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VARIATIONS OF THE MEASURED  
HEIGHTS OF PRESSURE SURFACES

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# VARIATIONS OF THE MEASURED HEIGHTS OF PRESSURE SURFACES

BY D. H. JOHNSON, M.Sc.

**Summary.**—The 6-hr. and 12-hr. apparent diurnal variations of the measured heights of standard pressure surfaces have been evaluated for levels up to 100 mb. at Larkhill, Lerwick, Malta and Nicosia. Calculated values of the apparent diurnal variation, based on estimates of the radiation errors made by Scrase, tend to underestimate the observed variation, but nevertheless provide a reasonable first approximation to the diurnal changes, except for the 2100–0300 G.M.T. variation, when both ascents are made whilst the sun is low in the sky. Tables are given which enable heights of pressure surfaces computed from radio-sonde observations made by stations in the British Isles, Malta and Nicosia to be corrected for diurnal variation.

**Introduction.**—Analysts of upper air data have noticed that there are systematic diurnal changes, which vary with the season and become increasingly important with height, in the measured heights of pressure surfaces. At 100 mb. the diurnal variations may be up to four times as great as the average 12-hr. change due to developments in the synoptic situation, and the former, together with the random errors of measurement, may mask the latter. The random errors are partially smoothed out in the process of chart construction. To eliminate diurnal effects, the analysts either have applied approximate seasonal corrections based on experience or have considered 24-hr. height tendencies only. In order to provide a basis for strict comparison with each other of heights measured at different synoptic hours, the diurnal variations appropriate to all times of the year have been computed for Larkhill ( $51^{\circ}12'N.$   $1^{\circ}48'W.$ ), Lerwick ( $60^{\circ}08'N.$   $1^{\circ}11'W.$ ), Malta ( $35^{\circ}50'N.$   $14^{\circ}27'E.$ ) and Nicosia ( $35^{\circ}09'N.$   $33^{\circ}17'E.$ ).

There has been much speculation in the past as to whether the observed diurnal changes genuinely occur in the atmosphere. Recent work by Scrase<sup>1\*</sup> leads to the conclusion that the observed variations are largely false, being due to the effect of solar radiation on the thermometer element of the radio-sonde rather than on the atmosphere itself. The synoptic analyst, however, does not need to discriminate between the real and the spurious, provided that the variations occur, as the evidence suggests they do, on the scale of tides rather than that of depressions and anti-cyclones. In either case he wishes to eliminate them in order to see clearly the changes associated with developments in the synoptic situation.

**Observed variations.**—Upper air charts are constructed for the hours 0300, 0900, 1500 and 2100 G.M.T., and it is customary to think of the plotted observations as referring to those times. In fact, the British ascents normally start within a few minutes of 0200, 0800, 1400 and 2000 G.M.T., and they reach the 100-mb. level about 40 min. later. Ascents from Lerwick are exceptional in that they normally commence at 0145, 0745, 1345 and 1945 G.M.T. Conventionally the 6-hr. variations will be referred to as the 0300–0900, etc. variations, even though the actual measurements are made during the hour or so preceding 0300, 0900, etc.

The diurnal changes have been computed for the standard pressure levels: 700, 500, 300, 200 and 100 mb. For Larkhill and Lerwick four-year monthly mean 6-hr. variations of contour height have been calculated for the years 1948–51,

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\*These index numbers refer to the bibliography on p. 19.

TABLE I—6-HR. VARIATIONS OF HEIGHT OF STANDARD PRESSURE LEVELS COMPUTED FROM OBSERVATIONS IN 1948-51

Period	Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
G.M.T.		feet											
		100 mb.											
0300	Larkhill	109	81	194	230	302	298	305	194	247	148	200	127
-0900	Lerwick	46	64	151	268	216	253	218	247	184	160	45	26
0900	Larkhill	110	93	84	57	42	121	93	117	63	121	-15	58
-1500	Lerwick	165	61	39	55	88	72	89	72	52	62	25	119
1500	Larkhill	-177	-212	-212	-300	-274	-309	-307	-307	-265	-255	-133	-186
-2100	Lerwick	-126	-181	-172	-249	-221	-231	-207	-201	-218	-151	-118	-123
2100	Larkhill	-25	31	-41	17	-68	-88	-68	8	-31	-5	-50	-43
-0300	Lerwick	-53	8	-17	-2	-80	-165	-95	-60	-9	-69	1	-41
		200 mb.											
0300	Larkhill	56	22	84	126	142	126	149	118	145	81	41	39
-0900	Lerwick	-2	-6	68	133	113	131	105	106	85	51	4	26
0900	Larkhill	81	84	86	71	42	121	88	88	38	80	20	35
-1500	Lerwick	37	85	44	68	48	64	37	67	57	22	19	52
1500	Larkhill	-93	-128	-162	-173	-119	-184	-179	-179	-141	-152	-67	-53
-2100	Lerwick	-14	-94	-126	-145	-110	-104	-88	-147	-110	-63	-37	-50
2100	Larkhill	-49	22	-8	-24	-71	-63	-53	-27	-42	-9	-6	5
-0300	Lerwick	-48	-11	4	-21	-70	-91	-71	-26	-32	-10	22	9
		300 mb.											
0300	Larkhill	29	27	51	52	81	75	88	52	52	40	28	-7
-0900	Lerwick	24	-16	19	68	81	82	67	54	35	19	-7	10
0900	Larkhill	30	47	64	76	56	94	60	76	65	59	37	3
-1500	Lerwick	18	67	40	59	53	51	40	69	60	16	11	17
1500	Larkhill	-69	-50	-106	-100	-81	-114	-109	-119	-95	-83	-44	-21
-2100	Lerwick	-25	-55	-62	-100	-85	-59	-48	-106	-72	-33	-26	-27
2100	Larkhill	-45	-24	-14	-28	-61	-55	-43	-9	-22	-16	-21	4
-0300	Lerwick	-12	6	5	-13	-60	-74	-64	-17	-23	-2	22	3
		500 mb.											
0300	Larkhill	12	16	11	19	26	22	30	14	26	22	8	-5
-0900	Lerwick	-11	3	6	35	27	35	14	24	13	13	-12	-1
0900	Larkhill	14	10	29	49	20	58	47	50	24	11	21	0
-1500	Lerwick	10	29	16	37	33	35	23	38	33	15	6	4
1500	Larkhill	-9	-23	-24	-37	-41	-34	-56	-43	-30	-18	-4	-15
-2100	Lerwick	-2	-12	-22	-37	-47	-34	-29	-40	-18	-10	-15	-8
2100	Larkhill	-20	-3	-16	-29	-35	-46	-23	-21	-20	-15	-19	20
-0300	Lerwick	-9	-11	9	-39	-30	-36	-12	-22	-28	-18	23	7
		700 mb.											
0300	Larkhill	7	1	13	7	6	17	6	7	7	8	6	9
-0900	Lerwick	-3	-3	0	15	14	9	0	-2	1	2	-5	-1
0900	Larkhill	-1	17	12	35	37	30	31	27	25	11	1	-5
-1500	Lerwick	9	23	0	24	27	31	21	24	21	2	1	2
1500	Larkhill	14	-2	-14	-18	-16	-9	-19	-18	-13	-3	-5	-1
-2100	Lerwick	11	-2	-7	-11	-18	-23	-14	-10	-8	3	4	4
2100	Larkhill	-8	-16	-18	-24	-25	-38	-10	-16	-19	-16	-11	11
-0300	Lerwick	-22	-24	0	-26	-24	-17	-7	-12	-14	-7	0	0

and five-year monthly mean 12-hr. variations have been calculated for 1948-52. Monthly totals of heights of pressure surfaces for individual hours, which had been obtained by Hollerith punched-card methods, were used in calculating the variations at levels up to 200 mb. Apparent anomalies in these totals were checked by reference to individual observations given in the *Daily Aerological Record* and to the working charts which are prepared at the Central Forecasting Office, Dunstable. The 100-mb. monthly mean variations were computed from occasions when 100-mb. heights were given in the *Daily Aerological Record* for the appropriate times  $t$  and  $t + 6$  hr. or  $t$  and  $t + 12$  hr. on the same day.

