LARGE SCALE ANALYSIS OF METEOROLOGICAL PHENOMENA FOR THE PERIOD OF THE "FIRST HIMALAYAN SOARING EXPEDITION"

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INTRODUCTION

The meteorological data obtained by the expedition to the Kali Gandaki Valley in the Nepalese Himalayas are limited to this relatively small area and to atmospheric layers up to approximately 4000 m m.s.l. In order to determine the synoptic situation dominating the weather development during this period a three-dimensional analysis of the wind and temperature distribution was attempted on a large scale. Available for this purpose were plotted 6-hourly surface weather charts and upper air charts for 00 and 12 UTC for 300 hPa, 200 hPa and tropopause/maximum wind in polar stereographic projection, scale 1:15 Mio. Jet stream cores were analyzed by daily vertical cross sections along 78 E.[1]

Owing to the sparsity and partial unreliability of the data, the results cannot be quantitatively exact in each case. They are nevertheless presented here as long as they are felt to provide a qualitatively useful description of the synoptic situation.

SURFACE PRESSURE DISTRIBUTION AND TRACKS OF CYCLONES

During the first days of the expedition an extended cold anticyclone was centered, as usual during this season, between the Tibetan (Qinghai-Xizang) Plateau and the Bogi. Frontal depressions were passing over the Turan Basin and north of the Tien-Shan. Over Arabia, the Persian/Arabian Gulf and the Indian Subcontinent weak depressions could be analyzed. Only few of these could be traced for longer periods. Those in the western part seemed to vanish from the charts. Their later reappearance in the north, however, is indicated by weather reports from the Turan Basin and the Pamir area. In particular the station Horog (37.5 N 71.5 E, 2080 m m.s.l.) indicates the passage of a depression or trough from SW on 4 February. It is therefore most likely that these depressions passed over the data-void areas of Iran and Afghanistan, along the western side of the anticyclone mentioned above.

This anticyclone gradually disappeared during the second half of the expedition period, surface pressures being approximately 30 hPa lower than at the beginning. This difference cannot only be explained by the thermal effect of pressure reduction. On 31 January, most likely in connection with the low pressure indicated at Horog, a lee-depression formed in the south of Pakistan. This depression moved over the Indian plains adjacent to the Himalayas towards Burma (**Figure 1**). It passed south of Nepal between 4 and 5 February. While the expedition found the Kali Gandaki Valley closed by clouds on these days, the depression does not seem to be accompanied by any surface fronts. However, the 850 hPa temperature data of New Delhi and Lucknow resp. show on 4 February, 12 UTC the absolute maxima of the whole period with 15.2 and 15.6°C., followed on 6 February, 00 UTC by a temperature drop to 7.6 and 6.0°C. After an initial warming period it appears that cooler air from the Panjab area and from the foothills of the Himalayas has advanced into the rear of the depression thus giving it the character of a frontal wave.

The depression may have been member of a 4-day-wave which is apparent in the surface pressure reports of northern

1) Charts, cross-sections and archived data were provided by the Deutscher Wetterdienst (DWD), Offenbach, from material used for the ICAO Regional Area Forecast Center.

