

# Forecasting of cirriform clouds over Northern India, Pakistan and Afghanistan from constant pressure charts

SURENDRA KUMAR

*Meteorological Office, Safdarjung Airport, New Delhi*

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**ABSTRACT.** Advection of vorticity at an upper air level below tropopause is indicative of the vertical motions in the upper troposphere. It has been shown that the regions of positive advection of vorticity at 300 mb are most probable regions for the occurrence of high clouds in winter. The forecasting value of this relationship has also been briefly discussed.

## 1. Introduction

With the rapid growth of high speed jet aviation, high clouds are assuming greater importance day-by-day. The performance of the supersonic aircraft while climbing may be affected by cirriform clouds with the associated hazard of severe turbulence. The abrasive effect of hydrometeors may damage the surface of the plane or produce static electricity.

Forecasting of high level clouds over India has been rather difficult. A number of techniques have been developed for forecasting the occurrence of high clouds in temperate latitudes. James (1957) suggested a synoptic approach based on vertical wind shear, dew point depression, contour and thickness patterns and location of jet stream and surface fronts. French and Johannessen (1954) have developed an objective method of forecasting extensive layers of high clouds above 25,000 ft by relating these to the regions of positive vorticity advection at 300 mb. Most of these studies were confined to extra-tropical regions. Very little work has been done to develop forecasting techniques for cirriform clouds in the tropics.

In India, some studies on mean heights and temperatures of high clouds have been carried out. Deshpande (1965) observed from the post flight reports that the bases of cirriform clouds over India were mainly between 35,000 and 45,000 ft., being lowest in winter and highest in summer.

Cirriform clouds are known to occur over Afghanistan, Pakistan and northern India during winter ahead of eastwards moving upper air troughs in the westerlies. An attempt has been made in this note to investigate the relationship between the significant layers of cirriform clouds and advection of vorticity at 300 mb during winter.

It may be mentioned that our approach in this investigation is similar to that followed by French and Johannessen (*loc. cit.*) in their forecasting technique for high level clouds. However, in the present study occurrence of high clouds is based on observations from the surface instead of aircraft observations.

## 2. Observations

In order to increase the confidence in the surface observations of high clouds, only those situations were chosen for this study when mostly high clouds were present.

Although the constant pressure charts of 00 GMT have been mainly used, to avoid unreliable observations during the hours of darkness, high cloud observations made 2 to 4 hours later have been included in the maps.

The high cloud layers of 5 octas or more have been termed as significant. Average temperature at 30,000 ft over north India during winter is about  $-35^{\circ}$  to  $-40^{\circ}\text{C}$ , a range in which several authors have found that abundant freezing nuclei become active. In other words, 30,000 ft is roughly a level above which clouds are predominantly ice-crystal clouds.

## 3. Divergence and vertical motion near the tropopause

Let us assume that the vertical motion leading to the formation of high level clouds may be slow, large scale ascent of air.

In order to infer the vertical motion in the high cloud region from 300-mb charts, let us consider the vorticity equation (1) and the equation of continuity (2) in isobaric coordinates.

$$\frac{d}{dt} (\zeta_p + f) = - (\zeta_p + f) \nabla_p \cdot \mathbf{V} +$$

$$+ \left( \frac{\partial w}{\partial y} \cdot \frac{\partial u}{\partial p} - \frac{\partial w}{\partial x} \cdot \frac{\partial v}{\partial p} \right) \quad (1)$$

$$\nabla_p \cdot \mathbf{V} + \frac{\partial}{\partial p} \left( \frac{dp}{dt} \right) = 0 \quad (2)$$

Here  $\zeta_p$  is the vertical component of relative vorticity (Isobaric),  $f$  the coriolis parameter,  $\mathbf{V}$  velocity and  $\nabla_p$  the horizontal del operator applied to a quantity in an isobaric surface;

$$\text{and} \quad \left( \frac{\partial w}{\partial y} \cdot \frac{\partial u}{\partial p} - \frac{\partial w}{\partial x} \cdot \frac{\partial v}{\partial p} \right)$$

the vortex tube term representing the rate of conversion of horizontal vorticity into vertical vorticity by differential vertical motion through the pressure surface may be neglected. Then the equation of vorticity reduces to the form;

$$\frac{1}{\zeta_p + f} \cdot \frac{d}{dt} (\zeta_p + f) + \nabla_p \cdot \mathbf{V} = 0$$

$$\text{or} \quad \frac{d}{dt} \log (\zeta_p + f) + \nabla_p \cdot \mathbf{V} = 0 \quad (3)$$