TABLE II—12-HR. VARIATION OF HEIGHT OF STANDARD PRESSURE LEVELS COMPUTED FROM OBSERVATIONS

Station	Years	Period: 0300–1500 G.M.T.											
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
		feet											
		100 mb.											
Larkhill	1948–52	172	162	248	322	364	388	404	328	294	254	224	140
Lerwick	1948–52	166	154	214	324	320	356	316	336	280	184	108	162
Malta	1949–52	161	174	230	238	370	212	211	237	203	216	138	121
Nicosia	1948–52	139	168	261	192	240	246	278	211	189	147	116	67
		200 mb.											
Larkhill	1948–52	129	102	159	211	194	247	224	218	176	153	72	62
Lerwick	1948–52	8	95	161	188	184	214	153	189	129	84	35	41
Malta	1949–52	65	127	92	138	249	177	126	125	119	96	92	42
Nicosia	1948–52	46	64	172	139	193	201	191	111	107	68	68	45
		300 mb.											
Larkhill	1948–52	81	74	85	133	135	175	152	134	114	92	68	11
Lerwick	1948–52	18	43	32	117	141	147	122	124	98	31	20	22
Malta	1949–52	50	86	67	87	191	123	94	101	97	74	59	20
Nicosia	1948–52	51	80	124	119	143	143	122	85	88	56	47	57
		500 mb.											
Larkhill	1948–52	26	31	35	69	74	83	68	65	43	31	32	6
Lerwick	1948–52	7	22	17	74	77	73	45	58	38	28	–4	6
Malta	1949–52	17	38	69	83	102	68	69	48	48	36	34	9
Nicosia	1948–52	33	36	57	60	89	100	76	74	61	38	23	20
		700 mb.											
Larkhill	1948–52	–2	21	27	42	43	52	34	39	27	21	10	0
Lerwick	1948–52	–2	22	4	42	40	41	20	19	34	0	–3	2
Malta	1949–52	1	20	30	27	56	45	35	41	20	6	17	–7
Nicosia	1948–52	20	16	40	40	55	59	36	52	43	21	12	8

Upper air observations are made regularly at Malta and Nicosia at 0300 and 1500 G.M.T., and for these stations only the 12-hr. 0300–1500 variations could be computed. These refer to the years 1948–51 for Malta and 1948–52 for Nicosia. Hollerith totals were again used except for those months when less than 25 observations were made at either hour. In these latter months recourse was made to the pairing procedure described above, the individual observations being obtained from the *Overseas Supplement* to the *Daily Weather Report* or from tabulations supplied by the Upper Air Climatology Branch.

All the computed 6-hr. and 12-hr. variations in the measured heights of pressure levels are contained in Tables I and II.

**Methods of smoothing the observed values.**—The observed diurnal variations contain “errors”, due to real random variations associated with developments in the synoptic situation and to random errors of measurement of the contour heights. The effect of these “errors” can be seen in the graphs of the annual march of the diurnal variations contained in Figs. 1–4. These graphs, while showing clear trends, are irregular, but there is no reason to suppose that an accurate graph of the mean seasonal variation would not be quite smooth. Where the curve forms are approximately sinusoidal, smoothing by fitting one or two harmonics is feasible. In some cases, however, the curves are not nearly sinusoidal, and it is necessary to investigate theoretically the forms which the seasonal variations should take.

F. J. Scrase<sup>1</sup> has given a method by which the radiation and lag errors of the Meteorological Office radio-sonde can be estimated. Scrase’s calculations suggest that a large part of the observed diurnal variation of temperature can be accounted for in terms of radiation error. Integration of these estimated temperature errors can therefore be expected to provide a reasonable indication of the form which the annual march of the observed diurnal variation of contour height takes.

Scrase<sup>1</sup>, in his Table V, gives the calculated radiation errors at a number of heights for five solar altitudes from 10° to 90°. Interpolation within this table is not sufficiently accurate for present purposes, so the radiation errors have been calculated afresh from data given in Fig. 2 and Table III of Scrase's paper, at 1° intervals over the range from -5° to 0° solar altitude, at 5° intervals from 0° to 40° solar altitude and at 10° intervals from 40° to 70° solar altitude. It was necessary to extrapolate slightly certain of the curves given in Scrase's Fig. 2 to obtain rates of absorption of radiation, by the thermometer element and its shield, at negative solar altitudes. Lag errors have been neglected since, according to Scrase, these are not appreciably affected by time of day at levels up to 100 mb. Radiation emitted (as distinct from reflected) from below the instrument has also been neglected since this, too, does not contribute an appreciable amount to the diurnal variation. Following Scrase, to allow for depletion of the sun's radiation by absorption and scattering before it reaches the radio-sonde, use has been made of a diagram prepared by Väisälä<sup>2</sup>, which gives the radiation intensity at the radio-sonde, as a percentage of the radiation intensity at the top of the atmosphere, in terms of the true solar altitude and the height of the instrument. This diagram takes into account the refraction of the sun's rays.

For the present work, diagrams have been prepared which enable the radiation temperature errors at any level up to 20 Km. to be read off for true solar altitudes between -5° and 70°. These are given in Fig. 5. The true solar altitude at any place and at any time was calculated from the formula  $\sin A = \sin \delta \sin \phi + \cos \delta \cos \phi \cos \theta$  where  $A$  is the true solar altitude,  $\delta$  is the sun's declination,  $\phi$  is the latitude and  $\theta$  is the local hour angle. Curves giving the solar altitudes at the time the radio-sonde leaves the surface and at the time the radio-sonde reaches 100 mb., have been calculated for each of the hours of observation at Larkhill, Lerwick, Malta and Nicosia. These are contained in Figs. 6-9. The small effects of the equation of time have been neglected in computing the curves.

Interpolating where necessary, the temperature errors at all levels for the routine ascents were obtained using Figs. 6-9. The consequent errors in the measured heights of the pressure levels were then calculated using a convenient derivation of the hydrostatic equation

$$\delta h' = 122.8 \{ \log_{10} (p_1/p_2) \} \delta T$$

where  $\delta T$  is the temperature error in degrees Fahrenheit,  $p_2$  and  $p_1$  are pressures in millibars at the top and the bottom of the layer whose thickness in feet is  $h'$ .

Increments in thickness of each 100-mb. layer up to 300 mb. and each 50-mb. layer between 300 mb. and 100 mb. were calculated using the mean temperature error appropriate to each layer. The apparent diurnal variations of contour height which would result from these estimated radiation errors were computed for dates approximately at the beginning and centre of each month of the year. Figs. 1-4 contain curves which show graphically the results of these calculations.

It is clear from Figs. 1-4 that the diurnal variations computed from estimated radiation errors are mostly of similar magnitude to the variations computed from observations. Further, they illustrate the way in which a number of features of the "observed-variation" curves can be explained in terms of the sun's altitude. For example, for most of the year at Lerwick, the radio-sonde is affected by direct radiation from the sun at the time of the 0900 G.M.T. observation, but at 100 mb. the radio-sonde is also in sunlight at the time of the 0300 G.M.T. observation for a period in the summer; in consequence the 0300-0900 G.M.T. Lerwick curve at 100 mb. in Fig. 2 is flat-topped. At Larkhill, on the other hand, the radio-sonde is never affected by direct sunlight during the 0300 G.M.T. ascent, and the 0300-0900 G.M.T. Larkhill curve at 100 mb. in Fig. 1 therefore tends to have a sharper peak than the corresponding Lerwick curve.

