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Seasonal variation of precipitable water vapour in the atmosphere over India

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ABSTRACT. Based on the upper air data for the six-year period, 1956 to 1961, the mean monthly precipitable water vapour at 12 Indian radiosonde stations have been calculated. The seasonal and diurnal variations of precipitable water vapour and its relation to mean monthly rainfall have been discussed.

1. Introduction

The depth in centimetres of liquid water that would result by the precipitation of the entire water vapour present in a vertical atmospheric column of one square centimetre cross-section is known as the precipitable water vapour in the column. Since the density of water is unity the depth in cm of the liquid water is also equal to its mass in grams. As it is a measure of the total moisture content of the atmosphere, the study of the seasonal and geographical variations of precipitable water is of interest from meteorological and hydrological standpoints. We have, therefore, undertaken such a study for the atmosphere over India making use of the radiosonde data of the following 12 stations for the 6-year period 1956—1961.

Station	Latitude (N)	Longitude (E)	Elevation (metres)
Allahabad	25°27′	81°44′	98
Bombay	19°07′	72°51′	15
Calcutta	22°39′	88°27′	6
Gauhati	26°05′	91°43′	54
Jodhpur	26°18′	73°01′	224
Madras	13°00′	80°11′	16
Nagpur	21°06′	79°03′	310
New Delhi	28°35′	77°12′	216
Port Blair	11°40′	92°43′	79
Trivandrum	08°28′	76°57′	8
Veraval	20°54′	70°22′	8
Visakhapatnam	17°43′	83°14′	3

2. Method of calculation

2.1. If q is the specific humidity of the atmosphere (mass in grams of water vapour per gram of moist air) at the height z where the pressure and density are p and ρ respectively, then the precipitable water in the atmosphere is given by

$$W = \int q \rho \, dz = -\frac{1}{g} \int q \, dp \qquad (1)$$

Since $q = r/(1+r)$, where r is the humidity mixing ratio (mass of water vapour per gram of dry air), we can write

$$W = \frac{1}{g} \int \frac{r}{1+r} \, dp \qquad (2)$$

2.2. Since $g \approx 980$ cm/sec^2 and r is of the order of ·01 to ·02 near the surface, $g(1+r)$ is ≈ 1000 near the surface. At higher levels although the value of $g(1+r)$ is slightly less than 1000, the error introduced in setting it equal to 1000 is quite small in the computation of total precipitable water vapour. Hence with sufficient accuracy we can write

$$W = \int \frac{r}{1000} \, dp \qquad (3)$$

If pressure is expressed in millibars we have

$$W = \int r \, dp \qquad (4)$$

If r is expressed as grams of water vapour per kilogram of dry air, the precipitable water

vapour in an isobaric layer of 100-mb thickness whose mean mixing ratio is r gm/kg is,

$$\triangle W = r/10$$

If the atmosphere is divided into 100-mb layers whose mixing ratios are r_1, r_2, r_3, ..., then the total precipitable water is given by

$$W = \frac{1}{10}(r_1 + r_2 + r_3 + \ldots\ldots) \qquad (5)$$

The mean of the values of r corresponding to the bottom and top of an isobaric layer can be taken with sufficient accuracy as the mean mixing ratio for the layer. The value of r decreases with height and for all practical purposes the contribution to W from layers above 200 mb is negligible even when the atmosphere is highly humid as in the monsoon months.

3. Evaluation of data

3.1. From the mean monthly data of upper air soundings for 00 and 12 GMT the values of the humidity mixing ratio were evaluated for the surface and for the isobaric levels 900, 850, 800, 700 ..... mb. The Indian radiosondes use a wet-bulb element for the estimation of the moisture content of the atmosphere. Above the freezing level the readings of the wet element are not reliable and as such are not accepted. The values of r are normally available only upto the level of freezing. Although the major contribution to the precipitable water comes from the layers between the surface of the earth and the freezing level, it was considered desirable to get an approximate estimate of the contribution of the higher layers also. For this purpose the values of r were plotted as a function of pressure using the observational data. By graphical extrapolation the values of r for standard pressure levels above the freezing level were determined. Since the variation of r with pressure was found to be regular in respect of the monthly mean values, the extrapolation could be done with reasonable accuracy. The extrapolated values of r were utilized to calculate the contributions to the total precipitable water from the layers above the freezing level.

3.2. If the surface pressure in millibars is p_0 then the precipitable water in the layer from the surface to 900 mb is $r/1000\ (p_0 - 900)$ gm where r is the mean value of the mixing ratio for the layer. Monthly mean values of the precipitable water vapour were calculated for each of the layers, surface—900, 900—800, 800—700, ... mb in respect of the individual stations for the individual years. The calculations were made separately for the two hours of observation, 00 and 12 GMT.

4. Results

The mean monthly values of precipitable water in gm/cm^2 for isobaric layers for the 12 stations are given in the Appendix. Table 1 gives the mean monthly precipitable water vapour taken as the average of the values for 00 and 12 GMT. Table 2 gives the mean monthly rainfall for the 12 stations. This table has been included to bring out the relationship between precipitable water and rainfall.

5. Discussion

5.1. The general feature shown by all the stations is a rise of precipitable water in the atmosphere from a minimum in the winter months to a maximum in the monsoon months. The lowest values occur over the north Indian stations of Jodhpur, Delhi and Allahabad in the month of February, when the precipitable water is only slightly more than 1 gm. The highest value of slightly over 7 gms occurs at Gauhati in July and August. The amplitude of the seasonal variation is large for stations in north India as compared with the southern stations.

(*i*) *Trivandrum*—The precipitable water is about 3·5 gms during the months December to March, the value being least in January. There is a fairly sudden increase from March to April followed by a further small increase from April to May. A slight decrease occurs from May to June. The value remains near about 4·5 gms during the months June to November. It is interesting to see that no striking increase in the precipitable water content of the atmosphere occurs with the

onset of the southwest monsoon in May—June. Trivandrum has two peaks in its annual rainfall, one in June and the other in October. However, the precipitable water changes very little during the months April to November. This shows that the presence of moisture by itself is only a necessary condition for rainfall; the synoptic-climatological features that give rise to vertical motions in the atmosphere have also to be considered for understanding rainfall variations.

(*ii*) *Port Blair* — The moisture content of the atmosphere over Port Blair is higher than that of Trivandrum in all the months. During the months December to March the value of W varies between 3·8 and 4·1 gms. There is a sudden increase from March to April and a further increase from April to May. The magnitude of W fluctuates around 5·5 gms from May to October and decreases sharply to 4·8 gms in November. Port Blair has two rainfall peaks, in June and September respectively.

