Inversions and Stable Layers in the free atmosphere over India—Part I

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1. Introduction

A study of the incidence of inversions and stable lapse rates in the free atmosphere and their seasonal variations is of interest not only from the standpoint of the physical and dynamical causes which give rise to them but also because of their practical importance in problems such as control of atmospheric polution, propagation of high frequency radio waves, etc. The conventional representation of upper air data in the form of tables and diagrams for standard levels does not highlight this feature. It was, therefore, considered to be of interest to undertake such a study in respect of the free atmosphere over India. The material for the study was provided by the results of upper air soundings made twice daily at 00 and 12 Z from 12 radiosonde stations. The study has been based on the data collected during the five-year period 1956-1960. In Part I of the study which is the subject matter of the present paper, the results for five stations to the south of latitude 20° N are presented. The stations are—

	Lat.	Long.
1 Trivandrum	8°29′N	76°57′E
2 Port Blair	11°40′N	92°43′E
3 Madras	13°00′N	80°11′E
4 Visakhapatnam	17°43′N	83°14′E
5 Bombay	19°05′N	72°53′E

Results in respect of seven stations to the north of latitude 20°N will be presented in a subsequent paper of this series. The bifurcation of the stations at latitude 20°N has not been done purely arbitrarily; as will be seen from the results, the northern stations show certain features quite distinct from the southern ones. A detailed discussion of the results contained in this paper highlighting the physical and dynamical causes that would account for the salient features brought out by the analysis will form the subject matter of Part II of this series.

2. Data for Study and Method of Analysis

The original tephigrams of the ascents plotted at the radiosonde stations as well as the tabulation registers of the stations were utilised in the present study. The frequency of occurrence of stable lapse rates (which also includes inversions and isothermal layers) in the free atmosphere are tabulated as a routine measure at all the radiosonde stations. The tabulated figures provided the bulk of the data. In respect of the upper troposphere and lower stratosphere the tabulations in some cases needed to be supplemented or modified with the help of the original ascent data.

For the purpose of the present study, an atmospheric layer has been considered to be thermally stable if the lapse rate in the layer is 2° C/km or less. This definition obviously includes all cases of isothermal layers and inversions. It may be mentioned that the limiting lapse rate stipulated for the definition of the tropopause is also 2° C/km. Hence, in the upper troposphere, such stable lapse rates are in most cases identifiable with the tropopause. Thus the statistics in respect of these lapse rates at the upper levels furnish useful information about the height of the tropopause and its seasonal variations.

The analysis of the data was carried out separately in respect of the 00 and 12 Z ascents. In general over 95 per cent of all ascents for each of the hours of observation reached upto 6 km; about 50 per cent reached a height of 14 km; nearly 25 per cent of the ascents reached upto 17 km; and 10 per cent upto 20 km. Table 1 which gives the consolidated figures for the 12 Z ascents for the five-year period illustrates the manner in which the observations decreased with height in respect of the various stations.

The data were analysed with two aims in view. In the first instance, the frequency of occurrence of bases of stable layers (irrespective of thickness) in each 1 km stratum of the atmosphere was worked out month by month for each of the stations. In view of the decrease of observations with height the actual frequencies were converted into percentage frequencies. In the second instance, the layers of stable lapse rate were further classified according to their depths and the data grouped for the following four seasons— (*i*) December-February (winter season), (*ii*) March-May (hot weather season), (*iii*) June-September (monsoon season) and (*iv*) October and November (post-monsoon season).

3. Results

Table 2 (a) gives the percentage frequency of occurrence of bases of stable layers in strata of 1 km thickness from surface upto 20 km for each of the twelve months for the five stations. Table 2 (b) gives the frequency distribution of stable layers according to the thicknesses for the entire year obtained by combining the frequencies for the four different seasons. The combining of the four seasonal frequency tables into a single table was done since the frequency distribution of thicknesses showed more or less the same features in all the four seasons.

Stable layers occurring in the troposphere and lower stratosphere could be classified under the following three broad categories—

(*a*) *Those occurring between the surface and 1 km above*—These are largely associated with radiational cooling of the ground and the adjacent layers of the atmosphere. The frequency of this type of stable layer will be appreciably greater in respect of the morning observations (00 Z). The individual ascent curves actually show that such stable layers generally commence as marked ground inversions with thickness of a few hundred metres later merging into upper stable layers.

(*b*) *Those occurring between 1 and 6 km which are generally associated with subsidence in the troposphere*—These take the form of inversions, isothermal layers or layers of feeble lapse rate. Their bases can at time descend to even below 1 km level.

(*c*) *Those occurring above 14 km associated with the tropical tropopause*—These are almost always in the form of pronounced inversions characteristic of the transition from the troposphere to the stratosphere in the tropics.