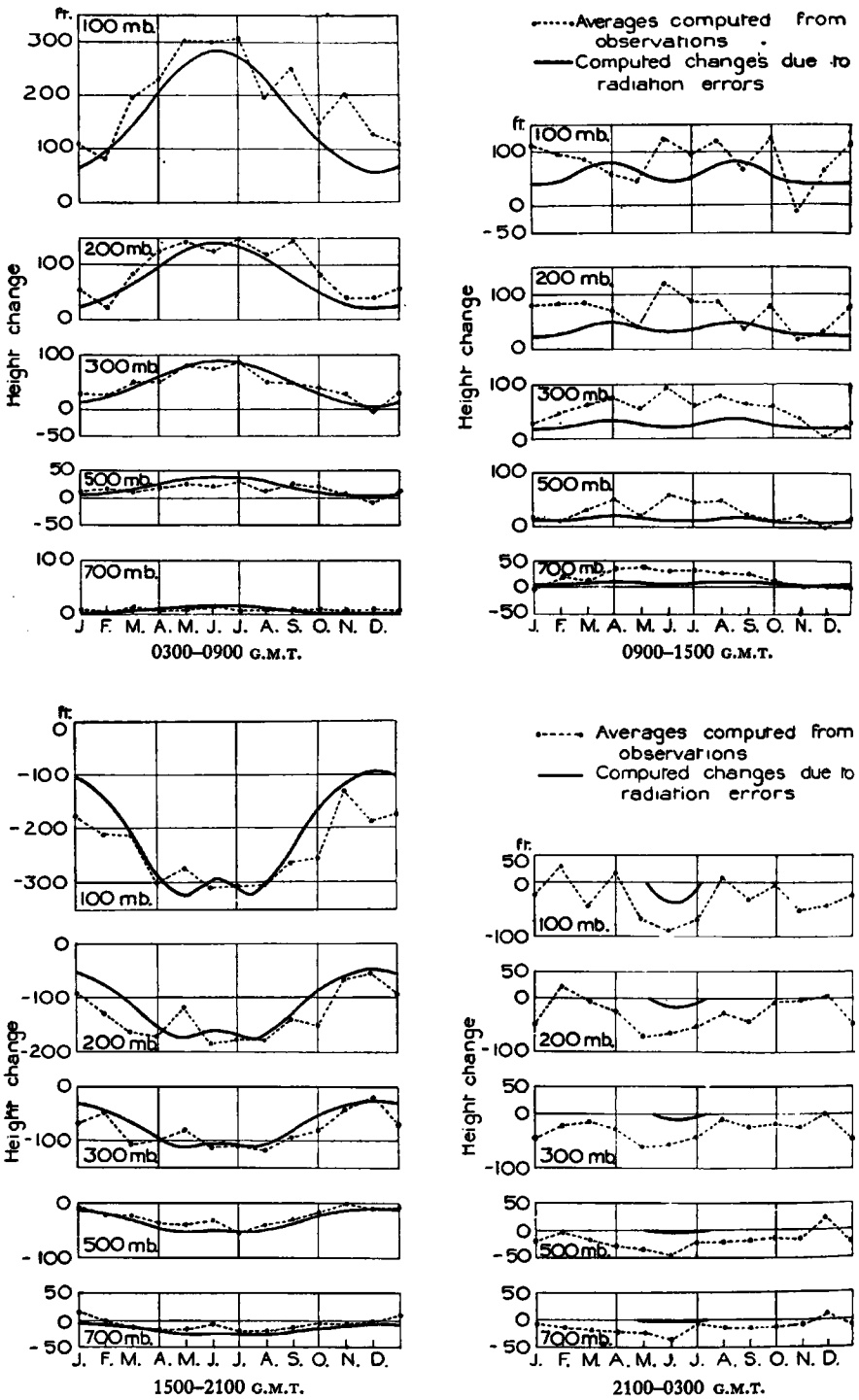


FIG. 1—MONTHLY MEAN SIX-HOURLY CHANGE OF HEIGHT OVER LARKHILL, 1948-51, OBSERVED VERSUS COMPUTED VALUES

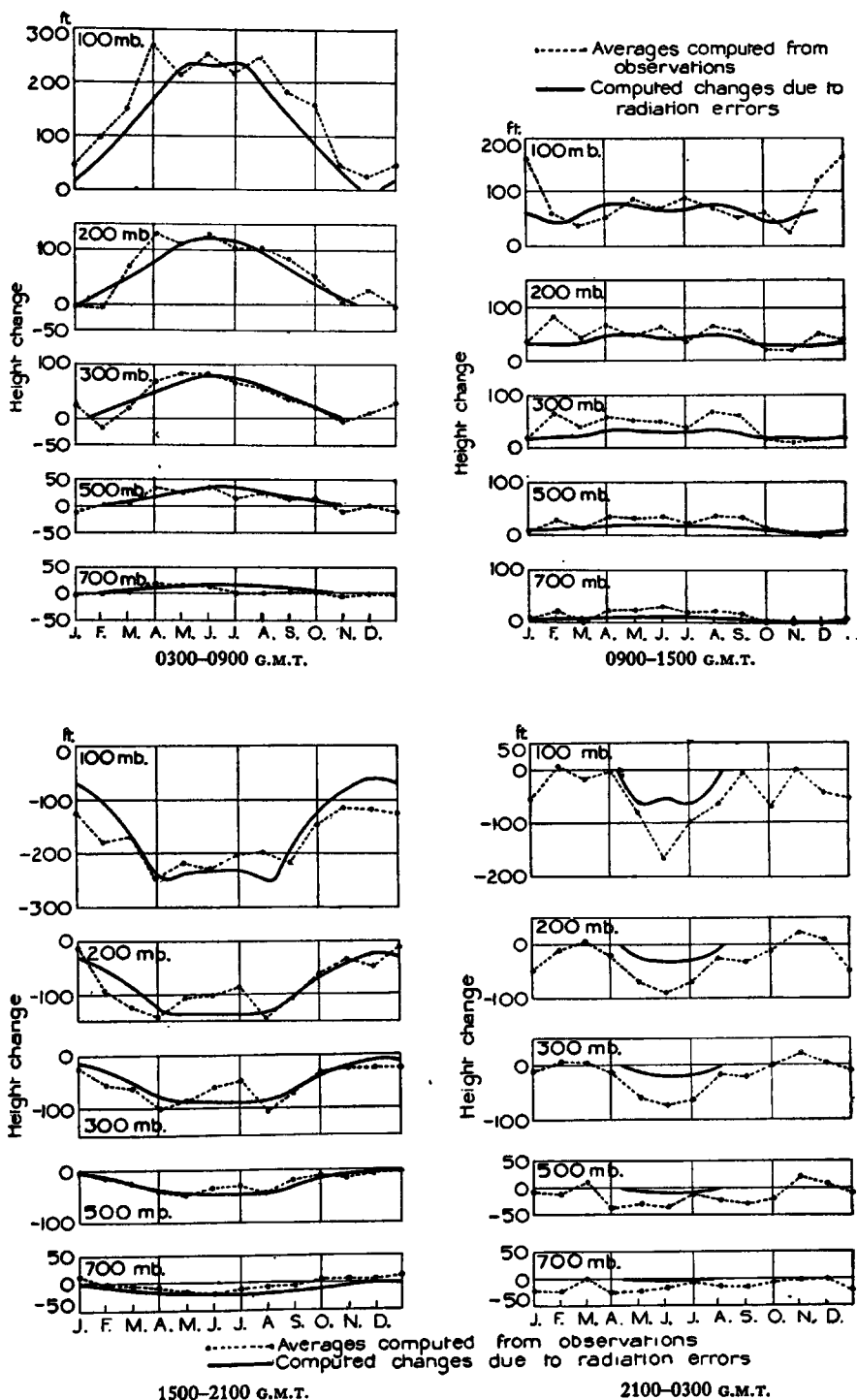


FIG. 2—MONTHLY MEAN SIX-HOURLY CHANGE OF HEIGHT OVER LERWICK, 1948-51, OBSERVED VERSUS COMPUTED VALUES

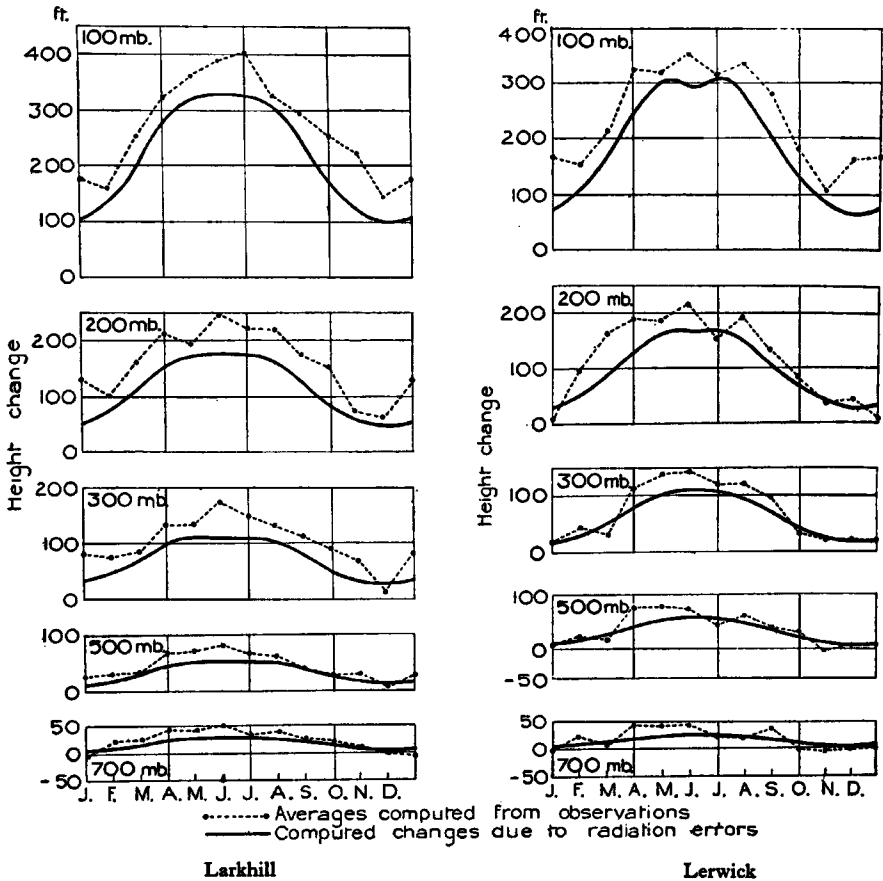


FIG. 3—MONTHLY MEAN 0300-1500 G.M.T. CHANGE OF HEIGHT OVER LARKHILL AND LERWICK, 1948-52, OBSERVED VERSUS COMPUTED VALUES

Examination of the 0300-1500 G.M.T. curves for Larkhill and Lerwick in Fig. 3 shows that the values based on estimated radiation errors underestimate the observed variations. A greater percentage underestimation occurs with the 2100-0300 G.M.T. variations at Larkhill (Fig. 1) and Lerwick (Fig. 2). It must not be assumed that these systematic differences between the observed variations and those computed from estimated radiation errors are due to real diurnal changes in the temperature of the atmosphere. It is possible that the differences are due largely to inaccuracies in the estimated radiation errors, since a number of approximations necessarily had to be made both by Scrase, in evolving his technique for calculating radiation errors, and also by Väisälä, in estimating the effect of absorption and scattering on the sun's radiation.

