Indian J. Met. Hydrol. Geophys. (1978), **29**, 1 & 2, 303-307

551.553.21 : 551.513 (267)

A simple calculation of the sea level trajectories over the Indian Ocean

G. V. RAO* & W. C. BOLHOFER*

St. Louis University, St. Louis

and

H. M. E. VAN DE BOOGAARD

National Center for Atmospheric Research, Boulder†

ABSTRACT. Quasi-horizontal, 48 hr air trajectories are constructed over the Indian Ocean utilizing a mean sea level map for July and a series of daily maps in June 1970. The purpose of this calculation is to provide a field of trajectories based on the broad scale pressure gradient. Special emphasis is placed on those trajectories associated with the East African jet, the southern equatorial trough and the monsoon trough.

Results included in this article showed that reasonably representative trajectories were calculated. Furthermore, the derived vorticity and divergence fields (not shown here) showed fair association with the significant synoptic features.

1. Introduction

Intense observational and theoretical studies of the monsoon are being contemplated in connection with MONEX (*see* WMO Joint Organizing Committee 1976).

A correct description of the low level atmospheric flow across the equator in the summer months in the Indian Ocean is very important to understand some aspects of the Southwest Monsoon. Although such a flow is reasonably well delineated near the East African coast, its detailed description in the Central Equatorial Indian Ocean is very difficult because of the presence of a Southern Equatorial Trough [SET, called Southern Hemisphere Equatorial Trough by Raman (1965)], and lack of adequate observations.

An objective of this article is to provide a field of sea level trajectories emphasizing their association with the East African jet, the SET, and the monsoon trough. Steady, and later, time dependent pressure fields are employed to calculate the 48-hr trajectories.

2. The model

The model Lagrangian equations

$$\frac{du}{dt} = -\alpha \frac{\partial p}{\partial x} + fv - \lambda u \qquad (1)$$

and

$$\frac{dv}{dt} = -\alpha \frac{\partial p}{\partial y} - fu - \lambda v \qquad (2)$$

similar to those employed by Gordon and Taylor (1975) are integrated using the Hamming's (1959) modified predictor-corrector technique over the

*Summer visitors to NCAR where the computations reported were made in 1975 and 1976.

†The National Center for Atmospheric Research is sponsored by the National Science Foundation.

area bounded by 20°N, 35°S, 35°E and 95°E. This area can be identified in Fig. 1. Standard notation is employed in Eqns. (1) and (2). Frictional force is assumed to be λ times the wind speed. The values of λ used by the earlier investigators varied between 0.6 and 2.5×10^{-5} s^{-1}. However, realistic trajectories are obtained in this study by varying λ as follows :

(a) $\lambda = 1.5 \times 10^{-5}$ s^{-1} between 25°N and 5°N;
(b) a near zero value (10^{-8} s^{-1}) between 5°N and 5°S;
(c) $\lambda = 10^{-5}$ s^{-1} between 5°S and 40°S.

According to Gordon and Taylor (1975) errors in the pressure field of the order of 0·3 mb in 500 km result in displacement errors, δx, of 4·5° in 70 hrs. Further more, errors in the initial velocity field of the order of 1 m s^{-1} are not believed to severely distort the computed trajectory field.

A possible total of 156 trajectories are launched—one from each of the 5×5 degree grid squares.

3. The initial data

Fig. 1 shows the mean July pressure field (van de Boogaard 1976). The principal features are the Mascarene High, the SET, the ridge along the African coast, the heat trough over Arabia and the monsoon trough.

Fig. 2 depicts the initial wind-field of a mean July map (van de Boogaard 1976). Strong winds are observed in the Indian Ocean near 10°S and in the Arabian Sea. Moderately strong winds occur in the Bay of Bengal. Weak winds characterize the SET area.

Fig. 3 shows the surface pressure field for 12 GMT of 14 June 1970*. Noteworthy features are the Mascarene High, the SET and the monsoon trough. The 48-hr trajectories were calculated on the basis of three pressure fields (14, 15 and 16 June) available at intervals of 24 hours. Although the calculation was made for 11, 13, 14, 15 and 16 June, only those for the 14th are shown in this article.

