M.O. 711b

METEOROLOGICAL OFFICE

Geophysical Memoirs No. 107
(SECOND NUMBER, VOLUME XIV)

REPORT ON A TORNADO AT MALTA

14 OCTOBER 1960

BY

T. H. KIRK, B.Sc. and D. T. J. DEAN

LONDON: HER MAJESTY'S STATIONERY OFFICE

SEVEN SHILLINGS NET

Geophysical Memoirs

Many previous titles are still available from the bookshops of Her Majesty's Stationery Office at the addresses shown on page 4 of cover, or through any bookseller. Details of pre-war ones are contained in Government Publications: Sectional List No. 37. Post-war ones are as follows.

80. Hourly ranges of magnetic elements during the Polar Year 1932–3 at the observatories of Lerwick and Eskdalemuir.
With a discussion by F. E. Dixon, B.A. M.O. 419h. 1949. 5s. (5s. 7d.)

81. Aurora of January 25 to 26, 1938 and associated magnetic storm.
By F. E. Dixon, B.A. M.O. 499a. 1948. 2s. (2s. 4d.)

83. Wind at 100,000 feet over south-east England.
Observations and a discussion of the monsoon theory of wind at great heights. By R. J. Murgatroyd, B.Sc.(Eng.) and C. J. B. Clews, Ph.D. M.O. 499c. 1949. 6d. (9d.)

84. Atmospheric electricity during disturbed weather.
By Sir George Simpson, K.C.B., F.R.S. M.O. 499d. 1949. 3s. 6d. (4s. 1d.)

88. Humidity of the upper troposphere and lower stratosphere over southern England.
By J. K. Bannon, B.A., R.Frith, Ph.D. and H.C. Shellard, B.Sc. M.O. 530c. 1952. 2s. 6d. (2s. 10d.)

89. Temperature and humidity gradients in the first 100 m. over south-east England.
By A. C. Best, M.Sc., E. Knighting, B.Sc., R. H. Pedlow, B.Sc. and K. Stormonth, B.Sc. M.O. 530d. 1952. 7s. 6d. (7s. 11d.)

90. Seasonal change of surface temperature of the North Atlantic Ocean.
By T. H. Kirk, B.Sc. M.O. 530e. 1953 5s. 6d. (5s. 10d.)

91. Vertical profiles of mean wind in the surface layers of the atmosphere.
By E. L. Deacon, B.Sc. M.O. 530f. 1953. 4s. 6d. (5s. 1d.)

92. Day-to-day variations in the tropopause. By J. S. Sawyer, M.A. M.O. 530g. 1954. 5s. (5s. 4d.)

94. Meteorological results of the Balaena Expedition, 1946–47.
By H. H. Lamb, M.A. M.O. 584b. 1956. 8s. 6d. (9s.)

95. Wind and temperature to 50 km. over England.
Anomalous sound propagation experiments, 1944–45. By R. J. Murgatroyd, B.Sc.(Eng.). M.O. 584c. 1956. 5s. (5s. 4d.)

96. The free atmosphere in the vicinity of fronts.
Analysis of observations by the Meteorological Research Flight, 1950–52. By J. S. Sawyer, M.A. M..O 584d. 1955. 5s. (5s. 4d.)

97. Some features of jet streams as shown by aircraft observations.
By R. Murray, M.A. M.O. 584e. 1956. 4s. 6d. (4s. 10d.)

98. Glazed frost of January 1940.
By C. E. P. Brooks, D.Sc. and C. K. M. Douglas, B.A. M.O. 584f. 1956. 7s. 6d. (7s. 11d.)

100. World distribution of atmospheric water vapour pressure.
By G. A. Tunnell, B.Sc. M.O. 584h. 1958. 10s. (10s. 6d.)

101. Upper air temperature over the world.
By N. Goldie, B.Sc., J. G. Moore, B.Sc. and E. E. Austin, M.A. M.O. 631a. 1958. 30s. (31s. 9d.)

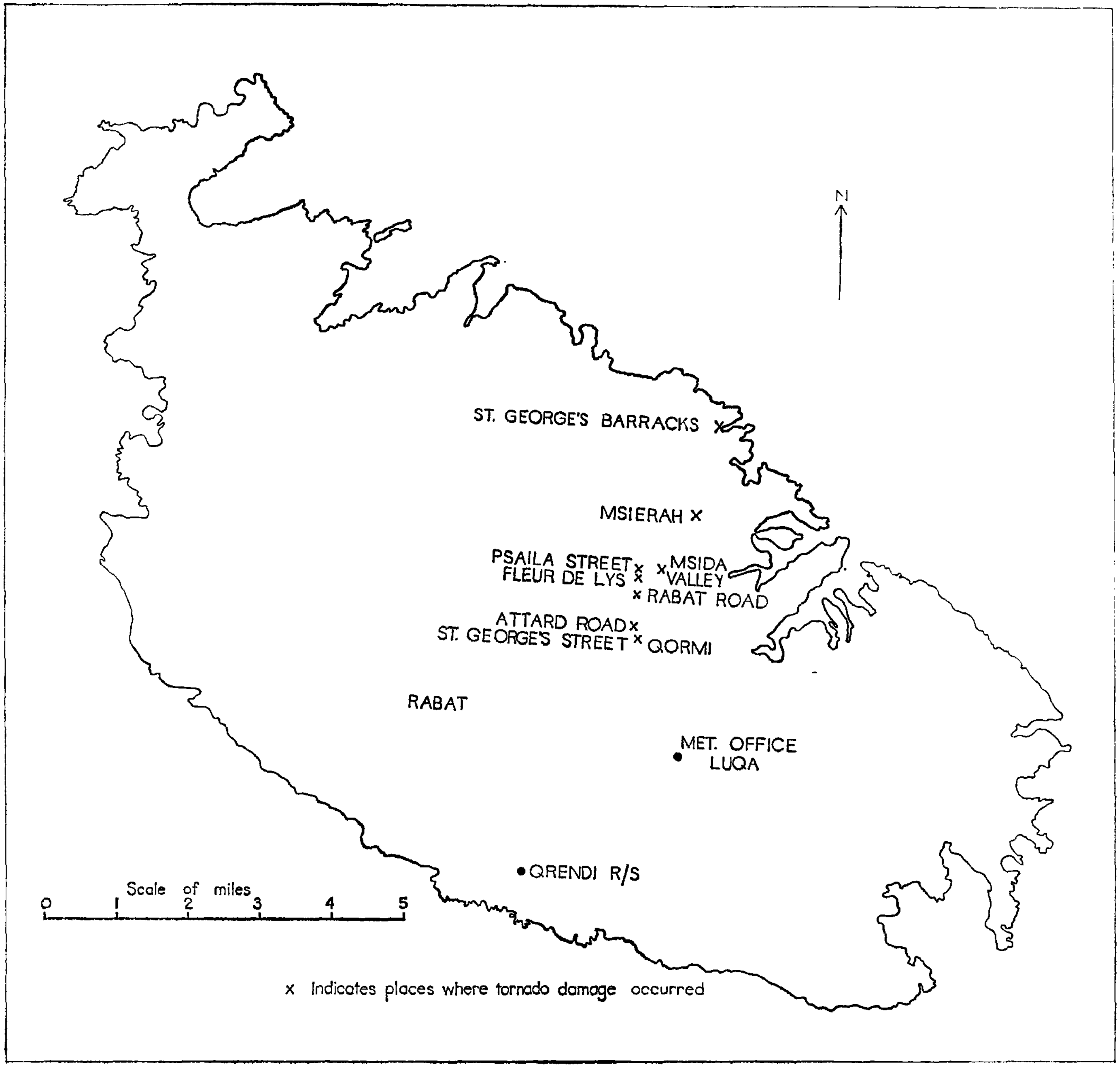
102. Average water-vapour content of air.
By J. K. Bannon, B.A. and L. P. Steele. M.O. 631b. 1960. 8s. 6d. (8s. 11d.)

103. Upper winds over the world. By H. Heastie, M.Sc. and P. M. Stephenson, M.Sc. M.O. 631c. Parts I and II. 1960. 30s. (31s. 6d.)

104. Exchange of energy between the atmosphere and the oceans of the southern hemisphere.
By D. W. Privett, M.Sc. M.O. 631d. 1960. 8s. 6d. (8s. 11d.)

105. Upper winds over the world.
By G. B. Tucker, Ph.D. M.O. 631e. Part III. 1960. 25s. (25s. 11d.)

106. Meso-synoptic analysis of the thunderstorms of 28 August 1958.
By D. E. Pedgley, B.Sc. M.O. 711. 1962. 12s. 6d. (13s.)



MAP OF MALTA SHOWING PLACES WHERE TORNADO DAMAGE OCCURRED

M.O. 711b

METEOROLOGICAL OFFICE

Geophysical Memoirs No. 107
(SECOND NUMBER, VOLUME XIV)

REPORT ON A TORNADO AT MALTA

14 OCTOBER 1960

BY

T. H. KIRK, B.Sc., and D. T. J. DEAN

LONDON: HER MAJESTY'S STATIONERY OFFICE

1963

U.D.C.
551.506.2 (458.2):
551.509.327: 551.515.3

Geophys. Mem., London,
14, No. 107, 1963

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

REPORT ON A TORNADO AT MALTA

14 OCTOBER 1960

SUMMARY

An account is given of the tornado which occurred at Malta on 14 October, 1960. The attendant meteorological conditions are examined and it is shown that a close parallel exists with those associated with tornadoes in the United States of America. This suggests that the techniques employed in the U.S.A. in forecasting "severe weather" can, with advantage, be applied also in the Mediterranean. Contrary to American experience, the wind field, on a synoptic scale, does not appear to show features of significance and it is suggested that the low-level convergence necessary for the maintenance of the tornado is provided by the thunderstorm downdraught, probably at the margin of the thunderstorm cell. The possible significance of internal waves is also discussed.

INTRODUCTION

On the morning of Friday, 14 October, 1960, after a period of thunderstorms, accompanied by heavy rain and hail, a tornado formed over the island and caused widespread damage. The newspaper accounts, based on information supplied by the Meteorological Office, used the term "tornado". This aroused considerable interest and comment, for the local word describing a phenomenon of this kind (including waterspout) is "tromba", as in Italian. By "tornado" is meant:[1]* "an intense spiral motion around a vertical or inclined axis, averaging about 250 yards across, with its lower part often characterized by a narrow pendant cloud extending from a cumulonimbus cloud base to or nearly to the ground".

Trombe (waterspouts) are occasionally seen off the coasts of Malta and excite little comment but over land they are very infrequent. The last example[2] of a tornado occurred on 24 November, 1936, and damage was then confined to the vicinity of Hal Far aerodrome and the nearby village of Ghaxak. There is no recollection of other similar incidents in which appreciable damage has occurred. The tornado of 1936 happened in extreme cyclonic weather ("gregale") and, following American usage, may be described as of "cyclonic" type. The one of October 1960 was "convective" in the sense that no large-scale cyclonic activity was evident. Its impact was accordingly much greater.

It is perhaps appropriate to make some comment here on the frequency of tornadoes. They are usually considered to be rare except in Australia and the United States. In the United States[1] the highest annual frequencies per 10,000 square miles are found in north-eastern Kansas (3·2), central Arkansas (3·0) and throughout Iowa (2·5 to 2·3). This frequency level would entail for Malta three to four tornado occasions per 100 years. Judged by this standard there is no real justification for describing occurrences of tornadoes in Malta as rare.

The scope of the report is defined as follows:

(i) to assemble and record the facts, with particular attention to the attendant meteorological circumstances;

(ii) to ascertain whether these facts are in agreement with the results already known of the occurrence and behaviour of tornadoes;

(iii) to examine the possibility of forecasting tornadoes or of issuing warning notices of the possibility of tornadoes.

A brief account of the damage done and of the human impact of the occurrence, based on reports in the local press, is included. No attempt has been made, however, to deduce characteristics of the tornado from the extent and disposition of the damage. It is felt that these aspects have already received attention[3] in circumstances which afforded better documented data covering a larger area than Malta.

* The index numbers refer to the bibliography on page 9.

THE SYNOPTIC SITUATION

It is logical to view the development of the tornado in terms of the large-scale synoptic features modified as necessary by local or small-scale effects. Figures 1 to 14 give the following synoptic charts: Surface, 850 mb, 700 mb and 500 mb: 0001 GMT and 1200 GMT, 14 October; 300 mb and 200 mb: 1200 GMT, 13 October, 0001 GMT and 1200 GMT, 14 October, 1960.

Surface charts.—An elongated flat cell of high pressure extending from the Levant to the Alps slowly gave way over Italy as a small depression moved from off Valencia to a position north-east of the Balearic Islands. A south-easterly low-level flow was maintained over the central Mediterranean.

At 850 *mb.*—A light south-westerly flow from the Gulf of Gabes to Greece at 0001 GMT backed to a more southerly direction by 1200 GMT as the trough from the depression in the west Mediterranean deepened and moved slowly east.

At 700 *mb.*—A west-south-westerly flow at 0001 GMT showed some backing and increase of wind speed by 1200 GMT.

At 500 *mb.*—A west-south-west to south-westerly flow of some 30 to 40 knots showed little change from 0001 GMT to 1200 GMT.

At 300 *mb.*—The 1200 GMT chart of 13 October showed a small cut-off low south of the Atlas Mountains. At 0001 GMT on the 14th a separate centre was no longer apparent but a marked trough extending south-east over the desert suggested the presence of a cold pool as drawn. By 1200 GMT this cold pool was lying to the south-west of Malta as indicated by the thermal winds at Malta and Wheelus Field.

At 200 *mb.*—The charts show a similar transference of a cold pool from south of the Atlas Mountains at 1200 GMT on the 13th to south of Malta at 1200 GMT on the 14th.

DISCUSSION OF THE OBSERVATIONS

(i) *Thunderstorm activity.*—Figure 15 shows plots of "SFLOCS" as determined by stations of the British Sferic Organization in the United Kingdom, Gibraltar, Malta and Cyprus. Between 0001 GMT and 0200 GMT there were two separate aircraft reports of cumulonimbus cloud near and over Point Beta (34° 07′N, 13° 18′E). Observations on the Air Traffic Control radar at Luqa revealed echoes at 120/130 miles range on bearings 200° and 220° during that period. By 0200 GMT lightning was visible in this direction. The echoes grew, approached Malta from this direction, and became elongated along a line bearing 200°/020°. By 0613 GMT precipitation had begun at Luqa.

(ii) *Weather observations at the Meteorological Office, Luqa.*—The observations made at the Meteorological Office are listed below (extract from the daily register, Figure 16). They show that the thunderstorm started at 0810 GMT and continued until 1103 GMT. The significant observations are:

At 1015 GMT the wind speed was 18 knots gusting to 32 knots. At 1045 GMT the wind had backed from 140 degrees to 120 degrees, and had dropped to 10 knots but remained gusty. At 1100 GMT the wind had backed farther to 100 degrees and increased in speed to 18 knots. A funnel cloud was reported to the north-north-east at 1107 GMT. By 1115 GMT the wind had veered to its original direction of 140 degrees and had dropped to 11 knots. Thunder was reported at 1115 GMT and "funnel cloud" reported at 1135 GMT with a note of a waterspout to the north-north-east at 1130 GMT.

The heaviest rain occurred at 1045 GMT when the visibility was reduced to 2000 yards.

The variations of wind speed and direction are shown more effectively and more accurately in Figure 29 and the relevant portion of the barogram in Figure 30 (local time = GMT + 1). The barometric fluctuation was quite small, amounting to less than a millibar; indeed there is nothing particularly remarkable at all in any of these observations with the exception of the funnel cloud. These records suggest a time of about 1048 GMT for the passage of the barometric minimum at its nearest point to Luqa.