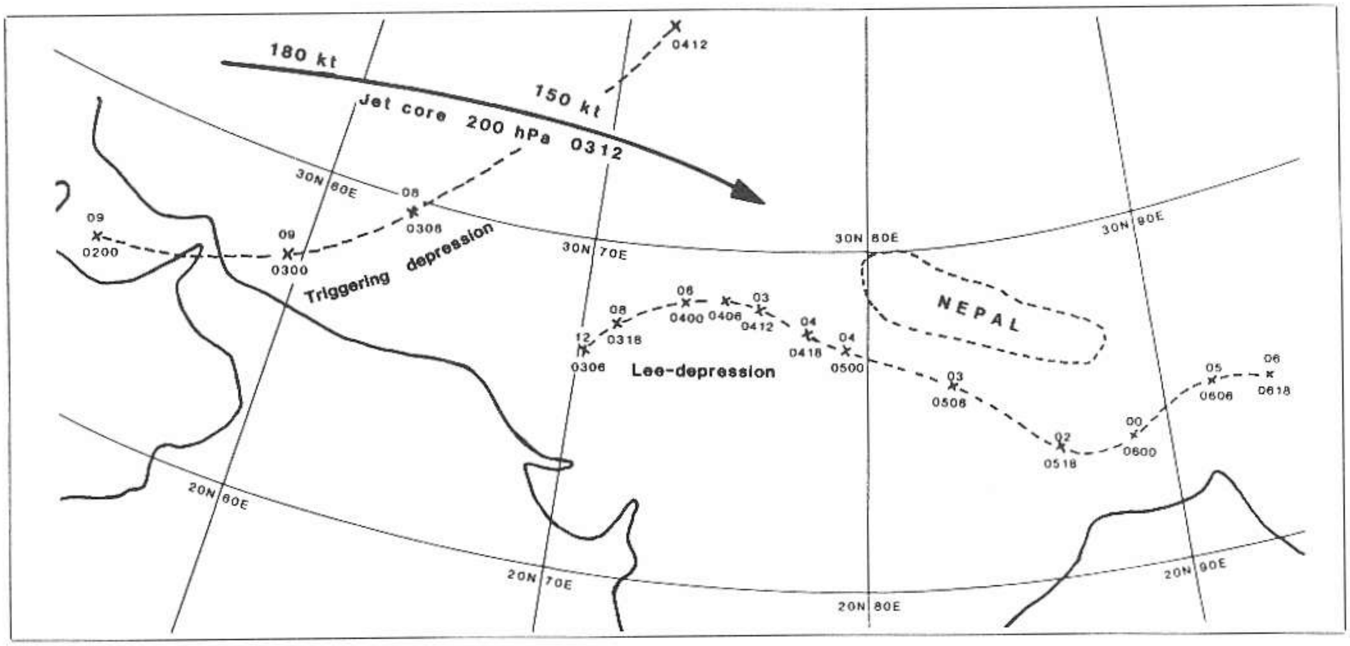

Figure 1. Formation of a lee-depression over Pakistan and its track from 3 to 6 February 1985. Legend PP x date/time.

India. Other depressions possibly existing within this series were not investigated as the expedition area was not affected.

The clouds connected with the depression can be recognized in the NOAA 9 satellite pictures. On 1 February a fibrous, not well organized cloud mass appeared over Afghanistan. During the following two days it crossed the Panjab and the Hindukush, reaching Nepal already on 3 February. From there it drifted slowly north- and eastwards covering central Tibet, Bangladesh and Burma around 5 and 6 February.

CIRCULATION IN THE UPPER TROPOSPHERE

At this time of the year the subtropical jet stream extends from northern Africa over adjacent parts of the Arabian Peninsula towards northern India. From there it continues towards Southeast-Asia crossing very high mountain barriers without obvious deflection. Isotach maxima exist, on the average, over Arabia and the Southwest-Pacific. India is generally characterized by a weak trough situation with a relative isotach minimum. Frequently however, it is passed by travelling isotach maxima. The minimum over India appears to show up better in daily synoptic charts than in climatological data. This bias must be attributed to the channeling effect of the mountain ranges and plateaus which leads to a concentration of high average wind speeds within a more narrow belt as compared to the two maxima situated over more open terrain. During the expedition period the jet stream pattern was largely in accordance with this situation. Troughs over India were apparent at 300 and 200 hPa on 29 January and from 31 January to 1 February. An isotach maximum was passing northern India between 5 and 7 February. The geopotential height of the 200 hPa level at New Delhi (**Figure 2**) shows a significant change possibly representing a long wave with the minimum during the first days of the expedition and the maximum during the latter half. The maximum coincides with the disappearance of the anticyclone at the surface. Around 5 February a short wave was passing through this maximum, connected with the cloudiness mentioned above. The average wind speed measured at 200 hPa above New Delhi shows similar changes.

