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Correlation of pressure changes at the surface with those in the upper atmosphere over India and neighbourhood

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ABSTRACT. The nature of the relationship between the pressure changes in the atmosphere at the 300 and 200-mb levels and the concurrent and subsequent pressure changes at the surface have been examined in this paper, analysing the data for 15 radiosonde stations in India and neighbourhood, during the period July 1944 to June 1945. The correlation between the changes aloft and the surface changes 24 and 48 hours later have been found to be generally negative. Tetrachoric correlation coefficients have been worked out to assess the magnitude of such out-of-phase correlation and these have been compared with the corresponding values in the U.S.A. The correlation data have been dispersed with respect to the different seasons of the year and the major regions comprising the Indian area. It has been found that the negative correlation is maximum during the period November to March and minimum when convective activity is predominant. It is felt that a study of the pressure fluctuations at the coastal radiosonde stations in the field of depressions and storms in the Bay of Bengal and the Arabian Sea might materially help in anticipating the courses these may subsequently take.

1. Introduction

Many conflicting views have been expressed by different investigators on the correlation between the pressure changes in the high atmosphere with those at the surface. In his classical work Dines (1919) correlated the absolute values of pressures at different heights in the free atmosphere using European meteorograph data. His studies led to the conclusion that the stratosphere is high and cold over high surface pressures and low and warm over low surface pressures. Haurwitz and Haurwitz (1939) have compared the isallobaric changes at the surface with those in the high atmosphere and infer that an out-of-phase relationship exists between the pressure changes at the surface with those at the high levels and that the surface changes precede those aloft. Von Schmidt (1940) has, however, expressed the view that the surface changes follow those at the high altitudes. Bice and Stephens (1944) have analysed the radiosonde data of the stations in the U.S.A. for the period March 1941 to February 1942 and conclude from their results that the 24-hour isallobaric minimum at the surface moves parallel to the upper wind flow to the current position of the 13-km isallobaric ridge line in 24 hours. Rossby (1944) suggests that the applicability of this statistical rule is confined only to those pressure systems, in which kinematic equilibrium relationship is not established between horizontal isobars and isotherms and to the systems whose movement is fairly rapid. Priestly (1945) has studied the 6-hourly radiosonde data of Larkhill for the period July 1944 to June 1945 and reports failure to find any sizable out-of-phase correlation between the high-level and subsequent surface pressure tendencies for various time-lags. Chiplonkar (1947) has investigated the variability of the mean diurnal pressure in the free atmosphere using the available data of Agra for the period November to April and infers therefrom that a positive or negative change of the mean pressure at 2 km signifies a like change in the atmosphere up to 14 km.

The views expreessed by different workers in the field are thus divergent. The existence of a genuine negative correlation between the pressure changes aloft and the subsequent surface tendencies would doubtless place in the hands of the synoptic meteorologist an extremely useful tool for the prognosis of the direction of movement of depressions over the surface. It was, therefore, felt worthwhile to undertake a study of the problem in regard to the Indian theatre, where the storms that form in the Indian Seas have too restricted a sea travel and are too fast-moving for attainment of kinematic equilibrium between the isobaric and isothermal systems. The western depressions that affect north India are also rapid in movement and have extensive land travel. The author has, therefore, carried out a study of the interrelationship between pressure tendencies aloft and at the surface over India and neighbourhood and the results are reported in this paper.

2. Data analysed and scope of the study

A fairly dense network of radiosonde stations is necessary to disclose genuine correlation between pressure tendencies at different levels in the atmosphere. The period chosen should also cover different synoptic situations. The year, June 1945 to May 1946 was chosen for this investigation as data from 15 radiosonde stations established during the war period over the Indian area were available for that year, which also showed varied synoptic situations. These stations were located at the following places— Allahabad, Bangalore, Barrackpore, Chabua, Chittagong, Cuttack, Delhi, Jiwani, Karachi, Lalmanirhat, Multan, Poona, Peshawar, Veraval and Vizagapatam.

