Air-Mass Dynamics or Subsidence Processes in the Arabian Sea Summer Monsoon?

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1. Introduction

Two papers with the same title, "The Summer Atmospheric Circulation over the Arabian Sea", were recently published in this JOURNAL (Ramage, 1966; Desai, 1967), which gave different opinions to a problem which has been under discussion for several years, i.e., Is the inversion over the Arabian Sea and over northwest India and West Pakistan due to conversative air-mass properties or due to subsidence? Desai considers the former interpretation, substantially valid up to some years ago, while Ramage's paper makes a contribution to more quantitative considerations of the effects of large-scale subsidence in causing the droughts in parts of the Arabian Sea and northwest India. In the Meteorological Institute of the University of Bonn investigations of this problem have also been made; the results will be presented in two maps.

2. Divergence and convergence over the Arabian Sea

In connection with detailed studies of summer air-sea interaction in the Arabian Sea, charts of horizontal divergence of the surface wind were constructed. Basic data for each of the 2°×2° fields were taken from the atlas published by the Royal Netherlands Meteorological Institute (1952).

Fig. 1 shows the smoothed surface divergence pattern for July, the month of the best developed southwest monsoon. Due to the strong correlation between the mean horizontal divergence and rainfall frequency (Riehl, 1954; Flohn, 1957), Fig. 1 may be compared with Ramage's Fig. 2. The striking features are:

1) The concentration of divergence in the western part of the Arabian Sea. This area is in rough agreement