The initial wind field for 12 GMT of 14 June can be seen in Fig. 4. Strong winds prevail near the African coast 5°S and 45°E, Central Arabian Sea and the Bay of Bengal. Weak winds exist in the vicinity of SET.

4. Results

Fig. 5 shows the 48-hr trajectories for the mean July map. Of interest are the southeasterly movement of the trajectories over the Central Indian Ocean near 10°S, the development of southerlies and southwesterlies near the West Central Indian Ocean forming part of the East African jet and the southerwesterly flow over the Arabian Sea. Furthermore, the clustering of the trajectories in the Bay of Bengal in conjunction with the monsoon trough and a similar clustering in the Central Indian Ocean in association with SET are the noteworthy features.

Since the pressure field is invariant locally in this part of the calculation the computed trajectories coincide with the streamlines. The intersection or clustering of some trajectories is simply a consequence of the quasi-horizontal motion constraint and is similar to the clustering experienced by a group of constant level balloons (Messinger 1965).

Figs. 6(a) and 6(b) show the 48-hr trajectories based on the 12 GMT of 14 June 1970 map. A linear interpolation in time utilizing the next two maps separated by 24-hr permitted a consideration of the temporal variation of pressure. While there are many similarities between these figures and Fig. 5, some differences in detail are also evident, *e.g.*, some of the mean July trajectories launched from 5°S and the equator west of 70°E showed a tendency to go either over the Arabian Sea or strike the west coast of India. The bulk of the trajectories in June tended to partake in the SET circulation. This resulted in the June SET developing more clustering of the trajectories than the one in mean July. Evidently this difference and others are as a consequence of the temporal variations in the pressure and the initial velocity fields.

On the basis of the calculation of the 48-hr trajectory fields for 11, 13, 15 and 16 June (not shown here) it can be said that in some areas trajectories launched from two adjacent points can describe widely differing air motions because of varying pressure gradient and coriolis forces.

Cadet and Ovarlez (1976) tracked some constant level balloons launched from Seychelles (4° 35′S, 55° 27′E) in June , July and August 1975. They observed that the courses of the balloons showed some important differences from time to time. These differences are partly attributable to the pressure changes in association with the Mascarene High, the SET and the monsoon trough. Our

*The June 1970 surface charts were analyzed as part of a basic data set by van de Boogaard in collaboration with J. C. Jusem of the University of San Jose, Costa Rica.

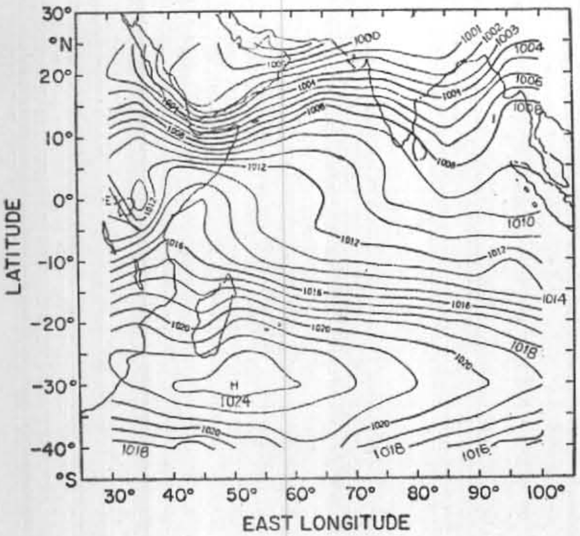

Fig. 1. July mean sea level isobars (mb). The main features are the Mascarene High, the Southern Equatorial Trough (SET) and the monsoon trough (from van De Boogaard 1976)