In addition to these three categories, stable layers also occur between 6 and 14 km in the upper troposphere over north India in the non-monsoon months. These form a separate class by themselves, some of them being identifiable as distinct extra-tropical type of tropopauses.

Brief accounts of the monthly and seasonal variations of the frequency of occurrence of stable layers in respect of the five radiosonde stations are given below.

(*i*) *Trivandrum*—In the lowest 1 km stratum adjacent to the ground, stable lapse rates are noticed on about 50 per cent of the days in the non-monsoon months and on about

25 per cent of the days during the monsoon season. Above this, the highest incidence of such lapse rates occurs in the stratum between 2 and 3 km, the precentage frequency being about 15 to 20 per cent in all the months. It is noteworthy that stable layers are practically absent between 6 and 14 km throughout the year. Above 14 km there is a rapid increase in frequency in association with the tropical tropopause. The height at which the tropopause occurs most frequently is between 16 and 17 km in all the months. However, in the monsoon months there is a distinct tendency for the tropopause to occur at a lower height on many days. It is also noticed that there is a tendency for the tropopause to occur at a greater height on some days during the non-monsoon months. An independent study of the seasonal variations of the tropopause height over Trivandrum confirms that the mean height during the monsoon months is about 1 km less than during the non-monsoon months.

The depths of stable layers observed in the lower troposphere seldom exceed 1 km. In the great majority of cases the depths vary from 0·2 to 0·6 km only in all the four seasons.

(*ii*) *Port Blair*—Stable lapse rates in the lowest kilometre stratum are observed on about 75 per cent of the days in the months February and March and on about 50 per cent of the days during the remaining months. Between 2 and 6 km stable lapse rates occur with appreciable frequency during the months November to March. As at Trivandrum, stable lapse rates rarely occur between 6 and 14 km. The features associated with the tropopause are also similar to those for Trivandrum. The depth of stable layers in the lower troposphere lies between 0·2 and 0·6 km in most cases.

(*iii*) *Madras*—Stable layers with bases within the first one kilometre above the ground occur on about 50 per cent of the days in the months February, March and April. The frequencies in the morning and evening are somewhat comparable in these months. However, during the southwest monsoon period June to September, such stable layers occur only on about 15 to 25 per cent of the days. It is noteworthy that during the months October to January the evening figures are much smaller than the morning ones. Another significant feature is the large frequencies of occurrence of stable layers in the lower troposphere between 1 and 4 km in the months December, January and February resulting from upper air subsidence. Such stable layers also occur on some days in the higher levels upto 6 km. Stable layers are practically absent between 7 and 14 km throughout the year. Higher up, the frequencies associated with the tropopause show a maximum between 16 and 17 km in all the months. As in the case of Trivandrum and Port Blair a tendency for the lowering of the tropopause during the southwest monsoon months is noticeable.

During the months December to May the stable layers that occur in the lower troposphere can be as deep as 1 km on some occasions. During the remaining months the depths of such layers rarely exceed 0·6 km. It is noteworthy that in the winter months stable layers more than 1 km deep occur with bases between 1 and 3 km.

(*iv*) *Visakhapatnam*—Stable lapse rates occur with appreciable frequency in the first one kilometre above the ground in all the months. The percentage frequency is over 80 per cent in the months March, April and May. During the second half of the year, the incidence of such stable lapse rates is appreciably less at 12 Z as compared with 00Z. Commencing from November, there is a rapid increase of frequency in the lower troposphere from 1 to 5 km in association with upper air subsidence and this continues till the end of April. During the months January to June stable layers also occur occasionally between 6 and 10 km. As will be seen from the tables, the tropopause occurs mostly between 16 and 18 km. The thickness of stable layers in the lower troposphere is generally less than 0·8 km in all the months.

(*v*) *Bombay*—During the non-monsoon months stable lapse rates in the first one kilometre are very conspicuous and occur on more than 75 per cent of the days in the mornings. During the monsoon months these are practically absent. Between 2 and 4 km, stable layers resulting from subsidence occur quite frequently during the months October to February; their incidence is fairly frequent also in the months May and June between 1 and 2 km. As contrasted with Trivandrum, Port Blair and Madras, the troposphere from 6 to 12 km over Bombay is characterised by the occurrence of layers of stable lapse rate during the months December to May. This feature is conspicuously brought out by a comparison of the monthly percentage frequency tables for the different stations. As a matter of fact, the tendency for such occurrence is already noticeable in the case of Visakhapatnam the latitude of which is between those of Bombay and Madras. It is noteworthy that stable layers hardly occur between 6 and 14 km in the monsoon months. In all the months the tropopause occurs mostly in the height interval 16 to 18 km. It will be seen from the frequency tables for Bombay that stable layers also occur in the upper troposphere between 12 and 15 km during the months December to May.

