

PROBLEMS OF TROPICAL METEOROLOGY AND THE RELATION BETWEEN THE CIRCULATIONS OF TROPICAL AND EXTRATROPICAL LATITUDES

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1. THE SCIENTIFIC basis of meteorology is the same, whether in the tropics or in the polar regions. But the tropics present special problems to the meteorologist, because they cover such a large part of the earth and, while the main source of energy of the atmospheric circulation is located there, the manner in which the energy of the absorbed solar radiation is transformed and converted into the energy of winds, zonal, meridional and as eddies can only be elucidated by reasoning based on extensive observation which is as yet available only in limited amounts.

Moreover, there is a seeming simplicity about the meteorology of the tropics, and the difficulties are hidden. The daily variations of temperature and pressure and of cloud formation and dissolution show up cellular and tide-like movements. Although some of the features of phenomena like the monsoons, tropical storms and easterly depressions are manifest at the surface and in the lower troposphere, the agencies controlling the movement of the disturbances are located higher in the atmosphere and observations of winds above clouds are as yet too few in the tropics.

The tropical tropopause is high and, during a large part of the year, there are strong upper easterlies whose maximum strength is reached generally at a higher level than that of the westerlies of middle latitudes.

Diagrams showing easterlies in the upper troposphere in different seasons prepared from radar observations made by the Indian Meteorological Department are shown in *Figs. 1* and *2*. For comparison, the upper wind data of Aden, Hongkong and Singapore taken from the publications of the scientific workers of the British Meteorological Service are also shown. The diagrams were prepared for me by my colleague Mr. K. P. RAMAKRISHNAN of the India Meteorological Department.

2. Tropical storms originate in warm seas in the region of the upper easterlies and move in the general direction of the currents in the upper troposphere and their movement is no doubt governed by the same general principles as those governing the movement of storms in middle latitudes, with upper tropospheric divergence in advance of the cyclone, and convergence behind. They move northward when they meet anticyclonic blocks and recurve eastward when they come under the influence of eastward-moving troughs in the upper westerlies of higher latitudes.

3. Besides the fully developed tropical storms, there occur waves in the upper easterlies with which are associated feebler disturbances of a cyclonic character. Often during the monsoon months in S.E. Asia, two or three cyclonic disturbances are present at the same time, all moving westward; one may be in Indo-China, another over the head of the Bay of Bengal and a third over Kathiawar. A certain spacing (of the order of 20°) seems to be required to maintain their individuality. If the westernmost depression meets an anticyclonic block, it either dies out or moves towards the northeast.

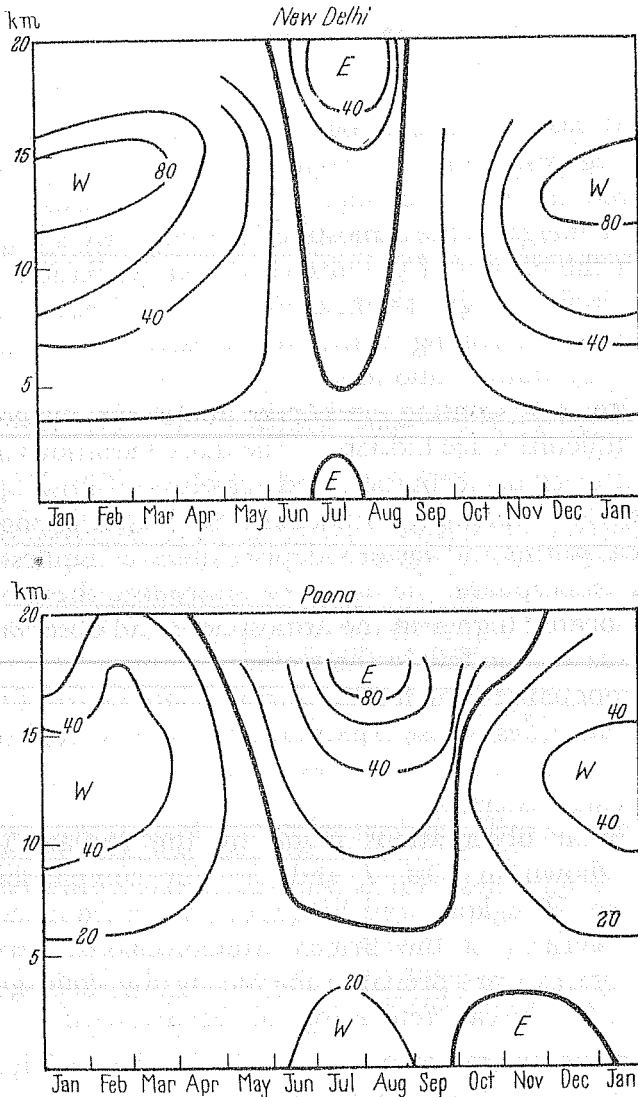


Figure 1

These disturbances are coupled to waves in the upper easterlies and often have large rainfall areas associated with them.

