PROBABLE REGIONS OF "JET" STREAMS IN THE UPPER AIR OVER INDIA

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FROM an examination of the normal meridional cross-sections of pressure, temperature and wind for every 20 degrees longitude over the Northern Hemisphere, Namias and Clapp[1] have given maps for January and July showing the average position and strength of the "jet" stream. These maps show a "jet" axis in January over North India at latitude 22°-25° N. while no such axis is shown over India in July. It appears possible from the normal upper wind pressure and temperature distribution over India to get an idea of the probable regions and heights where jet streams are likely to occur in the upper air over India.

Fig. 1 shows the normal distribution of temperature and the mean zonal west and east components of winds, determined from pilot balloon ascents, in the upper air over India along 78° E. in summer (monsoon) and winter. The temperature distribution is based on Indian Sounding Balloon data and the distribution of west and east components of winds have been taken from Venkiteshwaran's[2] diagrams with slight modification in respect of winds over South India above 16 km. on the basis of later data. The following conclusions can be drawn from an examination of this figure.

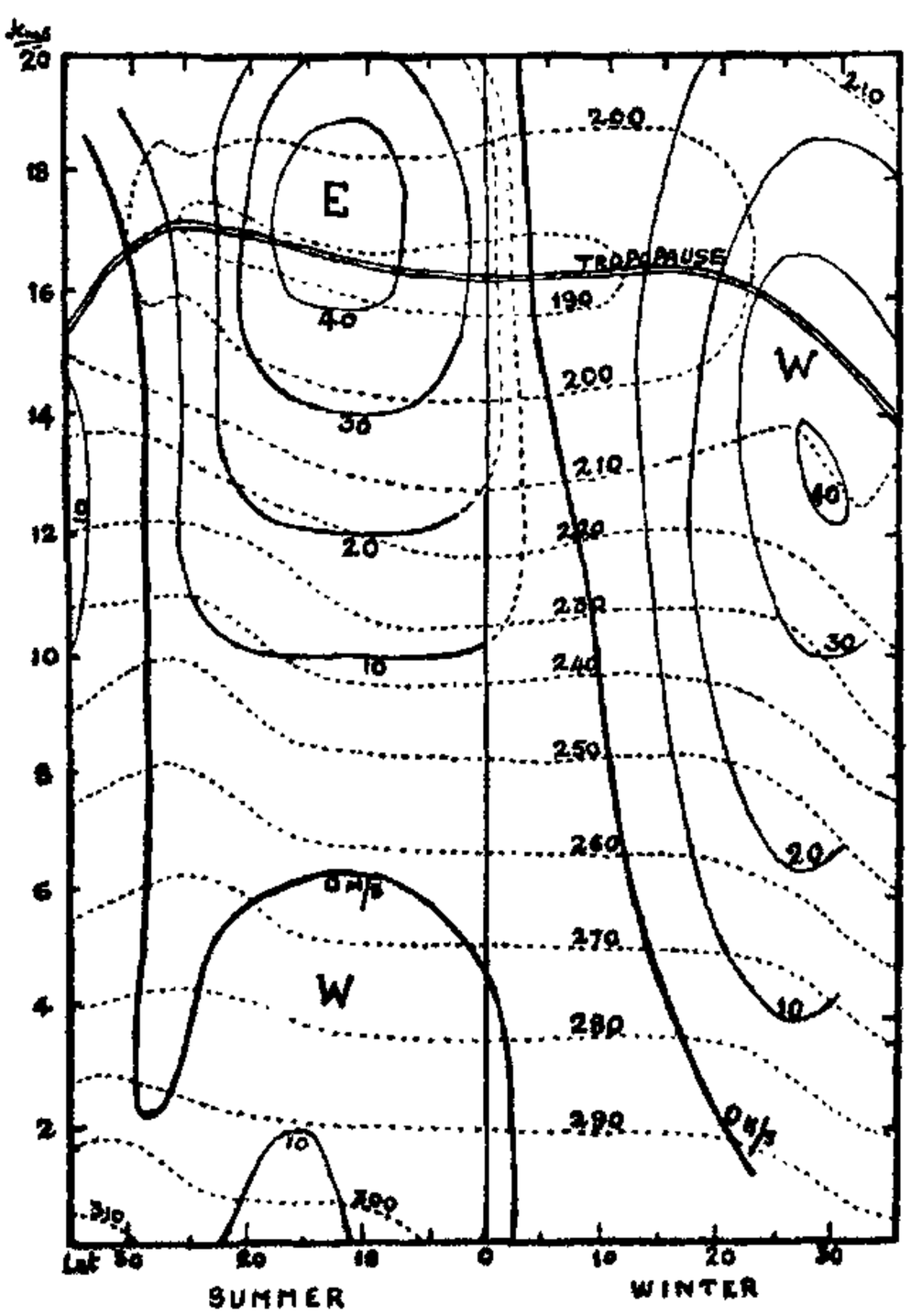

FIG. 1. East-West components of winds in m/sec. are shown by continuous lines and temperatures °K by dotted lines. Tropopause is shown by a double line.

(*a*) *In Summer* (*Monsoon*).—(*i*) Between latitudes 5° N. and 18° N., easterly winds increase rapidly with height above 10 km., reach a maximum of 40 metres per second (88 m.p.h.) between 7° N. and 15° N. at 16-18 km., near the tropopause, and decrease with height above 18 km. Thus, there is a well-marked vertical wind shear in these latitudes (5° to 18° N.) above 10 km. but very little horizontal wind shear. (*ii*) Between the equator and 5° N. and between 18° N. and 27° N. there is, above 10 km., a well-marked horizontal wind shear but very little vertical wind shear. In these latitudes, the highest wind speed in summer is apparently not reached at the tropopause but at some different height.