Stable layers occurring in the monsoon and post-monsoon months are generally less than 1 km in depth. There is tendency for stable layers of greater depth to occur in the remaining months.

4. Acknowledgements

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TABLE 1

Statement showing the total number of cases when radiosonde ascents for 1200 GMT reached various heights (1956-1960)

Stations	Heights								
	850 1·5	700 3·0	500 6·0	300 9·0	200 12·0	150 14·2	100 16·5	80 18	60 mb 20 km
Allahabad	1741	1741	1699	1495	1186	894	486	308	140
Dum Dum	1803	1800	1775	1532	1213	758	361	151	61
Gauhati	1780	1778	1748	1404	1116	506	235	59	30
Jodhpur	1737	1723	1670	1388	1057	781	441	314	141
Madras	1808	1799	1717	1428	1091	874	437	274	136
Nagpur	1736	1693	1595	1356	1078	877	551	428	223
New Delhi	1784	1792	1780	1668	1499	1288	854	651	381
Port Blair	1687	1678	1598	1221	794	540	225	160	80
Santacruz	1802	1792	1770	1457	1069	748	362	226	115
Trivandrum	1737	1730	1702	1562	1314	1118	717	513	285
Veraval	1748	1722	1645	1431	1143	917	599	571	310
Visakhapatnam	1751	1745	1714	1420	1061	790	438	382	198
Total	21114	20993	20413	17362	13621	10091	5706	4037	2100
Percentage cases when different levels were reached	100	99	97	82	65	48	27	19	10

TABLE 2 (a)

Percentage frequencies of bases of stable layers at 00 and 12 Z (1956-1960)

Layer (km)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					TRIVANDRUM							
19-20								5 (0)				
18-19		3 (0)			0 (3)				0 (3)		0 (3)	0 (7)
17-18	6 (9)	9 (16)	13 (3)	11 (20)	22 (5)	4 (22)	6 (9)	8 (5)		10 (10)	20 (10)	17 (11)
16-17	26 (20)	30 (38)	20 (35)	21 (18)	26 (35)	42 (30)	17 (22)	28 (28)	33 (12)	35 (36)	22 (37)	23 (37)
15-16	10 (11)	16 (6)	16 (7)	6 (7)	12 (8)	14 (16)	28 (22)	20 (27)	25 (34)	19 (24)	16 (16)	13 (12)
14-15	3 (3)	6 (3)	5 (11)	2 (6)	2 (2)	9 (11)	14 (18)	18 (13)	19 (15)	13 (15)	11 (7)	6 (5)
13-14				1 (2)	0 (2)	2 (1)	3 (2)	2 (3)	4 (2)	1 (3)	2 (4)	0 (3)
12-13						1 (2)			0 (3)			
11-12												
10-11												
9-10												
8-9												
7-8						3 (1)			0 (2)	2 (1)		2 (2)
6-7	3 (1)		4 (1)		3 (1)	1 (3)	2 (2)	3 (1)	4 (1)	5 (2)		5 (3)
5-6		5 (1)	3 (2)	3 (2)	4 (0)	2 (2)	9 (1)	6 (3)	3 (3)	9 (3)	2 (4)	5 (3)
4-5	4 (4)	3 (2)	8 (2)		5 (2)	4 (1)	5 (5)	4 (5)	3 (4)	7 (3)	4 (3)	3 (5)
3-4	8 (8)	8 (4)	14 (8)	6 (6)	5 (8)	10 (5)	13 (7)	9 (7)	12 (12)	5 (8)	6 (4)	6 (9)
2-3	15 (25)	14 (23)	19 (20)	14 (7)	11 (10)	16 (13)	13 (11)	14 (11)	13 (12)	19 (12)	11 (11)	21 (25)
1-2	21 (14)	18 (11)	14 (5)	8 (4)	4 (7)	8 (6)	7 (5)	16 (11)	15 (8)	9 (5)	11 (6)	17 (13)
Surf—1	39 (5)	45 (10)	34 (3)	50 (14)	38 (7)	30 (11)	22 (5)	25 (12)	24 (18)	36 (14)	37 (5)	52 (9)