(iii) *Weather observations at the Meteorological Office R/S, Qrendi.*—The radiosonde station at Qrendi is 445 feet above MSL and is situated about 2½ miles south-west of Luqa Airport. The following observations were made:

At 1035 GMT when the main thunderstorms had just passed Qrendi, the tornado cloud was to the south-south-west, low and ragged and black-grey in colour. The base was below 450 feet, since it could not be seen from the station. It was whirling in an anticlockwise direction and the "veins" could be seen turning round. The cloud extended between 220° and 240° at a distance estimated to be about two miles. The surface wind was 130° 13 knots.

At 1050 GMT the main thunderstorms were over Rabat with a clearance due west. The tornado cloud had stopped whirling but the remains of a waterspout could be seen about one to two miles away to the south-west. The leading edge of the extremely dark congested mamma cloud was at an elevation of above 70°. There appeared to be no precipitation.

At approximately 1100 GMT there was an audible lightning strike about one mile to the north-north-west and heavy hail at the north end of the north-west–south-east runway about 1500 yards north-west of the office. The hail could be heard but there was no precipitation at the station. At this time there appeared to be no rotation on the tornado cloud.

There was an abrupt fall of barometric pressure of about 1·3 mb at 1040 GMT and a temporary wind shift to north-easterly for about five minutes at about the same time.

Note: The times are subject to some uncertainty.

(iv) *The trail of damage.*—A map of Malta showing the places where damage occurred is given as frontispiece. Destructive effects were experienced in the path of the tornado. Houses collapsed and bulldozers were needed to clear blocked roads. A pole-mounted electrical transformer was lifted bodily and carried several yards, with severe damage to a nearby house. At least twelve people were injured and taken to hospital. The strength of the wind is perhaps best shown by the distorted television aerials in Plate I. Further illustrations of the damage are shown in Plates II and III.

(v) *Instability considerations.*—An examination of the synoptic charts shows that at the surface there was little evidence to suggest an outbreak of thunderstorms in the Malta area. Aloft, however, at the 300 mb and 200 mb levels the evolution was such as to maintain cold conditions at these levels over the Gulf of Gabes and Malta. It is tempting to think that the small cold pool aloft moving into this area from the south-west had some significance in providing a nucleus or focus for the tornado activity. It is, of course, well known that cold pools aloft at the 300 mb and 200 mb levels are of great significance in the forecasting of thunderstorms in the Mediterranean area.

It is, at this stage, however, profitable to examine the upper air ascents at Malta and Wheelus Field. Ascents for 0001 GMT are given in Figures 17 and 18 and that for 1200 GMT for Malta in Figure 19.

The probable temperature profile over the sea, some 50 to 100 miles north of Idris shows the possibility of convection from about 1500/2000 ft to 200 mb or tropopause level, and this region is where the aircraft first reported thunderstorms at this time. As the thunderstorms travelled north-north-east at approximately 15 knots the warmer and moister air in the surface layers invaded the stable régime of the Malta area.

Showalter[4] has established criteria for a stability index which is useful in assessing the probability of showers and thunderstorms. The 850 mb "parcel" is lifted dry-adiabatically to saturation level and then pseudo-adiabatically to 500 mb. The lifted 500 mb temperature is then subtracted algebraically from the observed 500 mb temperature. A negative number indicates instability and a positive number indicates stability. Experience has indicated that any positive index of +3°C or less is very likely to be associated with showers and quite likely to produce thunderstorms. Thunderstorms have increasing probability as the index falls from +1° to —2°. Negative values of —3° or greater may be indicative of severe thunderstorms and values of —6° or larger are suspect (in the United States) for tornadoes.

Applying this procedure the stability index at Malta at 0001 GMT is +7° whereas at Wheelus Field the value is —3°. The test at least emphasizes the necessity of taking full account of modifying factors leading to instability. The blind application of the criterion to the Malta ascent, as a forecast tool, would obviously have given a totally wrong result.

A feature of the Malta 0001 GMT ascent is the extreme dryness above the level of the base of the inversion at 820 mb and the sharp lapse of the wet-bulb potential temperature between 820 mb and 790 mb. Showalter has taken some account of this type of ascent in his definition of a "tornado index" as the potential temperature at the top of the moist layer minus the potential temperature at wet-bulb zero (the level at which the wet-bulb curve of a sounding falls to O°C). He adds the comment: "Both indices naturally require the usual synoptic skill in analyses and prognoses. Of particular importance is the identification of possible triggering mechanisms and favourable wind shear aloft which carry rain or hail areas out ahead of thunderstorms to drop through dry air. Experience to date indicates a very high probability of tornadoes in any warm sector that shows values of—4 or lower in both the stability index and the tornado index." Applying this criterion the tornado index at Malta appears to be —5½° and that at Wheelus Field —2°.

The distributions of the Showalter stability index at 0001 GMT and 1200 GMT on 14 October are shown in Figures 20 and 21. Owing to the absence of a deep dry layer in many of the ascents it is not possible to produce similar charts for the distribution of the tornado index but the following figures are relevant:

Wheelus Field	0001 GMT−2	1200 GMT+2
Malta	0001 GMT−5½	1200 GMT−1
Messina	0001 GMT−5	1200 GMT−1
Brindisi	0001 GMT−1	1200 GMT 0

Of prime importance in a discussion of instability is an examination of conditions at the surface. Figure 22 shows the distribution of dew-point temperature at 0001 GMT, 14 October. The main feature is a pronounced tongue of warm moist air extending from Cyrenaica across the Sea of Sidra, thence to the Sicilian narrows. The initial report of thunderstorms came from near the axis of this warm tongue. Subsequent distributions of dew-point temperature at 0600 GMT and 1200 GMT are shown in Figures 23 and 24. They show the northward movement of surface air of high dew-point to the Malta area.

The fundamental difference between the 0001 GMT ascents at Malta and Wheelus Field and the subsequent complete invasion and modification of the Malta régime by conditions akin to those at Wheelus Field are shown by the comparisons of wet-bulb potential temperature in Table I.

TABLE I—*Wet-bulb potential temperature at Malta and Wheelus Field*

Pressure level	0001 GMT, 14 October 1960		1200 GMT, 14 October 1960	
	Malta	*Wheelus Field*	*Malta*	*Wheelus Field*
mb		*degrees Celsius*		
1000	13	19	21	19
900	13	20	18	19
800	10	18	18	16
700	12	13	15	17
600	13	15	13	16
500	15	16	15	15
400	17	—	17	—

Figures 25 and 26 show the distributions of potential temperature and of wet-bulb potential temperature in vertical cross-sections between Wheelus Field and Brindisi at 0001 GMT and 1200 GMT.

The distribution of dew-point temperatures at 800 mb at 0001 GMT, 14 October emphasizes the profound difference between the air at Malta and at Wheelus Field at this level. Figure 27 shows the narrow tongue of air of low dew-point extending from the Tyrrhenian Sea across western Sicily to Malta where it reached its minimum value. The corresponding distribution at 1200 GMT (Figure 28) shows that the region of lowest dew-points has moved from the Malta area to Brindisi, corresponding to a speed of approximately 20 knots whereas the highest dew-point values have been transferred from the Tripoli area to Malta at a speed of approximately 15 knots.

The resulting aerological conditions immediately prior to the tornado may therefore be seen to correspond closely with those described as typical of American tornadoes.[1] "Typical aerological soundings of the maritime air in which tornadoes develop show that it has high relative humidity usually only up to about 1–3 km. A thin stable layer, which may be an inversion, separates the maritime air from the dry superior air aloft, which is characterized by a steep lapse rate. The thin layer is convectively unstable because of the rapid decrease of humidity with height."

(vi) *Interpretation of the autographic records.*—Figures 29 to 33 show the following records taken at the Meteorological Office, Luqa:

Figure 29—Wind speed and direction (anemogram)
Figure 30—Atmospheric pressure (barogram)
Figure 31—Air temperature (thermogram)
Figure 32—Relative humidity (hygrogram)
Figure 33—Duration and intensity of rainfall (tilting-siphon rain recorder)

Regular wave-like oscillations in both speed and direction are to be seen on the anemogram between 10 and 11 hours GMT. These were probably due to wave motion at one of the low-level inversions shown in the Malta ascent for 0001 GMT on 14 October. It would appear that the lowest layer of air had not at this time taken part in the general ascent that was producing the rain.

At about 10 hours GMT the sharp decreases of temperature and of relative humidity (despite falling rain) combined with sudden gustiness, reaching 30 knots, are interpreted as being due to a sudden downdraught from the thunderstorm. As Byers[5] has remarked, the discontinuity zone which marks the limit of cold downdraught air, also marks the passage of the cell core in an early mature stage. The sudden or "first" gust and the beginning of the sudden fall of temperature occur essentially together. The corresponding drop of relative humidity, often from nearly 100 per cent to as low as 60 or 70 per cent, even in heavy rain, is almost always present and is further evidence of the downdraught.

The anemogram shows the first gust at 1000 GMT but apart from an increase of the amplitude of the oscillation there was no immediate change in the character of the direction trace. However, at about 1040 the wind backed steadily to north-east and reached 18 knots with gusts to 24 knots, maintaining this direction and speed for 5 to 10 minutes. It then veered steadily to 220° before backing again to its original direction of about 130°.

The barogram clearly shows the increased amplitude of its oscillations after the first gust, and contemporary with the major wind fluctuations described above, a sudden fall of 1·5 mb was followed by a rapid recovery of 0·7 mb. The extreme backing of the wind to north-east corresponded with the downward plunge of the pressure at 1045 GMT to 1050 GMT and this was when the storm was at its worst.

Similar behaviour of wind and pressure occurred at Qrendi R/S at about 1040 GMT but corresponding wind and pressure fluctuations did not occur at the Royal Naval Air Station at Hal Far, nor was there evidence of a downdraught. The disturbance would therefore seem to have been on a local scale only.

The sequence of changes of direction in the wind oscillation is not obviously consistent with the passage of a small low centre either to the north or south of the station. The fact that the amplitude of variation is exactly 180 degrees suggests a response in the wind to pressure fluctuations travelling in the main current aloft that is from the south-west. Rapid changes of wind should respond directly to the pressure gradient and not achieve geostrophic balance, so that a rapid fall of pressure travelling from the south-west would induce a north-easterly wind and the subsequent sharp rise, a south-westerly wind—an amplitude of 180°.

We then visualize a small-scale disturbance of line-squall type, large enough to affect Luqa and Qrendi but not extending far enough to the south-east to affect Hal Far. This is consistent with the observations on the extent of the cumulonimbus cloud front as it approached Qrendi.

The sharp pressure fall and partial recovery are probably the result of a break-down of the surface stability below the low-level inversion or stable layer. This break-down would be the end point in a series of oscillations of larger amplitude in the stable air promoted by the downdraught. The fact that neither downdraught nor significant pressure and wind oscillations are evident in the Hal Far records seems suggestive of a close association between downdraught and subsequent break-down of stability.

If we accept this theory that the break-down of the wave motion at the stable layer initiates an increased degree of instability involving the surface layer, whereas previously throughout the thunderstorms this layer had not been involved, then we have a mechanism for the local development of tornadoes. A previously untapped source of energy is suddenly made available. We speak of tornadoes rather than one tornado not only because the observations at Qrendi suggest more than one but primarily because the mechanism of a squall cloud at a break-down of stability travelling in the main current above the surface layer affords a means of generating one or more tornadoes as it moves along its course.

This reconstruction does not rule out the possibility of contributory effects due to topography. On the contrary, the locality, Qormi, where damage first occurred is sufficiently close to a system of wieds (steep dry ravines) to the south-south-west to suggest this as the likely place of birth of the tornado. It seems quite possible, therefore, that the ravines may have caused an intensification in the circulation initiated by the fluctuations of wind through 180 degrees in response to the rapid variations of pressure.

Accepting as 1048 GMT the time of occurrence of the barometric discontinuity at Luqa and 1107 GMT the observation of a funnel cloud off Dragonara Point, we have 15 knots as the speed of the tornado, a value which agrees with that of the main thunderstorm along the track from Point Beta.

(vii) *Large-scale factors.*—We return now to considerations based on the synoptic situation already sketched in outline. Prior to the 14th the influx of recent maritime polar air to the Mediterranean was followed by the occurrence of subsidence aloft, evident to a marked degree in the Malta ascent at 0001 GMT on the 14th. At low levels the circulation round the high pressure in the east central Mediterranean led to the warm moist air supply across the Sea of Sidra. These two factors, of such profound importance for tornado development can be seen as direct products of the synoptic development and as such their forecasting must be a matter of skill and experience.

Of conditions aloft, we have already seen that the development at the highest levels was such as to give the possibility or probability of thunderstorms in the area to the south or south-west of Malta. This was confirmed by SFLOC reports at an early stage.

The thunderstorms occurred in the Gulf of Gabes immediately to the east of a cold front advancing eastwards. This is a usual tornado situation in the U.S.A. where the "instability line" or pre-frontal squall line is considered a favourite site for tornado development. In the present situation, SFLOC reports, and radar observations, confirmed that no instability line, as such, was present. Nevertheless we can regard the cold front as being of immediate relevance inasmuch as it is consistent with low-level convergence ahead of it, favourable to the development of convective activity.

The thunderstorms broke out at night over the Gulf of Gabes and this appears to be a factor of some importance. The nocturnal maximum of shower activity and thunderstorms is very real in the Mediterranean. The work of Neumann[6] has emphasized the role of concave coastlines as favourable for night-time convergence and the subsequent outbreak of convective activity. The Gulf of Gabes affords perhaps one of the best examples where this effect may be looked for. Blackadar[7] has stressed the formation of the low-level jet at a nocturnal inversion as a factor in the promotion of low-level convergence and it would appear reasonable to suppose that this effect, too, occurring over land areas is of significance in encouraging the outbreak of convective activity at night over the Gulf of Gabes. We can conclude that there is some justification for regarding the Gulf of Gabes as a preferred area for nocturnal thunderstorms.

(viii) *A comparison with United States tornadoes.*—We have already commented on some points of similarity with American tornadoes. The parallel is very close as will be seen from the following set of conditions cited by Fawbush, Miller and Starrett[8] as characterizing an area of tornado development:

(*a*) A layer of moist air near the earth's surface must be surmounted by a deep layer of dry air. Provided that the other criteria were satisfied, tornado development occurred where the upper dry tongue crossed the lower moist strip.

(*b*) The horizontal moisture distribution within the moist layer must show a distinct maximum along a relatively narrow band with dew-points over 55°F (13°C).

(*c*) The horizontal distribution of wind aloft must show maximum speed along a relatively narrow band at some level between 10,000 and 20,000 feet, the highest speed exceeding 35 knots.

(*d*) The vertical projection of the axis of wind maximum must intersect the axis of the moisture ridge.

(*e*) The temperature distribution in the air column as a whole must correspond to conditional instability.

(*f*) The moist layer must be subjected to appreciable lifting.

Evidence has already been presented to show that criteria (*a*) and (*b*) were satisfied. The horizontal distribution of wind did not however show any pronounced maximum and the highest speed before the occurrence of the tornado was only about 30 knots. The direction of the wind was such as to intersect the axis of the moisture ridge and in this respect (*d*) can be regarded as partially satisfied. Criterion (*e*) was not satisfied initially, judging from the 0001 GMT Malta ascent on the 14th but considerable modification occurred, as has already been described, and there seems little doubt that overall conditional instability was present at a later stage. Marked convective instability was evident at the level of the inversion at an early stage. Criterion (*f*) became satisfied at the time of break-down of the low-level stability.