(*iii*) *Madras* — The precipitable water at Madras is less than 3 gms in the first 3 months of the year. There is a steady increase from March, the maximum value of 5·4 gms being reached in June. The value remains slightly above 5 gms till September after which it decreases steadily to 3·2 gms in December. November is the rainiest month in Madras, the rainfall in this month being over 7 times that in June. However, the precipitable water is less in November than in June. This again emphasises the importance of synoptic features that give rise to vertical motions in the atmosphere in the production of rainfall.

(*iv*) *Visakhapatnam* — The moisture content of the atmosphere is between 2·5 and 3 gms during the months December to February. The value begins to increase from March and attains the maximum of nearly 6 gms in July. During the months June to September the precipitable water is nearly constant and ranges between 5·5 and 6 gms. After September there is a rapid decline. The station gets the maximum rainfall in October which is not the month of maximum moisture content in the atmosphere.

(*v*) *Bombay* — The precipitable water shows little variation during the months December to March when it is nearly 2·5 gms. From April W begins to increase and reaches the peak value of 6·2 gms in July. During the months June to September the value of W lies between 5·2 and 6·2 gms. July is the month of maximum rainfall for Bombay which in this case coincides with the month of maximum moisture content of the atmosphere. Although the rainfall decreases nearly by a factor of 2 from July to August, the decrease in moisture content is extremely small.

(*vi*) *Veraval* — February is the month of least moisture content in the atmosphere over this station. The general features are similar to those of Bombay although the actual moisture content is less for all the months.

(*vii*) *Nagpur* — The extreme dryness of this station during the months December to March is noteworthy. There is a steady increase of precipitable water from March to July-August and a decline thereafter. The station gets the maximum monthly rainfall in July.

(*viii*) *Calcutta* — December, January and February are the months of least moisture content in the atmosphere. The precipitable water exceeds 6 gms during the southwest monsoon months June to September which are the rainiest months.

(*ix*) *Gauhati* — The general features are the same as for Calcutta except for the fact that the value of W is higher at this station in all the months. However, the total annual rainfall and its seasonal variation are nearly the same at the two places. Among all the 12 stations studied, Gauhati has the highest moisture content in the atmosphere of slightly over 7 gms in the months July-August.

(*x*) *Allahabad, Delhi and Jodhpur* — These three stations present nearly similar features. The moisture content is less than 2 gms during the months November to April. The precipitable water increases steadily from

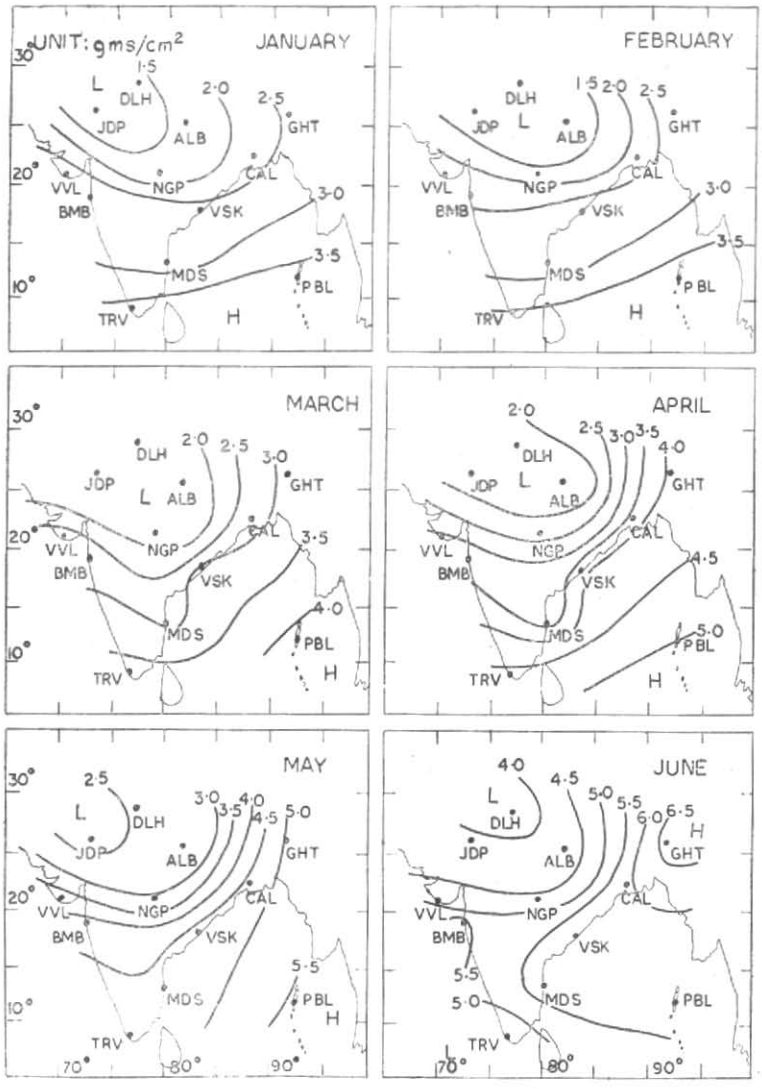

Fig. 1. Seasonal variation of precipitable water vapour

May and reaches the peak value in the months of July-August. The maximum value of W is 6·5 gms for Allahabad, 6 gms for Delhi and 5·5 gms for Jodhpur. The mean monthly rainfall is highest at Allahabad in July. New Delhi and Jodhpur experience the highest monthly rainfall in August, although the difference in rainfall amounts between July and August is not appreciable.