00 Z Frequencies : Unbracketed   12 Z Frequencies : Bracketed

TABLE 2 (a)—*contd*

Layer (km)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						PORT BLAIR						
19-20												
18-19			0 (20)		0 (12)	8 (0)		0 (50)			25 (17)	0 (10)
17-18	25 (0)		15 (0)	12 (0)	5 (7)	18 (25)				19 (9)	17 (25)	17 (7)
16-17	20 (8)	16 (7)	32 (14)	23 (7)	17 (31)	15 (10)	0 (23)	20 (40)	33 (43)	25 (11)	23 (24)	12 (5)
15-16	12 (8)	13 (19)	4 (4)	3 (4)	3 (8)	12 (9)	5 (4)	12 (0)	6 (11)	13 (19)	16 (12)	12 (21)
14-15	3 (6)	11 (3)	5 (0)	7 (0)	2 (0)	0 (7)	6 (6)	4 (5)	10 (14)	7 (7)	12 (4)	2 (0)
13-14	3 (2)	0 (2)	0 (2)	2 (0)	2 (0)		2 (0)			0 (4)		2 (2)
12-13	2 (0)		0 (2)			0 (2)	2 (0)			3 (0)	2 (0)	
11-12		0 (2)							0 (2)			
10-11		2 (0)	2 (1)									
9-10	2 (0)	4 (0)						2 (0)	2 (0)			
8-9			0 (2)	0 (2)		0 (2)						
7-8		1 (2)	1 (3)			2 (3)	2 (0)			3 (1)		2 (0)
6-7	1 (2)		1 (6)	3 (1)	2 (2)	0 (2)		2 (2)	3 (1)		3 (2)	2 (1)
5-6	6 (5)	4 (2)	2 (3)	2 (2)	3 (1)	4 (3)	5 (1)	7 (5)	5 (1)	3 (5)	6 (2)	3 (3)
4-5	5 (6)	7 (3)	7 (4)	2 (2)	3 (4)	0 (2)	3 (2)	5 (4)	5 (6)	1 (3)	3 (3)	4 (6)
3-4	10 (6)	6 (7)	4 (10)	6 (4)	3 (1)	3 (6)	7 (3)	2 (7)	3 (5)	3 (3)	4 (13)	7 (12)
2-3	22 (26)	13 (15)	3 (10)	8 (8)	2 (6)	5 (5)	1 (5)	6 (5)	4 (9)	4 (7)	9 (17)	19 (27)
1-2	24 (19)	16 (12)	11 (22)	11 (18)	3 (5)	8 (11)	7 (6)	7 (12)	4 (3)	5 (1)	3 (7)	27 (17)
Surf—1	42 (4)	73 (6)	77 (5)	66 (8)	36 (12)	42 (23)	44 (22)	40 (23)	50 (14)	51 (24)	51 (13)	43 (13)

TABLE 2 (a)—*contd*

Layer (km)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						MADRAS						
19-20	0 (7)		6 (0)	13 (8)	10 (0)		0 (14)				0 (14)	
18-19	22 (6)	4 (19)	8 (9)	22 (6)	14 (0)	8 (0)	6 (10)	0 (25)		5 (0)		5 (6)
17-18	21 (15)	11 (24)	21 (12)	18 (21)	20 (9)	11 (38)	19 (11)	17 (0)	0 (5)	14 (9)	0 (7)	6 (15)
16-17	16 (29)	20 (24)	12 (29)	27 (21)	13 (32)	19 (28)	13 (9)	18 (13)	29 (31)	22 (37)	29 (28)	54 (22)
15-16	14 (7)	10 (7)	3 (10)	2 (4)	11 (9)	21 (3)	23 (12)	18 (21)	23 (14)	14 (12)	23 (9)	9 (2)
14-15	2 (4)	3 (3)	5 (2)	2 (5)	3 (2)	3 (4)	3 (7)	5 (5)	4 (9)	7 (5)	3 (5)	1 (2)
13-14						0 (2)			2 (2)	3 (1)		
12-13												
11-12												
10-11												
9-10	2 (0)											
8-9												
7-8	4 (2)	1 (2)	1 (2)									
6-7	5 (3)	4 (1)			1 (4)							
5-6	1 (3)	3 (1)	1 (3)	1 (2)	2 (1)		3 (2)	3 (4)	0 (2)			2 (1)
4-5	4 (3)	4 (3)	5 (5)	4 (3)	3 (3)	0 (4)	1 (3)	3 (7)	3 (4)			1 (2)
3-4	11 (5)	14 (11)	7 (9)	3 (4)		3 (2)	2 (7)	3 (5)	5 (10)	8 (4)	3 (2)	12 (8)
2-3	28 (32)	28 (17)	8 (3)	2 (0)	2 (1)	4 (0)	3 (2)	0 (4)	2 (3)	3 (2)	5 (9)	26 (16)
1-2	39 (32)	30 (17)	29 (10)	14 (3)	7 (2)	1 (2)	5 (0)		2 (1)		15 (16)	34 (31)
Surf—1	31 (9)	50 (37)	63 (57)	48 (41)	32 (38)	28 (26)	14 (21)	17 (20)	16 (17)	24 (6)	22 (4)	19 (9)