In order to eliminate the variable effect of diurnal variation of pressures at different levels in the atmosphere, the changes of pressure were computed for 24 hours in all cases. As the earlier work shows sensible correlation only for levels above 10 km, the upper levels chosen were the 300 and 200-mb surfaces. Fluctuations in the altitude of these isobaric surfaces during 24 hours were worked out. Over 10,000 individual observations of surface pressure and the corresponding isobaric height data were analysed, taking into consideration magnitudes of change in the height of the isobaric surface exceeding 300 ft which

TABLE 1

Association between pressure changes of different signs at the surface and aloft

Surface	300 mb	
	+	—
+	a	b
—	c	d

corresponds to about 5 millibars of pressure change. Surface pressure changes corresponding to the isobaric height data were computed with time-lags of 0, 24 and 48 hours behind the time of occurrence of the changes aloft. There were in all 2622 pairs of observations of pressure changes aloft associated with the simultaneous and subsequent changes at the surface. Of these, 1463 were occasions when the magnitude of the change in the surface exceeded 1 mb.

The tetrachoric correlation co-efficient, R_T, has been employed in analysing the data in this paper, as this coefficient is very useful where the variables are in the form of numbers of cases in two different categories. Supposing the 24-hour pressure changes at the 300-mb level are divided into rises and falls, accompanying the rises there may be rises and falls at another, say, the surface level, which may be denoted by a and b. For the falls at the 300-mb level, there may again be rises and falls at the surface, which may be denoted by c and d respectively. The frequencies of positive and negative pressure changes at the surface and the 300-mb level are then, say, as arranged in Table 1.

The tetrachoric correlation co-efficient R_T is then given by $R_T = \cos\left(\dfrac{\pi\sqrt{bc}}{\sqrt{bc}+\sqrt{ad}}\right)$.

It is readily seen from this that if all the changes correlated are out-of-phase, then $a = d = 0$ and $R_T = -1$. If, however, they are all in-phase, $b = c = 0$ and $R_T = +1$.

The data used for the present study were taken from the Indian Daily Weather Report.

3. Results and discussion

The frequencies of like and unlike 24-hour changes of pressure at the 300 and 200-mb levels on the one hand and at the surface on the other, for time lags of 0, 24 and 48 hours are shown in Table 2. The symbols + +, + −, − − and − + have the same significance as in Table 1, the first sign in each pair denoting the nature of the change aloft and the second that of the change at the surface. In Table 2 are also given in brackets the percentage frequencies of association of like and unlike changes for each pair of levels.

The following inferences can be drawn from Table 2—

(1) There is a marked in-phase correlation between the pressure changes at both the upper levels and the simultaneous changes at the surface, about 60 per cent of the cases being of like change.

(2) On the contrary, the pressure changes aloft and the subsequent pressure changes at the surface 24 hours later display a greater out-of-phase relationship.

(3) Although the 48-hour-lag changes show a bias towards the association of unlike signs, the correlation is weak and does not hold for the rises at the 200-mb level.

In compiling Table 2, all finite changes of the surface pressure were taken into consideration, irrespective of their magnitude. It is of interest to see the effect of restricting the analysis to changes exceeding 300 ft aloft and 1 mb at the surface. In Table 3 are shown the results so obtained.

The results in Table 3 are in general accord with those in Table 2. They are more consistent among themselves, the percentage frequency of association of unlike changes varying between 54 to 57, with one significant exception. The 48-hour lag (+ −) frequency is only 45 per cent indicating rises at surface for rises at the 200-mb level, although for falls of pressure aloft, a weak negative correlation is displayed as for the other lags and at the other levels. Since the results in both Tables 2 and 3 show the same order of frequencies, it may also be inferred that the magnitude of the pressure change at the surface is not necessarily determined by the magnitude of the changes taking place aloft and that of the surface changes are less in magnitude than those aloft.