That the summer 2100-0300 G.M.T. variations should be so far underestimated suggests that some factor, which is particularly important at low solar altitudes, has been insufficiently allowed for. One factor contributing to the discrepancy may be the neglect of the effect of radiation from the sky, as opposed to direct radiation from the sun. According to Landsberg<sup>3</sup>, on clear days, at a solar altitude of 70°, about 15 per cent. of the total radiation at ground level comes from the sky, while at a solar altitude of 10° only 60 per cent. of the total radiation comes from the sun and 40 per cent. from the sky.



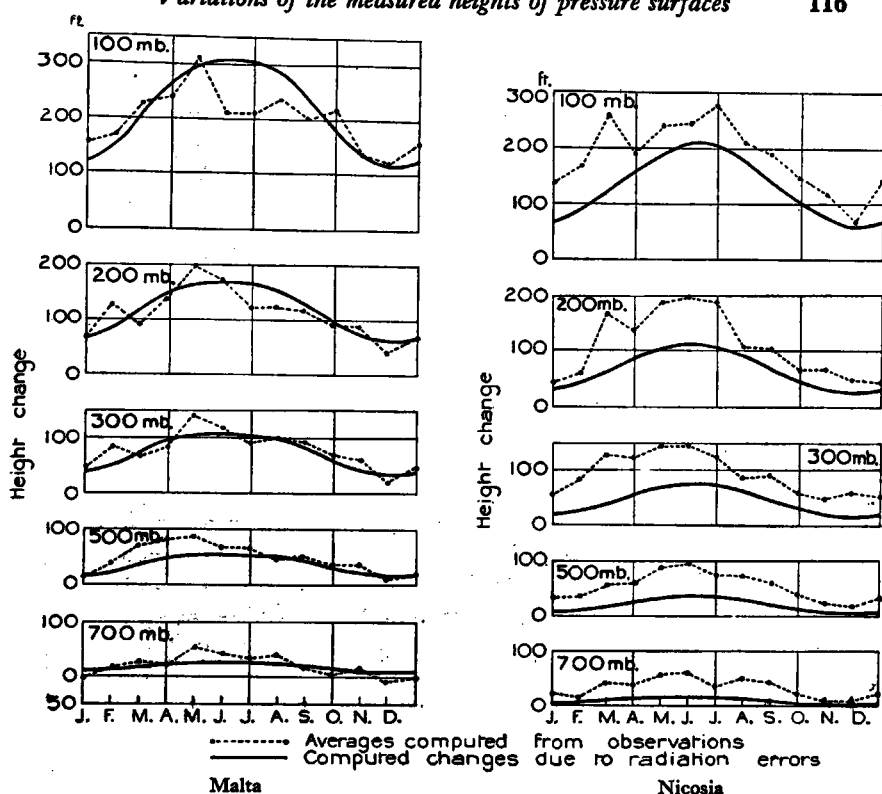


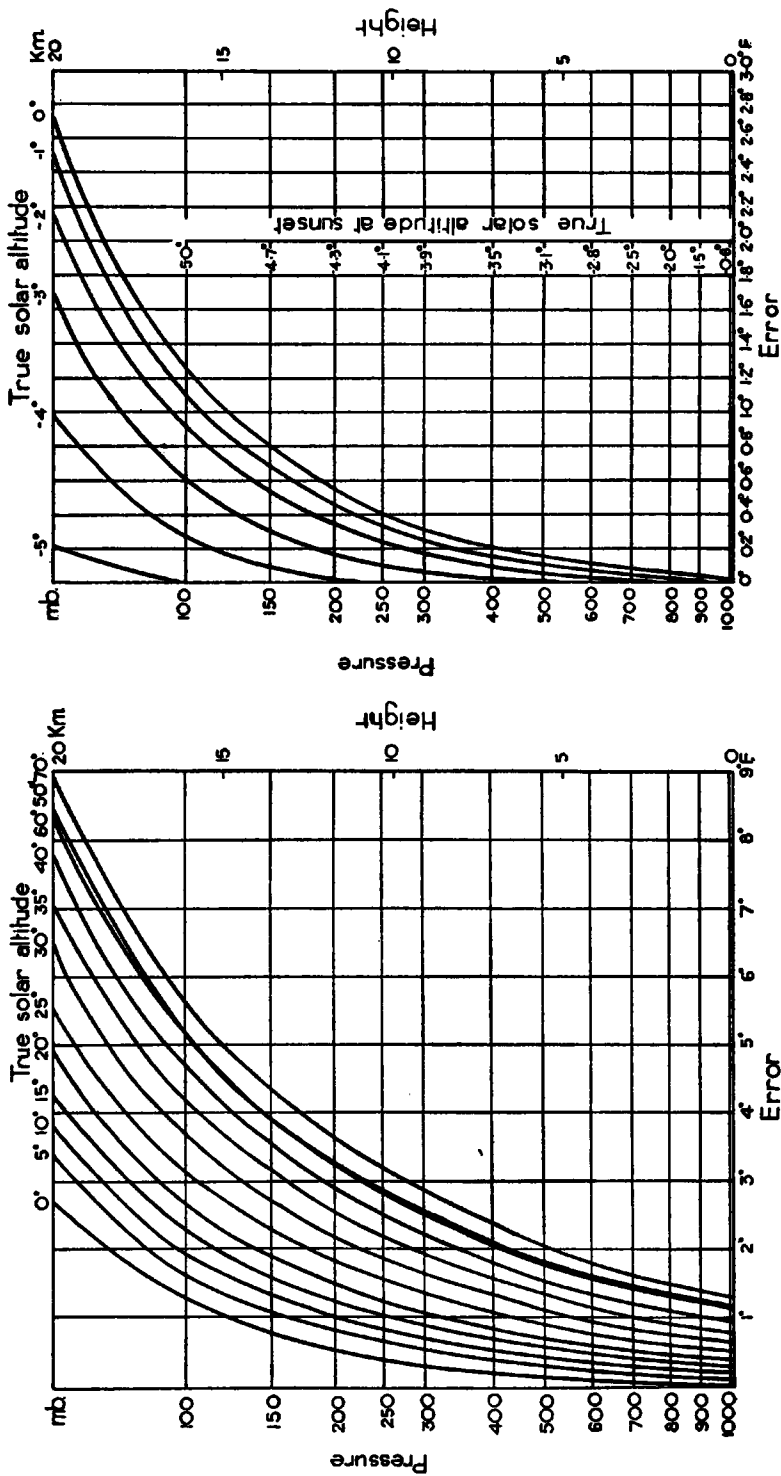
FIG. 4—MONTHLY MEAN 0300-1500 G.M.T. CHANGE OF HEIGHT OVER MALTA (1949-52) AND NICOSIA (1948-52), OBSERVED VERSUS COMPUTED VALUES

Fig. 4 shows that the observed diurnal variations are of similar magnitude at Malta and Nicosia. This is a surprising result since Nicosia is about  $19^\circ$  longitude farther east than Malta, and, as the curves giving the variations due to estimated radiation errors show, the Malta 0300-1500 G.M.T. variation would be expected appreciably to exceed the Nicosia variation on that account.

Whilst the estimated errors do not completely account for the observed variations, it is clear that they provide a reasonable basis for smoothing the curves computed from observations. Two methods of smoothing were tried experimentally on the 100-mb. variations:—

- (i) by relating the observed to the estimated variations by means of a regression equation
- (ii) by subtracting the estimated from the observed variations and smoothing the difference by taking weighted running means.