TABLE 2 (a)—*contd*

Layer (km)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						VISAKHAPATNAM						
19-20			5 (0)					17 (0)				
18-19	15 (0)	11 (0)	6 (0)	7 (0)	6 (0)	17 (0)						12 (0)
17-18	29 (28)	25 (37)	15 (29)	8 (26)	17 (22)	0 (21)	19 (26)	7 (29)	6 (3)	11 (14)	14 (33)	19 (30)
16-17	23 (32)	28 (42)	40 (28)	26 (35)	29 (25)	20 (22)	28 (26)	20 (38)	4 (34)	13 (23)	22 (13)	25 (35)
15-16	2 (17)	10 (13)	5 (8)	15 (13)	3 (9)	9 (8)	13 (18)	9 (13)	28 (28)	30 (20)	19 (12)	10 (19)
14-15	4 (3)	2 (3)	3 (6)	8 (5)	2 (0)	2 (2)	9 (4)	10 (10)	14 (9)	4 (7)	7 (2)	5 (8)
13-14	3 (3)			0 (2)	2 (0)		2 (0)	4 (0)		0 (4)	0 (2)	0 (2)
12-13	4 (1)	2 (0)			2 (0)							2 (0)
11-12		4 (1)	0 (4)				0 (2)			0 (2)		
10-11	0 (3)			3 (0)								2 (0)
9-10	0 (2)		4 (1)		0 (2)							
8-9	3 (1)	4 (1)	2 (7)	3 (1)		2 (0)						
7-8	2 (7)	3 (2)	6 (3)	1 (3)	2 (2)	3 (3)	2 (4)					
6-7	7 (4)	8 (4)	9 (5)	7 (4)	4 (1)	7 (4)	3 (4)				3 (3)	
5-6	3 (3)	12 (9)	8 (6)	5 (4)	12 (8)	5 (7)	4 (3)	3 (3)	1 (2)	2 (3)	4 (1)	
4-5	8 (10)	13 (7)	12 (10)	13 (12)	5 (5)	4 (4)	5 (3)	3 (4)	1 (2)	5 (3)	6 (4)	2 (2)
3-4	12 (18)	31 (23)	22 (21)	5 (3)		2 (1)	5 (5)	2 (3)	5 (4)	11 (3)	4 (9)	8 (7)
2-3	30 (30)	40 (27)	10 (4)		1 (3)	2 (2)	6 (9)	1 (5)	2 (6)	6 (7)	12 (14)	22 (25)
1-2	29 (16)	28 (8)	11 (5)	17 (12)	25 (9)	7 (6)	9 (8)	5 (8)	1 (4)	5 (3)	36 (21)	46 (26)
Surf—1	38 (23)	70 (53)	80 (78)	100 (92)	82 (82)	71 (57)	38 (26)	32 (17)	43 (12)	41 (7)	30 (11)	50 (18)

TABLE 2 (a)—*contd*

Layer (km)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					BOMBAY							
19-20				9 (0)	8 (0)			5 (6)	0 (11)			17 (0)
18-19	6 (10)	10 (13)	0 (11)	0 (39)	22 (27)	17 (21)	12 (17)	8 (13)	22 (0)	0 (18)	13 (19)	0 (10)
17-18	9 (31)	8 (32)	21 (21)	27 (39)	22 (43)	23 (30)	14 (44)	31 (28)	24 (28)	24 (33)	32 (32)	14 (38)
16-17	24 (32)	15 (24)	21 (33)	35 (26)	21 (31)	20 (19)	25 (19)	16 (29)	22 (25)	34 (43)	18 (35)	20 (31)
15-16	6 (17)	0 (17)	5 (11)	2 (11)	13 (3)	3 (9)	9 (6)	8 (9)	12 (20)	15 (6)	9 (10)	5 (20)
14-15	4 (11)	2 (2)	3 (2)	2 (3)	20 (6)	5 (7)	0 (2)		2 (3)	4 (0)	1 (6)	5 (11)
13-14	4 (5)	4 (7)	2 (6)	6 (1)	15 (5)						1 (5)	4 (3)
12-13	7 (5)	4 (3)	3 (1)		12 (0)	1 (2)	0 (2)					4 (2)
11-12	4 (4)	1 (2)	0 (5)									8 (3)
10-11	2 (12)	5 (0)	8 (4)	3 (3)	2 (0)	0 (2)			0 (3)			1 (3)
9-10	3 (3)	3 (4)	12 (3)	2 (4)	9 (3)			0 (2)		0 (2)		5 (2)
8-9	4 (4)	2 (3)	4 (2)	2 (3)	0 (2)		1 (3)	1 (3)		0 (2)	1 (2)	1 (4)
7-8	6 (9)	5 (2)	6 (4)	0 (2)	8 (2)	1 (3)	3 (1)	1 (2)				2 (4)
6-7	8 (8)	9 (5)	5 (5)	2 (1)	6 (3)	2 (4)	4 (6)	4 (1)	2 (1)	2 (3)	3 (1)	3 (1)
5-6	5 (6)	5 (5)	5 (7)	10 (9)	14 (5)	7 (8)	5 (5)	7 (4)	4 (4)	3 (3)	4 (3)	1 (3)
4-5	11 (5)	9 (8)	12 (7)	7 (8)	10 (7)	8 (8)	3 (5)	5 (5)	10 (4)	8 (8)	4 (7)	5 (7)
3-4	23 (17)	19 (20)	6 (5)	3 (1)	3 (1)	3 (3)	5 (3)	5 (6)	7 (9)	25 (15)	18 (11)	12 (9)
2-3	37 (28)	16 (19)	2 (4)	3 (1)	11 (5)	14 (9)	14 (11)	21 (12)	10 (16)	10 (9)	20 (17)	27 (33)
1-2	11 (5)	16 (11)	13 (7)	11 (5)	41 (21)	20 (12)	4 (0)	3 (3)	4 (3)	5 (6)	5 (7)	14 (11)
Surf—1	90 (55)	92 (62)	82 (69)	90 (70)	40 (44)	13 (11)	5 (3)	3 (3)	8 (4)	48 (19)	76 (26)	90 (38)