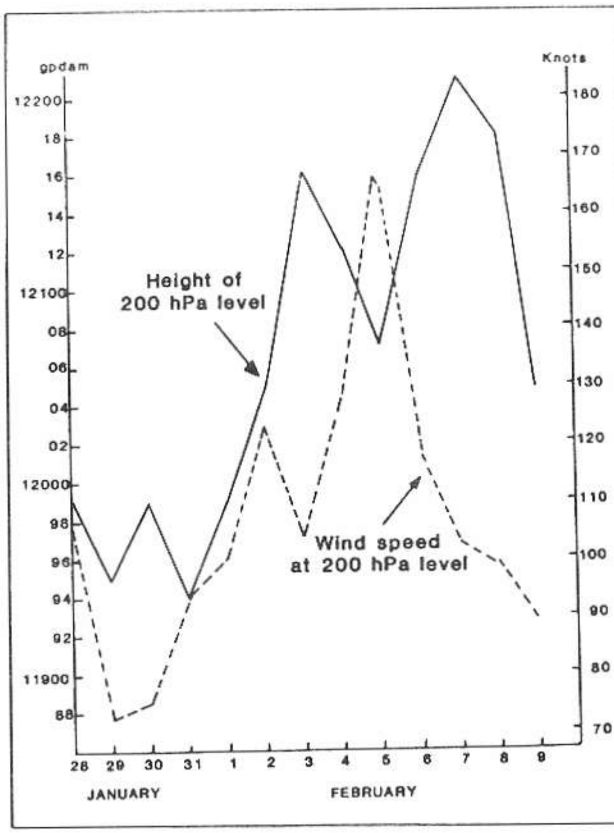

Figure 2. Height of the 200 hPa level (gpdam) and corresponding wind speed (knots) above New Delhi averaged between 00 and 12 UTC.

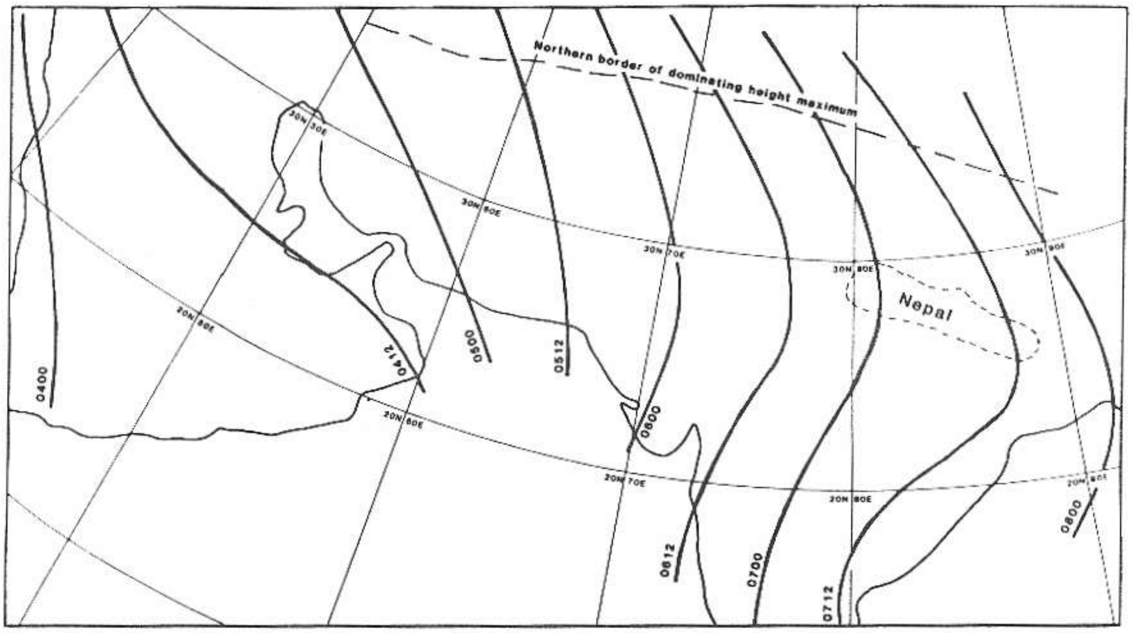

Figure 3. Position of height maximum in 200 hPa between 4 and 8 February 1985.

The time of occurrence of the height maximum in the 200 hPa level reveals a systematic geographical distribution. It shows up first on the western edge of the charts over the coast of the Red Sea on 4 February and disappears on the Burma coast on 8 February, thus travelling approximately 12 degrees longitude per day (**Figure 3**). As a dominating maximum this phenomenon can be followed as far north as the tropical tropopause extends across the jet stream. Farther to the north the distribution of maxima and minima is far more complex and has not been investigated in detail.

Simultaneously with the passage of the long and short waves mentioned above the jet stream cores were performing latitudinal shifts. These are studied in more detail in the following section.

VERTICAL CROSS SECTIONS THROUGH THE SUBTROPICAL JET STREAM

The dominating zonal direction of the subtropical jet stream permits its analysis by vertical cross sections fixed along certain meridians. On the basis of an optimum selection of stations the DWD had chosen the longitude 78 E for this purpose. Though this longitude is situated 5 degrees to the west of the Kali Gandaki Valley and thus crosses the Himalayas approximately 3 degrees farther to the north it was also used for this investigation.