(*b*) *In Winter*.—(*iii*) Between latitudes 10° N. and 18° N. there is a well-marked horizontal wind shear above 6 km. with westerly winds but very little vertical wind shear. In this latitude range also, the highest wind speed in winter is apparently not reached at the tropopause but at some different height. (*iv*) Between 18° N. and 30-35° N., there is both horizontal and vertical wind shear, with westerly winds. The vertical wind shear is most prominent and well marked between 22° N. and 32° N. above 10 km. The westerly winds increase in speed with height, reaching a maximum of 40 metres per second (88 mp.h.) at a height of 12 to 14 km. between 25° and 30° N., and decrease with height above 14 km. It is thus seen that in these latitudes (25° to 30° N.) the maximum wind speed is reached at a height of 2 to 3 km. below the tropopause.

(c) Both in summer (monsoon) and winter, the regions in which there is marked vertical wind shear are separated by regions where there is marked horizontal wind shear. The marked horizontal wind shear is cyclonic to the north and anti-cyclonic to the south of the region of marked vertical wind shear.

3. As 'Jets' are narrow streams of air of small vertical extent, confined to a few degrees of latitude, with well-marked vertical wind shear with decrease of wind speed above and below them and with well-marked horizontal wind

shear to the north and south of them, it seems (para 2) that 'jet' streams are most likely to occur in the following regions over India. (*a*) Between latitude 5° N. and 18° N. in the south-west monsoon season near about the tropopause (16 to 18 km.) and specially between 7° and 15° N., the 'jet' wind will be easterly. (*b*) Between latitude 22° and 32° N. in winter, at 12 to 14 km., specially between 25° and 30° N., the 'jet' wind will be westerly.

4. It is known that a 'jet' stream is associated with a concentration of horizontal temperature gradient below it and occurs in a field of pronounced baroclinity. Horizontal temperature gradients calculated from Indian Sounding Balloon data over different latitudes show that there is a concentration of positive horizontal temperature gradients (*i.e.*, temperature increasing with latitude) below region (*a*) *i.e.*, 5° to 18° N. in the summer (monsoon) and of negative horzontal temperature gradients below region (*b*), *i.e.*, 22° to 32° N. in winter. This can also be seen from the slope of the isotherms in Fig. 1 which also indicate pronounced baroclinity in the regions (*a*) and (*b*).