There is therefore a surprisingly close parallel between the meteorological conditions associated with the Malta tornado and those regarded as common to most of the tornadoes occurring in the U.S.A. The Sea of Sidra may be considered as a source of heat and moisture playing much the same sort of role as does the Gulf of Mexico in its relevance for the formation of tornadoes in the southern states of the U.S.A.

THE FORECASTING PROBLEM

The rarity of tornadoes suggests that many separate requisite conditions must be satisfied simultaneously before tornadoes can come into existence. The complexity involved has already been amply demonstrated in this paper and the forecasting problem must obviously be extremely difficult.

There do, however, seem to be sufficient points of similarity between the situation examined in this paper and those described in American publications to make an examination of American procedures (see for example Petterssen[9]) well worth while as a basis for forecasting severe weather in the Mediterranean.

In general, it would appear that one essential condition is the presence of a low-level "anticyclonic-type" flow, with a dry inversion or stable layer above the turbulence level. Ultimately this level must be surmounted by air unstable enough to develop active thunderstorms. Normally, this means great modification either by advection or thermodynamic processes or a combination of both. Here is the main difficulty. To predict the development of thunderstorms and tornadoes in a restricted area when observations are few, and close, say, to a well developed anticyclonic cell, is no easy task for the forecaster. It can certainly not be compared with the straightforward advection of marked cold fronts, known to be thundery long before they arrive.

There are, however, two powerful aids to forecasting; the Sferic network and airfield radar. The former, essentially a long-range device, gives a good general indication on most occasions; the latter, a short-range precision instrument, is invaluable at night. These tools may give the necessary confirmation of the existence of thunderstorms, from which time the possibility of tornado development must be considered.

SOME THEORETICAL CONSIDERATIONS

Perhaps the best theoretical discussion of the probable mechanism of tornado development has been given by Showalter[4]. His theory of tornado genesis is primarily thermodynamic in origin and utilizes three features commonly noted in connexion with tornado situations. These are:

(i) The presence of a dry inversion or stable layer above the layer of moist air at the surface.
(ii) The presence of dry air above the inversion.
(iii) The occurrence of hail in the vicinity.

All three features were discernible in the case of the Malta tornado. Moreover, there was little unusual in the wind field, as already mentioned, and nothing on the synoptic scale to suggest unusually marked convergence in the surface layers. Showalter's argument that the tornado is primarily thermodynamic in origin because the dynamic conditions or flow patterns (at least in the horizontal plane) associated with tornadoes are frequently observed in the absence of tornadoes is supported by the present evidence. Local convergence in the lowest layers is required however to feed the tornado. In this instance it seems probable that this was provided not by large-scale convergence in a pattern of synoptic scale but by small-scale convergence initiated at the boundary of the thunderstorm cell by the downdraught of the thunderstorm and therefore primarily of thermodynamic origin.

Showalter argues that cooling by precipitation, in particular, hail, plays a predominant part by modifying the stability of the lowest layers thus leading to a local release of convective energy. He places great emphasis on the need for a ceiling to the convective process in a tornado, thus

"... it is likely that the convective process within the tornado vortex would be more violent if restricted in vertical extent.

" Little is known from observations or photographs about the cloud structure at great heights directly above the tornado vortex but if stratification rather than vertical development is present then it would seem that there is a convective ceiling on the tornadic cell.

"The emphasis on establishing a ceiling on convection seems to be necessary in order to differentiate between the thunderstorm and its parasite—the tornado. If the falling hail and rain cooled all of the dry air to its wet-bulb temperature at the same rate, an unstable lapse rate would be established from the ground up to the base of the overhanging cloud which released the precipitation. If, however, maximum cooling of the air took place near the base of the superposed dry layer the desired ceiling to convection could be established at a low level."

Evidence has shown that a ceiling on convection in the Malta area was present at 0001 GMT, 14 October and that the thunderstorms originated in an area where the vertical structure was profoundly different. Their progress north-north-east would result, at any stage, in a modification of the pre-existing vertical structure but it is possible, even probable, that the degree of modification would not be uniform in character but would have a pattern related to the structure of the thunderstorm cells. The evidence of wave motion in the anemogram and barogram suggests that the inversion was maintained at Luqa until the time of occurrence of the tornado. This interpretation depends on the recognition of the wind and pressure oscillations as manifestations of internal waves at the low-level inversion. The cessation of the oscillations at the time of the tornado presumably implies a local breakdown of the stable layer and penetrative convection to this level, and possibly above. It might perhaps be argued that the oscillations in the wind and pressure traces were due to convection cells and that the above deduction is inadmissible. Haurwitz[10] has shown however that a close connexion exists between internal waves and convection patterns and it would appear as a consequence that this objection has little weight.

No information exists as to the height to which the tornado penetrated. Reports from eyewitnesses establish however that the tornado was not an integral part of the main thunderstorm cloud system but depended from a separate squall cloud of much smaller dimensions. Whereas, according to reports from a Canberra aircraft, the main thunderstorm cloud system extended to over 40,000 feet, the top of the tornado cloud appears to have been at approximately 10,000 feet.

An eyewitness report confirms that the tornado first formed in the Qormi area and that it did not maintain a continuous identity but, as is usual with tornadoes, dissipated and re-formed, damage occurring at each re-establishment of the pendant cloud. Before each development evidence of rotation was discernible at the base of the cloud. This tendency of the tornado to dissipate or skip between "strikes" is so characteristic that it would appear that an explanation is not to be sought in the character of the terrain but rather in the field of motion aloft. It is suggested, as a surmise, that this behaviour is conditioned by the internal waves at the stable layer, these providing patterns of low-level convergence and divergence alternately spaced.

CONCLUSIONS

(i) This report has presented, for the first time, a closely documented instance of tornado activity in the central Mediterranean area.

(ii) It has established a close parallel between the thermodynamic factors present at the time of the Malta tornado and those common to most tornadoes in the U.S.A.

(iii) One striking difference has been noted. In this present instance little significance could be discerned in the properties of the wind field, assessed on a synoptic scale. Rather did it appear that small-scale factors were relevant in providing the low-level convergence necessary for the formation of the tornado. These factors could be, firstly, the downdraught from the thunderstorm which is instrumental in creating a pattern of convergence and divergence and secondly internal wave motion at the inversion or stable layer.

(iv) While it is difficult to generalize from a single instance there does appear to be evidence for supposing that the Sea of Sidra functions as a warm moist source region in much the same way as does the Gulf of Mexico and its significance for tornado formation is similar. If this is so, the Malta area is a preferred region for tornado formation.

(v) The systematic use of a form of stability analysis together with a series of criteria, after the American model, will provide a firm basis for attempts to issue "severe weather" forecasts in the Mediterranean area.

(vi) This account incidentally provides evidence of the value of Sferic reports and of the local use of airfield surveillance radar as auxiliary aids in the tracking of thunderstorms, a necessary step in the forecasting of tornado activity.

ACKNOWLEDGMENT

The authors gratefully acknowledge the assistance of Captain J. Agius, Chairman of Allied Malta Newspapers Ltd., who has permitted the use of news extracts and photographs.

BIBLIOGRAPHY

1. BROOKS, E. M.; Tornadoes and related phenomena. Compendium of meteorology, Boston, Mass., 1951, p. 673.
2. BEST, A. C., and CLINCH, E. L.; The weather at Malta. *Met. Mag., London*, **72**, 1937, p. 33.
3. LAMB, H. H.; Tornadoes in England, May 21, 1950. *Geophys. Mem., London*, **12**, No. 99, 1957.
4. SHOWALTER, A. K., and FULKS, J. R.; Preliminary report on tornadoes. U.S. Weather Bureau, Washington, D.C., 1943.
5. BYERS, H. R.; Thunderstorms. Compendium of meteorology, Boston, Mass., 1951, p. 681.
6. NEUMANN, J.; Land breezes and nocturnal thunderstorms. *J. Met., Boston, Mass.*, **8**, 1951, p. 60.
7. BLACKADAR, A. K.; The low-level jet phenomenon. New York, Inst. aero. Sci., Sherman M. Fairchild Publication Fund preprint No. 519, 1955.
8. FAWBUSH, E. J., MILLER, R. C., and STARRETT, L. G.; An empirical method of forecasting tornado development. *Bull. amer. met. Soc., Lancaster Pa.*, **32**, 1951, p. 1.
9. PETTERSSEN, S.; Weather analysis and forecasting (2nd edition). New York (Mcgraw-Hill Book Co., Inc.), 1956.
10. HAURWITZ, B.; Internal waves in the atmosphere and convection patterns. *Ann. Acad. Sci., New York*, 1947, p. 727.

