet.

3. It appears, however, that when the jet is broken into branches, the LMWs are replaced by separate cores.

4. Connected to each core of the subtropical jet and lying below it is found a subtropical front whose base is the extension southward of the middle latitude tropopause.

5. The subtropical jet commonly lies in the break between the middle and the tropical tropopauses. But its connection to the breakline between the middle and the subtropical tropopauses is not very clear. In fact subtropical tropopause is not traceable in the cases studied.

6. No two cores were observed in the vertical in any of these cases as observed by Newton and Persson.

It may be appropriate to remark at this stage that the polar-front jet, as defined by Koteswaram (1953), may most appropriately be called the subtropical jet according to the definition of Defant and Taba. It may be recalled that in the case studied by Koteswaram (1953) the polar tropopause was located at 192 mb at a temperature of —59°C. These characteristics are actually those of the middle tropopause according to Defant *et al.* who note that the polar tropopause always occurs lower than 300 mb at a characteristic temperature of about —50°C.

It may also be noted that when the bifurcation of the subtropical jet takes place (Case III) the southern branch is the same as the main jet observed over India classified as subtropical by Koteswaram (1953). The northern branch at the same time is similar to his polar-front jet. Thus it can be inferred that over north India the commonly observed jet from October to May is the southern branch of the bifurcated subtropical jet whose northern branch lies at a northern latitude.

### 4. Acknowledgement

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