5.2. The diurnal variation of precipitable water is illustrated by Table 3 in which the increase of W from 00 to 12 hrs GMT is given as a percentage of the morning value. In general, the evening value is a few per cent higher than the morning value for all the stations almost throughout the year. This increase is particularly conspicuous in the case of Gauhati, Trivandrum and Veraval in the non-monsoon months when the evening values are about 15 to 20 per cent higher than the morning values. The diurnal varia

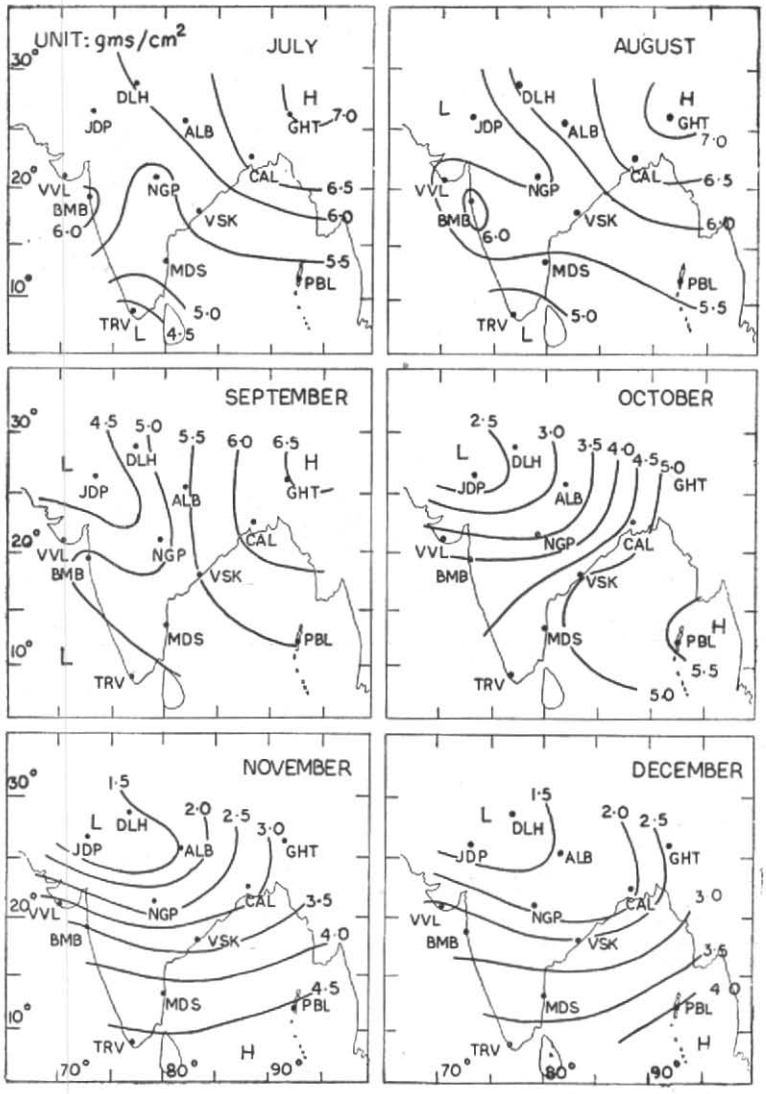

Fig. 1. Seasonal variation of precipitable water vapour

tion is least in the monsoon months.

5.3. The seasonal variations of precipitable water vapour over the country are diagrammatically represented in Fig. 1 (see also page 374). The 12 Z values at the 12 radiosonde stations have been utilized for drawing the isopleths. Over northeast India the gradient of W as well as the actual values increase steadily from March to June. In July the lowest values of W occur at the extreme south of the peninsula while the highest values occur over Assam. The rapid changes that occur with the onset and withdrawal of the southwest monsoon are clearly brought out by the figure.

6. Acknowledgement

Our thanks are due to several members of the Investigation and Development Section of the Office of the Deputy Director General of Observatories (Forecasting) for help in the collection of data and compilation of the Tables.

TABLE 1

Monthly mean precipitable water in gms (1956—1961)

$\frac{1}{2}(00+12)\,Z$

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Allahabad	1·62	1·24	1·54	1·60	2·57	4·43	6·40	**6·45**	5·48	3·31	1·54	1·50
Bombay	2·61	2·35	2·63	3·35	4·34	5·52	**6·19**	6·01	5·25	4·17	3·42	2·58
Calcutta	2·10	1·97	2·82	3·51	4·79	6·02	**6·55**	6·55	6·20	4·74	2·69	1·95
Gauhati	2·44	2·57	3·22	3·99	5·17	6·47	6·92	**7·10**	6·32	5·09	3·69	2·56
Jodhpur	1·12	1·08	1·51	1·71	2·41	4·03	**5·51**	5·06	4·35	2·37	1·50	1·17
Madras	2·96	2·63	2·81	3·47	4·49	**5·42**	5·33	5·40	5·14	4·97	4·23	3·24
Nagpur	1·87	1·55	1·89	2·42	3·08	4·49	**5·48**	5·41	4·73	3·21	2·18	1·68
New Delhi	1·48	1·17	1·73	1·89	2·53	3·92	**6·10**	6·03	4·83	2·70	1·45	1·25
Port Blair	3·92	3·91	4·08	4·78	5·70	**5·73**	5·49	5·57	5·55	5·42	4·80	4·08
Trivandrum	3·29	3·34	3·55	4·38	**4·85**	4·57	4·42	4·55	4·52	4·54	4·65	3·64
Veraval	2·37	2·19	2·49	3·23	3·55	4·64	**5·61**	5·39	4·76	3·64	2·76	2·48
Visakhapatnam	2·90	2·93	3·26	4·04	4·79	5·55	**5·82**	5·77	5·49	4·86	3·16	2·66

Note—Highest values given in bold figures

TABLE 2

Mean monthly rainfall (cm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Allahabad	2·2	1·6	1·4	0·4	1·6	12·8	**31·9**	25·5	21·2	5·9	0·8	0·9
Bombay	0·4	0·2	0·1	0·1	1·7	48·4	**61·6**	34·0	26·4	6·5	1·3	0·2
Calcutta	0·9	3·0	3·5	4·4	13·9	29·7	32·5	**32·8**	25·3	11·4	2·1	0·5
Gauhati	1·0	3·0	5·1	14·5	23·6	**31·2**	**31·1**	26·1	16·7	7 1	1·4	0·4
Jodhpur	0·4	0·6	0·3	0·3	1·0	3·6	10·1	**12·3**	6·1	0·8	0·3	0·3
Madras	3·6	1·0	0·7	1·5	2·6	4·7	9·1	11·6	11·9	30·6	**35·5**	13·8
Nagpur	0·9	1·7	1·5	1·5	1·9	22·4	**37·1**	29·0	20·3	5·5	1·9	1·2
New Delhi	2·5	2·1	1·3	0·8	1·3	7·7	17·9	**18·4**	12·3	1·0	0·3	1·1
Port Blair	4·5	2·8	2·9	6·0	38·4	**55·2**	39·1	41·4	44·2	**31·8**	**26·7**	20·1
Trivandrum	2·0	1·9	3·9	11·6	22·3	**33·5**	19·7	12·0	11·5	27·3	17·7	6·3
Veraval	0·1	0·2	0·1	0·0	0·7	11·8	**19·8**	9·2	6·3	1·6	0·4	0·2
Visakhapatnam	1·1	2·4	1·2	1·8	5·1	10·5	11·2	13·1	16·6	**19·9**	11·9	12·5