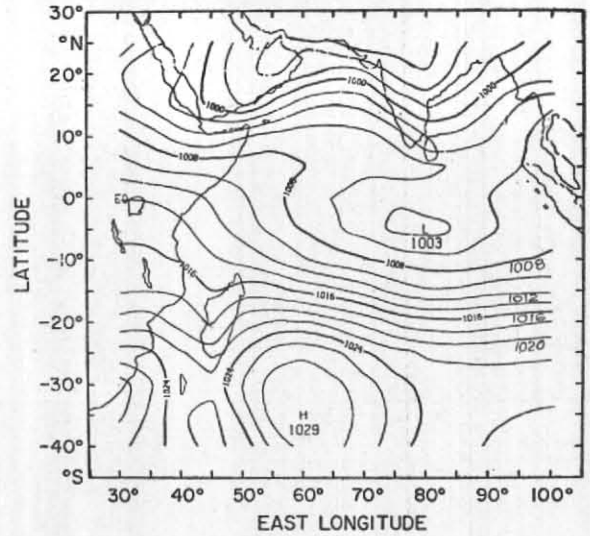

Fig. 3. Sea level isobars (mb) for 12 GMT of 14 June 1970

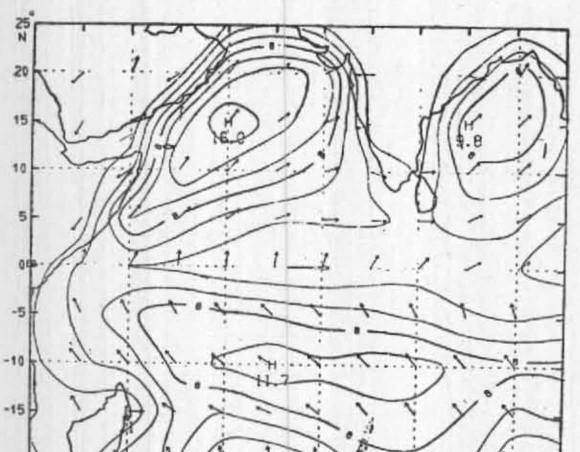

Fig. 2. Initial winds (ms^{-1}) used in conjunction with Fig. 1

(July mean wind, contour interval of 2m sec^{-1})

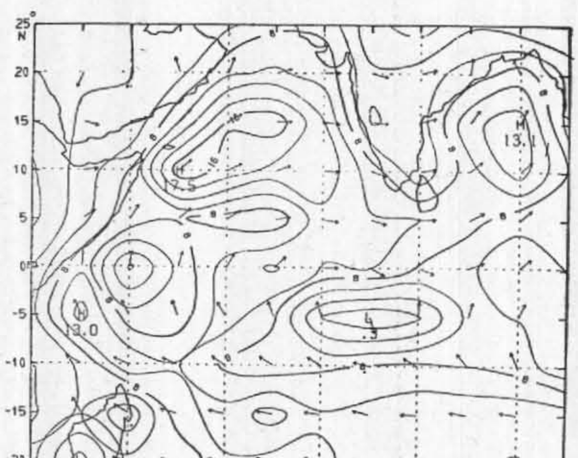

Fig. 4. Initial winds (ms^{-1}) used in conjunction with Fig. 3. (Initial wind on 14 June 1970 at 1200 GMT. Contour interval at 2 m sec^{-1})