The plotting program was based on a model developed by DWD for ALPEX. Later it was simply shifted to Asia to serve the purpose of the ICAO Regional Area Forecast System. The abscissa corresponds to the scale and projection of the synoptic charts used, the ordinate to the Stüve-Diagram up to 100 hPa. Reports from within the belts of 5 degrees longitude west and east of the central meridian and referring to 00 UTC were plotted into the section. The following data were included:

- Wind direction and speed (knots) extracted from radiosonde and aircraft reports, using bars and arrows;
- Temperature (°C) at significant points of radiosonde ascents or as derived from thickness values obtained by satellite;
- Tropopause and maximum wind data.

The plotting program was discontinued on 31 January, 1985. For the period until 12 February manual extracts of wind and temperature were made using coded radiosonde reports only. Altogether 19 sections were prepared, including three sections for 12 UTC.

The analyses were limited to the scalar wind speed with isotach intervals of 20 knots, commencing with 40 knots.

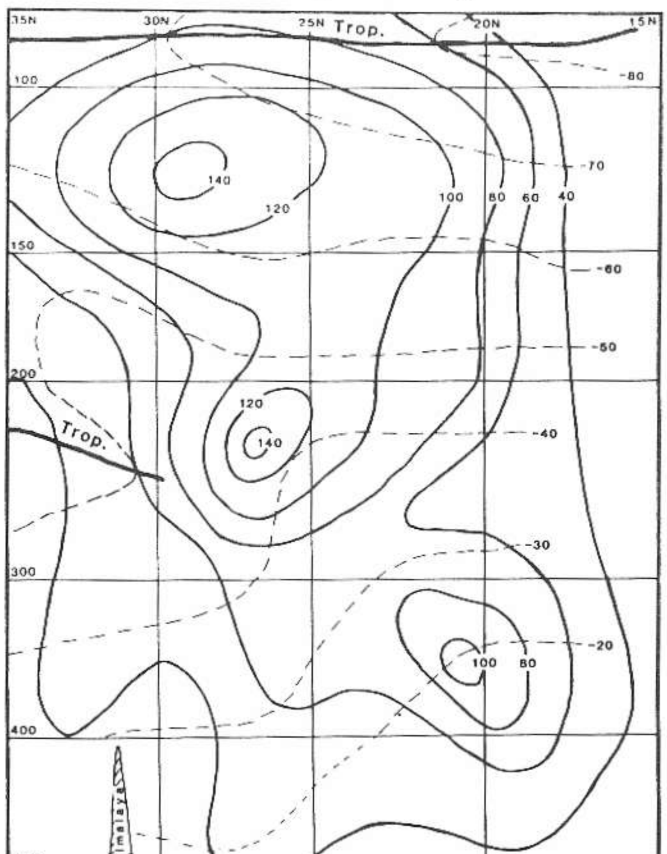

Figure 4. Vertical section along 78 E for 1 February 1985, 00 UTC. Jet stream cores south of the expedition area.
Isotachs with interval of 20 knots—thin solid lines.
Isotherms °C—thin broken lines
Tropopauses—thick solid lines