Arguments can be advanced in favour of each of these two methods. Experiment showed that there was little difference between the smoothed curves obtained by the two methods. Method (ii) was adopted for all levels, since it is easier to apply and does not restrict the form of the curve to quite the same extent as method (i). The smoothed curves were also adjusted slightly, (a) so as to be symmetrical about the solstices and (b) so that the sum of the 0300-0900 and the 0900-1500 variations should be equal and opposite to the sum of the 1500-2100 and 2100-0300 variations. Neglecting a small effect due to the equation of time, solar altitude varies sym-



Positive solar altitudes  
Negative solar altitudes  
FIG. 5—RADIATION ERRORS OF THE METEOROLOGICAL OFFICE RADIO-SONDE

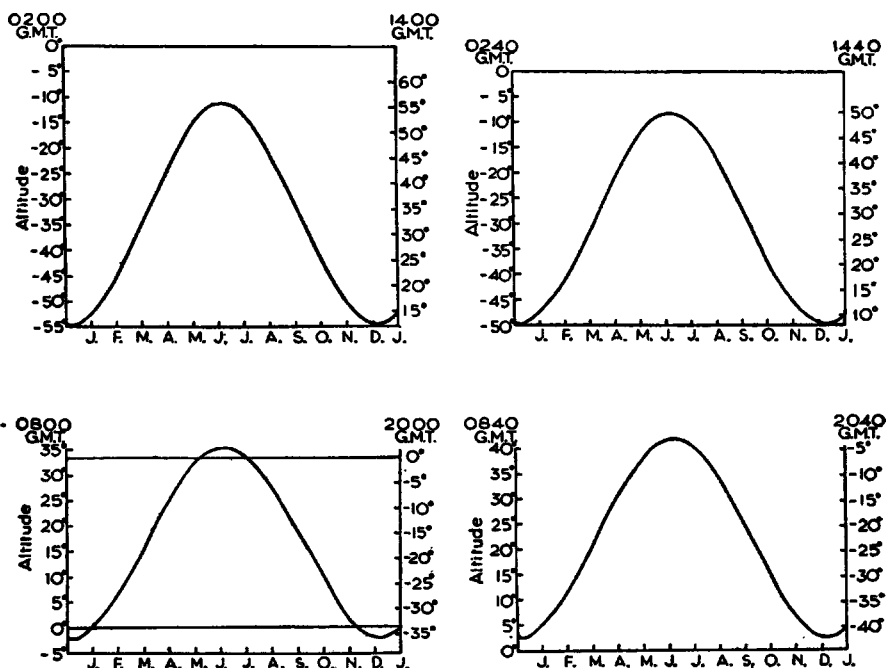


FIG. 6—ANNUAL VARIATION OF SOLAR ALTITUDE AT LARKHILL

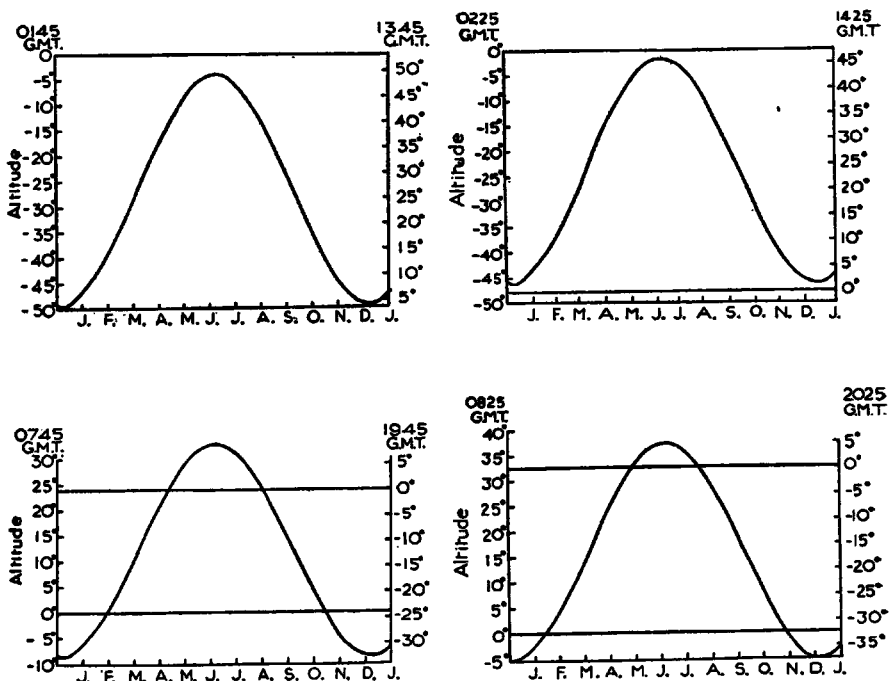


FIG. 7—ANNUAL VARIATION OF SOLAR ALTITUDE AT LERWICK

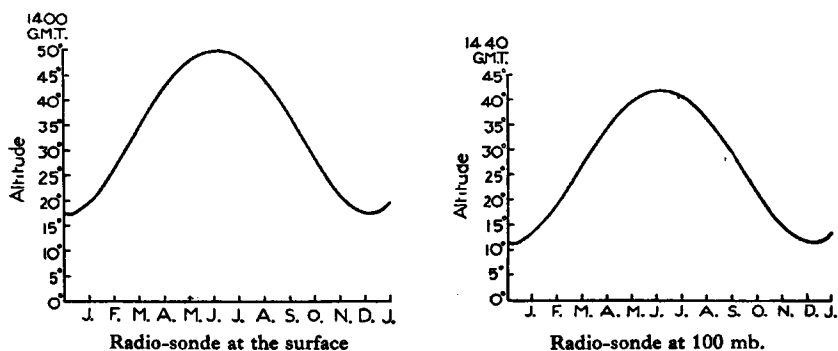


FIG. 8—ANNUAL VARIATION OF SOLAR ALTITUDE AT MALTA

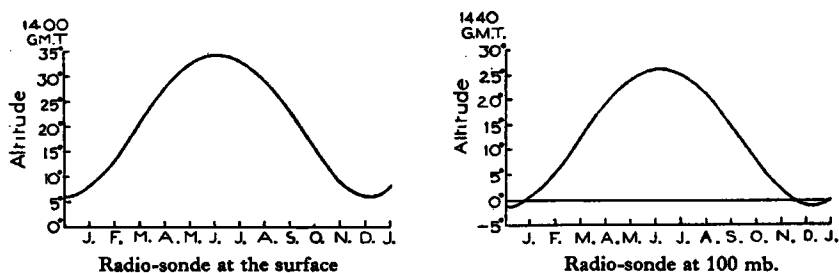


FIG. 9—ANNUAL VARIATION OF SOLAR ALTITUDE AT NICOSIA

metrically about the solstices; the effects of radiation on both the radio-sonde and the atmosphere are functions of solar altitude. Moreover, in the early stages of this work, the first harmonics of the measured 0300–1500 variations were calculated for Larkhill and Lerwick data. It was found that the position of the maximum of the sine curve, taking an average over all levels from 700 mb. to 100 mb., occurred on June 22. Thus there is both theoretical and practical justification for adjustment (a). One effect of adjustment (b) is to remove those parts of the 6-hr. variations which are due to the seasonal variation of height of the pressure levels. Fig. 10 contains graphs of the change of height of the pressure levels in 24 hr. due to the seasonal variation. After suitable smoothing these graphs would enable an analyst to allow for the seasonal variation of the height if he wished, but at no season or level does the 24-hr. change exceed 25 ft., a change which is unimportant in forecasting.

The final smoothed versions of the observed diurnal variation curves are contained in Figs. 11–14, where they may be compared with the unsmoothed observed diurnal changes. The root-mean-square difference between the observed and the final smoothed monthly values of the 6-hr. variations, calculated for the Larkhill and Lerwick 100-mb. data, was found to be 28.3 ft. The standard errors of the December and June monthly mean 6-hr. changes at Larkhill and Lerwick as deduced from the standard deviations of the individual 6-hr. changes have a root-mean-square value of 31.4 ft., which suggests that the degree of smoothing attained is of the correct order.

For over half the year the radio-sonde is in darkness at both 2100 and 0300 G.M.T. over British stations. It will be noted from Figs. 11 and 12 that during this period there is a small negative 2100–0300 variation. This corresponds to the nocturnal cooling, of about  $\frac{1}{2}^{\circ}\text{F.}/6$  hr. in the lower stratosphere, found by Kay<sup>4</sup>.