Note—Highest values given in bold figures

TABLE 3

Diurnal variation of precipitable water

$[(W_{12} - W_{00})/W_{00}]\%$

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Allahabad	— 7	— 3	1	3	— 4	— 2	— 2	— 1	1	0	—13	7
Bombay	19	12	7	9	— 2	1	1	5	— 3	— 1	1	9
Calcutta	9	2	3	2	2	1	5	3	1	6	1	0
Gauhati	17	14	16	14	9	5	2	3	6	4	14	12
Jodhpur	0	— 7	12	2	1	0	0	1	2	0	— 8	9
Madras	3	— 3	0	— 1	6	7	5	3	5	1	6	1
Nagpur	— 1	5	— 1	5	— 2	— 2	— 2	3	2	3	2	11
New Delhi	3	— 3	2	0	6	— 2	0	0	3	— 4	6	10
Port Blair	0	— 2	— 3	12	2	— 2	— 3	2	— 2	— 4	— 1	— 5
Trivandrum	16	17	14	15	4	— 1	0	— 2	5	9	5	10
Veraval	19	27	16	— 1	15	6	6	5	9	— 2	24	17
Visakhapatnam	1	0	7	6	6	9	— 3	— 2	2	8	2	4

APPENDIX

Mean precipitable water (in gm) for isobaric layers (1956—1961)

Layer (mb)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ALLAHABAD : Lat. 25° 27′N, Long. 81° 44′E ; Elevation : 98 m ; Time of obsns. : 00/12 GMT												
00 Z												
Surf—900	0·673	0·557	0·633	0·615	0·793	1·263	1·696	1·707	1·632	1·277	0·750	0·649
900—800	0·432	0·333	0·387	0·405	0·611	1·153	1·587	1·566	1·385	0·884	0·448	0·365
800—700	0·287	0·204	0·271	0·301	0·482	0·906	1·245	1·215	1·021	0·559	0·254	0·221
700—600	0·189	0·121	0·174	0·181	0·323	0·610	0·915	0·882	0·706	0·301	0·140	0·138
600—500	0·084	0·045	0·075	0·066	0·179	0·370	0·611	0·616	0·454	0·204	0·051	0·033
500—400	0·011	0·000	0·010	0·008	0·095	0·165	0·321	0·354	0·216	0·089	0·006	0·009
400—300	0·000	0·000	0·000	0·000	0·033	0·024	0·092	0·117	0·047	0·000	0·000	0·00
300—200	0·000	0·000	0·000	0·000	0·005	0·000	0·006	0·012	0·003	0·000	0·000	0·000
Total	1·676	1·260	1·550	1·576	2·521	4·491	6·473	6·476	5·464	3·314	1·649	1·455
12 Z												
Surf—900	0·726	0·592	0·624	0·581	0·778	1·244	1·626	1·760	1·641	1·288	0·771	0·723
900—800	0·419	0·325	0·417	0·442	0·664	1·156	1·584	1·581	1·431	0·904	0·384	0·391
800—700	0·252	0·178	0·272	0·326	0·497	0·877	1·237	1·194	1·031	0·552	0·176	0·211
700—600	0·130	0·089	0·153	0·192	0·320	0·585	0·894	0·861	0·695	0·291	0·080	0·179
600—500	0·043	0·037	0·057	0·076	0·199	0·348	0·591	0·584	0·442	0·183	0·025	0·040
500—400	0·000	0·000	0·010	0·010	0·118	0·151	0·309	0·335	0·212	0·082	0·000	0·009
400—300	0·000	0·000	0·000	0·000	0·028	0·019	0·088	0·108	0·045	0·000	0·000	0·000
300—200	0·000	0·000	0·000	0·000	0·005	0·000	0·006	0·007	0·003	0·000	0·000	0·000
Total	1·570	1·221	1·533	1·627	2·609	4·380	6·335	6·430	5·500	3·300	1·436	1·553
BOMBAY : Lat. 19° 07′N, Long. 72° 51′E ; Elevation : 15 m ; Time of obsns. : 00/12 GMT												
00 Z												
Surf—900	1·007	0·926	1·105	1·317	1·674	1·791	1·832	1·783	1·781	1·560	1·282	1·070
900—800	0·633	0·523	0·551	0·659	0·991	1·337	1·426	1·374	1·308	1·020	0·338	0·653
800—700	0·423	0·380	0·425	0·523	0·699	0·921	1·075	1·029	0·941	0·731	0·586	0·407
700—600	0·211	0·233	0·279	0·385	0·513	0·628	0·793	0·739	0·632	0·449	0·329	0·207
600—500	0·089	0·113	0·127	0·213	0·317	0·444	0·557	0·521	0·417	0·271	0·199	0·101
500—400	0·019	0·036	0·045	0·089	0·147	0·271	0·337	0·301	0·207	0·135	0·087	0·026
400—300	0·000	0·005	0·008	0·025	0·035	0·078	0·130	0·107	0·043	0·016	0·002	0·000
300—200	0·000	0·000	0·000	0·002	0·000	0·026	0·017	0·014	0·000	0·000	0·000	0·000
Total	2·382	2·216	2·540	3·213	4·376	5·496	6·167	5·868	5·329	4·182	3·323	2·464

APPENDIX (*contd*)