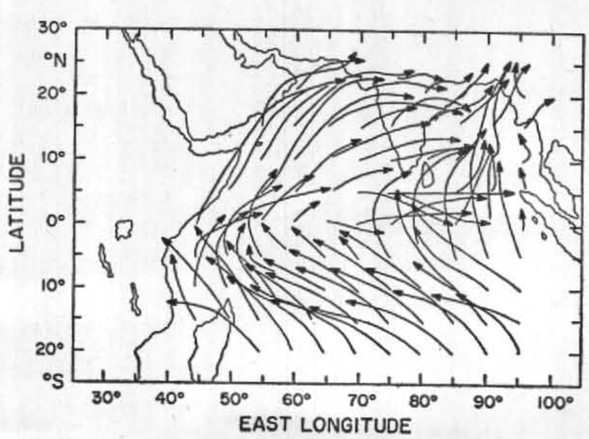

Fig. 5. 48-hr trajectories based on the mean July map

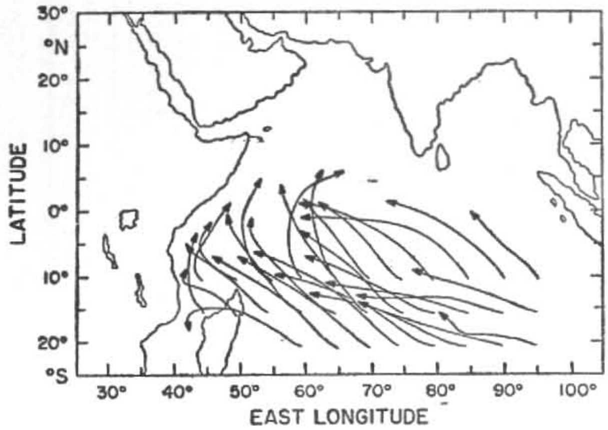

Fig. 6 (a). A partial set of 48-hr trajectories based on 12 GMT of 14 June 1970

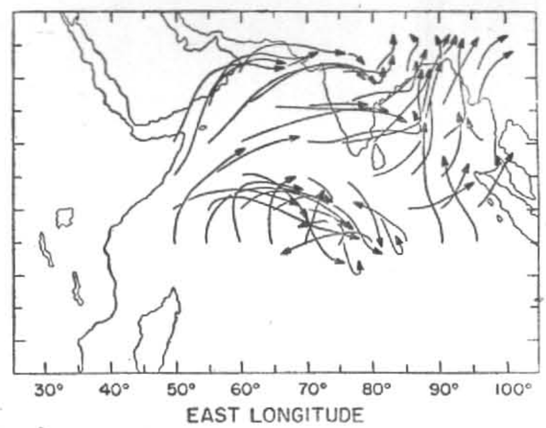

Fig. 6 (b). Same as Fig. 6 (a). To preserve clarity in the vicinity of SET only portions of the 48-hr trajectories are shown

calculation for certain days in June 1970 also noted such temporal dissimilarities in the courses of trajectories.

5. General remarks

The above account shows that the observed low level cross-equatorial flow in the Indian Ocean can be reproduced through a Lagrangian calculation based on a given pressure field and an initial velocity field. It also demonstrated the feasibility of calculating a field of such trajectories and using the results to supplement our understanding of the flow patterns in data-deficient areas such as the equatorial oceanic tropics. The clustering of the trajectories denotes the convergence locations, *e.g.*, areas like SET and the monsoon trough while the areas void of trajectories signify divergence; *e.g.*, those west of Sri Lanka in Fig. 6(b).

REFERENCES

Cadet, H. and Ovarlez, H. 1976 *Quart. J. R. Met. Soc.*, **102**, pp. 805-816.

Gordon, A. H. and Taylor, R. C. 1975 *I.I.O.E. Met. Monogr.*, **7**, 112 pp., Univ. of Hawaii Press.

Hamming, R. W. 1959 *J. Assoc. Comp. Mach.*, **6**, pp. 37-47.

Messinger, F. 1965 *J. atmos. Sci.*, **22**, pp. 479-492.

Raman, C. R. V. 1965 Cyclonic vortices on either side of the equator and their implications Symp. Met. Res. of I.I.O.E., Bombay, pp. 115-163.

Van de Boogaard, H. M. E. 1976 Quasi-steady state regime of the atmospheric circulation in the tropics, **3**, July NCAR/TN—118 STR.

WMO, Joint Organizing Committee 1976 *The Monsoon Experiment*, GARP Publ. Series, **18**, 123 pp.

DISCUSSION

(Paper presented by G.V. Rao)

K.R. SAHA : In one of your initial pressure maps you showed a low pressure centered almost on the equator. What sort of trajectory of air you obtained in this case?

AUTHOR : As seen from another figure clear convergence is taking place into that low.

COMMENT

P.R. PISHAROTY : Very interesting paper. It is gratifying to note that the computed trajectories and the observed trajectories by Dr. Daniel Cadet agree. Looking at the trajectories only those which cross the equator west of long. 50°E, reach the west coast of India. Hence to investigate the contribution of the evaporation from the Arabian Sea to the flux of water vapour across the west coast of India, instead of using a rectangular box extending all along the equator to 75°E, one should compute the flux from southern hemisphere only for the equatorial strip westwards of 50° E to the Garissa. Of course we should confine ourselves to that part of the Arabian Sea, which is north of the trajectory across equator at 50°E and moving along the Arabian Sea to Cape Comorin.