By combining (2) and (3) and integrating between pressure levels  $P$  and  $P_T$ , we obtain the well known relationship—

$$\left( \frac{dp}{dt} \right)_p - \left( \frac{dp}{dt} \right)_T = \frac{d}{dt} \overline{\log (\zeta_p + f)} (p - p_T) \quad (4)$$

where the bar indicates average value between pressure levels  $p$  and  $p_T$ . As boundary condition, we assume that the individual pressure change at the tropopause or some level near tropopause is small in magnitude compared to the individual pressure change at a lower level. It may be a reasonable assumption that  $(dp/dt)_T \approx 0$ , where  $T$  is some level near tropopause.

Let us assume pressure level  $p$  as 500 mb. Now for  $\overline{d \log (\zeta_p + f)/dt}$  we may substitute the values at 300 mb, assuming it to be representative for the layer between  $p$  and  $p_T$ . For the wind and vorticity geostrophic values were used.

Neglecting the intensification rate of vorticity field, vertical transport of vorticity and change in  $f$  along the contours, the individual change of logarithmic vorticity is expressed as—

$$\frac{d}{dt} \log (\zeta_p + f) = (\zeta_p + f)^{-1} (V_g - C) \frac{\partial \zeta_g}{\partial s} \quad (5)$$

where  $C$  is the speed of vorticity line along the contours. Writing  $1 - C/V_g = K$ , where  $K$  measures the relative speed with which the air flows through the vorticity pattern, the relation between

vertical motion and vorticity advection is expressed as

$$\left( \frac{dp}{dt} \right)_p = \left[ (\zeta_g + f)^{-1} K V_g \frac{\partial \zeta_g}{\partial s} \right]_{300\text{mb}} (p - p_T) \quad (6)$$

In most cases  $K > 0$ . In other words the synoptic 300 mb pressure pattern moves with a speed less than that of the air at that level and the individual air parcel moves through the various systems.

In the region where  $\partial \zeta_g / \partial s > 0$  at 300 mb there is a descending motion increasing downwards below tropopause. In regions where  $\zeta_g / \partial s > 0$  at 300 mb there is ascending motion increasing downwards below tropopause.

Thus, we can estimate vertical velocities at 500-mb level as a function of vorticity advection at 300 mb. If the vertical motion at 500-mb level is sufficient enough to cause slow large scale ascent of air in the upper troposphere, the high clouds are likely to form provided sufficient moisture is available. Thus we conclude that favourable regions for formation of high clouds would be the regions of positive vorticity advection at 300-mb level.

The geostrophic vorticity was computed by the finite difference approximations—

$$\zeta_g = \frac{4g}{fd^2} (\bar{Z} - Z_0) \quad (7)$$

where  $\bar{Z} = (Z_1 + Z_2 + Z_3 + Z_4)/4$  is the space averaged contour height,  $Z_0$  is the observed contour height at the grid centre and  $d$  the grid length.  $d$  was taken equal to 400 km at 30°N on the chart. Since the factor  $4g/fd^2$  varies slowly in the north-south direction on the map, the isopleths of  $(\bar{Z} - Z_0)$  may be taken to be the isopleths of vorticity. The change in  $f$  along the contour of upper air isobaric chart such as 500 or 300 mb is generally small as compared to the change in  $\zeta_g$  and hence may be neglected. Thus the absolute vorticity patterns will not be much different from the patterns of geostrophic relative vorticity as obtained from  $(\bar{Z} - Z_0)$ .

To investigate the relationship between positive vorticity advection and occurrence of significant layers of high clouds, vorticity patterns for various days were prepared as follows—

(i) The values of  $(\bar{Z} - Z_0)$  were calculated at each 5-degree grid point between the longitudes 60° East and 90° East and latitude 35° North to 25° North using a finite difference grid.