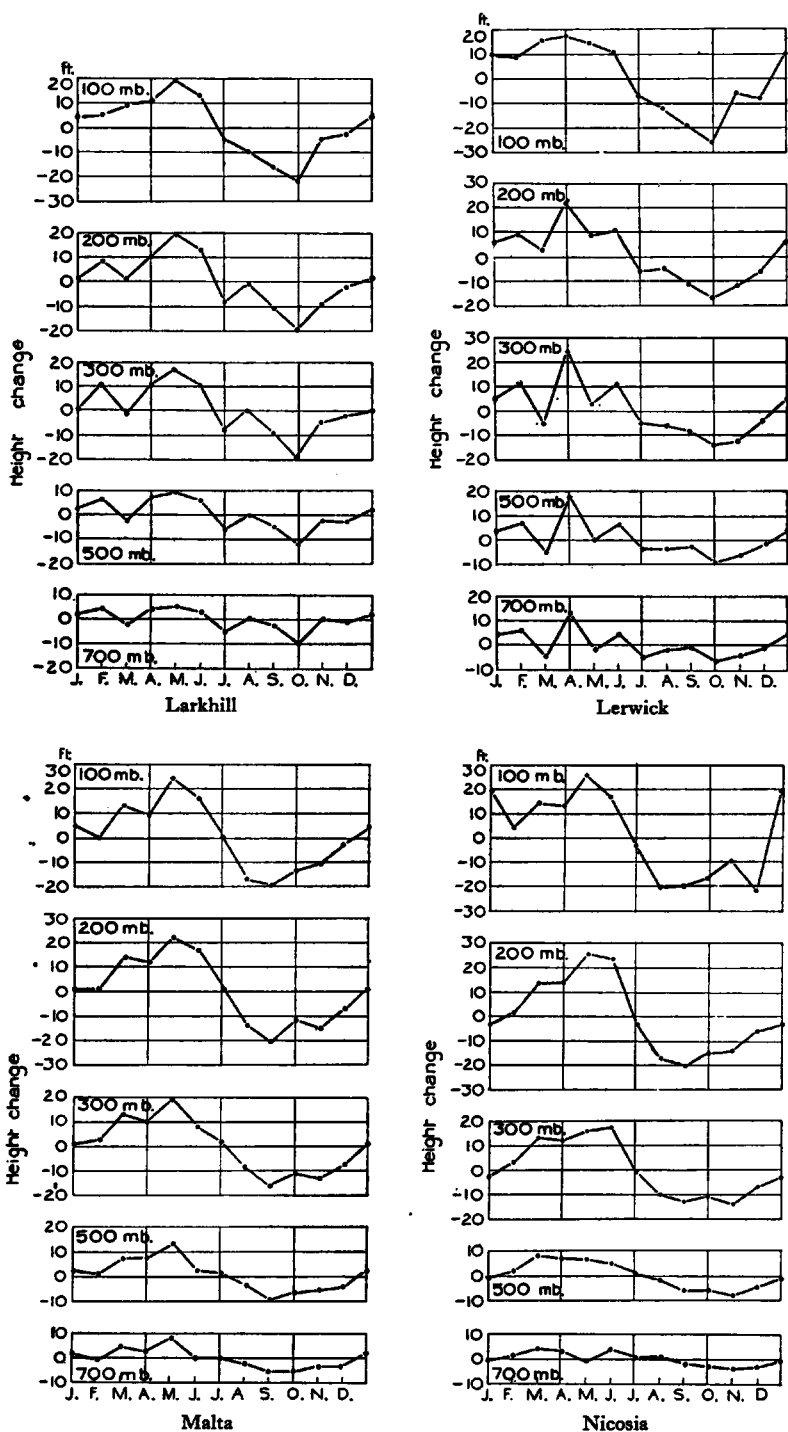


FIG. 10—24-HR. CHANGE IN HEIGHT OF STANDARD PRESSURE LEVELS DUE TO SEASONAL VARIATION IN 1948-52

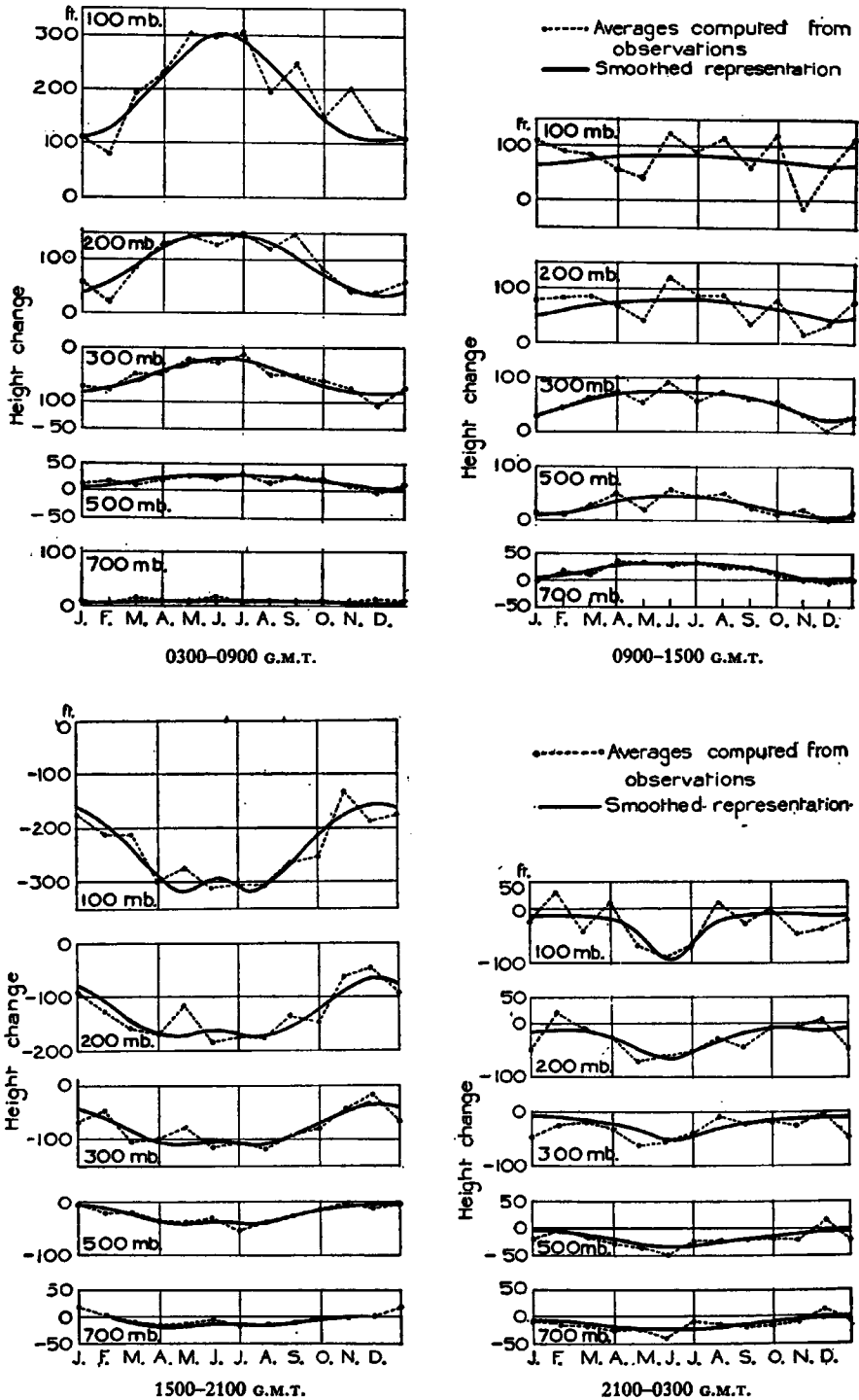


FIG. 11—MONTHLY MEAN SIX-HOURLY CHANGE OF HEIGHT OVER LARKHILL, 1948-51, OBSERVED VERSUS SMOOTHED VALUES

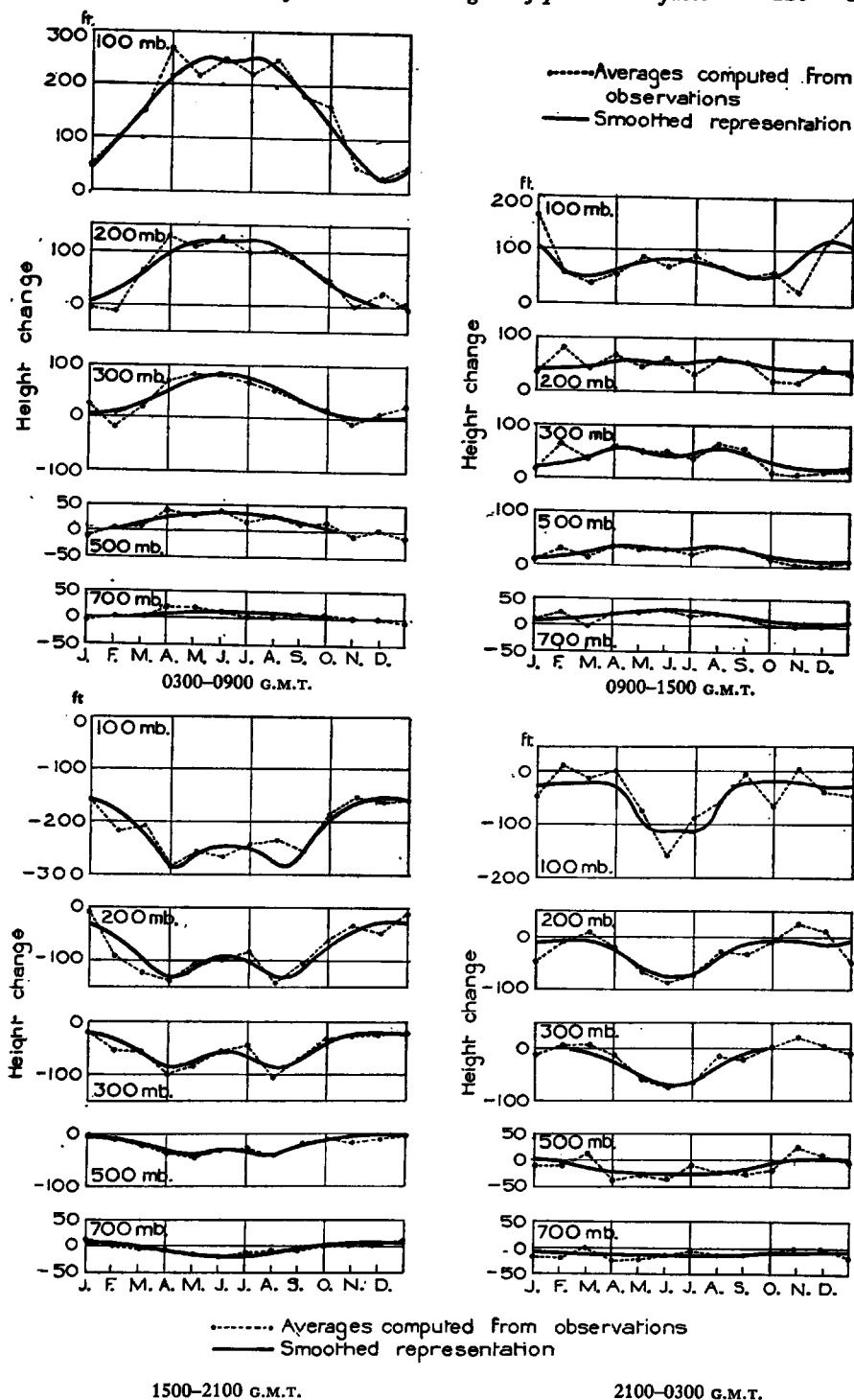


FIG. 12—MONTHLY MEAN SIX-HOURLY CHANGE OF HEIGHT OVER LERWICK, 1948-51, OBSERVED VERSUS SMOOTHED VALUES

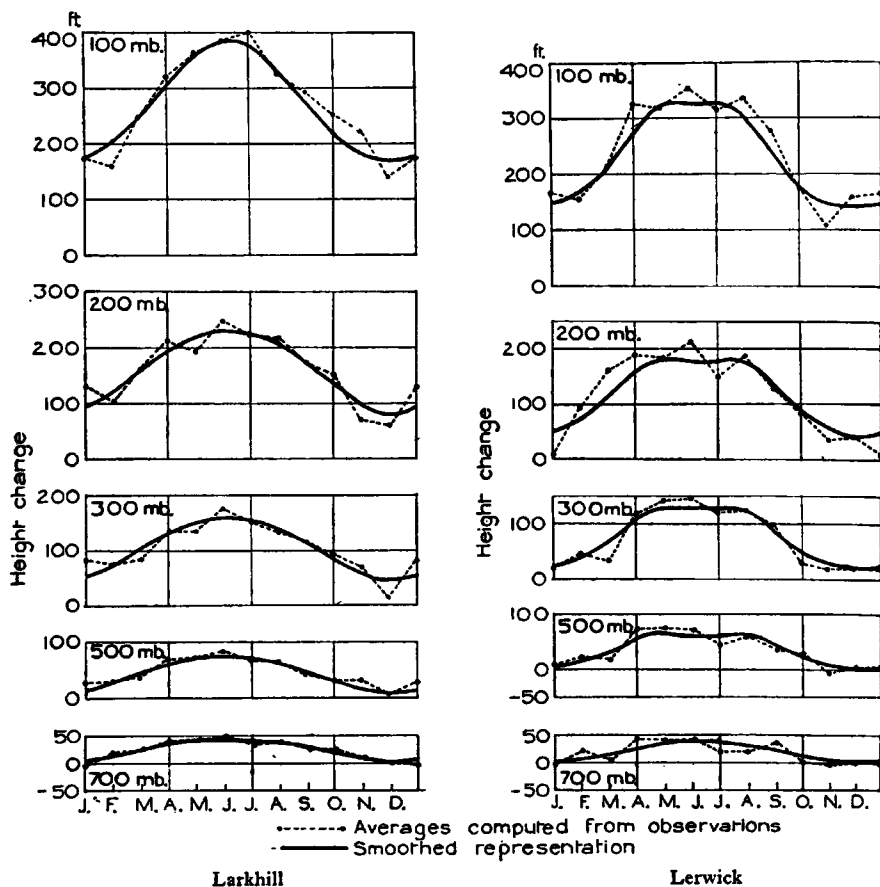


FIG. 13—MONTHLY MEAN 0300-1500 G.M.T. CHANGE OF HEIGHT OVER LARKHILL AND LERWICK, 1948-52, OBSERVED VERSUS SMOOTHED VALUES

**Practical application.**—The smoothed representation given in Figs. 11-14 enables corrections to be made to observations from Larkhill, Lerwick, Malta and Nicosia to remove the diurnal variation. For practical purposes it may be found more convenient to use a set of tables, such as those in Table III, to reduce the observations to some standard time. Table III contains the amount, to the nearest 10 ft., which should be subtracted from the 0900, 1500 and 2100 G.M.T. observations to make them comparable with 0300 G.M.T. observations. Linear interpolation is sufficiently accurate to give the reduction applicable to any day of the year from these tables. Likewise, suitable interpolation between the Larkhill and Lerwick figures will give values applicable to any station in the British Isles.