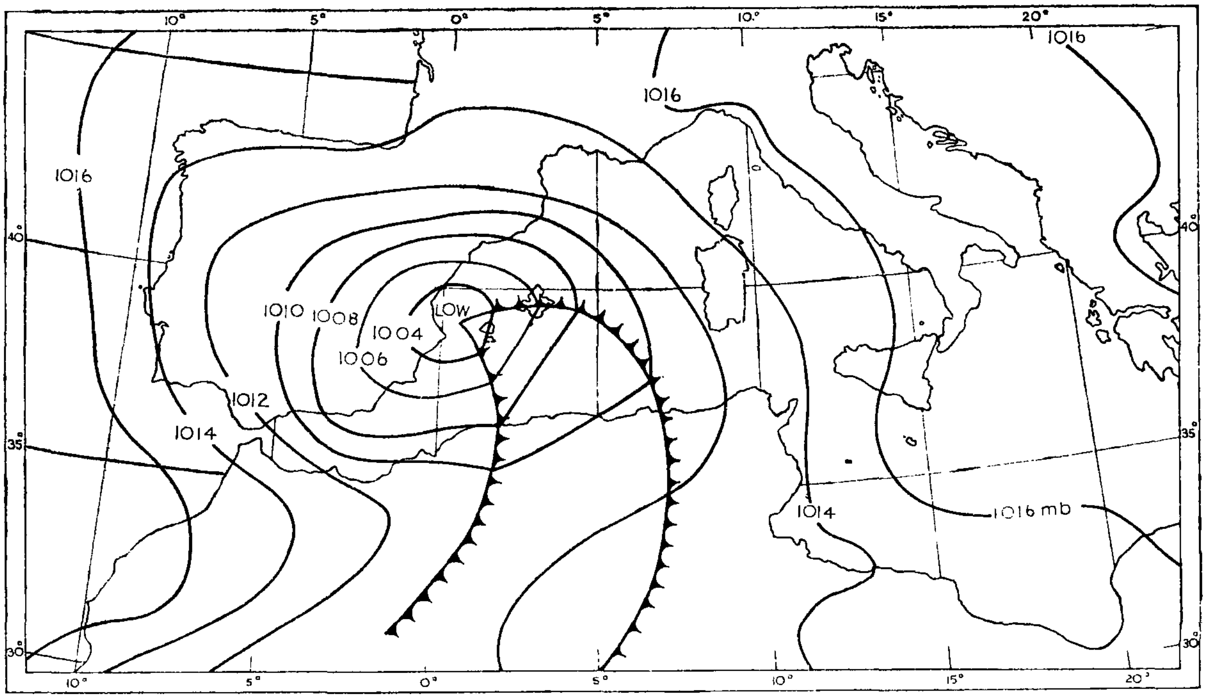


FIGURE 1—SURFACE SYNOPTIC CHART, 0001 GMT, 14 OCTOBER 1960

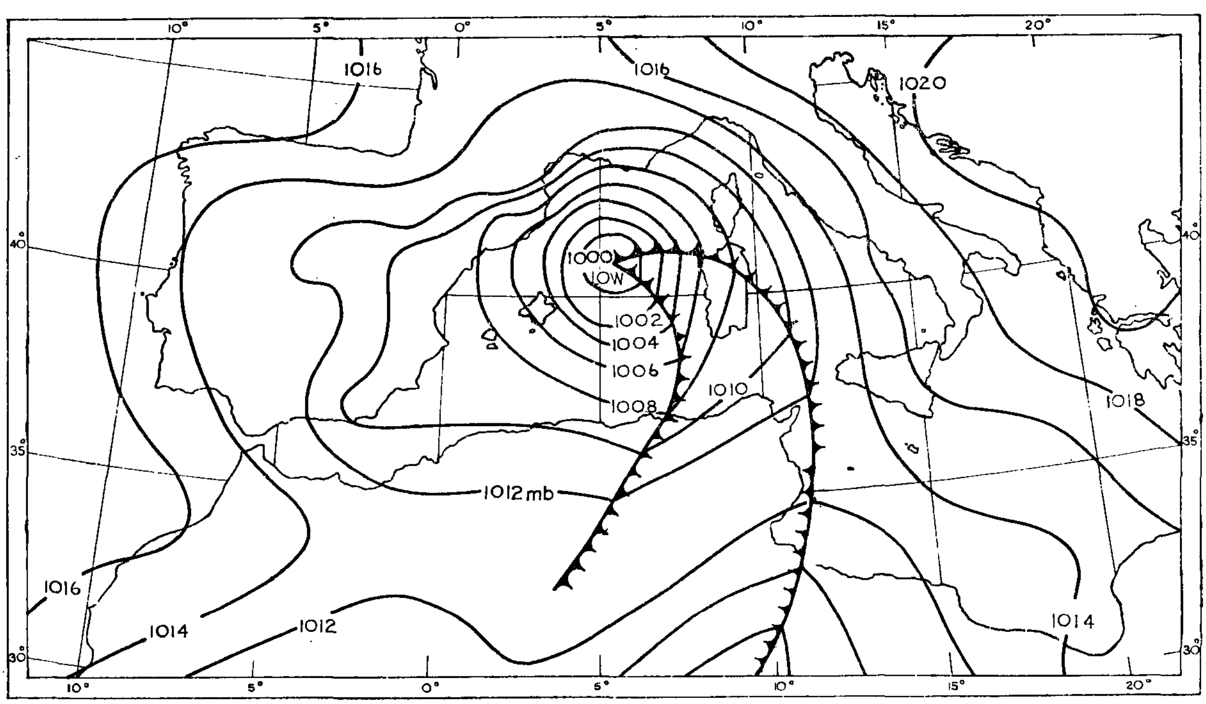


FIGURE 2—SURFACE SYNOPTIC CHART, 1200 GMT, 14 OCTOBER 1960

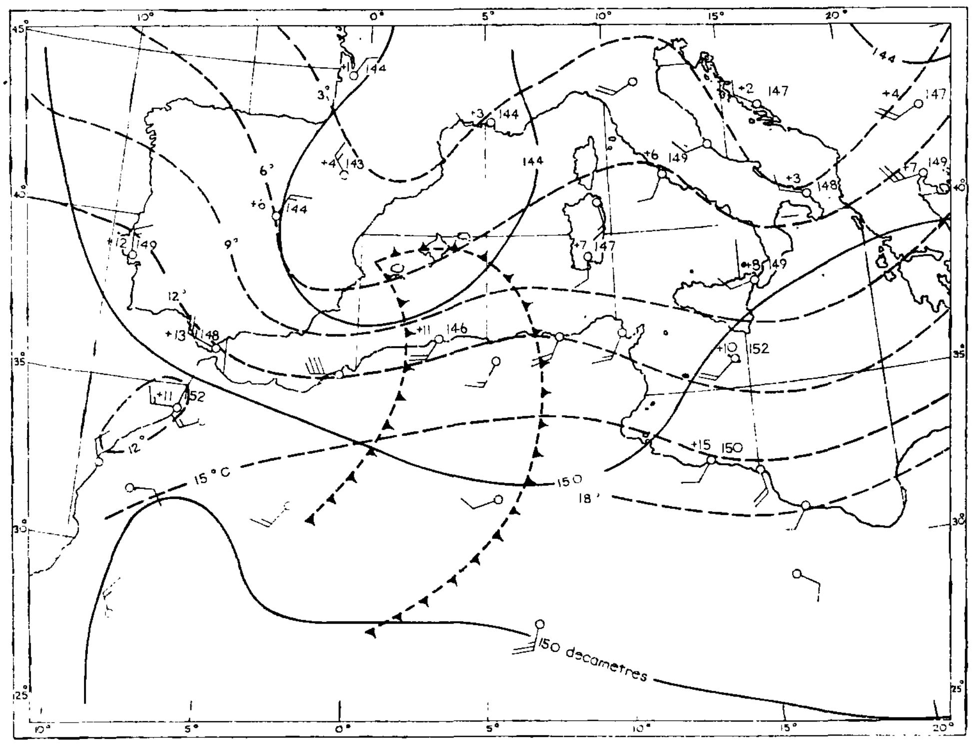


FIGURE 3—UPPER AIR CHART FOR 850 MB, 0001 GMT, 14 OCTOBER 1960

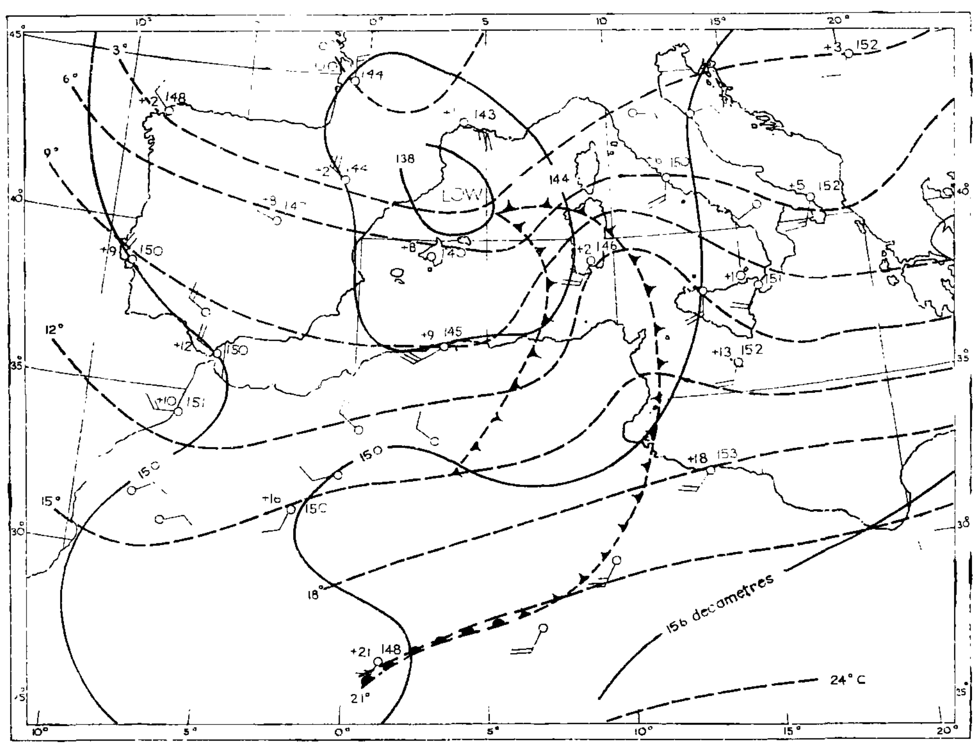


FIGURE 4—UPPER AIR CHART FOR 850 MB, 1200 GMT, 14 OCTOBER 1960

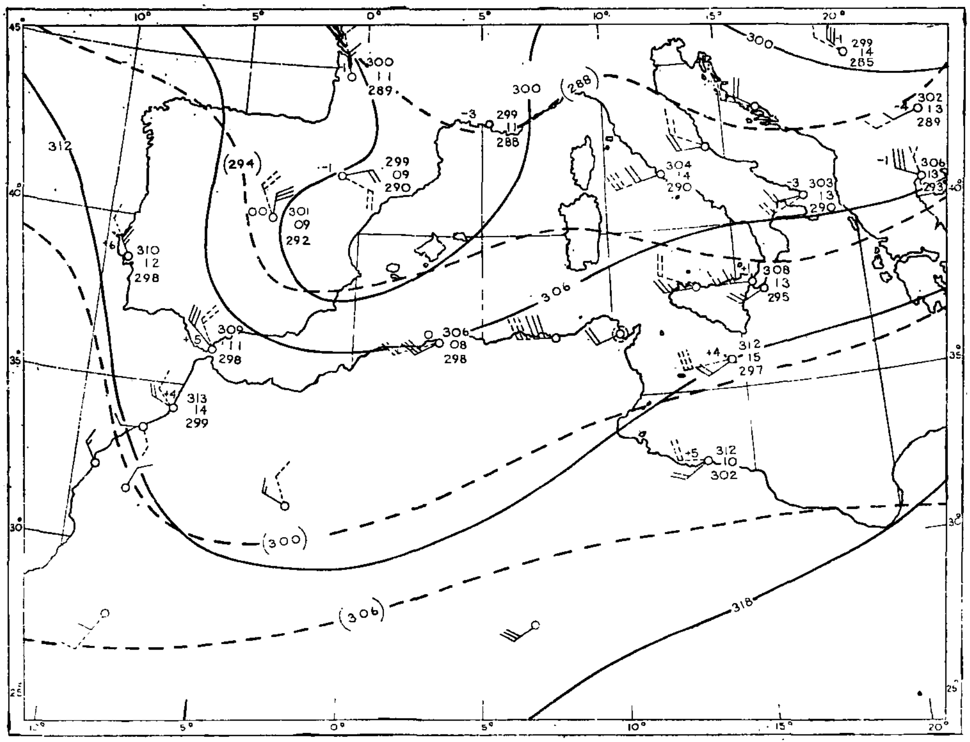


FIGURE 5—UPPER AIR CHART FOR 700 MB, 0001 GMT, 14 OCTOBER 1960
(units: geopotential decametres)

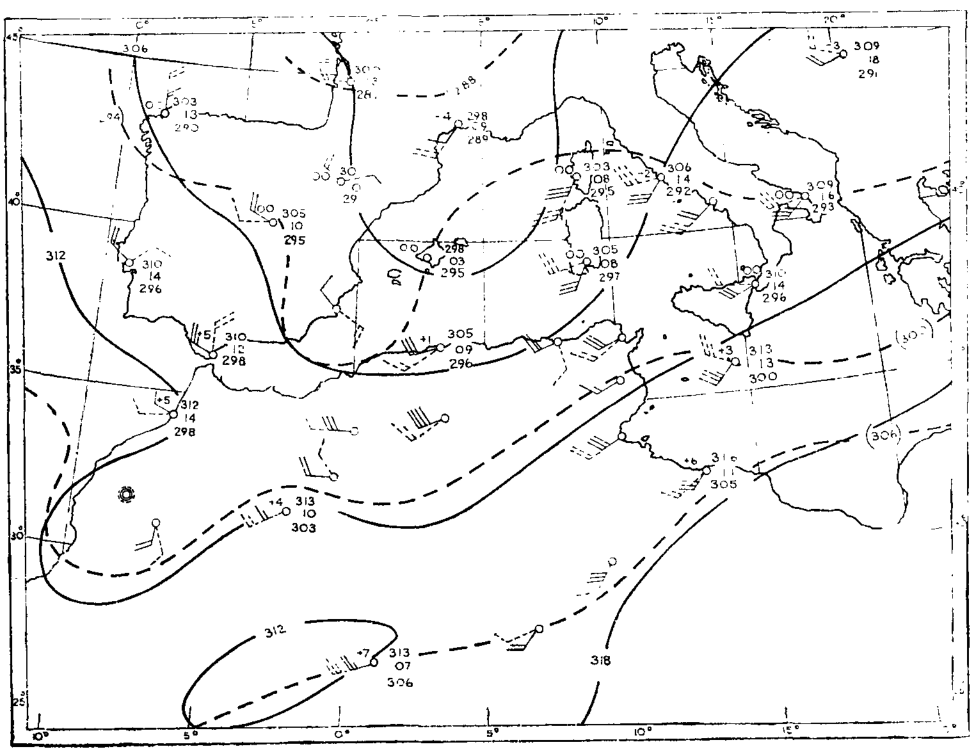
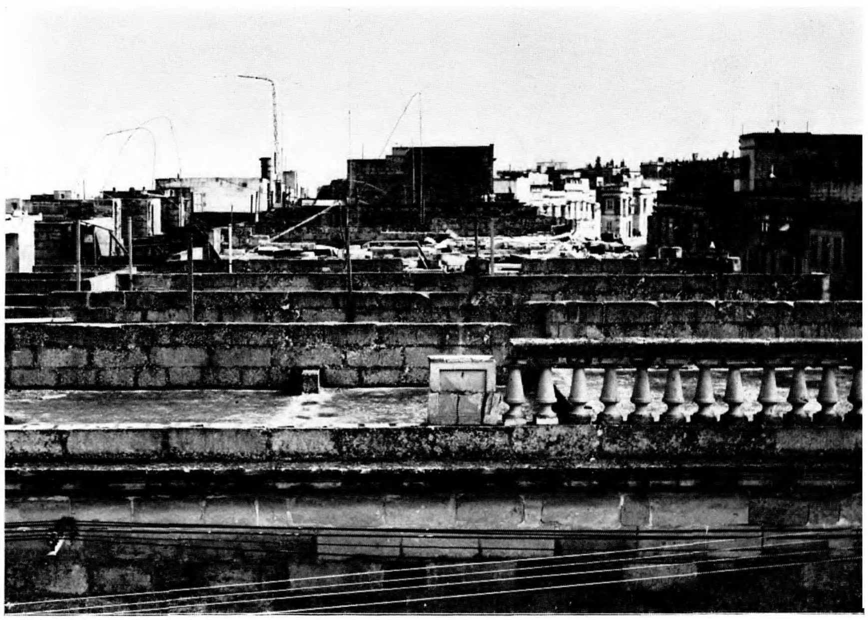
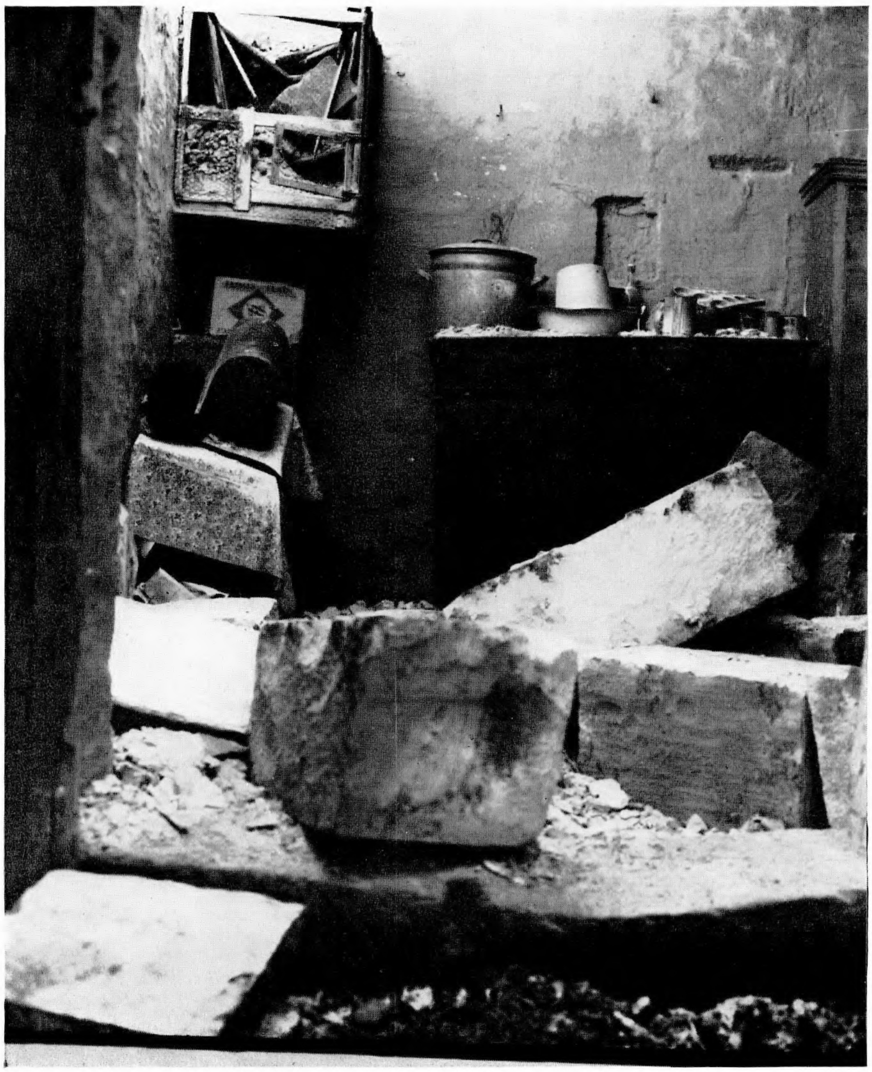


FIGURE 6—UPPER AIR CHART FOR 700 MB, 1200 GMT, 14 OCTOBER 1960
(units: geopotential decametres)



Allied Malta Newspapers, Ltd.

PLATE I—Damaged balustrades and television aerials in Fleur-de-Lys



Allied Malta Newspapers, Ltd.

PLATE II—House demolished in St. George's Street, Qormi

Allied Malta Newspapers, Ltd.

PLATE III—One of the worst hit areas—corner of Brighella Street and Fleur-de-Lys Road, Birkirkara

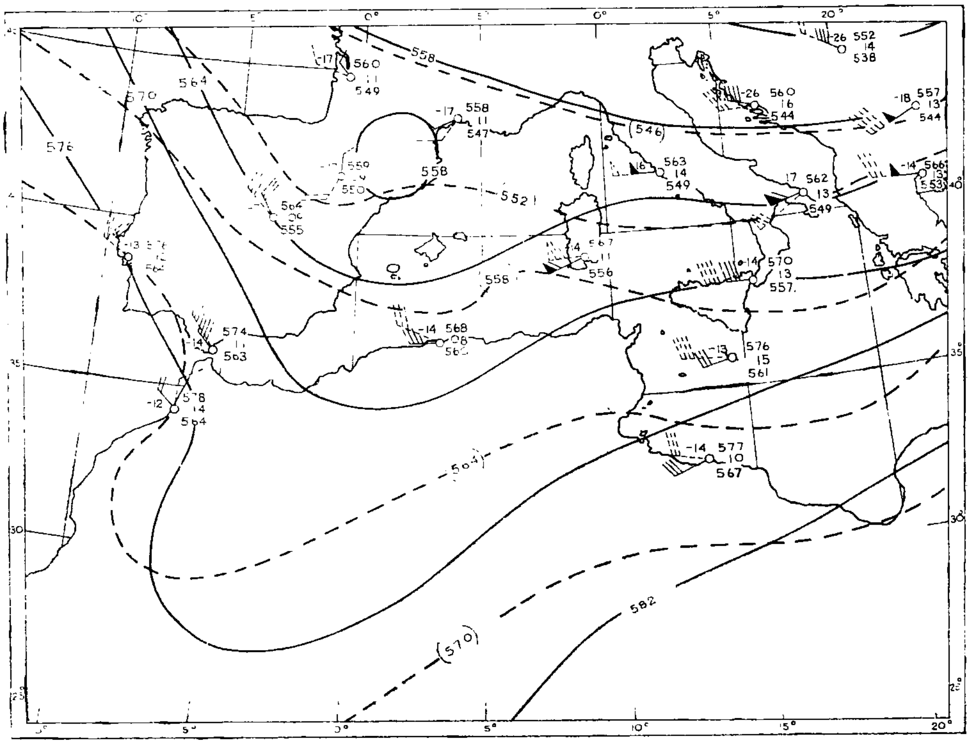


FIGURE 7—UPPER AIR CHART FOR 500 MB, 0001 GMT, 14 OCTOBER 1960
(units: geopotential decametres)