00 Z Frequencies ; unbracketed 12 Z Frequencies : bracketed

TABLE

Frequencies of stable layers of

Stratum (km) / Thickness (km)	Surf-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
TRIVANDRUM								
0—0·20	136 (22)	34 (22)	23 (16)	15 (10)	8 (8)	7 (0)	3 (2)	2 (2)
0·21—0·40	254 (75)	72 (64)	94 (116)	53 (54)	28 (26)	25 (16)	10 (15)	5 (2)
0·41—0·60	90 (43)	41 (30)	58 (73)	36 (35)	12 (13)	25 (13)	8 (4)	4 (7)
0·61—0·80	33 (18)	18 (13)	31 (34)	9 (19)	8 (5)	5 (9)	9 (2)	
0·81—1·00	9 (2)	10 (6)	9 (11)	5 (3)	2 (3)	1 (1)	3 (2)	2 (2)
1·01—1·20	2 (1)	5 (1)	3 (7)	1 (1)	2 (1)		2 (0)	
1·21—1·40			0 (3)		1 (0)		2 (0)	
1·41—1·60	1 (0)		0 (1)	1 (0)				0 (1)
1·61—1·80		0 (2)			0 (1)			
1·81—2·00								
>2·00			1 (0)					
Thickness not known								
f_{00}	525	180	219	120	61	63	37	13
N_{00}	1450	1450	1450	1447	1439	1428	1404	1362
f_{12}	161	138	261	122	57	39	25	14
N_{12}	1738	1737	1731	1724	1715	1703	1679	1630

f_{00}=Total frequency of stable layers at 00 Z

f_{12}=Total frequency of stable layers at 12 Z

N_{00}=Total number of ascents which passed through the layer at 00 Z

N_{12}=Total number of ascents which passed through the layer at 12 Z

2 (b)

various thicknesses (1956-1960)

	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
						TRIVANDRUM						
	0 (1)					2 (0)						
	2 (2)		1 (0)		2 (3)	0 (3)						
		0 (1)			1 (2)	2 (3)						
	1 (1)				0 (2)	4 (3)						
			0 (1)	0 (2)		1 (0)						
	0 (1)			0 (1)								
		0 (1)										
				0 (1)		0 (1)						
						1 (0)						
						0 (1)						
						3 (4)						
						0 (9)	77 (94)	116 (145)	152 (193)	45 (47)	3 (5)	2 (0)
	3 1324	0 1266	1 1204	0 1142	3 1067	13 973	77 856	116 714	152 572	45 411	3 293	2 241
	5 1585	2 1517	1 1436	4 1354	7 1264	24 1167	94 1037	145 878	193 673	47 491	5 381	0 283