Layer (mb)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						BOMBAY (*contd*)						
						12 Z						
Surf—900	1·189	1·089	1·176	1·395	1·605	1·793	1·849	1·825	1·759	1·645	1·456	1·241
900—800	0·735	0·594	0·600	0·737	0·953	1·317	1·421	1·413	1·247	1·058	0·885	0·698
800—700	0·471	0·400	0·447	0·586	0·726	0·933	1·052	1·065	0·897	0·699	0·549	0·403
700—600	0·267	0·232	0·288	0·408	0·529	0·643	0·774	0·775	0·618	0·408	0·295	0·204
600—500	0·134	0·119	0·144	0·220	0·308	0·448	0·579	0·567	0·397	0·211	0·212	0·111
500—400	0·031	0·043	0·061	0·105	0·141	0·268	0·361	0·349	0·196	0·117	0·114	0·034
400—300	0·003	0·005	0·014	0·031	0·035	0·113	0·144	0·141	0·054	0·016	0·005	0·000
300—200	0·000	0·000	0·000	0·003	0·002	0·033	0·028	0·027	0·000	0·000	0·000	0·000
Total	2·830	2·482	2·730	3·485	4·299	5·548	6·208	6·162	5·168	4·154	3·516	2·691
	CALCUTTA : Lat. 22° 39′N, Long. 88° 27′E ; Elevation : 6 m ; Time of obsns. : 00/12 GMT											
						00 Z						
Surf—900	0·909	0·910	1·246	1·503	1·758	1·898	1·884	1·913	1·913	1·729	1·266	0·902
900—800	0·515	0·483	0·675	0·793	1·142	1·405	1·470	1·492	1·410	1·102	0·611	0·481
800—700	0·328	0·311	0·465	0·564	0·789	1·047	1·135	1·150	1·064	0·772	0·353	0·281
700—600	0·187	0·181	0·273	0·368	0·528	0·742	0·826	0·841	0·783	0·506	0·233	0·171
600—500	0·068	0·069	0·106	0·182	0·329	0·511	0·575	0·587	0·549	0·326	0·146	0·092
500—400	0·000	0·004	0·017	0·059	0·161	0·298	0·347	0·338	0·320	0·150	0·056	0·023
400—300	0·000	0·000	0·000	0·005	0·032	0·085	0·138	0·120	0·114	0·022	0·055	0·000
300—200	0·000	0·000	0·000	0·000	0·000	0·000	0·031	0·020	0·017	0·001	0·000	0·000
Total	2·007	1·958	2·782	3·474	4·739	5·986	6·406	6·461	6·170	4·608	2·670	1·950
						12 Z						
Surf—900	1·036	0·972	1·243	1·463	1·814	1·914	1·930	1·947	1·928	1·780	1·263	0·980
900—800	0·555	0·518	0·744	0·897	1·229	1·478	1·565	1·553	1·476	1·181	0·638	0·475
800—700	0·342	0·298	0·467	0·619	0·818	1·072	1·190	1·181	1·097	0·815	0·355	0·256
700—600	0·175	0·147	0·270	0·372	0·537	0·759	0·870	0·870	0·780	0·523	0·226	0·163
600—500	0·075	0·050	0·120	0·160	0·305	0·495	0·603	0·601	0·526	0·359	0·151	0·075
500—400	0·005	0·000	0·014	0·043	0·120	0·272	0·361	0·349	0·300	0·186	0·069	0·011
400—300	0·000	0·000	0·000	0·002	0·019	0·078	0·149	0·124	0·114	0·028	0·007	0·000
300—200	0·000	0·000	0·000	0·000	0·000	0·000	0·033	0·020	0·017	0·000	0·000	0·000
Total	2·188	1·895	2·858	3·556	4·842	6·068	6·701	6·645	6·238	4·872	2·709	1·960

APPENDIX (*contd*)

Layer (mb)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
GAUHATI : Lat. 26° 05′N, Long. 91° 43′E; Elevation : 54 m; Time of obsns. : 00/12 GMT												
00 Z												
Surf—900	0·906	0·919	1·141	1·359	1·625	1·813	1·887	1·942	1·874	1·654	1·220	0·988
900—800	0·612	0·587	0·757	0·963	1·240	1·480	1·556	1·568	1·440	1·157	0·787	0·660
800—700	0·395	0·404	0·529	0·671	0·862	1·141	1·219	1·227	1·088	0·837	0·475	0·403
700—600	0·214	0·256	0·333	0·429	0·575	0·835	0·911	0·906	0·789	0·587	0·258	0·230
600—500	0·099	0·133	0·171	0·223	0·407	0·580	0·641	0·649	0·535	0·419	0·122	0·105
500—400	0·023	0·045	0·046	0·066	0·195	0·331	0·396	0·431	0·300	0·247	0·029	0·022
400—300	0·002	0·009	0·003	0·007	0·047	0·119	0·180	0·213	0·101	0·080	0·000	0·000
300—200	0·000	0·000	0·000	0·000	0·000	0·022	0·044	0·059	0·011	0·013	0·000	0·000
Total	2·251	2·353	2·980	3·718	4·951	6·321	6·834	6·995	6·138	4·994	2·891	2·408
12 Z												
Surf—900	1·671	1·049	1·249	1·585	1·783	1·887	1·950	1·969	1·980	1·777	1·404	1·143
900—800	0·687	0·719	0·880	1·136	1·419	1·589	1·632	1·649	1·544	1·258	0·897	0·709
800—700	0·443	0·484	0·624	0·784	0·988	1·203	1·258	1·275	1·134	0·881	0·556	0·448
700—600	0·262	0·302	0·401	0·459	0·620	0·848	0·905	0·933	0·815	0·595	0·288	0·265
600—500	0·136	0·167	0·221	0·214	0·373	0·586	0·629	0·662	0·560	0·397	0·115	0·119
500—400	0·032	0·053	0·076	0·064	0·172	0·349	0·410	0·434	0·333	0·209	0·023	0·025
400—300	0·003	0·010	0·012	0·009	0·031	0·126	0·181	0·223	0·121	0·063	0·000	0·000
300—200	0·000	0·000	0·000	0·000	0·000	0·022	0·036	0·064	0·011	0·013	0·000	0·000
Total	2·634	2·784	3·463	4·251	5·386	6·610	7·001	7·209	6·498	5·193	3·283	2·709
JODHPUR : Lat. 26° 18′N, Long. 73° 01′E; Elevation : 224 m; Time of obsns. : 00/12 GMT												
00 Z												
Surf—900	0·408	0·345	0·430	0·534	0·720	1·170	1·335	1·292	1·229	0·770	0·494	0·417
900—800	0·327	0·303	0·387	0·468	0·657	1·184	1·454	1·387	1·207	0·678	0·459	0·328
800—700	0·199	0·232	0·294	0·357	0·469	0·780	1·075	0·999	0·839	0·463	0·312	0·199
700—600	0·121	0·152	0·181	0·205	0·304	0·496	0·762	0·656	0·530	0·242	0·178	0·115
600—500	0·055	0·071	0·086	0·099	0·159	0·283	0·513	0·437	0·325	0·137	0·093	0·049
500—400	0·006	0·017	0·032	0·032	0·066	0·110	0·277	0·221	0·147	0·071	0·026	0·007
400—300	0·000	0·000	0·005	0·000	0·016	0·010	0·078	0·041	0·020	0·000	0·000	0·000
300—200	0·000	0·000	0·000	0·000	0·003	0·000	0·003	0·000	0·000	0·000	0·000	0·000
Total	1·116	1·120	1·415	1·695	2·394	4·033	5·497	5·033	4·297	2·361	1·562	1·115