Comparison with the results of Bice and Stephens

The higher percentage frequency of association of unlike changes displayed by Tables 2 and 3 for time lags of 24 hours and more is not very pronounced to be of practical use. The results of Bice and Stephens based on the daily radiosonde data for stations in U.S.A. during the period October to December 1941 show a percentage frequency of 77·8 for falls at the surface corresponding to rises at the 13-km level and 65·5 for rises at surface following falls aloft. The maximum and minimum isallobaric centres at the surface were compared by them with the minimum and maximum isallobaric centres at the 13-km level on the preceding day. Their study was thus synoptic in character and confined to individual synoptic situations and showed that a katallobaric centre aloft was followed next day at the surface in about the same position by an anallobaric centre and *vice versa*. Frequencies based on such data are bound to be of a higher order of magnitude, as all erratic values get smoothed out in preparing synoptic isallobaric charts. Similar isallobaric maps have also been prepared by the author for the Indian theatre but it has not been possible to fix the patterns uniquely due to the inadequacy of the available data. The present study was, therefore, limited to a comparison of the pressure changes aloft with those at the surface for each radiosonde station.

The author's results can be compared only with results obtained on similar lines elsewhere. Bice and Stephens have also carried

TABLE 2

Frequency of pressure changes in the high atmosphere associated with concurrent and subsequent changes at the surface

Time lag in hours	With rises aloft > 300′ — At surface — No. of cases of rise ++	With rises aloft > 300′ — At surface — No. of cases of fall +—	Total No.	With falls aloft > 300′ — At surface — No. of cases of falls ——	With falls aloft > 300′ — At surface — No. of cases of rise —+	Total No.
			(a) 300-mb level—surface			
0	138 (62)	83 (38)	221	149 (60)	100 (40)	249
24	88(43)	118(57)	206	107(45)	129(55)	236
48	95(48)	110(52)	205	101(44)	128(56)	229
			(b) 200-mb level—surface			
0	122 (61)	77(39)	199	113(51)	111(49)	224
24	98(48)	103(52)	201	90(39)	139(61)	229
48	104(52)	99(48)	203	106(48)	114(52)	220

TABLE 3

Frequency of pressure changes aloft (exceeding 300 ft) associated with concurrent and subsequent changes of more than 1 mb at the surface

Time lag in hours	With rises aloft > 300′ — Changes at surface > 1 mb — No. of cases of rise ++	With rises aloft > 300′ — Changes at surface > 1 mb — No. of cases of fall +—	Total No.	With falls aloft > 300′ — Changes at surface > 1 mb — No. of cases of fall ——	With falls aloft > 300′ — Changes at surface > 1 mb — No. of cases of rise —+	Total No.
			(a) 300-mb level—surface			
0	78(61)	51(39)	129	83(61)	54(39)	137
24	48(43)	64(57)	112	64(45)	78(55)	142
48	52(44)	65(56)	117	55(43)	74(57)	129
			(b) 200-mb level—surface			
0	68(62)	42(38)	110	58(54)	50(46)	108
24	48(46)	57(54)	105	58(43)	77(57)	135
48	66(55)	53(45)	119	66(45)	54(55)	120

TABLE 4

Tetrachoric correlation co-efficients (R_T) for the 300 and 200-mb levels and surface pressure changes in 24 hours for different time lags

Time lag in hours	India		U.S.A.	
	300 mb-surface	200 mb-surface	6 km-surface	13 km-surface
0	+0·35	+0·19	—	—
24	—0·19	—0·19	—0·55	—0·52
48	—0·15	—0·02	—	—

out a similar investigation for the year March 1941 to February 1942, with the U.S.A. radiosonde data. Table 4 shows the tetrachoric correlation factors computed by the author from the results in Table 2 along with the values of Bice and Stephens, based on similar methods of approach to the problem. Their values are available only for a time-lag of 24 hours for the 6 km and 13-km levels.