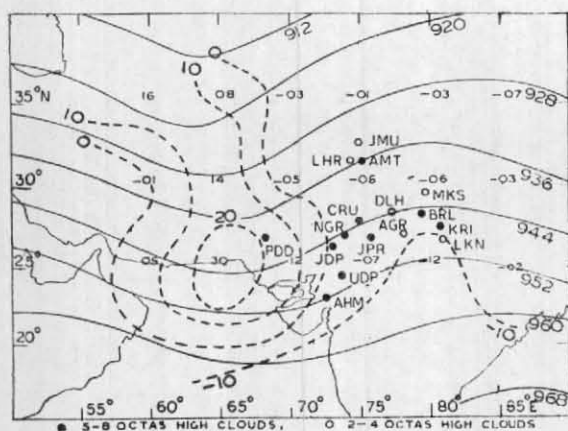


Fig. 1. 300-mb chart at 00 GMT of 22 December 1967

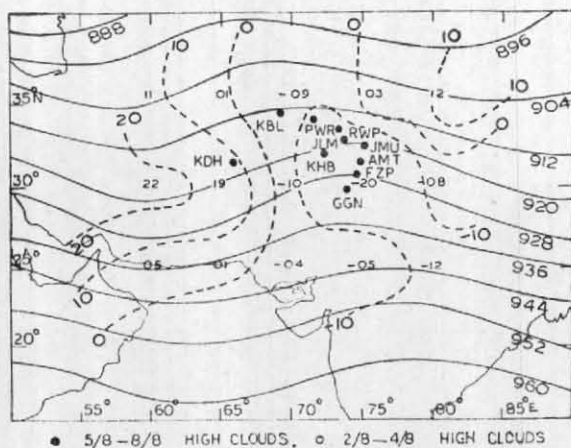


Fig. 2. 300-mb chart at 00 GMT of 22 January 1968

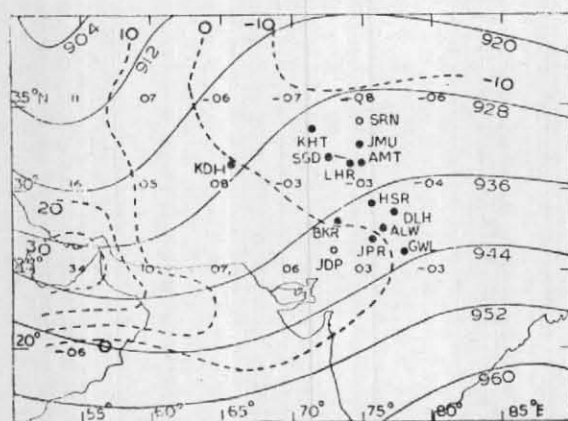


Fig. 3. 300-mb chart at 12 GMT of 23 February 1968

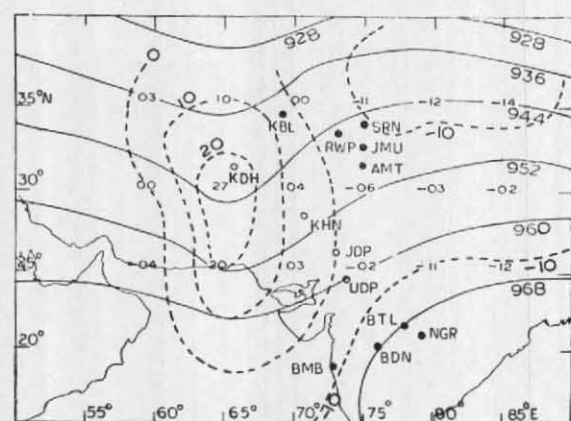


Fig. 4. 300-mb chart at 00 GMT of 4 November 1967

(ii) The isopleths of  $(\bar{Z} - Z_0)$  at 10 gpm intervals were drawn. These could be considered as isopleths of relative vorticity.

#### 4. Occurrence of significant high cloud layers in relation to vorticity advection at 300 mb

On the 300-mb charts reproduced in the Figs. 1-6 contour lines are at intervals of 80 gpm and isopleths of  $(\bar{Z} - Z_0)$  at 10 gpm.

The magnitude of the advection of vorticity has not been determined quantitatively in the present study. However, a fairly good idea of advection of vorticity can be made by a keen observation of the charts if we consider the size of the quadrilateral formed by the two consecutive contour lines and two consecutive isopleths of vorticity bearing in mind the following points—

(1) Advection of vorticity may be taken to be inversely proportional to the area of the quadrilateral formed by the intersection of the

two consecutive contour lines with the consecutive isopleths of relative vorticity, and

(2) Advection of vorticity along stream lines varies directly with the wind speed.