Unbracketed frequencies relate to 00 Z and bracketed frequencies to 12 Z

TABLE

Stratum (km) Thickness (km)	Surf-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
				PORT BLAIR				
0—0·20	179 (63)	8 (29)	8 (3)	2 (7)	1 (4)	1 (1)	1 (1)	
0·21—0·40	341 (113)	29 (55)	42 (85)	25 (45)	21 (26)	21 (19)	9 (13)	4 (4)
0·41—0·60	106 (51)	73 (81)	31 (73)	20 (37)	12 (12)	14 (15)	7 (11)	4 (5)
0·61—0·80	28 (7)	10 (7)	11 (20)	5 (9)	1 (11)	8 (8)	1 (2)	2 (3)
0·81—1·00	29 (3)	6 (10)	3 (5)	6 (5)	5 (5)	6 (1)		2 (0)
1·01—1·20	3 (0)	10 (4)	4 (7)	2 (1)	3 (2)	0 (2)	1 (1)	1 (0)
1·21—1·40	1 (0)		0 (2)	3 (1)	2 (1)		1 (0)	0 (1)
1·41—1·60	2 (0)	4 (0)	1 (1)		1 (0)	0 (1)		
1·61—1·80		2 (1)	1 (1)			1 (0)		
1·81—2·00	1 (0)	0 (1)	0 (1)					
>2·00								
Thickness not known								1 (0)
f_{00} N_{00}	690 1335	142 1315	101 1308	63 1292	45 1276	51 1256	20 1198	14 1100
f_{12} N_{12}	237 1688	188 1686	198 1679	105 1664	61 1634	47 1606	28 1526	13 1399
				MADRAS				
0—0·20	72 (37)	33 (19)	9 (6)	5 (5)	3 (5)		1 (0)	
0·21—0·40	250 (220)	82 (48)	69 (5[illegible])	[illegible]0 (39)	18 (14)	11 (10)	3 (8)	5 (3)
0·41—0·60	123 (110)	87 (73)	40 (33)	33 (25)	13 (16)	11 (8)	10 (6)	2 (0)
0·61—0·80	42 (50)	15 (7)	25 (24)	16 (20)	6 (9)	2 (10)	5 (1)	3 (2)

2(**b**)—*contd*

8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
PORT BLAIR											
	1 (0)										
1 (4)	0 (1)	2 (0)		1 (2)	1 (1)						
0 (6)	2 (1)		2 (0)	0 (1)							
	0 (2)	0 (1)	0 (1)	2 (0)	1 (1)						
	1 (0)		0 (1)								
		1 (0)		1 (0)							
			0 (1)								
	0 (1)										
	1 (0)			1 (0)							
					2 (0)	1 (0)					
	1 (0)				1 (4)	21 (18)	27 (28)	43 (35)	19 (9)	3 (5)	
1 1008	6 903	3 797	2 687	5 585	5 494	22 401	27 309	43 221	19 156	3 99	0 65
10 1280	5 1144	1 1002	3 860	3 725	6 601	18 472	28 337	35 234	9 115	5 67	0 43
MADRAS											
1 (0)					0 (1)	0 (1)	0 (1)				
1 (0)	0 (1)	1 (0)			0 (1)	0 (1)	0 (6)	0 (3)			
1 (0)					1 (1)	0 (1)		0 (2)	0 (1)		

TABLE

Stratum (km) / Thickness (km)	Surf-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
				MADRAS—*contd*				
0·81—1·00	46 (10)	22 (13)	7 (6)	7 (3)	1 (4)	2 (2)	5 (0)	0 (2)
1·01—1·20	6 (1)	16 (8)	10 (8)	2 (7)	0 (6)	0 (2)	2 (0)	1 (1)
1·21—1·40	1 (0)	5 (4)	1 (2)	1 (1)	1 (0)			
1·41—1·60	1 (0)	4 (3)	2 (0)	1 (1)				
1·61—1·80			2 (0)					
1·81—2·00	1 (0)		0 (1)	1 (1)				
>2·00								
Thickness not known					1 (0)			
f_{00}	542	264	165	106	43	26	26	11
N_{00}	1792	1792	1782	1762	1737	1708	1656	1579
f_{12}	428	175	133	102	54	32	15	8
N_{12}	1808	1808	1801	1785	1753	1733	1669	1573
				VISAKHAPATNAM				
0—0·20	140 (79)	26 (19)	3 (13)	7 (8)	5 (6)	3 (5)	1 (1)	0 (2)
0·21—0·40	474 (421)	150 (98)	79 (113)	70 (77)	52 (61)	45 (45)	32 (21)	17 (21)
0·41—0·60	127 (112)	58 (47)	46 (31)	28 (29)	20 (16)	15 (13)	9 (12)	5 (12)
0·61—0·80	49 (56)	23 (14)	24 (28)	17 (19)	9 (10)	3 (8)	7 (5)	0 (1)
0·81—1·00	13 (20)	13 (0)	7 (5)	1 (5)	3 (3)	3 (0)	2 (3)	1 (0)
1·01—1·20	1 (3)	2 (2)	2 (1)	2 (1)	2 (0)		3 (1)	
1·21—1·40	2 (0)	1 (2)	0 (2)	0 (1)				
1·41—1·60					0 (1)			