The correlation co-efficients for India are thus seen to be much less than the corresponding ones in the U.S.A. The question arises whether the negative correlation found for India is merely fortuitous and if not why the co-efficients in India are so low compared with the values for the U.S.A. That the negative correlation is not fortuitous is shown by the fact that R_T is negative for all levels for all lags of time equal to and exceeding 24 hours in contradistinction to the pronounced positive values for the simultaneous changes. The co-efficients worked out for India and the corresponding values for the U.S.A. as reported by Bice and Stephens represent the averages for the year as a whole. If the nature of the correlation between the pressure changes aloft and those at the surface has a seasonal trend, then the percentage frequencies and correlation co-efficients taken over the year as a whole will not be significant. The seasonal variation of the tetrachoric correlation is, therefore, worth a careful examination.

Seasonal variation of the tetrachoric correlation

Bice and Stephens offer the following explanation for the high negative correlation in the U.S.A. The pressure rise at the 13-km level is due to the flow of cold tropical air at high levels into the particular area. The building up of a high pressure to the right of the cold current at the high levels causes the low-level winds to back gradually from west to south and, as a result, transport warmer air into the lower levels, which soon compensates the rise at the higher levels. Within 24 hours, there is a sufficient inflow of warmer air in the lower levels to produce a pressure fall at the surface. Incursion of warm arctic air at the higher levels produces large pressure rises at the surface on the following day, in a similar way. Although no special study of the mechanism causing the pressure changes has been made, examination of the wind trajectories on a few occasions showed that the negative correlation of the pressure changes in India is also traceable to similar causes. Such advective processes would, however, be disrupted by the large-scale convection in India during the summer and the monsoon months, when no logical relationship can hold between the high-level and the surface pressure changes. The low annual values for R_T in India must be a direct consequence of the fact that vigorous convection prevails over the the whole of the country for the major part of the year. The seasonal distribution of thunderstorm frequencies over India and neighbourhood, compiled from the available data for the various radiosonde stations included in this study, is shown region-wise in Table 5. For this purpose, the year has been divided into the following seasons—(*a*) December-February: Winter, (*b*) March—May : Summer, (*c*) June—September: Monsoon and (*d*) October and November: Post monsoon season. The stations have been distributed into three groups as follows :

1. *The Peninsula* comprising of Bangalore, Poona, Visakhapatnam and Cuttack ;

2. *Northeast region* with 4 stations located at Barrackpore, Chabua, Lalmanirhat and Chittagong ;

3. *Northwest region* with 7 stations at Allahabad, Delhi, Jiwani, Karachi, Multan, Peshawar and Veraval.

This division of India and the neighbouring areas into three regions has been made, taking into consideration the types of weather which the various parts of India experience more or less uniformly, from the point of view of this investigation.

TABLE 5

Seasonal distribution of number of days of thunder over India and neighbourhood

Region	Winter	Summer	Monsoon	Post monsoon
Peninsula	0·8	14·4	16·8	5·9
Northeast region	2·4	14·7	31·0	4·5
Northwest region	2·3	4·8	9·3	1·1
Whole area	1·8	11·3	19·0	3·8

It is clear from the above figures that the maximum thunderstorm activity occurs over the whole of the Indian area during the monsoon and the summer months and that it reaches its peak value during the monsoon months. The debriefing notes provided by pilots of the Comet Jet Airliners during their flights across India during May to August 1952, indicate that the tops of cumulonimbus clouds in this area often extend to as great heights as forty to forty five thousand feet. If such large scale convective forces come to play in the atmosphere, adiabatic and advective process would be totally disrupted and no logical relationship can hold under such conditions between the high-level and the surface pressure changes. It may, therefore, reasonably be expected that the seasons in which the conditions in India approximate more to the extra-tropical weather, as in the post monsoon and winter months, a higher order of negative correlation may be found. In Table 6 are reproduced the seasonal frequencies for India worked out by the author for pressure changes at the 200 and 300-mb levels exceeding 300 ft and the subsequent changes at the surface 24 hours later, exceeding 1 mb. The values of Bice and Stephens for the U.S.A. corresponding to the 300-mb and 200-mb changes in India are also shown in this table for comparison. The values for the 6-km and the 13-km levels in the U.S.A. have been taken to correspond to the 300 and 200-mb levels in India.