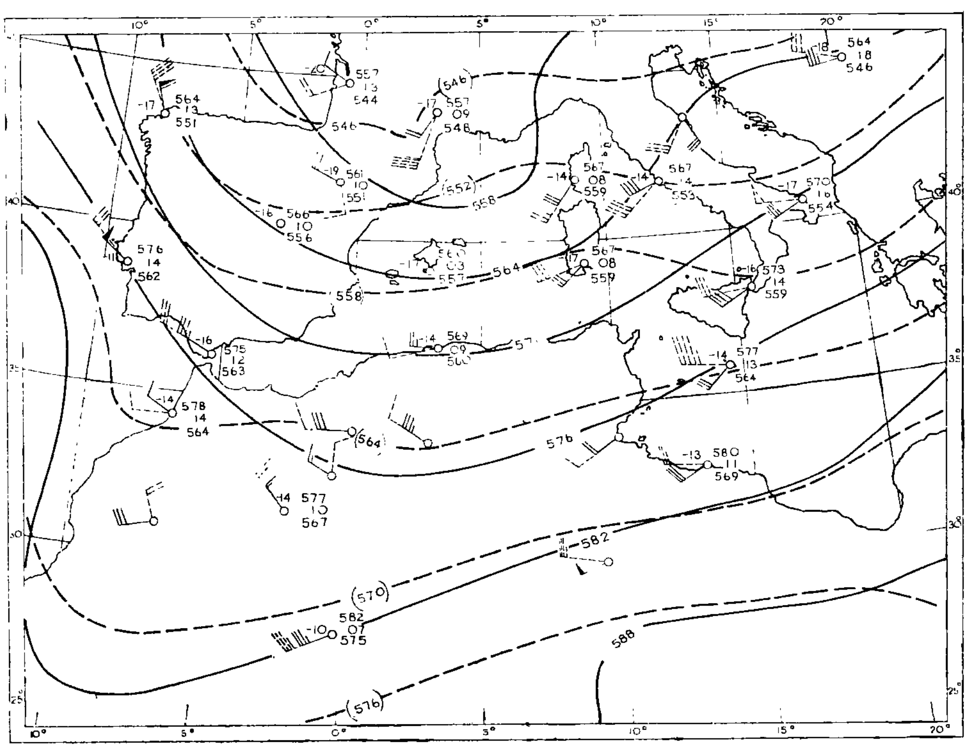


FIGURE 8—UPPER AIR CHART FOR 500 MB, 1200 GMT, 14 OCTOBER 1960
(units: geopotential decametres)

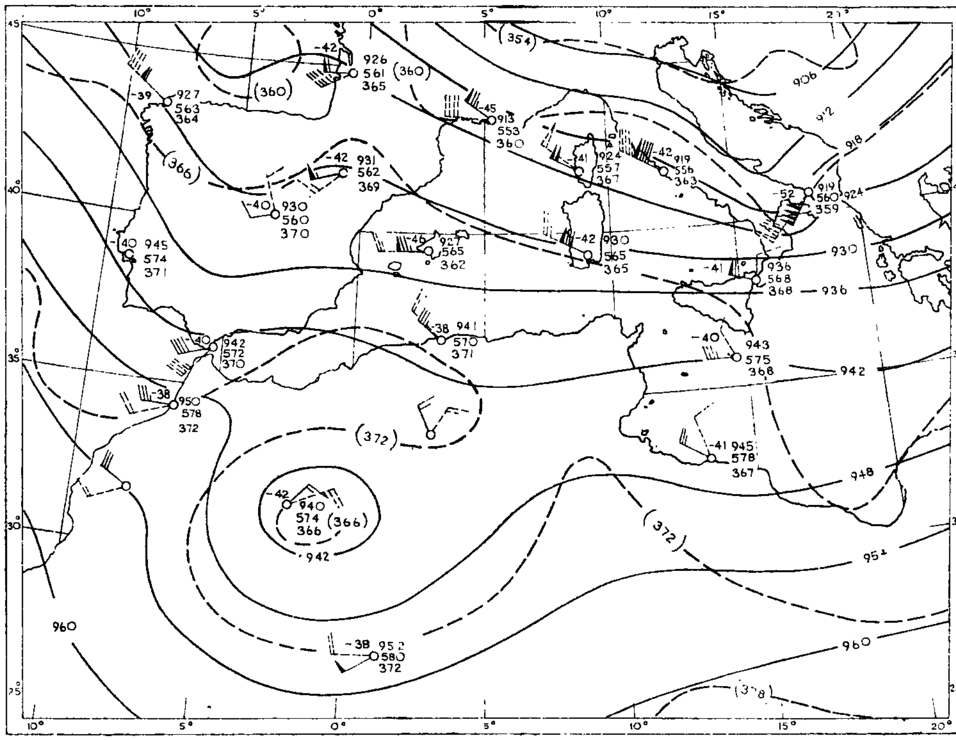


FIGURE 9—UPPER AIR CHART FOR 300 MB, 1200 GMT, 13 OCTOBER 1960
(units: geopotential decametres)

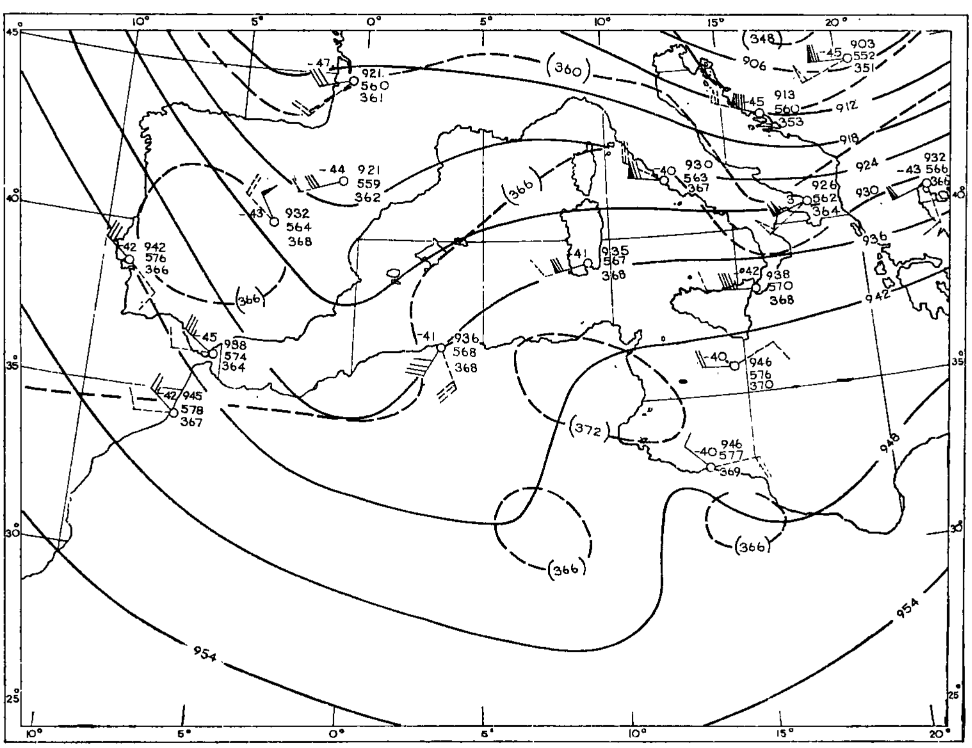


FIGURE 10—UPPER AIR CHART FOR 300 MB, 0001 GMT, 14 OCTOBER 1960
(units: geopotential decametres)

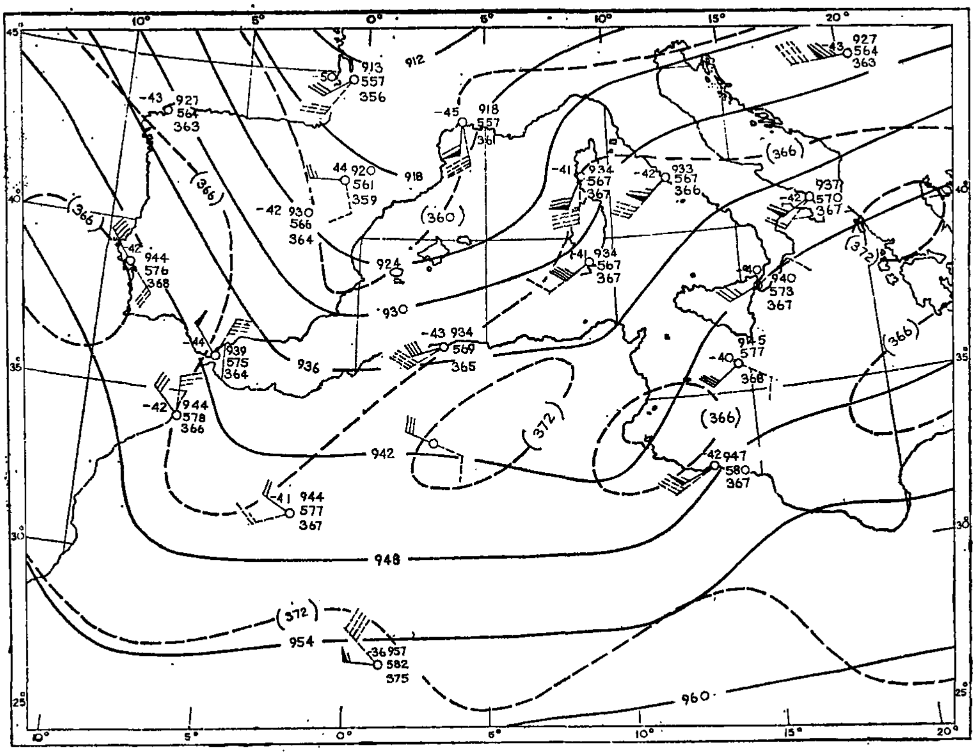


FIGURE 11—UPPER AIR CHART FOR 300 MB, 1200 GMT, 14 OCTOBER 1960
(units: geopotential decametres)

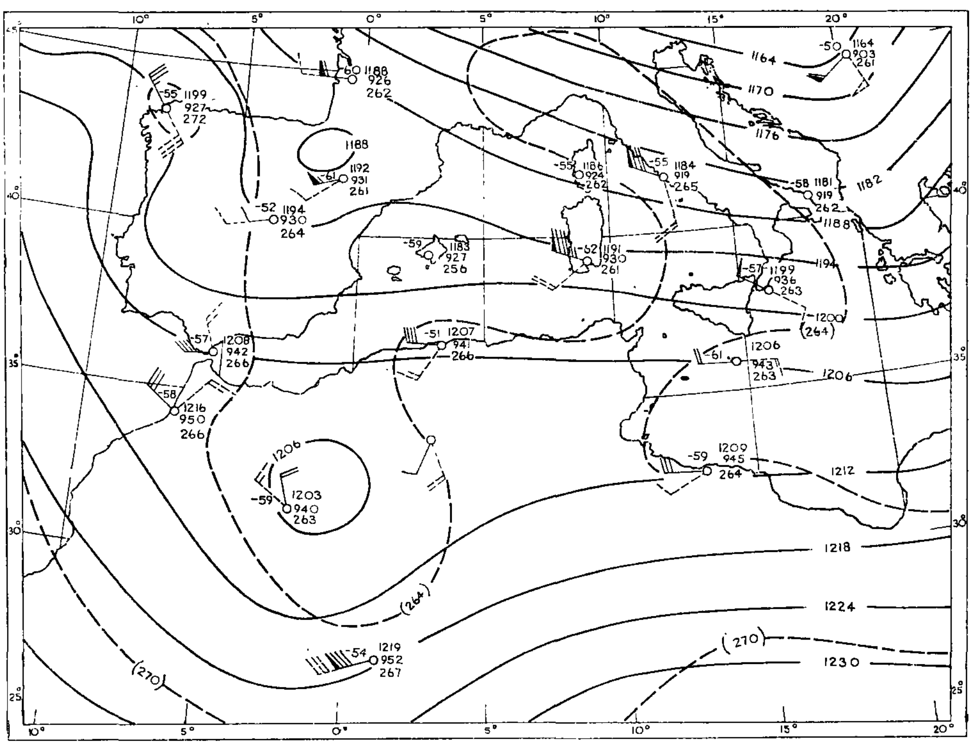


FIGURE 12—UPPER AIR CHART FOR 200 MB, 1200 GMT, 13 OCTOBER 1960
(units: geopotential decametres)

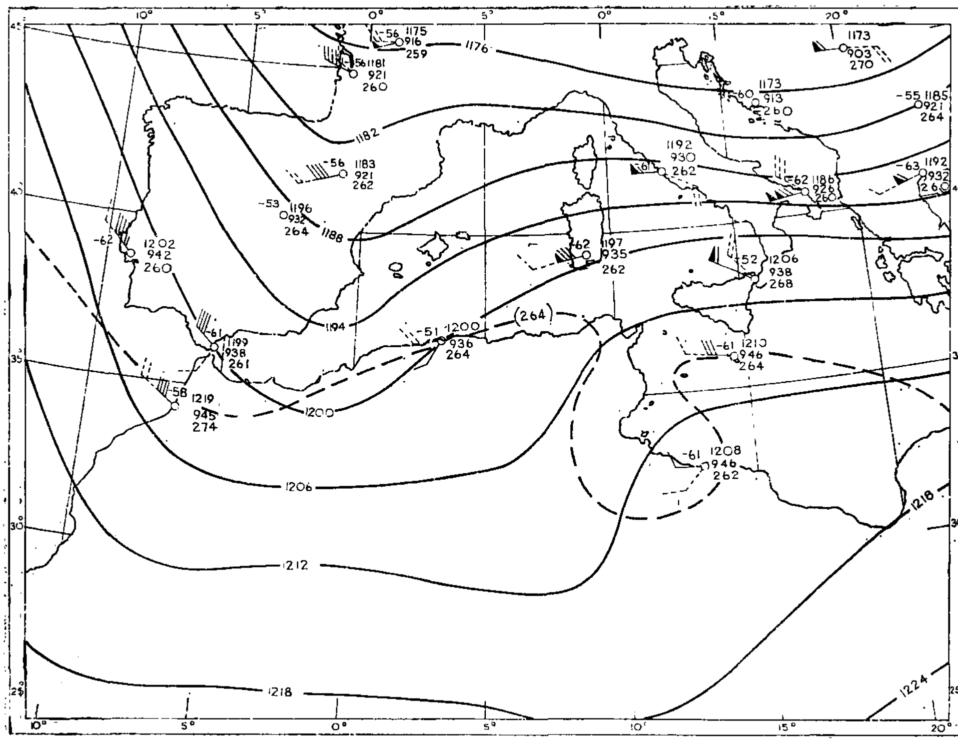


FIGURE 13—UPPER AIR CHART FOR 200 MB, 0001 GMT, 14 OCTOBER 1960
(units: geopotential decametres)