APPENDIX (*contd*)

Layer (mb)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
JODHPUR (*contd*)												
12 Z												
Surf—900	0·419	0·350	0·474	0·517	0·629	1·059	1·315	1·267	1·211	0·738	0·502	0·468
900—800	0·320	0·299	0·444	0·480	0·667	1·205	1·540	1·411	1·239	0·691	0·414	0·369
800—700	0·209	0·201	0·335	0·361	0·513	0·829	1·123	1·033	0·899	0·493	0·270	0·211
700—600	0·114	0·123	0·204	0·234	0·306	0·495	0·754	0·681	0·568	0·255	0·167	0·117
600—500	0·049	0·058	0·100	0·113	0·183	0·301	0·492	0·439	0·322	0·131	0·075	0·052
500—400	0·007	0·013	0·038	0·027	0·101	0·127	0·241	0·213	0·131	0·031	0·009	0·003
400—300	0·000	0·000	0·005	0·000	0·019	0·010	0·059	0·042	0·022	0·000	0·000	0·000
300—200	0·000	0·000	0·000	0·000	0·003	0·000	0·000	0·000	0·000	0·000	0·000	0·000
Total	1·118	1·044	1·600	1·732	2·421	4·026	5·524	5·086	4·392	2·339	1·437	1·223
MADRAS : Lat. 13° 00′N, Long. 80° 11′E; Elevation : 16 m; Time of obsns. : 00/12 GMT												
00 Z												
Surf—900	1·425	1·336	1·382	1·615	1·650	1·597	1·583	1·621	1·679	1·710	1·642	1·485
900—800	0·741	0·629	0·642	0·812	1·064	1·228	1·184	1·207	1·216	1·169	1·013	0·834
800—700	0·385	0·372	0·409	0·502	0·723	0·958	0·923	0·932	0·938	0·871	0·682	0·449
700—600	0·250	0·227	0·248	0·343	0·498	0·690	0·682	0·700	0·635	0·602	0·455	0·288
600—500	0·128	0·100	0·113	0·174	0·278	0·451	0·468	0·466	0·356	0·367	0·243	0·143
500—400	0·022	0·013	0·023	0·041	0·107	0·227	0·260	0·281	0·148	0·173	0·076	0·021
400—300	0·000	0·000	0·002	0·000	0·030	0·071	0·089	0·088	0·033	0·052	0·000	0·000
300—200	0·000	0·000	0·000	0·000	0·000	0·005	0·009	0·014	0·000	0·009	0·000	0·000
Total	2·951	2·677	2·819	3·487	4·350	5·227	5·198	5·309	5·005	4·953	4·111	3·220
12 Z												
Surf—900	1·402	1·276	1·349	1·547	1·673	1·677	1·649	1·693	1·740	1·715	1·645	1·459
900—800	0·736	0·607	0·627	0·796	1·133	1·336	1·312	1·318	1·299	1·197	1·067	0·841
800—700	0·396	0·365	0·411	0·517	0·812	1·029	1·029	1·007	0·971	0·875	0·740	0·484
700—600	0·271	0·219	0·263	0·353	0·534	0·728	0·693	0·712	0·658	0·602	0·506	0·305
600—500	0·138	0·101	0·127	0·192	0·318	0·484	0·461	0·455	0·401	0·367	0·285	0·148
500—400	0·020	0·018	0·029	0·058	0·131	0·260	0·252	0·229	0·174	0·172	0·098	0·023
400—300	0·000	0·000	0·002	0·003	0·033	0·087	0·073	0·067	0·033	0·052	0·011	0·000
300—200	0·000	0·000	0·000	0·000	0·000	0·008	0·000	0·002	0·002	0·009	0·000	0·000
Total	2·963	2·586	2·808	3·466	4·634	5·609	5·469	5·483	5·278	4·989	4·352	3·260

APPENDIX (*contd*)

Layer (mb)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NAGPUR : Lat. 21° 06′N, Long. 79° 03′E ; Elevation: 310 m; Time of obsns. : 00/12 GMT												
00 Z												
Surf—900	0·616	0·472	0·531	0·589	0·673	0·980	1·117	1·129	1·109	0·952	0·712	0·580
900—800	0·599	0·479	0·547	0·631	0·788	1·208	1·404	1·387	1·282	0·970	0·681	0·496
800—700	0·397	0·331	0·440	0·544	0·657	0·966	1·191	1·090	0·959	0·651	0·431	0·278
700—600	0·198	0·173	0·261	0·383	0·504	0·690	0·819	0·801	0·659	0·378	0·235	0·156
600—500	0·059	0·050	0·095	0·175	0·315	0·417	0·587	0·534	0·424	0·177	0·093	0·071
500—400	0·000	0·003	0·017	0·040	0·135	0·161	0·318	0·285	0·199	0·043	0·009	0·014
400—300	0·000	0·000	0·000	0·002	0·036	0·023	0·087	0·099	0·044	0·002	0·000	0·000
300—200	0·000	0·000	0·000	0·000	0·000	0·000	0·013	0·017	0·002	0·000	0·000	0·000
Total	1·869	1·508	1·891	2·364	3·108	4·445	5·536	5·342	4·678	3·173	2·161	1·595
12 Z												
Surf—900	0·621	0·471	0·477	0·558	0·590	0·928	1·115	1·136	1·107	0·907	0·706	0·612
900—800	0·629	0·489	0·541	0·643	0·767	1·213	1·429	1·425	1·318	0·987	0·684	0·568
800—700	0·394	0·354	0·449	0·569	0·659	0·965	1·115	1·112	0·985	0·686	0·449	0·331
700—600	0·171	0·200	0·289	0·423	0·528	0·687	0·851	0·813	0·677	0·383	0·243	0·165
600—500	0·048	0·070	0·107	0·208	0·332	0·464	0·561	0·561	0·436	0·209	0·101	0·077
500—400	0·000	0·005	0·015	0·062	0·143	0·225	0·263	0·309	0·208	0·075	0·013	0·014
400—300	0·000	0·000	0·000	0·012	0·036	0·045	0·083	0·103	0·047	0·000	0·000	0·000
300—200	0·000	0·000	0·000	0·000	0·000	0·002	0·013	0·017	0·002	0·000	0·000	0·000
Total	1·863	1·589	1·878	2·475	3·055	4·529	5·430	5·476	4·780	3·247	2·196	1·767
NEW DELHI: Lat. 28° 35′N, Long. 77° 12′E; Elevation : 216 m; Time of obsns.: 00/12 GMT												
00 Z												
Surf—900	0·503	0·438	0·591	0·579	0·702	1·048	1·443	1·497	1·339	0·947	0·565	0·476
900—800	0·387	0·321	0·449	0·499	0·662	1·109	1·584	1·591	1·317	0·750	0·405	0·325
800—700	0·268	0·218	0·321	0·389	0·505	0·837	1·209	1·203	0·932	0·486	0·241	0·207
700—600	0·189	0·139	0·226	0·259	0·344	0·548	0·859	0·837	0·607	0·263	0·132	0·125
600—500	0·092	0·057	0·112	0·131	0·177	0·304	0·577	0·549	0·381	0·142	0·057	0·051
500—400	0·017	0·006	0·020	0·035	0·057	0·113	0·321	0·284	0·162	0·059	0·006	0·006
400—300	0·004	0·000	0·000	0·002	0·006	0·007	0·099	0·067	0·023	0·000	0·000	0·000
300—200	0·000	0·000	0·000	0·000	0·000	0·000	0·003	0·000	0·000	0·000	0·000	0·000
Total	1·460	1·179	1·719	1·894	2·453	3·066	6·095	6·028	4·761	2·647	1·406	1·190