A comparison of Tables 5 and 6 would at once show that the higher the thunderstorm frequency, the less the frequency of association of the out-of-phase pressure changes. It is also seen that there is a very high order of negative association of pressure changes in the winter period, equalling and in some cases even surpassing the corresponding frequencies for the U.S.A. Convection is at a minimum in India in the winter period when the tropical continental air prevails over the whole land mass, punctuated by occasional western disturbances in north India and waves in the easterlies in south India. The incursion of cold tropical air in the high levels and the consequent formation of a ridge of high pressure aloft as, for instance, with the approach of a western depression in north India, would induce the flow of warm southerlies in the lower levels, to counteract the increase of pressure aloft. During the course of the subsequent 24 hours, the inflow of warm air at the surface levels might be sufficient for the occurrence of a sizeable fall of the surface pressures. The high frequency of pressure falls at the surface for pressure rises aloft even in summer is interesting. On scrutiny of the monthly dispersion of the frequencies, it has been found that the major contribution to the out-of-phase association of pressure changes during summer was from the month of March, when the convective activity is not yet sufficient to destroy advective processes in the atmosphere. It is significant that this high frequency holds only for pressure rises

TABLE 6

Frequencies of pressure changes aloft and corresponding changes next day at the surface in the different seasons

Season	Level (mb)	No. of changes at surface next day: Rises	Falls	Total	Percentage of falls at surface: 300 mb	200 mb	Corresponding frequencies for U.S.A.: 6 km	13 km
(a) For pressure rises aloft								
Winter	300	9	15	24	63	—	62	—
	200	7	9	16	—	56	—	55
Summer	300	14	26	40	65	—	63	—
	200	16	25	41	—	61	—	59
Monsoon	300	17	15	32	47	—	51	—
	200	18	15	33	—	45	—	58
Post monsoon	300	8	8	16	50	—	59	—
	200	7	8	15	—	53	—	55
Year	300	48	64	112	57	—	60	—
	200	48	57	105	—	54	—	56
(b) For pressure falls aloft					Percentage of rises at surface			
Winter	300	24	15	39	62	—	67	—
	200	24	10	34	—	71	—	60
Summer	300	17	18	35	49	—	64	—
	200	21	16	37	—	57	—	54
Monsoon	300	21	18	39	54	—	61	—
	200	16	23	39	—	41	—	58
Post monsoon	300	14	13	27	52	—	64	—
	200	16	9	25	—	64	—	63
Year	300	78	64	142	55	—	65	—
	200	77	58	135	—	57	—	59

aloft and breaks down for falls. This is as it should be because the contribution to negative association can only be due to advection of cold tropical continental air aloft with consequent pressure rises that would happen when the March or early April conditions relapse to the winter conditions at times.

In the post monsoon month, October, with its high thunderstorm frequency and partaking of the monsoon conditions occasionally, contributes less to the negative association of pressure changes than November, which shows frequencies of the order of those for the winter. The net effect is one of reduced frequencies for the post monsoon season.

It is also worth noting that the seasonal variation of the frequencies in the U.S.A. follows the same trend as in India, being generally lowest in the summer and the fall months and highest in the winter.

The tetrachoric correlation co-efficients for the different seasons, in India, worked

TABLE 7

Seasonal variation of the tetrachoric correlation co-efficient of the 24-hour pressure changes aloft with the surface pressure changes next day

Surfaces compared	Winter	Summer	Monsoon	Post monsoon	Year
300 mb-surface	—0·37	—0·22	—0·01	—0·03	—0·19
200 mb-surface	—0·42	—0·27	+0·21	—0·27	—0·18
13 km-surface (Bice and Stephens)	—0·50	—0·53	—0·52	—0·54	—0·52

out from Table 6 for the 300-mb and 200-mb levels and the surface are shown in Table 7. In this table are also reproduced the 13-km surface co-efficients of Bice and Stephens for comparison.