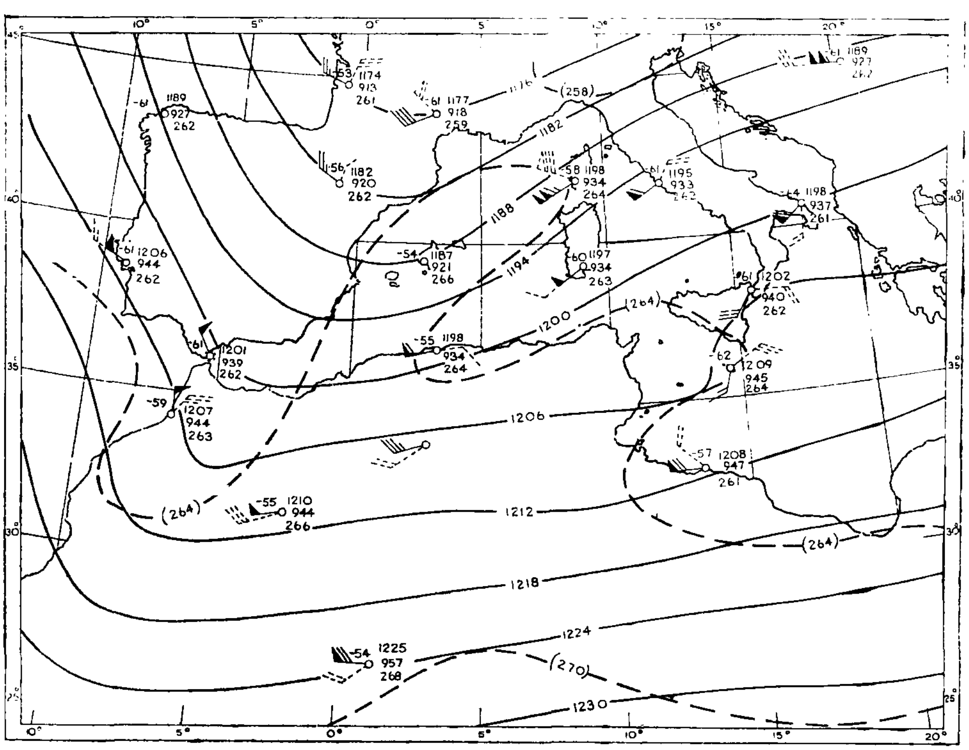


FIGURE 14—UPPER AIR CHART FOR 200 MB, 1200 GMT, 14 OCTOBER 1960
(units: geopotential decametres)

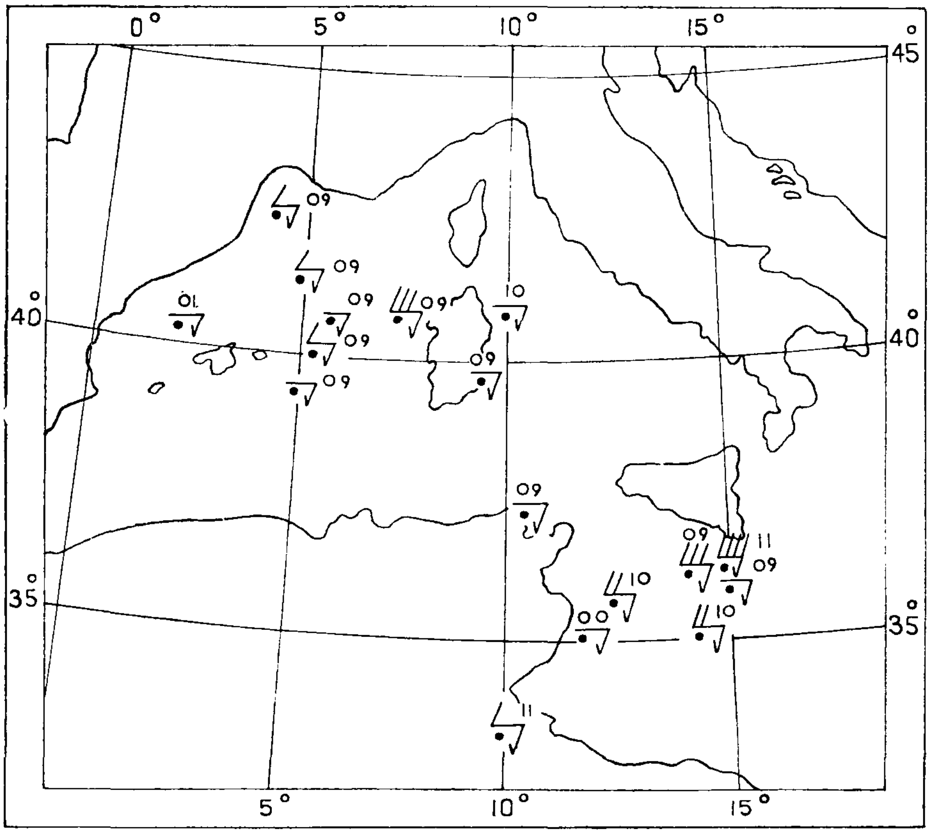


FIGURE 15—MAP SHOWING SFERIC REPORTS, 0001 GMT TO 1100 GMT, 14 OCTOBER 1960

FRI day 14th OCTOBER 19 60

For use with reports of sudden changes		Time G.M.T.*	Wind				Weather		Barometer			Temps.			Cloud						Tendency		
Indicator	GGggw2	Station Number	Total Cloud	Direction See note 5	Speed See note 6	Visibility	Present	Since last Observation See note 7	QFE QNH	Att. Therm Corrn.	As read Sea Level	Dry Bulb	Wet Bulb	V.P. R.H.	Amt. of low†	Form of Low	Height of Low**	Form of Medium	Form of High	Dew point	Characteristic	Amount	V^{pp}_{99} ††
		iii	N	dd	ff	VV	ww	W			PPP	TT			N_h	C_L	h	C_M	C_H	T_dT_d	a	pp	99ppp
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
		0615	7	100	7	22	cpro	c	04.9	294.5	08.8	69.8								62.5			
		16597	7	10	07	81	80	2	15.9				65.3										
		0645	7	100	8	15	cpro	cpro	05.4	295	09.3	69.5								62.2			
		16597	7	10	08	74	80	8	16.3				65.0										
		0715	7	100	9	15	ciro	cpro	05.4	295	09.3	69.8								65.6			
		16597	7	10	09	74	60	8	16.3				67.2										
		0745	7	110	6	10	ciro	ciro	05.4	295	09.3	69.9								65.4			
		16597	7	11	06	66	60	6	16.3				67.0										
		0815	7	130	8	10	ctho	ciro	05.8	295	09.7	69.7								65.6			
MMMMM	08158	16597	7	13	08	66	95	6	16.7				67.1										
		0845	7	130	10	10	ctho	ctho	05.7	295	09.6	69.4								65.7			
		16597	7	13	10	66	95	9	16.6				67.0										
	(09)	0900	7	140	8	10	ctho	ctho	05.7	295	09.6 16.5	71.0		23.3	6	St.7	2100 6	Ac.8	Ci.1	67.9	2	08	
		16597	7	14	08	66	95	9	16.6	302	165	71	69.0	89	6	7	5	8	1	68	2	08	
		0915	7	150	10	5	ctho	ctho	05.6	295.5	09.6	69.3								65.6			
		16597	7	15	10	58	95	9	16.6				66.9										
MMMMM	09382	16597	7	16	12	56	95	9															
		0945	7	160	12	3¾	ctho	ctho	05.7	295.5	09.7	70.0								68.3			
SPECIAL		16597	7	16	12	56	95	9	16.7				68.9										
		1015	7	140	18	2	ctho	ctho	05.3	295.5	09.3	69.1								67.5			
SPECIAL		16597	7	14	18	32	95	9	16.3				68.1										
	SPECIAL	1045	8	120	10	2000yds	ctl	ctho	05.3	295.5	09.3	69.3								68.4			
MMMMM	10452	16597	8	12	10	19	95	9	16.3				68.7										
BBBBB	11002	16597	7	10	18	58	95	9															
		1115	7	140	11	5	ctl ‡	ctho	04.7	296.0	08.8	69.8								68.1			
SPECIAL		16597	7	14	11	58	17	9	15.6				68.7										
BBBBB	11358	16597	7	14	09	58	19	9															
		1145	7	120	9	5	c/tl	ctl ‡	04.5	296	08.6	73.1								70.1			
		16597	7	12	09	58	29	9	15.4				71.1										

* See note 4.
** See note 9.
† See note 8.
†† See note 10.

Rainfall read at 06h. ....mm.
" " " 09h. 2.0 mm. (0.08 ins.)
" " " 18h. ....mm.
" " " 21h. ....mm.
Rainfall 18—06 ....mm.
(reported at 06h.)

Rainfall 06—18 .... mm.
(reported at 18h.)
Rainfall 21—09 2.0 mm.
Rainfall 09—21 ....mm.

Max. Gust (00—24h.) ....knots.

Max. Temp. read at 06h. .... °F.
" " " " 09h. 71 °F.
" " " " 18h. ....°F.
" " " " 21h. ....°F.
Max. Temp. 06—18 ....°F.
(reported at 18h.)

FIGURE 16—EXTRACT FROM DAILY REGISTER, METEOROLOGICAL OFFICE, LUQA

TIME MARKS Baro. 1149Z Thermo. 1148Z Hygro 1148Z Anemo. — Rain Recorder. 1148Z

Indicator	Rainfall See notes 11, 16	Extreme Temp. See notes 11, 17	Clouds (See note 12) Indicator	Amount	Form	Height above Station	Indicator	Amount	Form	Height above Station	Indicator	Amount	Form	Height above Station	Indicator	Amount	Form	Height above Station	Temperatures for AERO reports See note 13			Special Phenomena See note 14	State of Ground	Airfield Fitness	REMARKS Plain Language and Q-code additions to AERO messages. Additional Groups for D.W.R. $2T_gT_gE_s$ "NUREP." Main Cloud layer N_m/Type/h_mh_m ML N_m/h_mh_m. Neph ($Cddf_rf_r$). Air mass, etc., data (selected stations only)	Initials
(7	RR	T_xT_x)	(8	N_s	C	h_sh_s)	(8	N_s	C	h_sh_s)	(8	N_s	C	h_sh_s)	(8	N_s	C	h_sh_s)	(0	TT	T_dT_d)	($9S_pS_ps_ps_p$)	E	(F_n)	M_1M_2n P_t B_cB_c $F_rF_dF_aF_a$ vyvy dydy	
25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
			8	7	6	30													0	21	17				pro 0613Z	
			8	7	6	30													0	21	17					
			8	7	6	15													0	21	17					
			8	7	6	15													0	21	17					
			8	7	6	21													0	21	19					
			8	7	6	21													0	21	19					
			8	7	6	21													0	21	19					
			8	7	6	21													0	21	19					
			8	7	6	21													0	21	19				thro 0810Z	
			8	7	6	21													0	21	19					
			8	7	6	21													0	21	19					
			8	7	6	21													0	21	19					
			8	6	7	21	8	2	3	62	8	TA	0	75									2		25520	
			8	6	7	21																			25520	
			8	5	7	21	8	3	3	60									0	21	19					
			8	5	7	21	8	3	3	60									0	21	19					
			8	5	7	21	8	6	4	59																
			8	5	7	21	8	6	4	59									0	21	20					
			8	5	7	21	8	6	4	59									0	21	20					
			8	3	7	16	8	3	9	30	8	6	4	59					0	21	20	QNT. 32				
			8	3	7	16	8	3	9	30	8	6	4	59					0	21	20	QNT. 32				
			8	5	9	16	8	8	4	59									0	21	20	QNT. 29				
			8	5	9	16	8	8	4	59									0	21	20	QNT. 29				
			8	5	9	12	8	7	4	59															iro stopped 1103Z	
			8	5	9	12	8	7	4	59									0	21	20				Funnel cloud observed - 1107Z	
			8	5	9	12	8	7	4	59									0	21	20				to NNE.	
			8	4	7	12	8	6	3	59															Waterspout observed - 1130Z to NNE.	
			8	4	7	12	8	6	3	59									0	23	21					
			8	4	7	12	8	6	3	59									0	23	21					

Max. Temp. 21—09..........°F.
Max. Temp. 09—21..........°F.

Sunshine (forenoon).......... hours
„ (afternoon).......... hours
„ (Day Total).......... hours

Min. Temp. read at 06h..........°F.
„ „ „ 09h. 68 °F.
„ „ „ 18h..........°F.
„ „ „ 21h..........°F.
Min. Temp. 18—06 ....°F.
(reported at 06h.)

Min. Temp. 21—09..........°F.
Min. Temp. 09—21..........°F.

Grass Min. read at 09h. 56 °F.
Earth Temp. at 09h. 1ft..........°F.
„ „ „ „ 4ft..........°F.