The significant high clouds of 5 octas or more have been shown by black circles and 2-4 octas high clouds by clear circles. The charts for 22 December 1967 and 22 January 1968 at 00 GMT are shown in Figs. 1 and 2 respectively.

In both the cases, the high clouds are found in the regions of marked positive vorticity advection. All high cloud observations, except one, lie some distance downstream from the line of zero advection. It may be due to the fact that the saturation will be reached only after some ascending motion.

Figs. 3 and 4 show that high clouds lie in the regions of positive vorticity advection. However, a few high clouds also extend to some distance

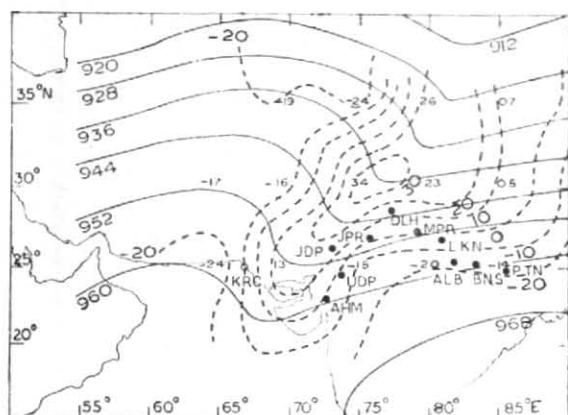


Fig. 5. 300-mb chart at 00 GMT of 15 December 1967

upstream from the line of zero advection. Fig. 5 shows that while significant high clouds are found in the regions of positive vorticity advection, there are other areas of marked positive vorticity advection where no high clouds are observed. This indicates that humidity observation at high levels may be required for forecasting the areas of formation of high clouds with greater certainty. Fig. 6 shows that high clouds are found in the region of positive vorticity advection but there are also regions of marked vorticity advection with no high clouds; indicating the significance of humidity at high level.

##### 5. Conclusions

The above discussion leads to the following results—

- (1) Cirriform clouds were mostly found in the regions of positive vorticity advection at the 300-mb level which normally would lie between a ridge line and the following trough line to the west.
- (2) High clouds were not always found centred on the areas of maximum positive vorticity advection.
- (3) All the areas of positive vorticity advection

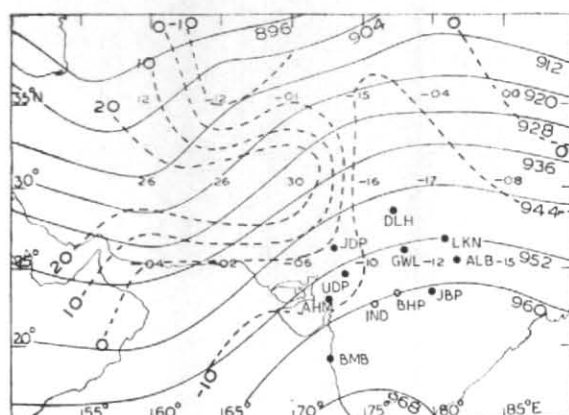


Fig. 6. 300-mb chart at 12 GMT of 26 January 1968

were not found to have high clouds. This probably suggests that the humidity distribution at high level is also important. Since the synoptic humidity observations at 500 mb and above are either non-existent or unreliable especially during winter this parameter had not been investigated in the present study.

As the gradients of vorticity patterns were not generally found to be large, a quantitative estimation of advection terms at 300 mb as a function of cloud cover was not attempted in the present study.

We have made no attempt to forecast the areas of positive vorticity advection and occurrence of high clouds. However, if the vorticity patterns are computed from the 300-mb prognostic chart, the regions of positive vorticity advection can also be forecast with the same accuracy as the prognostic chart.

##### 6. Acknowledgement

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##### REFERENCES

- |                                      |      |                                                                     |
|--------------------------------------|------|---------------------------------------------------------------------|
| James, D. G.                         | 1957 | Met. Office Prof. Note, 123, London.                                |
| French, J. E. and Johannessen, K. R. | 1954 | Proc. Toronto Met. Conf. 1953 pp. 160-171., Roy. Met. Soc., London. |
| Deshpande, D. V.                     | 1965 | <i>Indian J. Met. Geophys.</i> , <b>16</b> , 4, pp. 635-640.        |
| Rao, D. Venkateswara                 | 1955 | <i>Ibid.</i> , <b>6</b> , pp. 299-316.                              |