Although the percentage frequencies of the author are of the same order as those of Bice and Stephens for the U.S.A., the tetrachoric correlation co-efficients of the author are lower for the reason that, in working out the seasonal percentages, Bice and Stephens also took into consideration the number of cases of 0-change of pressure at the surface that did not find a place in either category of finite changes. Their percentage frequencies would otherwise have been slightly higher than the author's. Few such instances of nil change of pressure at the surface were found with the data of each station individually studied by the author.

The tetrachoric correlation is most pronounced in India during the winter when it approaches the co-efficient for the U.S.A. in value. It is apparent that the influence of tropical convection contributes mainly to a lowering of R_T, which is even reversed in sign during the monsoon months. It may, therefore, be inferred that out-of-phase pressure correlations do subsist in the Indian area and are of about the same frequency as in the temperate latitudes during the period November to March, when the advective processes in the atmosphere approximate to those in the extra-tropical regions. Such correlations fail in the event of disruption of the advection by convective and non-adiabatic processes. The 200-mb level, which is likely to be out of the reach of convection on the majority of occasions is likely to show a higher negative correlation with the surface than the 300-mb level.

Regional dispersion of frequencies of out-of-phase correlation in India and neighbourhood

Bice and Stephens have found that the correlations are numerically greater in the central and northern U.S.A. than elsewhere from the data at their disposal. In the case of the Indian area, where part of the sub-continent lies in the extra-tropical latitudes, correlation data might display marked regional variation. Further, classification of the year uniformly into different seasons for the whole of the sub-continent does not bring out the higher correlations, if any, that might exist for certain regions in certain portions of the year. The available data of 24-hour changes of pressure at the 300 and 200-mb levels and the surface changes 24 hours later have been dispersed regionally in Table 8 with respect to the Peninsula, northeast region and northwest region.

Taking a frequency of more than 60 per cent as significant, there is seen to be a pronounced negative association of changes of unlike sign aloft and at the surface during the winter and post monsoon periods for all the regions in the Indian area with the exception of northeast egion, for which the correlation is poor. On examining the data for the season, it has been found that

TABLE 8

Percentage frequencies of association of changes of pressure level exceeding 300 ft in the upper atmosphere with changes exceeding 1 mb in surface pressure and of opposite sign 24 hours later

Season	Peninsula		Northeast region		Northwest region		Whole area	
	300 mb	200 mb	300 mb	200 mb	300 mb	200 mb	300 mb	200 mb
Winter	63	60	57	40	62	71	62	66
Summer	58	53	71	59	54	62	58	59
Monsoon	67	50	50	44	46	41	51	43
Post Monsoon	60	67	50	40	56	67	51	60
Year	62	55	58	51	54	58	56	56

the majority of out-of-phase changes of surface pressure in this area were of small magnitudes less than 1 mb. Taking these also into consideration, the correlation percentages for the 300 mb - surface and the 200 mb - surface changes came to 63 and 56 per cent respectively for the winter period although for post monsoon months, they remained about the same. It may, therefore, be inferred that a fairly high order of negative correlation between the high level and surface changes exists for northeast region also during the winter season, just as for the other regions. Only the order of magnitude of the changes in the surface pressure is less in this region for equal changes of pressure aloft.

During the summer months also, the correlation is fairly high over the whole of India and, as already stated, the contribution to this high value comes from the month of March when convection is yet feeble over the country. In the monsoon months, the negative correlation breaks down completely for north India and appears to hold only for the Peninsula for the 300 mb - surface changes. The percentage frequency of negative correlations between pressure changes at 300 mb and at the surface decreases from the monsoon to the post monsoon season over the Peninsula. The frequency for the 200-mb level over the Peninsula as well as over northwest egion increases from the monsoon to the post monsoon season, to a common value of 67 per cent.