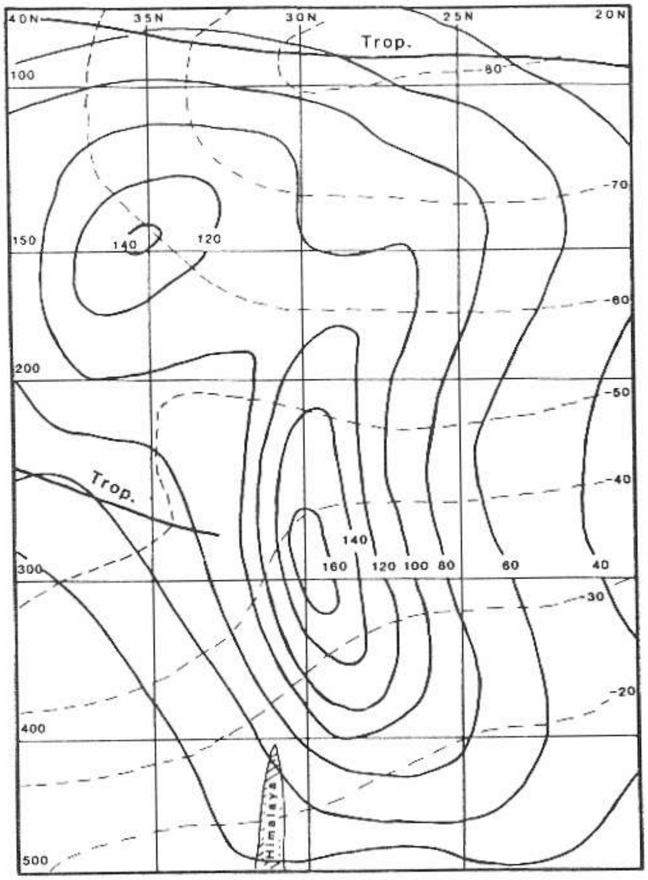

Figure 5. Vertical section along 78 E for 4 February 1985, 00 UTC. Jet stream cores above the expedition area, lowest jet engulfed in the medium jet.

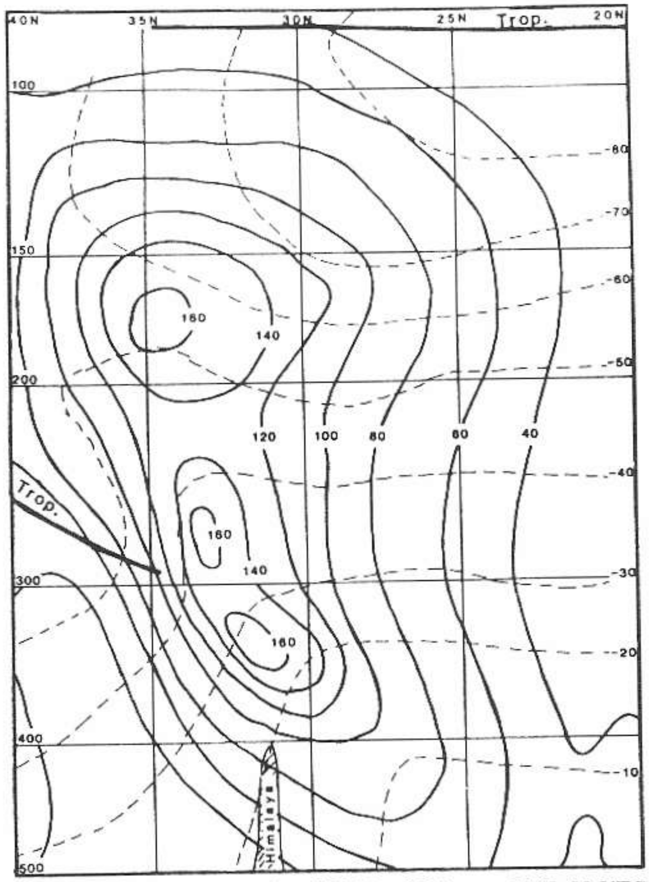

Figure 6. Vertical section along 78 E for 9 February 1985, 00 UTC. Jet stream cores north of the expedition area.

When available tropopause heights were indicated. As far as possible the isotach analyses in the vertical sections and in the charts for the standard pressure levels 300 and 200 hPa were adjusted to each other. Typical sections with jet stream positions in the south of, above and north of the expedition area are shown in **Figures 4 to 6**. The positions of the individual cores extracted as far as possible from all the sections are shown in **Figure 7**. The findings can be summarized as follows:

1. There is a velocity maximum gradually sloping upwards from south to north. The sloping angle closely corresponds with that of the potential temperature isotherms.
2. Within this maximum three individual jet stream cores can be analyzed one above the other most of the time. Each higher core is shifted slightly northward from the lower one.
3. The upper cores are found just below the 150 hPa and 250 hPa levels, i.e. within the large break or fold between the tropical and polar tropopauses. They thus correspond with the conventional appearance of the subtropical jet stream not regarding the somewhat unexpected duplicate structure.
4. The highest core appears to be situated slightly above the level at which the latitudinal isobaric temperature gradient reverses. Its existence, on the other hand, is confirmed by several radiosonde stations of different meteorological services. Whether this thermodynamic contradiction is a true phenomenon or the consequence of systematic measurement or evaluation errors could not be ascertained.
5. Between 300 and 400 hPa a lower jet stream shows up in most of the sections. During a period of approximation to