FIGURE 16—CONTINUED

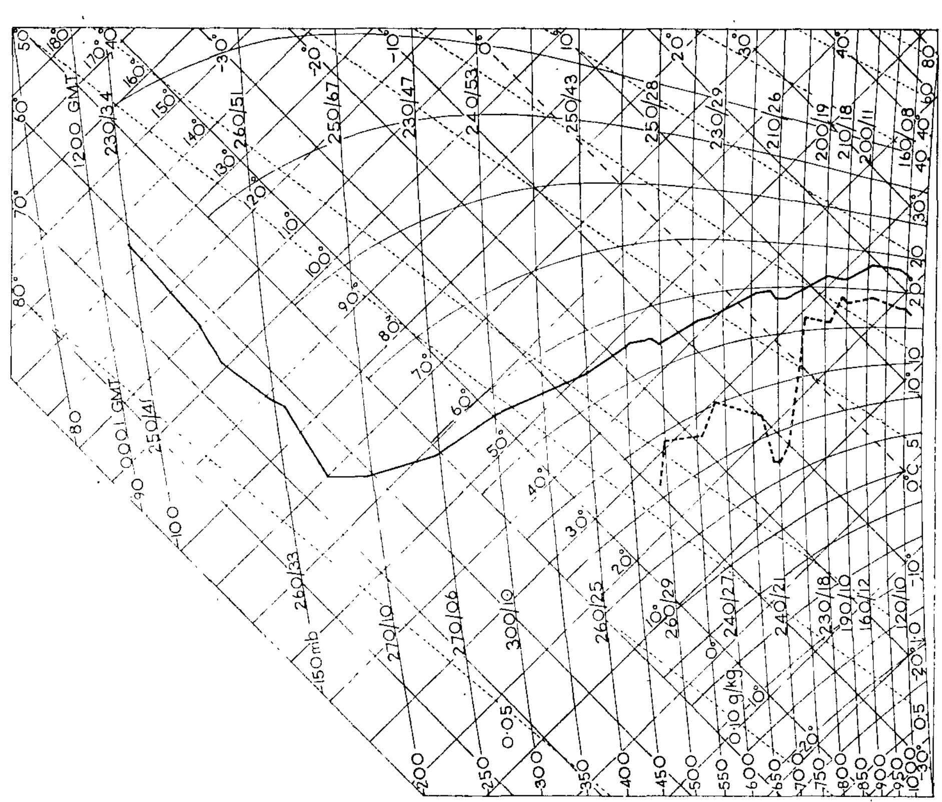


FIGURE 18—UPPER AIR ASCENT FOR WHEELUS FIELD, 0001 GMT, 14 OCTOBER 1960

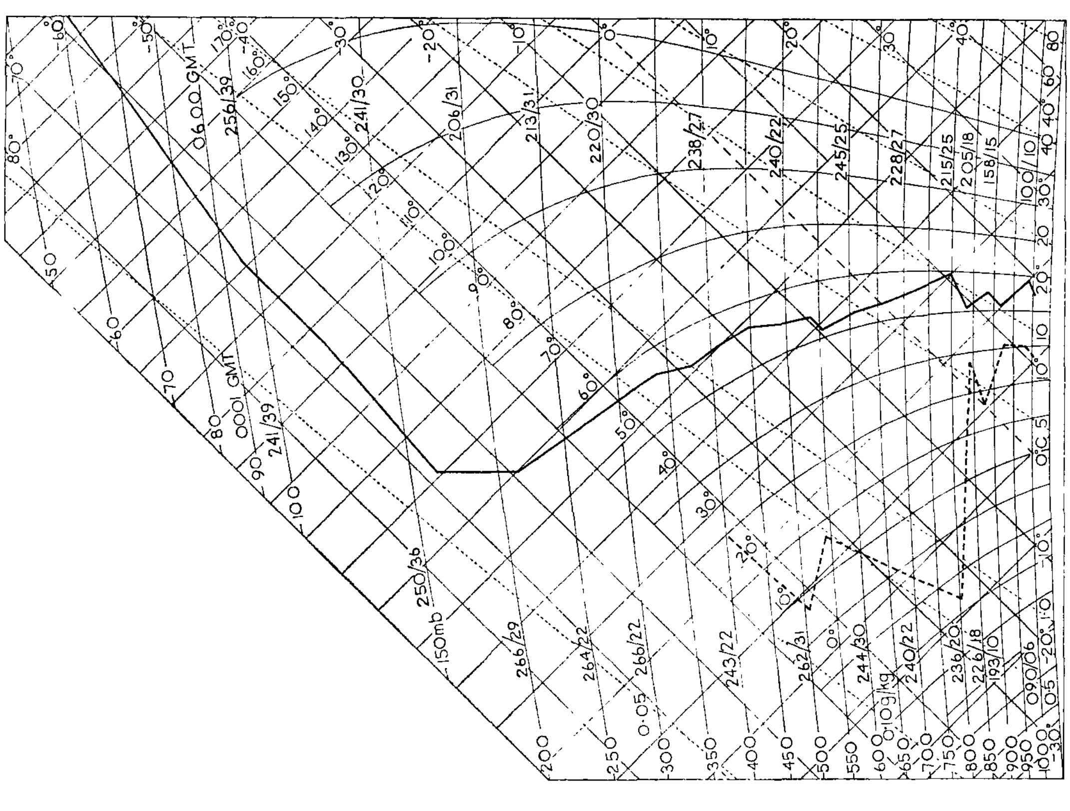


FIGURE 17—UPPER AIR ASCENT FOR MALTA, 0001 GMT, 14 OCTOBER 1960

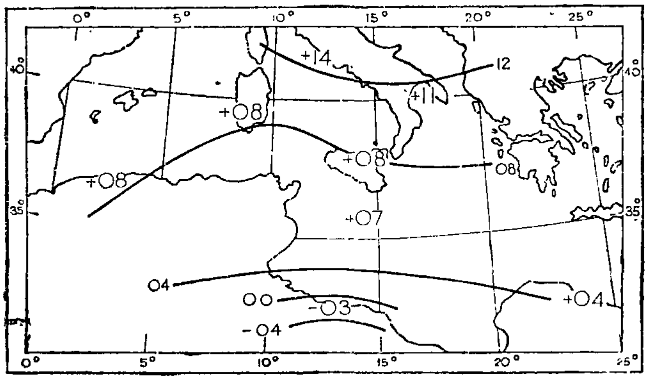


FIGURE 20—DISTRIBUTION OF SHOWALTER STABILITY INDEX, 0001 GMT, 14 OCTOBER 1960

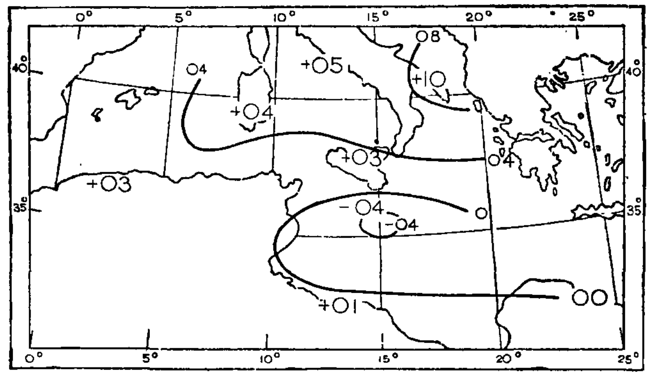


FIGURE 21—DISTRIBUTION OF SHOWALTER STABILITY INDEX, 1200 GMT, 14 OCTOBER 1960

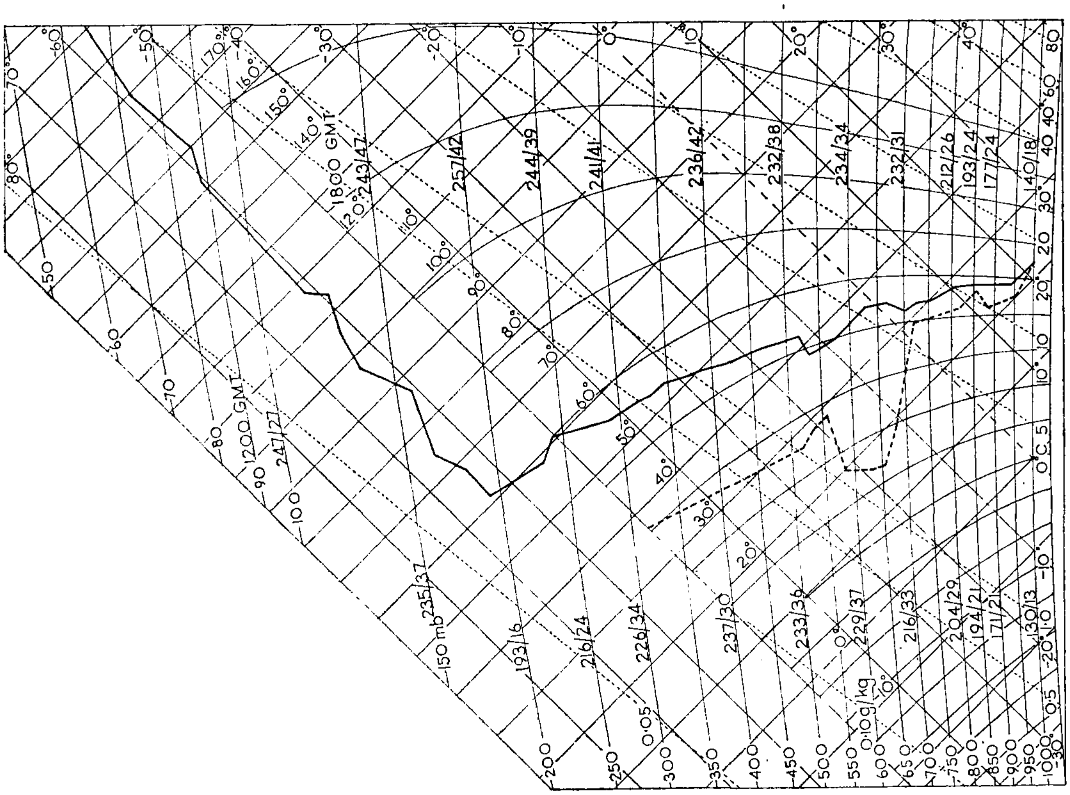


FIGURE 19—UPPER AIR ASCENT FOR MALTA, 1200 GMT, 14 OCTOBER 1960

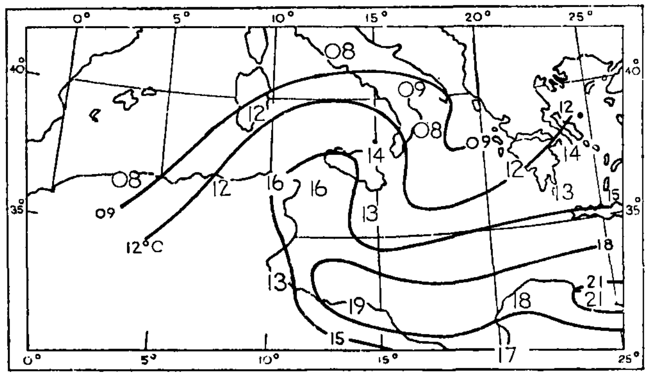


FIGURE 22—DISTRIBUTION OF SURFACE DEW-POINT TEMPERATURE, 0001 GMT, 14 OCTOBER 1960

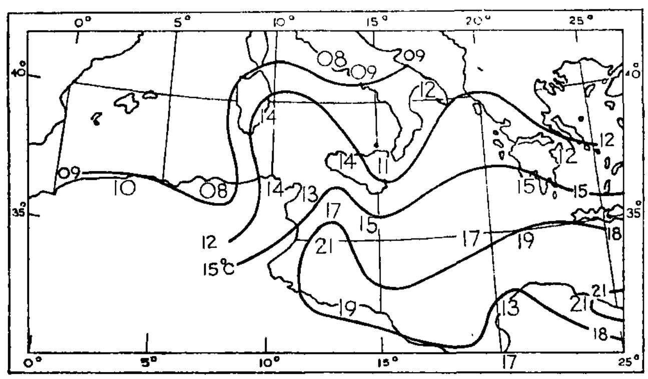


FIGURE 23—DISTRIBUTION OF SURFACE DEW-POINT TEMPERATURE, 0600 GMT, 14 OCTOBER 1960

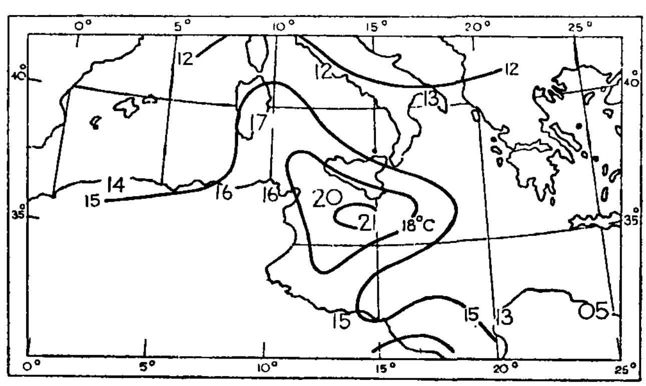


FIGURE 24—DISTRIBUTION OF SURFACE DEW-POINT TEMPERATURE, 1200 GMT, 14 OCTOBER 1960

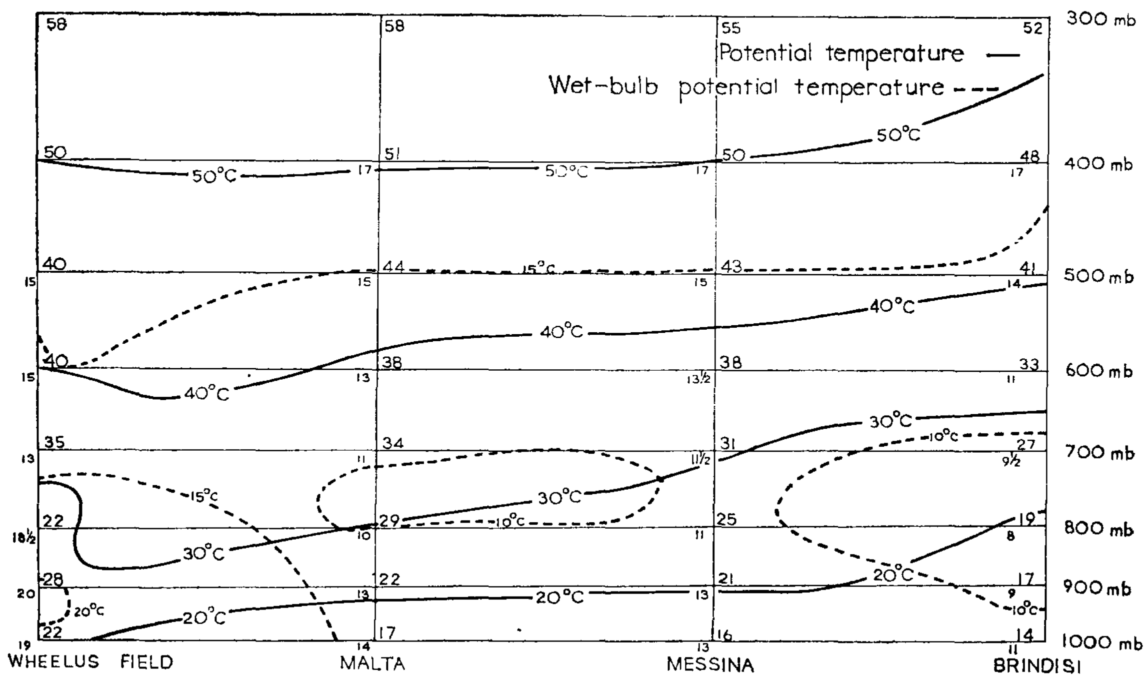


FIGURE 25—DISTRIBUTION OF POTENTIAL TEMPERATURE AND WET-BULB POTENTIAL TEMPERATURE IN VERTICAL CROSS-SECTION BETWEEN WHEELUS FIELD AND BRINDISI AT 0001 GMT, 14 OCTOBER 1960

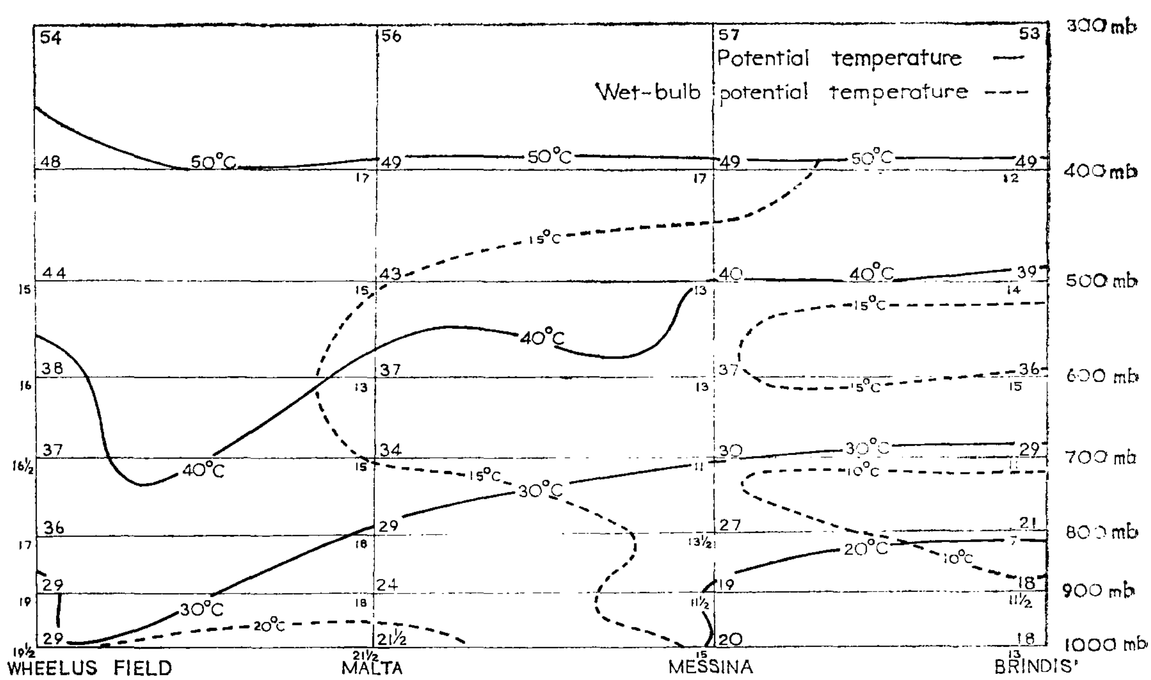


FIGURE 26—DISTRIBUTION OF POTENTIAL TEMPERATURE AND WET-BULB POTENTIAL TEMPERATURE IN VERTICAL CROSS-SECTION BETWEEN WHEELUS FIELD AND BRINDISI AT 1200 GMT, 14 OCTOBER 1960