2(b)—*contd*

8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
					MADRAS—*contd*						
	2 (0)	0 (1)						0 (4)	0 (1)		
1 (0)		1 (0)		1 (0)			0 (2)	0 (5)	0 (1)		
						0 (1)	0 (1)	1 (1)			
							0 (1)	1 (0)	1 (0)		
					1 (0)	0 (1)		0 (2)			
							0 (1)	0 (3)			
					2 (3)	8 (13)	10 (14)	16 (32)	9 (7)		
				1 (0)	2 (1)	20 (13)	76 (30)	86 (60)	34 (29)	18 (0)	5 (0)
4 1502	2 1413	2 1297	0 1185	2 1046	6 944	28 800	86 633	104 464	44 321	18 222	5 185
0 1476	1 1370	1 1261	0 1151	0 1050	7 940	31 787	56 618	112 437	39 293	0 171	0 132
					VISAKHAPATNAM						
1 (0)		0 (1)	0 (1)		0 (1)						
7 (10)	6 (6)	4 (2)	2 (4)	2 (2)	2 (3)						
7 (4)	2 (2)	1 (1)	3 (2)	3 (1)							
0 (1)		1 (0)	0 (4)		0 (4)						
1 (2)			0 (2)								
0 (1)	1 (0)			1 (0)							
					0 (1)						
					1 (0)						

TABLE

Stratum (km) / Thickness (km)	Surf-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
				VISAKHAPATNAM—*contd*				
1·61—1·80	1 (0)							
1·81—2·00				1 (0)				
>2·00		1 (0)		1 (0)				
Thickness not known								
f_{00}	807	274	161	127	91	69	54	23
N_{00}	1458	1458	1457	1453	1443	1433	1384	1295
f_{12}	691	182	193	140	97	71	43	36
N_{12}	1751	1751	1747	1741	1729	1718	1666	1566
				BOMBAY				
0—0·20	91 (66)	31 (19)	29 (35)	21 (23)	15 (9)	13 (12)	8 (5)	4 (4)
0·21—0·40	311 (189)	83 (48)	110 (107)	75 (49)	46 (38)	37 (33)	29 (16)	13 (19)
0·41—0·60	306 (218)	65 (44)	88 (60)	60 (44)	49 (30)	30 (29)	20 (18)	13 (12)
0·61—0·80	139 (76)	15 (18)	35 (27)	24 (20)	20 (23)	15 (8)	10 (12)	2 (4)
0·81—1·00	75 (38)	17 (4)	13 (11)	12 (9)	6 (12)	8 (3)	4 (2)	2 (1)
1·01—1·20	19 (12)	8 (1)	3 (4)	2 (1)	1 (4)	0 (3)	1 (2)	0 (2)
1·21—1·40	9 (4)				1 (2)	0 (1)		0 (1)
1·41—1·60	5 (2)	0 (1)	2 (0)		1 (2)	0 (1)		
1·61—1·80	2 (0)			1 (1)				1 (0)
1·81—2·00	1 (0)	1 (0)	1 (0)					
>2·00				1 (0)	1 (0)	0 (1)	0 (1)	
Thickness not known							0 (1)	
f_{00}	958	220	281	196	140	103	72	35
N_{00}	1813	1813	1807	1803	1791	1784	1736	1652
f_{12}	605	135	244	147	120	91	57	43
N_{12}	1802	1802	1797	1788	1784	1777	1717	1612

f_{00}=Total frequency of stable layers at 00 Z

f_{12}=Total frequency of stable layers at 12 Z

N_{00}=Total number of ascents which passed through the layer at 00 Z

N_{12}=Total number of ascents which passed through the layer at 12 Z

2(**b**)—*contd*

8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20
					VISAKHAPATNAM—*contd*						
					0 (1)						
				0 (1)	4 (0)	37 (34)	66 (81)	97 (128)	46 (75)	11 (0)	2 (0)
16	9	6	5	6	7	37	66	97	46	11	2
1200	1109	1016	911	817	720	624	508	417	293	195	142
18	8	4	13	4	10	34	81	128	75	0	0
1471	1357	1241	1124	997	866	739	590	438	301	210	152
					BOMBAY						
2 (2)	2 (4)	3 (1)	4 (4)	1 1)	2 (1)						
10 (17)	10 (9)	4 (12)	7 (4)	9 (7)	7 (7)						
5 (11)	7 (6)	12 (10)	4 (3)	9 (1)	4 (6)						
5 (6)	2 (2)	1 (2)	2 (4)	1 (1)	1 (4)						
1 (1)	1 (2)	4 (1)	1 (3)	0 (3)	2 (1)						
	1 (0)	1 (0)	0 (1)	1 (0)	1 (1)						
1 (0)					0 (1)						
			0 (1)	1 (0)		1 (0)	5 (0)	8 (0)	11 (0)	2 (0)	1 (0)
			1 (0)		1 (0)						
					1 (1)	8 (0)	1 (0)	4 (0)	4 (0)		
		0 (1)		0 (1)	1 (1)	11 (31)	38 (61)	82 (108)	51 (87)	17 (25)	3 (2)
24	23	25	19	22	20	20	44	94	66	19	4
1564	1463	1352	1241	1111	982	776	610	442	300	193	128
37	23	27	20	14	23	31	61	108	87	25	2
1512	1389	1261	1133	990	835	870	515	357	258	182	134

Unbracketed frequencies relate to 00 Z and bracketed frequencies to 12 Z