When the upper easterlies are well established over India, there is a regular succession of waves. Indeed, the monsoon is made up of these disturbances.

4. In the lower atmosphere, the moisture supply for the depressions during the monsoon comes from the southern hemisphere, generally in pulses. During the war, there were island observatories in the Indian Ocean at

Addu Atoll at 1° S and at Diego Garcia: they were very useful stations. Mr. MALURKAR¹ of the India Meteorological Department, who has given a good deal of attention to this problem, often noticed easterly waves in the upper air moving westward in the Indian Ocean south of the equator preceding a strengthening of the northward flow of air across the equator. The associated changes of pressure at sea-level were small.

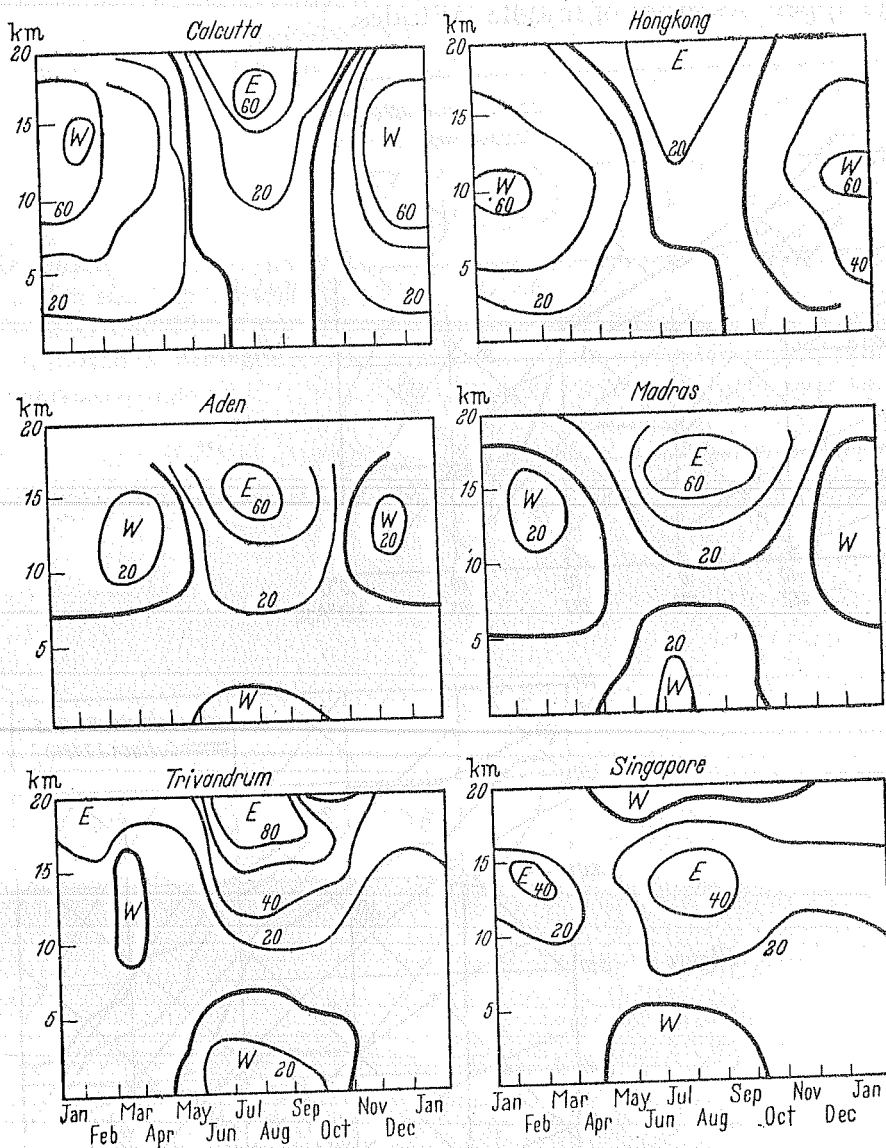


Figure 2. Upper winds over South Asia

5. The winter disturbances which move across N. India from December to April or May are wave-like disturbances in the upper troposphere. Not all of them cause clouding and rainfall. Southerly air at lower levels from the western side of the anticyclone is usually drawn in, but if this moist air originally formed part of the easterly stream at lower latitudes, the clouding and precipitation and vortex formation are more pronounced. Often, the upper wave above 6 km passes on, leaving a vortex in orographically favourable situation like the Punjab. These vortices gradually weaken and die.