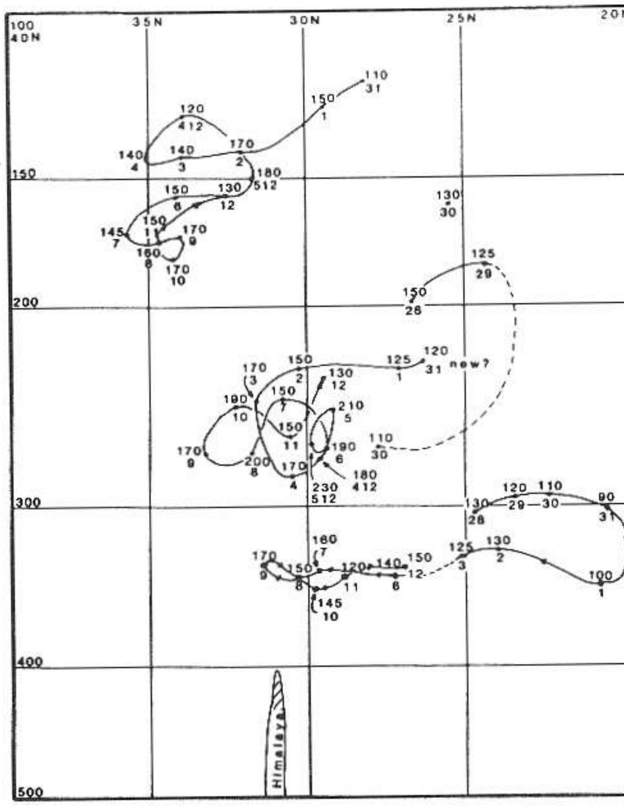

Figure 7. Position of jet stream cores and maximum wind speed for the period 28 January to 12 February 1985.

Upper figure at each position = maximum wind speed in knots. Lower figure at each position = date of observation (date without time refers to 00 UTC).

the medium core between 3 and 5 February the lower core is not discernible any more as a separate phenomenon. At that time it is probably engulfed in the extended area of the strengthened medium jet.

6. None of the cores is ideally represented in one of the upper level charts available. The vertical sections, therefore, are constituting the only basis for a detailed analysis.
7. The existence of three jet cores one above the other, with very limited lateral shifting, has possibly to be regarded as an effect of the Himalayas. This phenomenon is not known from the section 45 E for which analyses were also produced regularly by DWD. The lowest core may also be responsible for the fierce storms sometimes experienced by mountaineers on the Himalaya peaks.
   (From other years it is recalled that the lowest jet is not a regular phenomenon during the winter. It is most likely dependent on the strength of the temperature gradient at medium levels between India and the Tibetan Plateau.)
8. Velocity minima or short periods of disappearance of the jet cores are indicated during the passage of upper troughs on 29 January and 1 February, 1985. Maxima are connected with a weak anticyclonic curvature or a straight current.
9. Lateral shifts of the jet cores appeared to be loosely connected with each other. However, reversals from N to S and vice versa did not occur on the same date. During the few days investigated the reversals seem to have commenced at the lower level, while each higher core followed approximately one day later.
10. A significant shift to S with decreasing height (increasing pressure) was connected with the weakening of a jet stream or the disappearance of an isotach maximum eastwards. A significant shift to N was connected with increasing speed or the appearance of a new jet stream from W. The corresponding increase in height (decrease in pressure) was not observed. Velocity maxima were found during periods with no or very small shifts.
    This sequence corresponds to the passage of waves with velocity maxima in the ridges and minima in the troughs.
11. During the first days of the expedition the three cores were situated south of the Kali Gandaki Valley. The two upper cores crossed this area northward by 1 February. The lowest one followed between 6 and 7 February. The crossing was accompanied by variable cloudiness, the valley being closed to flight operations by clouds on 4 and 5 February. With the continued northward shift of the jet streams the weather improved. Fair weather conditions were observed on 7 February when all the jet cores were situated north of the Kali Gandaki Valley. Only on this day a pronounced up-valley circulation has developed. Though a reversal of the jets to south started between 7 and 9 February, they remained north of the expedition area until 11 or 12 February.
12. With the passage of a very short wave on 4 and 5 February (Fig. 2) the upper and middle cores were temporarily shifting back to south for about 3 degrees latitude. The lowest core had disappeared as a separate entity. Wind speeds at the middle core were reaching the maximum of the whole period with values well above 200 knots. They were measured at the radiosonde station New Delhi which had provided useful data most of the time. As these winds were also fitting reasonably well into the charts and vertical sections they appear to be correct.
13. The shifting of the jet cores across a fixed geographical position was accompanied by a change of air temperature in the upper troposphere in the order of 15 K. This change commences abruptly between 500 and 400 hPa, while below this layer it is limited to 5 K only.