Discussion of Priestly's comments

Priestly has analysed the data of a single station at Larkhill for the year July 1944 to June 1945 and has correlated the changes in the height of the 300-mb surface of 300 ft in 6 hours, 350 ft in 12 hours and 500 ft in 24 hours, with the subsequent surface pressure changes in units of 6 hours from 0 to 72 hours. The number of cases available in the three categories were 184, 201 and 74 respectively. With this meagre data, he computes 31 tetrachoric co-efficients between the 24-hour changes aloft and at the surface for different multiples of 6-hour time lags. Most of the tetrachoric correlation co-efficients were of small magnitude and he, therefore, concludes that there is no indication whatsover of correlations of magnitude comparable with those of Bice and Stephens. He, further concludes that the correlations found by those workers are merely a fortuitous result of the size and speed of the depressions they studied.

Priestly has himself found the value of —0·45 for the correlation between the 24-hour changes at the 300-mb level and at the surface for a 24-hour lag. This value compares quite favourably with that of —0·52 obtained by Bice and Stephens (Table 7) under identical conditions for the 13-km level. Priestly may have come to his conclusion by comparing his values for the various sub-multiple lags of 24 hours with the high value obtained by Bice and Stephens by preparing isallobaric charts and correlating the isallobaric centres aloft with those on the surface. Priestly would doubtless have obtained comparable values if he followed the synoptic method of Bice and Stephens instead of the single-station method. Although Priestly chose submultiples of 24 hours for computing the pressure changes and for time lags, he does not mention in his paper whether he has made allowance for the diurnal change of the surface pressure. If he had not taken that into consideration, his results might have been vitiated thereby to some extent. Further, the data of a single station cannot disprove the conclusions based on the data of a number of widely-dispersed sounding stations utilised by Bice and Stephens. In view of the wide seasonal and regional variation of the correlation found by the author, it is not unlikely that if Priestly worked out his values for the winter months he might have found a higher correlation. It might be worthwhile repeating Priestly's work for the British Isles with synoptic isallobaric charts for the 300-mb and surface levels, in view of an R_T of the order of —0·45 he obtained for the 24-hour pressure changes aloft and at the surface.

4. Conclusion

It is seen from the author's results that out-of-phase correlations between the pressure changes at the 300 and 200-mb levels and the subsequent changes at the surface of as high an order as in the U.S.A. can be expected to hold for the major part of the Indian area during the months of November to March. Such correlations are particularly pronounced over the Peninsula and obtain there sizably during the summer and monsoon months also for the 300 mb-surface changes. A denser network of stations in the Peninsula than at present would greatly help in preparing synoptic isallobaric charts for the high levels in the atmosphere and the advance indications afforded by such charts will undoubtedly be useful in anticipating the courses of cyclonic storms that form in the Bay of Bengal and the Arabian Sea during the pre-monsoon and post monsoon months. Even with the existing network of stations, a study of the pressure changes aloft at the coast may be of material help in judging the possibility for recurvature of the Bay storms, a problem with which the synoptic meteorologist engaged in storm-warning work is always beset.

REFERENCES

Bice, E. G. and Stephens, G. J.	1944	*Univ. Chicago, Inst. Met., Misc. Rep.* 12.
Chiplonkar, M. W.	1947	*India met. Dep. Sci. Notes*, **9**, 109.
Dines, W. H.	1919	*M.O. Geophys. Mem.*, 2 and 13.
Haurwitz, E. and Haurwitz, B.	1939	*Harward Met. Studies*, 3.
Priestly, C. H. B.	1945	*Quart. J. R. met. Soc.*, **71**, p. 385.
Rossby, C. G.	1944	*J. Met.*, **1**, 3 and 4.
Von Schmidt, G.	1940	*Met. Z.*