AIR-MASS DYNAMICS OR SUBSIDENCE PROCESSES IN THE ARABIAN SEA MONSOON

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Abstract

Soundings over the Arabian Sea during the International Indian Ocean Expedition period and climatological data over the west coast of India have been discussed to determine the cause of the low-level inversion and the influence of the Western Ghats on the inversion and precipitation. There does not appear relation between maximum divergence and lowest height of base of inversion as presumed by Flohn *et al.* The pattern of precipitation frequency on the west coast as seen from Fig. 2 of Ramage does not show the same trend either as the number of rainy days or rainfall at the coastal observatories. The depth of the moist layer and the height of base of inversion increase as the Western Ghats are approached, such changes not occurring off west Kathiawar-Kutch-Sind where there are no orographic barriers on the coast.

The air-mass considerations to explain the low-level inversion over the Arabian Sea, would appear substantially valid even now.

Introduction

Desai (1966, 1967–1, 2) has discussed this question and put forward the view that the low-level inversion over the Arabian Sea is an air-mass one. Ramage (1966) and Flohn *et al.* (1968) consider that the inversion is due to subsidence. As this question is important for understanding the problem of southwest monsoon, it is proposed to discuss the same with reference to the International Indian Ocean Expedition (IIOE) data over the Arabian Sea and other relevant climatological data for the west coast of India.

Discussion

(*a*) Study of individual sounding data during the IIOE period over the western Arabian Sea reveals the following:

(i) The inversion develops *from the sea-surface* off Somalia from north of about Lat. 8·5 to 12·5° N and over the Gulf of Aden and off the Arabian

coast, humidity decreasing with height. The inversion was generally deeper over the area of upwelled cold water off Somalia than elsewhere.

(ii) The inversion develops beyond 100–200 km. off the Somalia-Arabian coast *only above the sea-surface* at varying heights. The air in the surface layer below the inversion was moist and had unstable lapse, humidity being generally highest near the base of the inversion. There was higher temperature and lower humidity at the top of the inversion north of about Lat. 9° N than further south.

Temperature and wind conditions and synoptic features over the entire area from about Lat. 8·5° N off Somalia to 22° N off the Arabian coast where the inversion begins *at the surface* and further east where it begins *at some height above the sea-surface*, would not ordinarily appear such as to produce from the stable air-mass extending from the surface to the top of the inversion, a moist air-mass with unstable lapse within a short distance of 100–200 km. to the east with humidity more than 90% at the base of the inversion. The tephigrams show decrease generally with height both in relative and specific humidity in and above the low-level inversion. It would appear that the inversion developed *from* the surface due to air travelling over the colder sea-surface. Where it began *above* the surface, it was due to the warmer air overrunning the cool and moist air of oceanic origin or the latter advancing as a wedge under the former. The low-level inversion over the western Arabian Sea would thus appear to be an air-mass one.

(iii) South of Lat. 8·5° N inversion has not been noticed to develop *from* the sea-surface. Observations during the IIOE period at Lat. 7° N, Long. 52° E, Lat. 6·5° N, Long. 50° E, Lat. 5° N, Long. 49° E and Lat. 0·4° N, Long. 45° E have shown inversion or isothermal layer to begin *only above* the sea surface, there being generally deflected trades in the surface layers below. Thus between the Somalia coast and about Long. 56° E from Lat. 4 to 8° N, there would appear presence of inversion *only above* the sea-surface as further north beyond 100–200 km. off the coast from Lat. 8 to 12° N, with base at varying heights.

From the data about height of base of inversion in the western Arabian Sea given in (i) to (iii) above, it would appear that there is *no relation* between the lowest height of base (Fig. 2 of Ramage) and maximum divergence (Fig. 1 of Flohn *et al.*). Little or no precipitation over the area is apparently associated with the air-mass inversion, there being absence ordinarily of any mechanism sufficiently strong to break it up.

(iv) The air-mass stratification of the western Arabian Sea—moist cool air with unstable lapse in the lower levels and drier air with unstable lapse or less moist air with nearly saturation adiabatic lapse above with an inversion between the two, would appear to be present further east north of about Lat. 10° N; there was slight increase in the depth of the moist layer and in specific humidity from the Somalia–Arabian Coast upto Long. 68° E due to unstable lapse and strong wind conditions. According to Fig. 1 of Flohn *et al.*, there is divergence over most of this area.

(v) Within about 500 km. of the west coast of the Peninsula south of about Lat. 20° N, the depth of the moist layer appeared to increase and the inversion base raised appreciably as seen from some sounding data (also from Fig. 2 of Ramage) as the Western Ghats were approached although there were no major synoptic features over the area and even when the monsoon was weakening in terms of rainfall on the coast. Such changes in the depth of the moist layer and height of base of inversion would *not* appear to occur north of about Lat. 21° N off west Kathiawar-Kutch-Sind where there are no orographic barriers on the coast. One would, therefore, be inclined to consider that between about Lat. 10 and 20° N, the Western Ghats are responsible for increase in the depth of the moist layer and for raising the base of inversion.

(vi) No inversion is noticed at Bombay near Lat. 19° N, Long. 73° E and at Minicoy near Lat. 8° N, Long. 73° E, during July. Absence of inversion at Bombay is due to the influence of the Ghats to its east. At Minicoy absence of inversion cannot, however, be attributed to the same cause as the Ghats extend only upto about Lat. 8° N on the coast and their southern end is about 500 km. to its east. The air-mass stratification mentioned under (iv) does not ordinarily extend south of about Lat. 9° N. There is thus a different air-mass over Minicoy; it is similar to that over the south and southeast Bay of Bengal from the equatorial trough side, there being no low-level inversion near the equator east of about Long. 60° E as seen from Fig. 2 of Ramage as well as from the data for July at Gan just to the south of equator and near Long. 73° E.