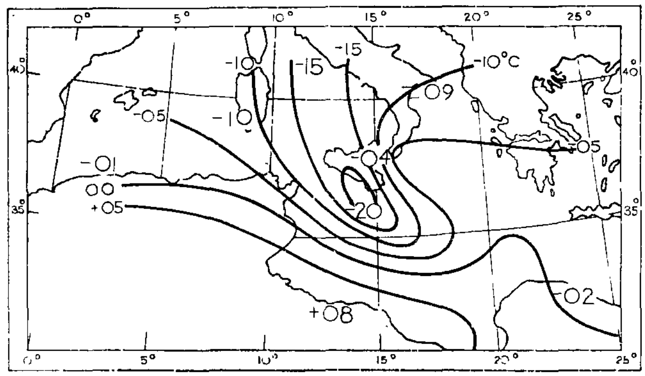


FIGURE 27—DISTRIBUTION OF DEW-POINT TEMPERATURE AT 800 MB, 0001 GMT, 14 OCTOBER 1960

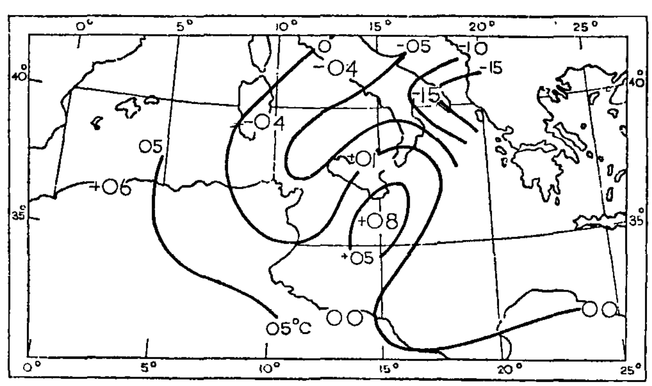


FIGURE 28—DISTRIBUTION OF DEW-POINT TEMPERATURE AT 800 MB, 1200 GMT, 14 OCTOBER 1960

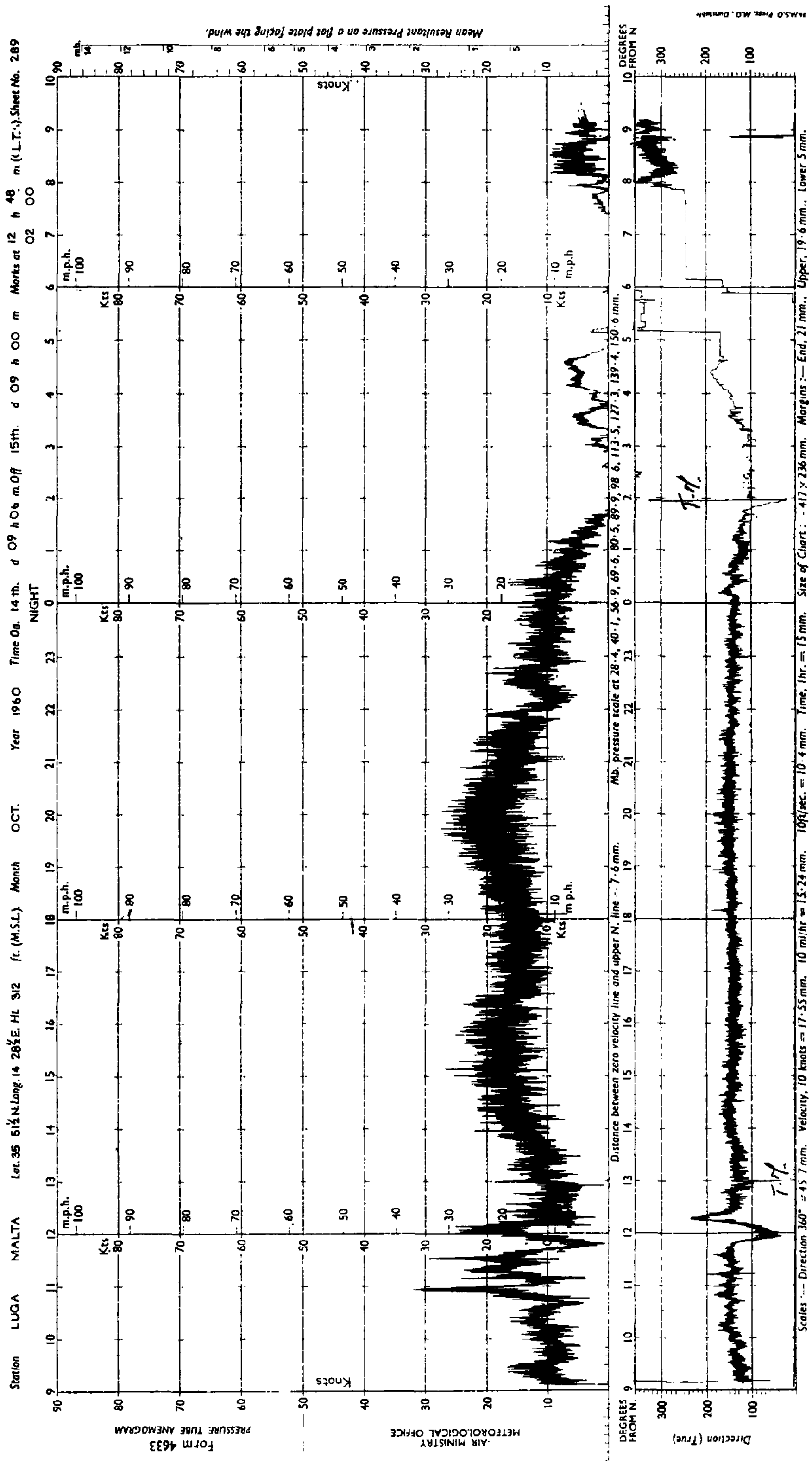


FIGURE 29—WIND SPEED AND DIRECTION AT LUQA, 14 OCTOBER 1960

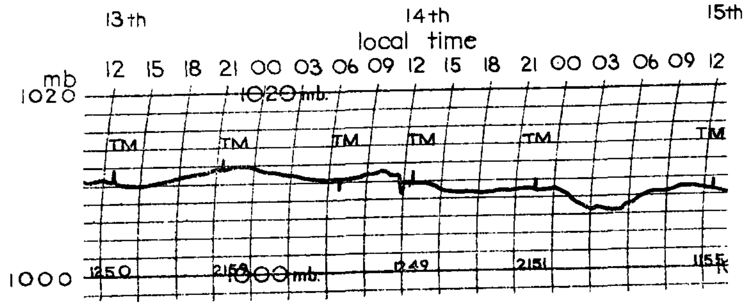


FIGURE 30—ATMOSPHERIC PRESSURE AT LUQA, 14 OCTOBER 1960

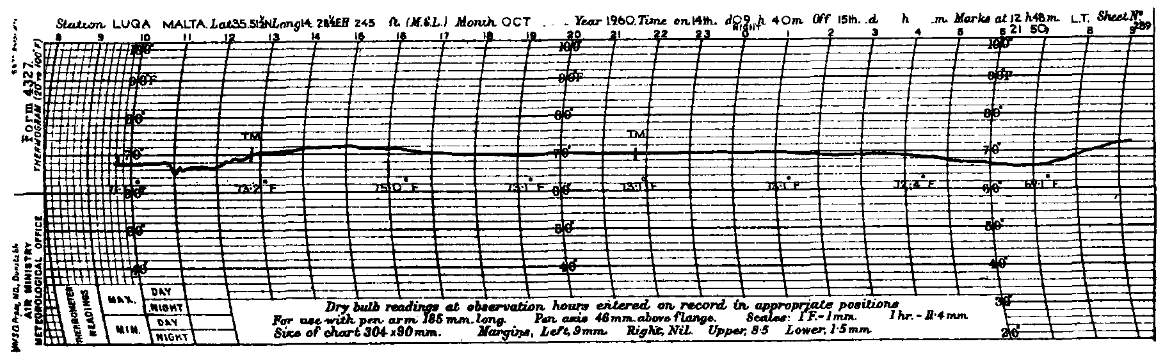


FIGURE 31—AIR TEMPERATURE AT LUQA, 14 OCTOBER 1960

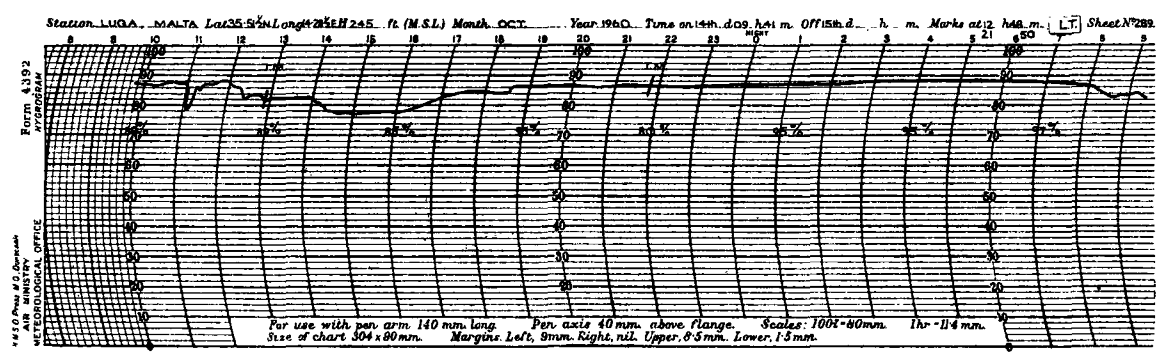


FIGURE 32—RELATIVE HUMIDITY AT LUQA, 14 OCTOBER 1960

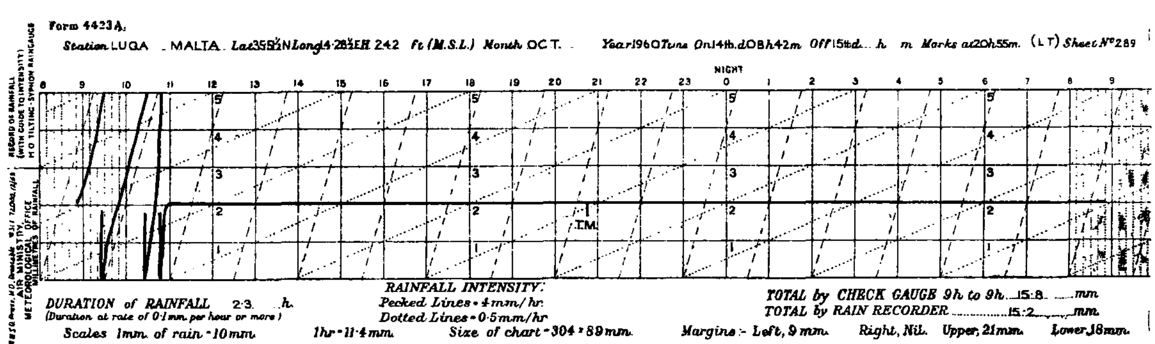


FIGURE 33—DURATION AND INTENSITY OF RAINFALL AT LUQA, 14 OCTOBER 1960

Printed in England for Her Majesty's Stationery Office by Dawson & Goodall Ltd., Bath
(5478) Wt.2438 62/63 BM4277 K 6 5/63 G453

SCIENTIFIC PAPERS

No. 1 **Airborne Measurements of the Latitudinal Variation of Frost-Point, Temperature and Wind.** By N. C. Helliwell, B.Sc. 3*s.* 6*d.* (post 4*d.*)

No. 2 **Conservation of Vorticity at 100 Millibars.** By J. R. Probert-Jones, B.A. 2*s.* 6*d.* (post 3*d.*)

No. 3 **The Rainfall of Malta.** By B. F. Bulmer, M.A., B.Sc., and K. Stormonth, B.Sc. 3*s.* (post 4*d.*)

No. 4 **Pressure Variation over Malaya and the Resonance Theory.** By R. Frost, B.A. 2*s.* 6*d.* (post 5*d.*)

No. 5 **An Experiment in Numerical Forecasting.** By E. Knighting, B.Sc., G. A. Corby, B.Sc., F. H. Bushby, B.Sc., C. E. Wallington, M.Sc. 5*s.* (post 5*d.*)

No. 6 **Seasonal Variation of the Sea Surface Temperature in Coastal Waters of the British Isles.** By F. E. Lumb, M.Sc. 3*s.* (post 4*d.*)

No. 7 **Forecasting in the Falkland Islands and Dependencies.** By S. D. Glassey. 3*s.* 6*d.* (post 4*d.*)

No. 8 **Factors Associated with the Formation and Persistence of Anticyclones over Scandinavia in the Winter Half of the Year.** By M. K. Miles, M.Sc. 3*s.* (post 4*d.*)

No. 9 **An Experiment in the Verification of Forecast Charts.** By C. E. Wallington, M.Sc. 4*s.* (post 4*d.*)

No. 10 **Incidence of, and some rules for Forecasting Temperature Inversions over the North-East Atlantic.** By H. C. Shellard, B.Sc. and R. F. M. Hay, M.A. 3*s.* (post 4*d.*)

No. 11 **Some Calculations of Terms in the Energy Balance for Monthly Periods at the Ocean Weather Stations I and J in the North Atlantic.** By H. C. Shellard, B.Sc. 3*s.* (post 3*d.*)

No. 12 **Some Statistical Relationships between the Temperature Anomalies in Neighbouring Months in Europe and Western Siberia.** 3*s.* 6*d.* (post 4*d.*)

No. 13 **Three Parameter Numerical Forecasts at Dunstable—A Study of the Error Fields.** By C. E. Wallington, M.Sc. 3*s.* 6*d.* (post 4*d.*)

No. 14 **Variations of the Difference between two Earth Temperatures.** By P. B. Sarson, M.A. 2*s.* 6*d.* (post 3*d.*)

No. 15 **The Errors of the Meteorological Office Radiosonde Mark 2B.** By D. N. Harrison, O.B.E., D.Phil. 5*s.* (post 4*d.*)

No. 16 **An Experiment in Operational Numerical Weather Prediction.** By E. Knighting, B.Sc., G. A. Corby, B.Sc., and P. R. Rowntree, B.A. 3*s.* (post 4*d.*)

No. 17 **Extremes of Wind Shear** by A. F. Crossley, M.A. 3*s.* (post 4*d.*)

Obtainable from

HMSO

or through any bookseller

A Course in Elementary Meteorology

Designed for the weather observer, this well illustrated book explains how the physical processes occurring in the atmosphere determine our weather. It has been written by an instructor at the Meteorological Office Training School who has had considerable experience of teaching meteorology to people with little previous knowledge of the subject. As an introductory textbook it requires of the reader only a modest knowledge of physics, equivalent to that of the Ordinary Level of the G.C.E. Each chapter combines the results of modern research with older ideas, and the selected bibliographies will enable the reader to extend his studies. The physical approach allows far more explanation to be given than is normally found in elementary books, which are often largely descriptive, but at the same time the extensive mathematics of advanced textbooks is avoided. Cloth bound. Index.

17s. 6d. (post 1s.)

Cloud Types for Observers

This publication has been prepared in the Meteorological Office, and is attractively produced on stout card of convenient size, being designed for outdoor as well as indoor use. It contains 37 photographs with descriptive notes which will help the observer to identify the main types of cloud. Additional notes, diagrams and coding instructions are also included to enable the observer to classify the state of the sky in accordance with the codes approved by the World Meteorological Organization.

This album replaces the earlier publications "Cloud Forms" and the "Cloud Card for Observers", which are now obsolete because of changes in cloud classification introduced by the World Meteorological Organization.

8s. (post 9d.)

Published by
HER MAJESTY'S STATIONERY OFFICE
To be purchased from
York House, Kingsway, London, W.C.2
423 Oxford Street, London W.1
13A Castle Street, Edinburgh 2
109 St. Mary Street, Cardiff
39 King Street, Manchester 2
50 Fairfax Street, Bristol 1
35 Smallbrook, Ringway, Birmingham 5
80 Chichester Street, Belfast 1
or through any bookseller

S.O. Code No. 40-156-7