In the preparation of synoptic charts, the correction of the British observations alone, for diurnal variation, would introduce inconvenient discontinuities between the British and neighbouring networks until such time as similar corrections can be made to foreign observations. This difficulty would not restrict the application of the corrections to the height tendencies because these are not normally analysed on a geographical basis.



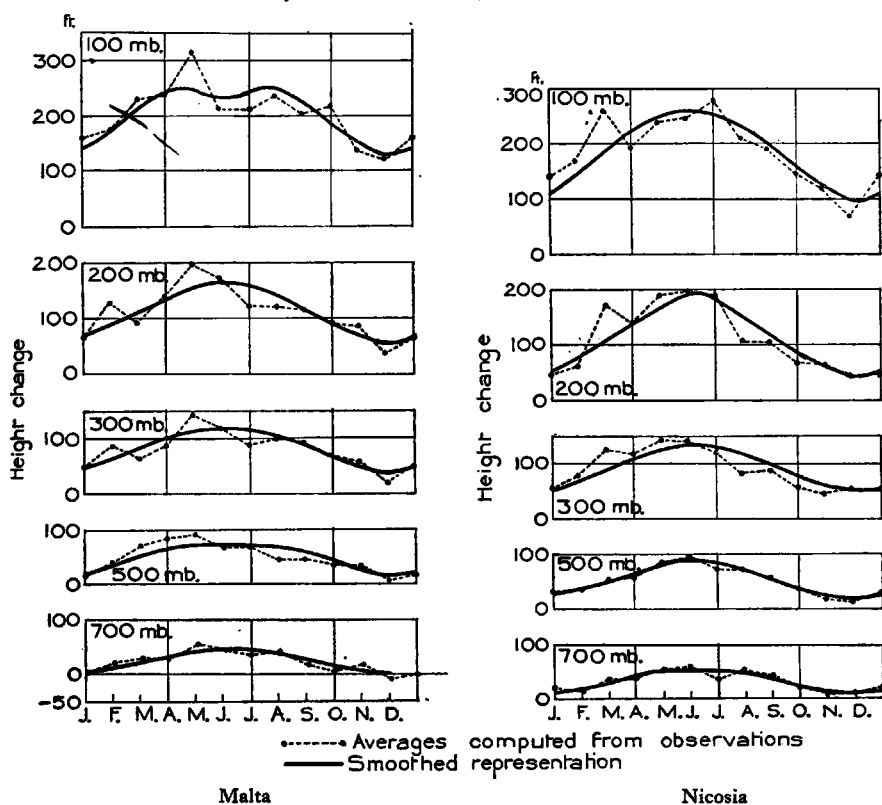


FIG. 14—MONTHLY MEAN 0300-1500 G.M.T. CHANGE OF HEIGHT OVER MALTA VALUES (1949-52) AND NICOSIA (1948-52), OBSERVED VERSUS SMOOTHED

**Interdiurnal variation of height of pressure levels.**—If  $\epsilon$  is the random standard error of measurement of the height of some pressure surface,  $S_{24}$  the true interdiurnal variation and  $D_{24}$  the root-mean-square 24-hr. variation of the measured height of the pressure surface then

$$D_{24}^2 = S_{24}^2 + 2\epsilon^2$$

since  $S_{24}$  and  $\epsilon$  are independent. Further, if  $d$  is the systematic variation of measured height over a given 12-hr. period,  $S_{12}$  is the root-mean-square 12-hr. variation due to random changes associated with developments in the synoptic situation and  $D_{12}$  is the root-mean-square variation of the measured 12-hr. changes, then also

$$D_{12}^2 = S_{12}^2 + 2\epsilon^2 + d^2.$$

$S_{12}$  and  $S_{24}$  are the variations which are important in forecasting.