CROSS SECTION OF TEMPERATURE BETWEEN NORTHERN INDIA AND THE TIBETAN (QINGHAI-XIZANG) PLATEAU

In order to assess the possibility of the development of a diurnal circulation between the Tibetan Plateau and the adjacent plains in the south during the winter, the temperature at various plateau stations was compared with radiosonde data of Lucknow (42369). The radiosonde data were available for 00 and 12 UTC. Uninterrupted series of station reports were available for 00 UTC (approx. 05 L.T.), corresponding to the temperature minimum, and for 06 UTC (approx. 11 L.T.). Approximate mean temperatures were obtained by averaging the 00 and 06 UTC data. Maximum temperatures were not available but must be expected to be 1 to 2 K higher than the 06 UTC data. Their use would enhance the findings obtained from the 06 UTC and the mean temperature data. **Figure 8** shows the approximate configuration of the isotherms at 00 and 06 UTC and of the mean values obtained. The section extends from Lucknow to the Gobi roughly perpendicular to the southern border of the Himalayas. It covers approximately 13 degrees of latitude.

The results show a gradient of the mean temperature of 10 to 15 K across the plateau concentrated in northern Tibet and very weak across the Himalayas. At 00 UTC, however, a fairly strong gradient is directed from northern India towards the southern mountain ranges, at 06 UTC it has changed in the opposite direction. Stations in the vicinity of the Himalayan ranges are indicating the relatively highest temperature and the largest amplitude.

The temperature differences indicate, that one of the essential conditions for the formation of diurnal up- and down-valley circulations is existing also during the winter. On the other hand, the aircraft data show the almost permanent existence of a temperature inversion above 3500 m m.s.l. which separates very dry air aloft from more humid air below. Also the wind regime at the entrance of the Kali Gandaki Valley at Pokhara Airport (827 m m.s.l.) appears to be different from that in its inner part around Jomson (2682 m m.s.l.). These phenomena point at a modification of the up- and down-valley circulations in the Himalayas in comparison with alpine regions.

A prerequisite for such circulations is the formation of slope winds. In the Himalayas, the supply of cold air feeding the slope winds at night will be almost unexhaustible in view of the vast extent of the Tibetan Plateau in its rear. This air, passing through gaps in the mountain barriers such as the Kali Gandaki Valley, will commence to slide down over the southern slopes. At the same time it will be subject to adiabatic heating. As the plateau area by far exceeds the slope area, this heating cannot be compensated by radiational cooling along the slopes. The air will therefore remain at greater heights and will most likely correspond with the air above the inversion found in the aircraft data. Due to this phenomenon the development of a uniform down-valley circulation from the level of the plateau to the bottom of the valley and finally to the adjacent plains of Nepal and India more than 400 m below the plateau cannot be expected. As minimum there may be two such circulations, one above and the other below the inversion, each of them corresponding with the average height differences experienced from alpine valleys. The different wind regimes in the valley during daytime and the