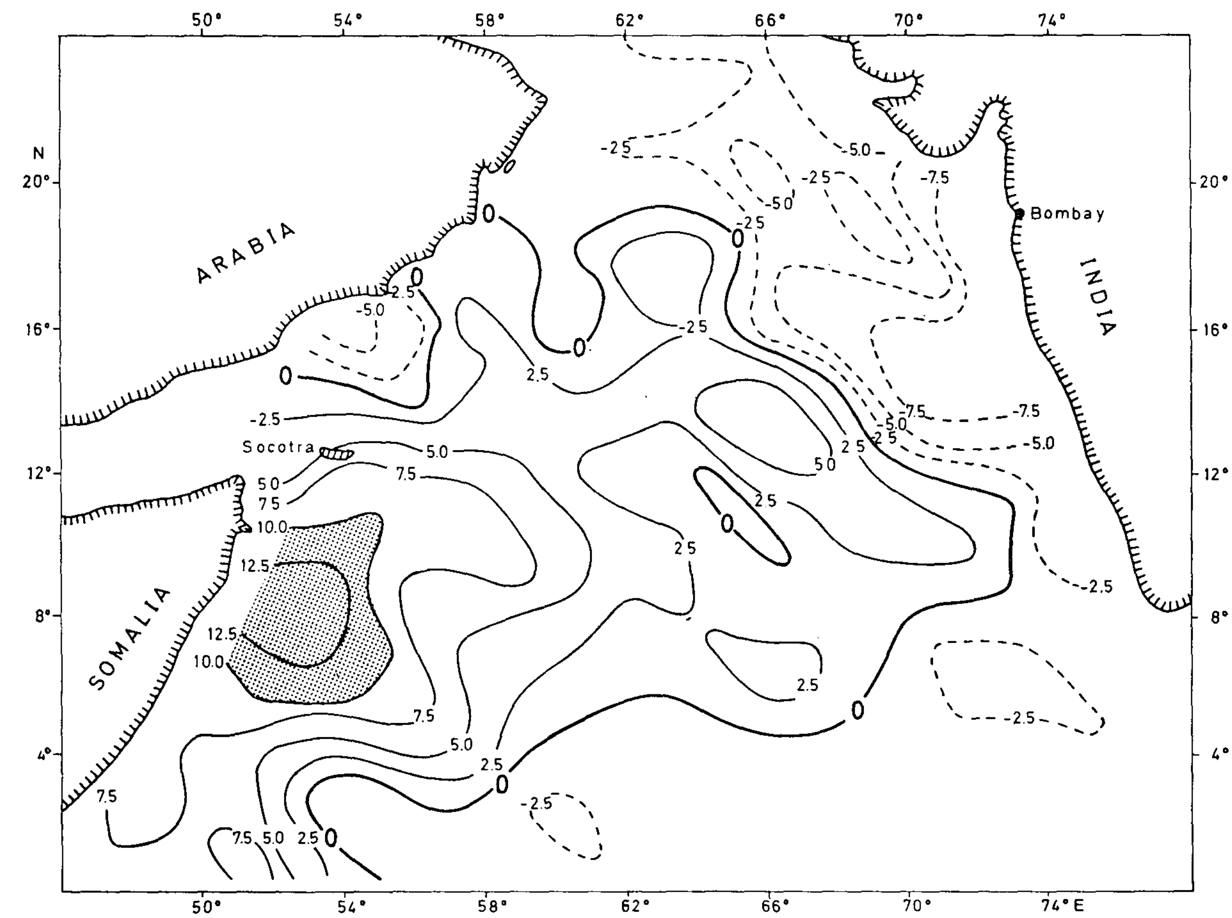

FIG. 1. Divergence [10^{-6} sec^{-1}] of surface wind, July.

with the region of minimum precipitation and with the region of lowest position of the inversion base level.

2) The concentration of convergence (div $\mathbf{v}<0$) in the eastern part of the Arabian Sea. This area agrees well with the region of maximum frequency of precipitation in the eastern Arabian Sea near latitude 15N.

The divergence patterns for the adjacent months are similar. While the absolute values are a little smaller, the maximum values in June and August nevertheless exceed $10\cdot10^{-6}$ sec^{-1}.

In a recent paper (Flohn, 1965) the large-scale divergence of the southwest monsoon along the Somali Coast has been correlated with the existence of a persistent heat low in the Danakil desert, which produces a strong zonal pressure gradient at latitude 8–12N. Therefore, the marked divergence seems to be of quasi-geostrophic origin.

3. Vertical velocity over northwest India and West Pakistan

In a separate investigation (Ruprecht, 1964), vertical velocities over northwest India and West Pakistan were calculated using the vertically integrated equation of continuity. Basic data were the pilot-balloon ascents