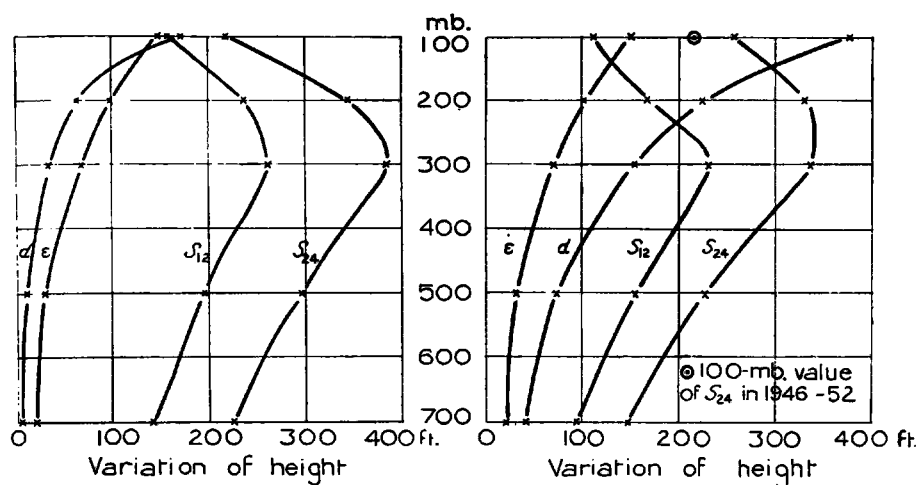
Fig. 15 shows how  $S_{12}$  and  $S_{24}$  compare in magnitude with  $\epsilon$  and  $d$  at all levels in the winter and summer seasons. For the winter period, data relating to the three months December-February 1952-53 at Larkhill and Lerwick were combined. The summer variations refer to June 1948-51 at Larkhill. The 12-hr. variations are for the period 1500 to 0300 G.M.T. and the 24-hr. variations were calculated from 0300 G.M.T. observations. The calculated  $S_{12}$  bears a reasonable

TABLE III—CORRECTIONS FOR DIURNAL VARIATION TO BE SUBTRACTED FROM OBSERVATIONS  
MADE AT STATED TIMES

	Time	Jan. 1 15	Feb. 1 14	Mar. 1 15	Apr. 1 15	May 1 15	June 1 15	July 1 15	Aug. 1 15	Sept. 1 15	Oct. 1 15	Nov. 1 15	Dec. 1 15
	G.M.T.	<i>tens of feet</i> 100 mb.											
Lerwick	0900	3 4	7 10	13 16	19 21	23 25	25 24	24 25	25 23	21 19	16 13	10 7	4 3
	1500	15 15	15 16	18 21	24 27	30 33	33 33	33 33	33 30	27 24	21 18	16 15	15 15
	2100	3 3	2 2	2 2	2 3	6 10	11 11	11 11	10 6	3 2	2 2	2 2	3 3
Larkhill	0900	11 11	12 13	15 17	20 23	25 28	30 30	30 30	28 25	23 20	17 15	13 12	11 11
	1500	17 18	19 20	23 25	28 31	34 36	38 39	39 38	36 34	31 28	25 23	20 19	18 17
	2100	1 1	1 1	1 1	2 2	2 4	7 9	9 7	4 2	2 2	1 1	1 1	1 1
Malta	1500	13 14	15 17	19 21	23 24	25 25	24 24	24 24	25 25	24 23	21 19	17 15	14 13
Nicosia	1500	9 11	13 15	16 19	20 22	23 24	25 26	26 25	24 23	22 20	19 16	15 13	11 9
		200 mb.											
Lerwick	0900	0 1	2 3	5 6	8 10	11 12	12 12	12 12	12 11	10 8	6 5	3 1	1 0
	1500	4 5	6 7	9 11	14 16	17 18	18 18	18 18	18 17	16 14	11 9	7 6	5 4
	2100	1 1	1 1	1 1	2 2	4 6	7 8	8 7	6 4	2 2	1 1	1 1	1 1
Larkhill	0900	4 4	5 6	7 9	11 12	13 14	14 14	14 14	14 13	12 11	9 7	6 5	4 4
	1500	9 9	10 12	14 16	18 19	21 22	23 23	23 23	22 21	19 18	16 14	12 10	9 9
	2100	2 1	1 1	1 1	2 3	3 5	5 6	6 5	5 3	3 2	1 1	1 1	1 2
Malta	1500	6 7	8 9	10 11	12 13	15 16	16 16	16 16	16 15	13 12	11 10	9 8	7 6
Nicosia	1500	5 5	6 8	9 11	12 14	15 17	19 19	19 19	17 15	14 12	11 9	8 6	5 5
		300 mb.											
Lerwick	0900	0 0	0 1	1 2	4 5	6 7	8 8	8 8	7 6	5 4	3 1	1 0	0 0
	1500	2 2	3 4	5 7	9 11	12 13	13 13	13 13	13 12	11 9	7 5	4 3	2 2
	2100	0 0	0 0	0 0	1 2	3 5	6 6	6 6	5 3	2 1	0 0	0 0	0 0
Larkhill	0900	2 2	2 3	3 4	5 6	7 7	8 8	8 8	7 7	6 5	4 3	3 2	2 2
	1500	4 5	6 7	9 10	12 13	14 15	15 16	16 15	15 14	13 12	10 9	7 6	5 4
	2100	1 1	1 1	1 2	2 2	3 4	5 5	5 5	4 3	2 2	2 1	1 1	1 1
Malta	1500	4 5	5 6	7 8	9 10	11 11	12 12	12 12	11 11	10 9	8 7	6 5	5 4
Nicosia	1500	5 5	6 7	8 9	10 11	12 13	13 13	13 13	13 12	11 10	9 8	7 6	5 5
		500 mb.											
Lerwick	0900	0 0	0 0	0 1	2 2	3 3	3 3	3 3	3 3	2 2	1 0	0 0	0 0
	1500	0 1	1 2	2 3	5 5	6 6	6 6	6 6	6 6	5 5	3 2	2 1	1 0
	2100	0 0	0 0	1 1	2 2	2 3	3 3	3 3	3 2	2 2	1 1	0 0	0 0
Larkhill	0900	0 1	1 1	1 1	2 2	2 3	3 3	3 3	3 2	2 2	1 1	1 1	1 0
	1500	1 2	2 3	3 4	5 6	6 7	7 7	7 7	7 6	6 5	4 3	3 2	2 1
	2100	0 1	1 1	1 2	2 2	2 3	3 3	3 3	3 2	2 2	2 1	1 1	1 0
Malta	1500	2 2	3 3	4 5	6 7	7 7	7 7	7 7	7 7	7 6	5 4	3 3	2 2
Nicosia	1500	2 3	3 3	4 5	6 7	7 8	9 9	9 9	8 7	7 6	5 4	3 3	3 2
		700 mb.											
Lerwick	0900	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0
	1500	0 0	0 1	1 2	2 3	3 3	3 4	4 3	3 3	3 2	2 1	1 0	0 0
	2100	1 1	1 1	1 1	1 1	2 2	1 1	1 1	2 2	1 1	1 1	1 1	1 1
Larkhill	0900	0 0	0 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 0	0 0
	1500	0 1	1 1	2 3	3 3	4 4	4 4	4 4	4 4	3 3	3 2	1 1	1 0
	2100	1 1	1 1	1 2	2 2	2 2	2 3	3 2	2 2	2 2	2 1	1 1	1 1
Malta	1500	0 0	1 1	2 2	3 3	4 4	4 4	4 4	4 4	3 3	2 2	1 1	0 0
Nicosia	1500	1 1	2 2	3 3	4 4	5 5	5 5	5 5	5 5	4 4	3 3	2 2	1 1

relation to the calculated  $S_{24}$  except at 100 mb. in June.  $S_{24}$  for June at 100 mb., however, was computed from only 39 observations. As can be seen from the diagram, the corresponding value of  $S_{24}$  calculated over a longer period, 1946-52, was smaller.

Fig. 15 illustrates the peculiar difficulties which arise in the lower stratosphere, where both the random and systematic errors increase markedly with height while the true variations become smaller.



Winter (Larkhill and Lerwick  
combined, December-February 1952-53)

Summer  
(Larkhill, June 1948-51)

FIG. 15—INTERDIURNAL VARIATION OF HEIGHT OF PRESSURE LEVELS

$d$  = diurnal variation

$S_{12}$  = 12-hr. variation due to developments  
in the synoptic situation

$\epsilon$  = standard error of measurement

$S_{24}$  = 24-hr. variation due to developments  
in the synoptic situation

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