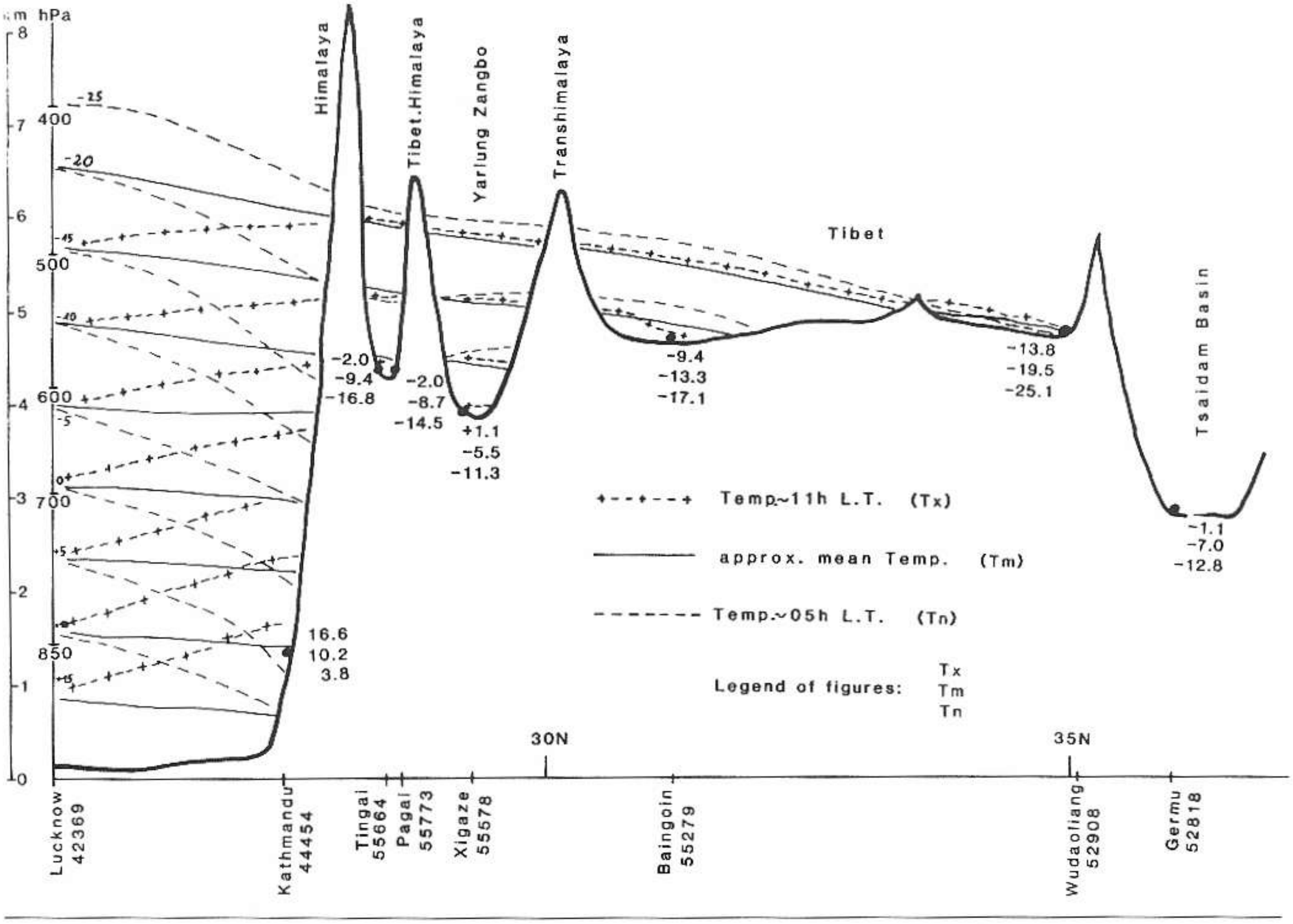

Figure 8. Temperature cross-section from northern India (Lucknow) to the Tsaidam Basin (Germu) across Nepal, averaged between 28 January and 8 February 1985.

uneven distribution of convection found by the expedition may be an indication that the up-valley circulation shows similar splittings.

CONCLUSION

The wind and temperature distribution at lower levels between northern India and the Tibetan Plateau indicates a modification of up- and down-valley circulations in comparison to alpine regions. This is attributed to the different geometrical relationships between high level plateau and slope area. The adiabatic heating of subsiding down-valley current originating over the vast plateau areas cannot be compensated by the radiational cooling along the slopes at night. This prevents airmasses from the plateau to reach the plains of southern Nepal and northern India by means of direct thermal circulations. These airmasses were therefore found at heights above 3500 m m.s.l.

The investigation reveals a close coupling between the weather phenomena experienced at lower levels and the position of the jet streams which appeared to be separated into three different cores. The cores were showing wave-like lateral shifts with no apparent modification when crossing from the plains into the Himalayan ranges. Changes of wind and temperature connected with these shifts were mainly limited to levels at and above 400 hPa while the lower troposphere remained amazingly conservative.

Tracks of surface depressions seemed to avoid the highest ranges or plateaus. The development of a lee-depression was observed over Pakistan. Its track over the plains along the southern side of the Himalayas could be followed as far as Burma. Though the depression appeared to be too weak initially for comparison with the behaviour of high latitude waves, the temperature changes at 850 hPa, the cloudiness and the jet stream patterns are showing similar phenomena.

The large scale circulations at jet stream levels and at the surface reveal a significant change during the expedition. Findings during the first days can therefore not strictly be compared with those at the end of the period.