APPENDIX (*contd*)

Layer (mb)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NEW DELHI (*contd*)												
12 Z												
Surf—900	0·600	0·478	0·602	0·601	0·767	0·971	1·421	1·533	1·353	0·966	0·642	0·547
900—800	0·419	0·328	0·478	0·515	0·703	1·087	1·604	1·625	1·356	0·783	0·439	0·350
800—700	0·222	0·199	0·327	0·383	0·549	0·833	1·215	1·181	0·953	0·501	0·251	0·213
700—600	0·163	0·105	0·212	0·233	0·353	0·541	0·856	0·822	0·629	0·285	0·125	0·140
600—500	0·090	0·037	0·108	0·110	0·196	0·308	0·579	0·531	0·406	0·159	0·039	0·060
500—400	0·013	0·006	0·023	0·031	0·085	0·127	0·226	0·273	0·185	0·061	0·003	0·000
400—300	0·000	0·000	0·000	0·002	0·011	0·014	0·104	0·072	0·028	0·005	0·000	0·000
300—200	0·000	0·000	0·000	0·000	0·000	0·000	0·004	0·000	0·000	0·000	0·000	0·000
Total	1·597	1·153	1·750	1·875	2·604	3·881	6·109	6·037	4·910	2·760	1·499	1·310
PORT BLAIR : Lat. 11° 40′N, Long. 92° 43′E; Elevation : 79 m; Time of obsns.: 00/12 GMT												
00 Z												
Surf—900	1·541	1·498	1·497	1·638	1·789	1·729	1·720	1·708	1·700	1·657	1·647	1·509
900—800	1·040	1·045	1·000	1·126	1·369	1·355	1·313	1·326	1·317	1·273	1·221	1·015
800—700	0·631	0·680	0·651	0·777	9·985	1·005	0·960	0·968	0·987	0·969	0·844	0·681
700—600	0·408	0·442	0·448	0·525	0·695	0·747	0·705	0·700	0·731	0·690	0·573	0·452
600—500	0·225	0·244	0·278	0·303	0·467	0·528	0·485	0·469	0·495	0·448	0·343	0·251
500—400	0·067	0·067	0·108	0·120	0·257	0·300	0·271	0·248	0·269	0·226	0·125	0·075
400—300	0·010	0·007	0·025	0·022	0·084	0·114	0·103	0·082	0·091	0·064	0·018	0·010
300—200	0·000	0·000	0·003	0·000	0·013	0·019	0·017	0·009	0·007	0·002	0·000	0·000
Total	3·922	3·983	4·010	4·511	5·641	5·797	5·574	5·510	5·597	5·329	4·771	3·993
12 Z												
Surf—900	1·446	1·504	1·597	1·760	1·774	1·718	1·699	1·728	1·707	1·706	1·685	1·587
900—800	1·052	1·037	1·075	1·306	1·397	1·353	1·293	1·355	1·315	1·312	1·236	1·096
800—700	0·651	0·636	0·667	0·880	1·019	0·985	0·931	0·993	0·969	0·985	0·844	0·671
700—600	0·429	0·398	0·453	0·592	0·728	0·712	0·678	0·720	0·704	0·707	0·575	0·463
600—500	0·246	0·199	0·249	0·342	0·486	0·500	0·452	0·481	0·469	0·469	0·353	0·263
500—400	0·078	0·056	0·083	0·137	0·255	0·284	0·245	0·254	0·254	0·252	0·123	0·074
400—300	0·009	0·007	0·017	0·027	0·089	0·100	0·086	0·083	0·083	0·081	0·012	0·013
300—200	0·000	0·000	0·003	0·000	0·016	0·014	0·012	0·007	0·006	0·007	0·000	0·000
Total	3·911	3·837	4·144	5·044	5·764	5·666	5·396	5·621	5·507	5·519	4·828	4·167

APPENDIX (*contd*)