(*b*) According to Fig. 1 of Flohn *et al.*, Amini Devi at Lat 11·12° N, Long. 72·72° E, is just near the boundary between the divergence and convergence zones. Yet, it has 17·2 rainy days (2·5 mm. or more rain in a day) in July against 26·5 at Calicut (Lat. 11·25° N, Long. 75·78° E) on the coast, the rainfall at the two places in the same month being 31·63 and 86·00 cm. respectively. Most of the rainfall over this area during July

is not due to convective processes set up by insolational heating; there are also no major synoptic features in the form of depressions and cyclones in July. The trough produced in the moist current over the east Arabian Sea when the monsoon is strong or strengthening, at a distance of 100–200 km. from the coast presumably due to the influence of the Ghats, is probably responsible for most of the precipitation. Such troughs are not produced north of Lat. 21° N off west Kathiawar-Kutch-Sind, there being no mountain barriers on that coast.

(*c*) The precipitation frequency in Fig. 2 of Ramage is maximum near Lat. 13° N (being more than 12), decreasing to about 6 at Lat. 20 and 8° N. In Table I are given rainfall and number of rainy days at the observatories on the west coast during July and August.

It will be seen that during July the number of rainy days increases from 15·6 at Lat. 8·48° N, to 29 at Lat. 14·28° N; thereafter, the variation is within 2 rainy days upto Lat. 17·82° N and the number is about 24 between Lat. 18·63 and 19·97° N. Rainfall increases from 21·54 cm. at Lat. 8·48 N to 117·62 cm. at Lat. 14·28° N; it then decreases northwards but there are peaks at Lat. 15·87, 16·98 and 19·12° N. The influence of the Ghats on rainfall is on the entire coast and *not only* on any particular area. In August there is the same trend although both the rainfall and number of rainy days decrease, the former more than the latter. The variations in rainfall at different stations are considered to be due to the distance of the Ghats from the station and the gradient of upslope of 150 m. contour (Raghavan, 1964). 150 m. contour is probably important because the deflected trades having high humidity, only a little uplift is enough to give considerable precipitation; it is known that nimbostratus base is as low as 100 m. at some of the coastal stations.

On the west Kathiawar-Kutch-Sind Coast rainfall is considerably small when compared with the west coast of the Peninsula due to absence of orographic barriers there.

The precipitation frequency on the coast from Fig. 2 of Ramage gives a picture much different from that given by the number of rainy days (Table I). In view of the distribution of rainfall and number of rainy days on the west coast and the fact that rainfall is relatively small on the east coast of peninsula, it would not appear advisable to use maximum precipitation frequency to draw conclusions about the influence of the tropical easterly jet as done by Flohn *et al.*

TABLE I

Station	Lat. ° N	July		August	
		Rainfall in cm.	Rainy days	Rainfall in cm.	Rainy days
Dahanu* ..	19·97	93·58	23·5	54·44	20·9
Santacruz* ..	19·12	94·54	24·3	66·04	24·2
Colaba ..	18·90	70·95	23·5	43·93	19·1
Alibag ..	18·63	69·93	24·2	44·47	21·0
Harnai* ..	17·82	95·20	26·7	63·87	24·1
Ratnagiri ..	16·98	96·91	27·4	66·10	25·7
Devgarh* ..	16·38	83·48	26·6	48·18	24·1
Vengurla* ..	15·87	114·97	28·0	58·58	25·4
Marmagaon ..	15·42	90·51	26·5	41·29	21·9
Karwar† ..	14·78	98·63	27·3	48·03	23·8
Honavar* ..	14·28	117·62	29·0	63·85	25·2
Mangalore ..	12·87	105·86	28·7	57·69	24·3
Calicut ..	11·25	86·00	26·5	40·49	20·0
Cochin ..	09·97	57·19	23·9	38·57	19·3
Alleppey* ..	09·25	52·13	21·7	31·33	17·5
Trivandrum ..	08·48	21·54	15·6	16·40	11·9

Note—1. Rainfall data for the period 1931–60 except for stations with mark * for which they are for the period 1951–60 and Karwar with mark † for the period 1901–1950.
2. Rainy day corresponds to rainfall of 2·5 mm. or more per day.

CONCLUDING REMARKS

The following remarks can be made on the basis of the foregoing discussions:

(1) There is no relation between maximum divergence and lowest height of base of inversion over the Arabian Sea.

(2) Strong correlation between horizontal divergence and precipitation frequency need not necessarily be cause-effect type.

(3) The inversion is due to air-masses and not due to subsidence; there is moist unstable air in the lower levels and drier unstable air or less moist air with nearly saturation adiabatic lapse above with an inversion between the two. As a result of absence ordinarily of any mechanism sufficiently strong to break-up the inversion, little or no precipitation occurs over the west and north Arabian Sea west of about Long. 68° E.

(4) East of Long. 68° E as the Western Ghats are approached, the thickness of the moist layer and the height of base of inversion and precipitation increase; no inversion is noticed on the coast south of about Lat. 20° N. North of that latitude off and on the west Kathiawar-Kutch-Sind coast no such changes are noticed in the depth of the moist current or precipitation presumably due to absence of orographic barriers on that coast.

(5) The precipitation on the west coast would not appear to be associated with the easterly jet.

The air-mass ideas to explain the low-level inversion over the Arabian Sea would appear valid; they explain majority of the facts of observations more satisfactorily than the subsidence ideas recently put forward.

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