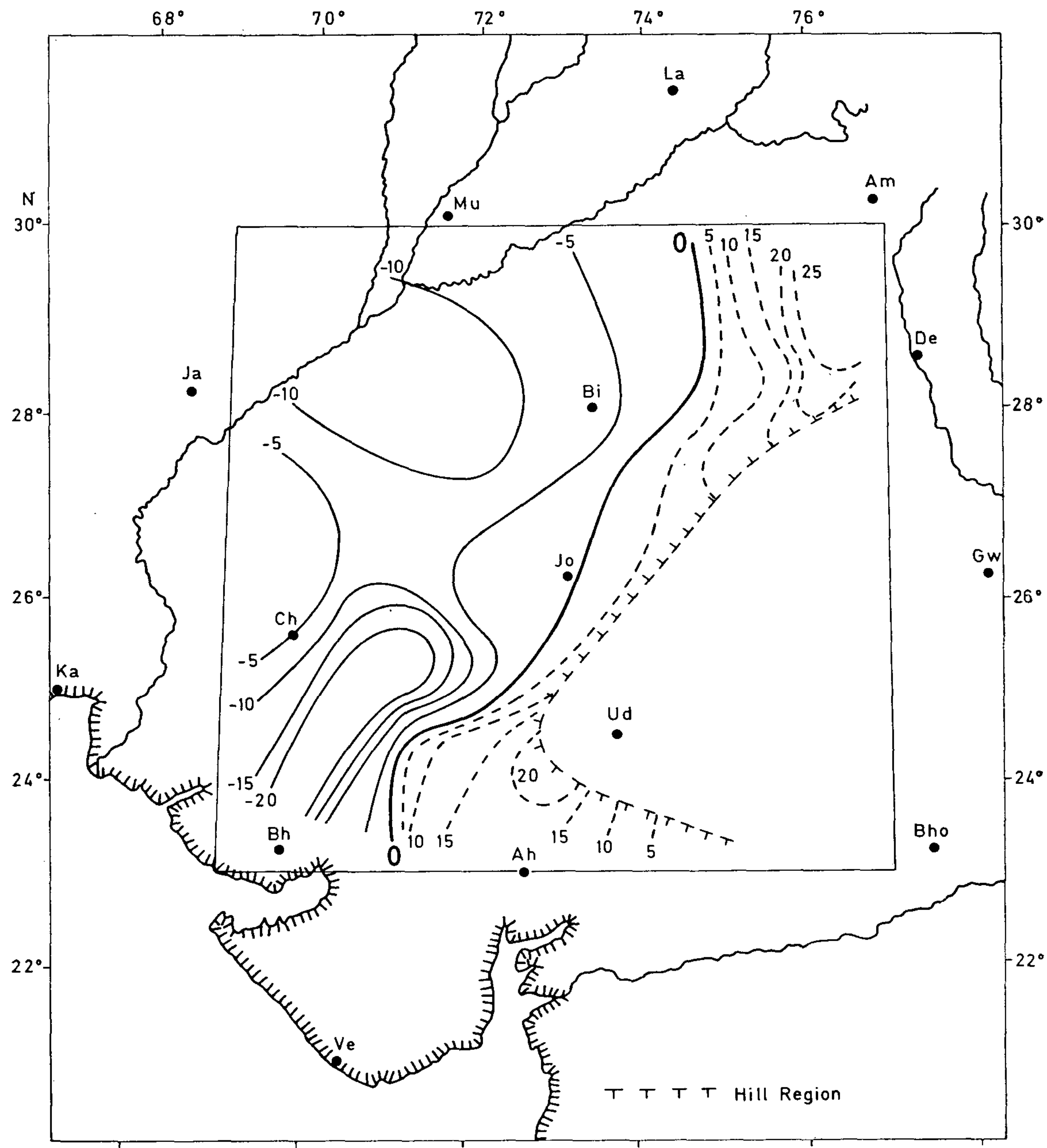

FIG. 2. Vertical velocity [mm sec^{-1}] at 1.5 km MSL, July–August. Pilot-balloon stations are indicated by dots.

of July and August 1951–1954. From these mean wind records, charts of the vertical velocities at three levels (0.6, 1.5 and 2.1 km MSL) were constructed. Fig. 2 gives the result, at 1.5 km.

The analysis agrees well with both 1) Ramage's description that the region of no or little precipitation (Desert of Thar) is covered by large-scale subsidence. (A vertical section taken from the three above-mentioned charts shows an increase of subsidence with height in the layer 0.6 up to 2.1 km.) As the wind speed decreases to the north a difluence of the horizontal wind produces this subsidence; and with 2) the investigation of Das (1962, Fig. 5) concerning the vertical motion over India during the monsoon. Das calculates the vertical velocity in pressure coordinates from the vorticity equation. In spite of this quite different method of computation his distribution of subsidence and lifting coincides quite well with the pattern of Fig. 2. Beyond that, the cm sec^{-1} order of magnitude of the vertical velocity is the same.

In this area the subsidence seems to be produced by two independent factors: 1) the difluence of the southwest monsoon current caused by the deep heat low in Punjab. The thermal wind pattern shows the temperature maximum of the lower troposphere to be located above the mountains of Baluchistan; and 2) the dynamically forced subsidence from above in the exit region of the tropical easterly jet east of 78E and north of its axis near 15N. The decrease of the wind speed along the core of the jet, as initiating the extended region with its dynamical implications, seems to be caused by the large vertical momentum exchange between the lower westerlies and the upper easterlies in the area of the convective maximum of monsoon showers along the west coast of the peninsula.

4. Concluding remarks

As in other areas, conservative air-mass properties are by no means self-explaining, but can be easily understood as related to the dynamics of the wind field produced by differential heating and orography. It seems to be somewhat unlikely that the 500-km wide convergence zone off the west coast of the peninsula is related to orography alone (Desai, 1967). There seems to be a mutual interaction between the vertical momentum exchange (also producing convergence in the lower westerlies) and the ferquency of convective showers. It is to be hoped that numerical evaluation of reliable and representative upper wind data may shed further light on the mechanism of the Indian summer monsoon and into its very complex relation to the seasonally varying rainfall pattern.

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