Layer (mb)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TRIVANDRUM: Lat. 08° 28′N, Long. 76° 57′E; Elevation : 8 m; Time of obsns. : 00/12 GMT												
					00 Z							
Surf—900	1·332	1·383	1·473	1·589	1·643	1·598	1·567	1·559	1·524	1·520	1·513	1·358
900—800	0·829	0·855	0·893	1·093	1·227	1·164	1·155	1·127	1·091	1·081	1·088	0 905
800—700	0·475	0·474	0·507	0·679	0·868	0·813	0·795	0·790	0·771	0·779	0·811	0·588
700—600	0·278	0·263	0·295	0·419	0·555	0·533	0·517	0·543	0·530	0·527	0·569	0·367
600—500	0·121	0·107	0·127	0·228	0·318	0·304	0·284	0·330	0·319	0·310	0·346	0·213
500—400	0·010	0·001	0·016	0·061	0·118	0·119	0·093	0·136	0·147	0·113	0·152	0·039
400—300	0·000	0·000	0·000	0·002	0·018	0·020	0·010	0·028	0·042	0·011	0·042	0·000
300—200	0·000	0·000	0·000	0·000	0·000	0·000	0·000	0·000	0·000	0·000	0·008	0·000
Total	3·045	3·083	3·311	4·071	4·747	4·551	4·421	4·513	4·424	4·341	4·529	3·470
					12 Z							
Surf—900	1·446	1·473	1·550	1·691	1·691	1·651	1·594	1·558	1·548	1·569	1·601	1·465
900—800	0·967	1·025	1·103	1·262	1·231	1·207	1·138	1·118	1·123	1·163	1·153	1·012
800—700	0·571	0·603	0·658	0·852	0·887	0·813	0·787	0·801	0·799	0·859	0·842	0·651
700—600	0·346	0·340	0·316	0·519	0·601	0·520	0·517	0·560	0·557	0·597	0·586	0·410
600—500	0·170	0·149	0·133	0·272	0·361	0·301	0·287	0·355	0·362	0·367	0·359	0·218
500—400	0·028	0·009	0·021	0·083	0·153	0·091	0·091	0·152	0·175	0·153	0·165	0·056
400—300	0·000	0·000	0·002	0·013	0·032	0·007	0·008	0·032	0·050	0·032	0·055	0·003
300—200	0·000	0·000	0·000	0·000	0·000	0·000	0·000	0·002	0·001	0·003	0·010	0·000
Total	3·528	3·599	3·783	4·692	4·956	4·590	4·422	4·578	4·615	4·743	4·771	3·815
VERAVAL: Lat. 20° 54′N, Long. 70°22′E; Elevation : 8 m; Time of obsns.: 00/12 GMT												
					00 Z							
Surf—900	0·809	0·764	0·925	1·304	1·462	1·788	1·817	1·719	1·687	1·582	1·021	0·874
900—800	0·502	0·418	0·541	0·770	0·688	1·094	1·293	1·269	1·143	1·015	0·650	0·538
800—700	0·354	0·301	0·418	0·497	0·499	0·642	0·887	0·894	0·795	0·570	0·421	0·375
700—600	0·264	0·230	0·238	0·347	0·361	0·429	0·621	0·635	0·479	0·325	0·241	0·263
600—500	0·152	0·141	0·130	0·215	0·203	0·343	0·464	0·447	0·288	0·143	0·117	0·157
500—400	0·057	0·056	0·046	0·088	0·079	0·186	0·270	0·241	0·142	0·041	0·020	0·068
400—300	0·020	0·015	0·009	0·024	0·014	0·032	0·085	0·071	0·017	0·000	0·000	0·017
300—200	0·006	0·001	0·000	0·004	0·000	0·000	0·012	0·000	0·000	0·000	0·000	0·000
Total	2·164	1·926	2·307	3·249	3·306	4·514	5·449	5·267	4·551	3·676	2·470	2·292

APPENDIX (*contd*)

Layer (mb)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					VERAVAL (*contd*)							
					12 Z							
Surf—900	1·092	1·189	1·252	1·432	1·611	1·723	1·807	1·768	1·748	1·585	1·427	1·156
900—800	0·587	0·490	0·541	0·627	0·749	1·136	1·339	1·287	1·212	0·885	0·765	0·619
800—700	0·395	0·351	0·397	0·487	0·567	0·754	0·963	0·924	0·859	0·575	0·493	0·397
700—600	0·276	0·248	0·277	0·345	0·443	0·546	0·686	0·659	0·563	0·313	0·254	0·262
600—500	0·163	0·141	0·157	0·207	0·284	0·367	0·507	0·491	0·372	0·173	0·105	0·156
500—400	0·049	0·041	0·052	0·094	0·121	0·183	0·318	0·280	0·182	0·070	0·014	0·065
400—300	0·008	0·003	0·007	0·023	0·027	0·048	0·133	0·083	0·029	0·000	0·000	0·017
300—200	0·000	0·000	0·000	0·003	0·000	0·006	0·016	0·004	0·000	0·000	0·000	0·000
Total	2·570	2·463	2·683	3·218	3·802	4·763	5·769	5·506	4·965	3·601	3·058	2·672
VISAKHAPATNAM : Lat. 17° 43′N, Long. 83° 14′E; Elevation : 3 m; Time of obsrs.: 00/12 GMT												
					00 Z							
Surf—900	1·244	1·261	1·329	1·506	1·657	1·630	1·622	1·665	1·695	1·575	1·287	1·137
900—800	0·728	0·749	0·724	0·906	1·058	1·279	1·394	1·383	1·312	1·137	0·789	0·643
800—700	0·437	0·471	0·534	0·685	0·737	0·989	1·070	1·080	1·004	0·848	0·495	0·370
700—600	0·276	0·283	0·346	0·465	0·565	0·703	0·800	0·792	0·722	0·591	0·345	0·268
600—500	0·155	0·139	0·167	0·246	0·379	0·448	0·558	0·527	0·452	0·352	0·173	0·157
500—400	0·035	0·025	0·044	0·097	0·188	0·204	0·319	0·283	0·208	0·144	0·038	0·031
400—300	0·000	0·002	0·004	0·020	0·057	0·051	0·119	0·085	0·052	0·025	0·003	0·002
300—200	0·000	0·000	0·000	0·000	0·003	0·000	0·014	0·000	0·000	0·000	0·000	0·000
Total	2·875	2·930	3·148	3·925	4·644	5·304	5·896	5·815	5·445	4·672	3·130	2·608
					12 Z							
Surf—900	1·302	1·263	1·388	1·583	1·721	1·700	1·667	1·671	1·718	1·659	1·326	1·185
900—800	0·750	0·743	0·751	0·941	1·165	1·358	1·392	1·358	1·350	1·199	0·808	0·674
800—700	0·457	0·492	0·605	0·703	0·805	1·041	1·033	1·043	1·030	0·960	0·502	0·410
700—600	0·265	0·287	0·394	0·509	0·573	0·768	0·737	0·769	0·733	0·701	0·345	0·279
600—500	0·122	0·131	0·174	0·292	0·389	0·529	0·517	0·518	0·455	0·369	0·175	0·130
500—400	0·026	0·023	0·054	0·111	0·222	0·283	0·291	0·281	0·207	0·141	0·039	0·026
400—300	0·000	0·002	0·003	0·017	0·053	0·096	0·102	0·085	0·050	0·021	0·003	0·002
300—200	0·000	0·000	0·000	0·000	0·003	0·010	0·013	0·008	0·000	0·000	0·000	0·000
Total	2·922	2·941	3·369	4·156	4·931	5·785	5·752	5·733	5·543	5·050	3·198	2·760