6. The coupling of tropical depressions and storms and upper easterlies have been guessed at, but not established.

7. Studies of the movement of cirrus cloud and of winds² between 12 and 18 km over India^{3, 4} show that even in seasons of generally clear weather, the movement in the upper troposphere is from SW to NE and E and rarely in the opposite direction. In the upper troposphere, the easterlies seem to feed into the upper westerlies of middle latitudes.

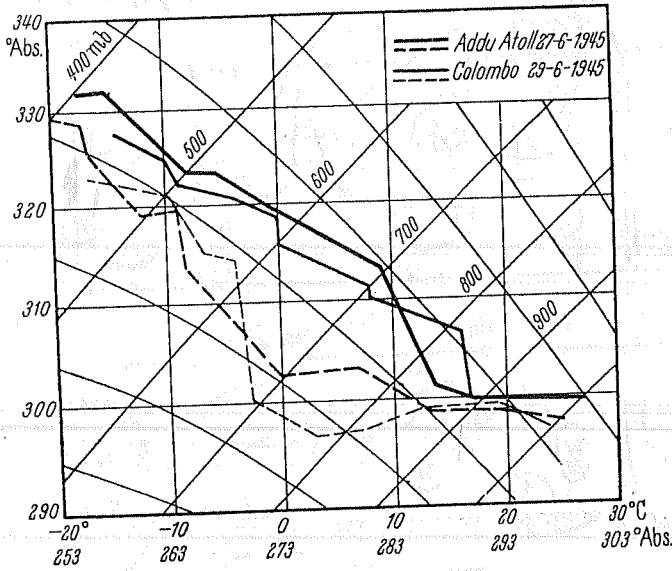


Figure 3

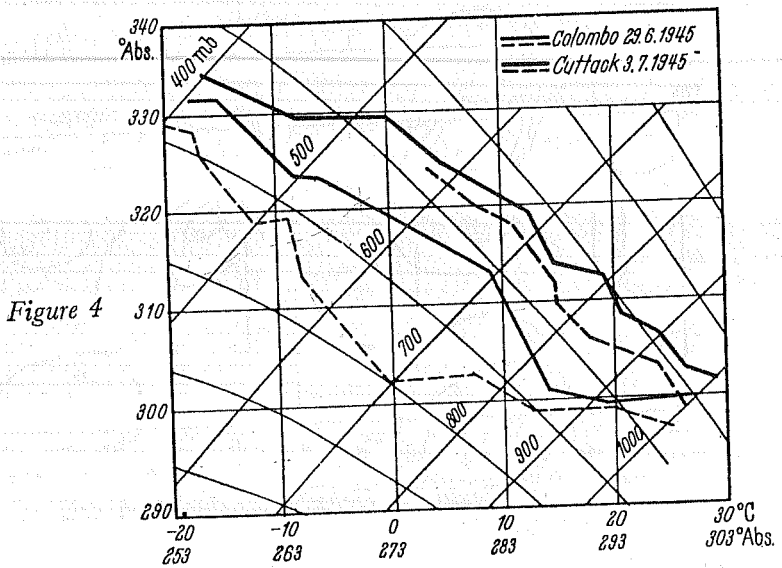


Figure 4

8. The trade inversion has been the subject of much study and is receiving further detailed attention from meteorologists in the U.S.A. It is a question of some interest to consider how the trades of the S. Indian Ocean transform into the monsoon of S. Asia. We do not know enough about it. Two diagrams prepared by Dr. PISHAROTI are of interest in this connection. On crossing the equator, the monsoon current is less than 2 km deep. Typical

tephigrams of ascents at Addu Atoll and Colombo at the end of June are shown in *Fig. 3*, and the tephigram of upper-air conditions over Colombo and Cuttack (20° N) in *Fig. 4* for comparison. The deepening of the moist stream seems to take place north of the equator as a result of low-level inflow from the southern hemisphere, convergence and ascent into the upper easterlies which carry away the excess of air westward.

More detailed comparative studies of the structure of the atmosphere in trade and monsoon regions are called for.

REFERENCES

- 1 MALURKAR, S. L., 'Analysis of Weather of India and neighbourhood' *Mem. Indian met. Dep.* 28 (1950) IV
- 2 RAMANATHAN, K. R. and RAMAKRISHNAN, K. P., 'The general circulation of the Atmosphere over India and neighbourhood' *Mem. Indian met. Dep.* 26 (1939) X.
- 3 VENKITESHWARAN, S. P., 'The upper winds at 10 km and above over India and its neighbourhood' *Mem. Indian met. Dep.* 28 (1950) II
- 4 KOTESWARAN, P. and PARTHESARATHY, S., 'The mean jet-streams over India' *Indian J. met. Geophys.* 5 (1954) 138