5. It is seen further that region (b) covers the range of latitudes over which the transition from the tropical to the polar stratosphere occurs in winter. In this range of latitudes in winter, *e.g.*, over Agra (Lat. 27° N.), the double type of tropopause is fairly frequent and there are also a number of occasions when the polar type of tropopause occurs there at a height of 11 to 12 km. It is also interesting to note that both regions (*a*) and (*b*) occur over latitudes where pressure is highest at the surface in the respective seasons. Palmen[3] has shown that "the strongest west wind in the upper troposphere must be observed almost vertically above the sub-tropical high pressure belt, *i.e.*, around latitude 30°." This is found to be true over India and it is found further that the strongest east winds, in the summer (monsoon) near the tropopause, also occur vertically above the region of highest pressure at the surface over India.

6. While the existence of a westerly jet over the middle latitudes has been recognised and studied by various authors, notably by Palmen and co-workers, an easterly jet such as might occur in region (*a*) above near the tropopause has not so far been announced. In the meridional cross-section for summer along longitude 80° W. given by Hess[4] and that for August-September over the tropical Atlantic given by Vuorela,[5] concentration of easterly winds is shown just above the tropopause over the tropical latitudes. It is seen that over India a region of strong easterly winds with the characteristics of a 'jet' exists near the tropopause over latitudes 7° to 15° N. All indications therefore point to the existence of an easterly jet at or near the tropopause in summer over the low tropical latitudes. Examination of some high pilot balloon ascent data on a number of consecutive days over stations in South India below latitude 15° N. points to the existence of an easterly jet at 16 to 18 km. on individual occasions. On some occasions, the easterly winds have reached speeds of 80 to 90 metres per second (175 to 200 miles per hour).

7. Chaudhury[6] has discussed the existence of two westerly jets in winter over India near about the 200 mb. level (i.e., at about 12 km.), a "Himalayan Jet" at latitudes 30° to 35° N. and an "equatorial jet" at latitudes 15° to 20° N. The "Himalayan" jet occurs in region (*a*) above but the possibility of the "equatorial" westerly jet is not indicated by the normal wind, temperature and pressure distribution. It appears probable that Chaudhury's equatorial westerly jet is not a separate jet with marked vertical wind shear both above and below it, but is a concentration of westerly winds in the southern edge of the wind field of the 'Himalayan' Jet. Yeh[7] discussing the circulation of the high troposphere over China in winter also finds a westerly 'jet' at about latitude 30° N. but not another westerly 'jet' to the south of it.

8. It has been pointed out by Palmen[3] that the jets seen on the mean meridional cross-sections are not identical with "meandering" jet streams associated closely with polar front disturbances and that the latter phenomenon can hardly be studied by the aid of climatological data. While this may be so, there can be no doubt that the regions of about 10° latitude width, where mean 'jet' streams are shown, are the most likely regions where "meandering" jet streams will occur although in individual cases the jets may occur at different positions and heights, and with greater intensities than indicated by the highest mean wind speed within the mean "jet" region.

A detailed study of the subject is being made and the results will be published separately.

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1. Jerome Namias and Jerome F. Clapp. *J. Met.*, 1949, **6**, No. 5, Pp. 330. 2. Venkiteshwaran, S. P., *Mem. Ind. Met. Dept.*, 1950, **28**, Part II. 3. Palmen, E., *Quart. J. Roy. Met. Soc.*, 1951, **77**, Pp. 337. 4. Hess, Seymour. L., *J. Met.*, 1948, **5**, Pp. 293. 5. Vuorela, Laouri, A., *Ibid.*, 1948, **55**, 115. 6. Chaudhury, A. M., *Tellus.*, 1950, **1**, No. 1, Pp. 56. 7. Yeh, T. C., *Ibid.*, 1950, **2**, No. 3, Pp. 173.