θμὸς ἠπειρωτικότητος εἶναι μικρότερος τῶν 30%. Τουναντίον, διὰ τοὺς σταθμοὺς τῆς Βορ. Ἀμερικῆς, τῆς Ἀσίας καὶ τῆς Ρωσσίας ὑπάρχει μία, κατὰ τὸ μᾶλλον ἢ ἧττον, στενὴ συσχέτισις μεταξὺ τῶν C καὶ e. Ὁ συντελεστὴς συσχετίσεως $r_{c,e}$ μεταξὺ ἐκκεντρότητος e καὶ βαθμοῦ ἠπειρωτικότητος C εἶναι διὰ μὲν τοὺς σταθμοὺς τῆς Βορ. Ἀμερικῆς $r_{c,e}=0{,}80$, διὰ δὲ τοὺς σταθμοὺς τῆς Ἀσίας καὶ Σοβ. Ρωσίας $r_{c,e}=0{,}68$.

Τέλος ἐκ τῆς γενικωτέρας ἐρεύνης συνάγεται ὅτι ἡ ἐκκεντρότης e, διὰ τόπους μὲ βαθμὸν ἠπειρωτικότητος μικρότερον τῶν 35 %, λαμβάνει τιμὰς κυμαινομένας πέριξ μιᾶς μέσης τιμῆς $\bar{e}=0{,}023$, ἐνῷ εἰς τόπους μὲ βαθμὸν ἠπειρωτικότητος μεγαλύτερον τοῦ 35 %, ὅπως εἶναι οἱ πλεῖστοι τῶν θεωρηθέντων τόπων τῆς Βορ. Ἀμερικῆς, Ἀσίας καὶ Σοβ. Ρωσίας, ἡ μέση τιμὴ τῆς ἐκκεντρότητος e βαίνει αὐξανομένη μετὰ τοῦ C (ἴδε εἰκ. 9).

ΜΕΤΕΩΡΟΛΟΓΙΑ. — Interpretation of the rainfall climate of Marathon, Greece, *by Wallace E. Howell and Photios P. Karapiperis**.

Ἀνεκοινώθη ὑπὸ τοῦ κ. Ἰωάννου Τρικκαλινοῦ.

Introduction

Although many questions remain unresolved regarding the physics and efficacy of precipitation stimulation, it is clear that the prevailing climate is a factor of prime importance.

Clouds, formed where the warmth and moisture rising from the earth are gathered together and piled up by inflowing winds, are mostly aggregations of water droplets too small to fall. At temperatures below freezing, natural particles called freezing nuclei give rise to ice crystals which grow rapidly in the cloud and soon fall out as precipitation. However, sufficient natural nuclei appear to be not always present.

Fundamental to precipitation stimulation was the discovery of means of introducing into clouds great numbers of freezing nuclei much more active than nearly all natural ones. The seeding of clouds with these nuclei may frequently speed up their conversion to precipitation. If the consequences are to be of important magnitude, however, the seeding must be eombined with thermal or dynamic instability of the atmosphere so that the initial increase gives rise to a further increase instead of being followed by dissipation of the clouds.

* WALLACE E. HOWELL καὶ ΦΩΤ. ΚΑΡΑΠΙΠΕΡΗ, Ἀνάλυσις τοῦ κλίματος τοῦ Μαραθῶνος ἀπὸ βροχομετρικῆς ἀπόψεως.

(Ἡ μελέτη αὐτὴ ἐγένετο ἐν τῷ Πανεπιστημίῳ τοῦ Harvard τῶν Ἡν. Πολιτειῶν τῆς Ἀμερικῆς κατὰ τὸ 1951).

The practice of precipitation stimulation is thus revealed as primarily a meteorological problem, requiring recognition and undertstanding not only of the local weather and terrain but also of the interaction of these with large-scale weather configurations. For this reason evaluation of potential benefits from precipitation stimulation begins with a study of the dynamic states that make up the complexion of the climate.

Some General Features

Marathon, lying nearly at the southeastern extremity of the Balkan Peninsula, experiences a variety of Mediterranean climate that tends toward that of the subtropical arid belt more than does the climate of the rest of Greece. Furthermore, being less mountainous than other regions to the west and northwest, it is in their rain-shadow. These two influences combine to place Marathon in the region of smallest annual rainfall in the entire country.

Four distinct seasons can be traced in the rainfall climete of Marathon, marked by the profound difference between the heat economies and the general atmospheric circulations of winter and summer. These seasons comprise an early summer period of scattered, intense showers, a late summer season of dryness punctuated by occasional showers, both distinguished by continental climatic characteristics; an autumn and early winter season of cyclonic storminess distinguished by maritime characteristics, and a late-winter and early-spring season of subdued cyclonic storminess during which maritime and continental influences alternate.

In May and June, intense rains of a showery type occur, associated with the intense solar heating of the ground that is then approaching its maximum. The showers occur almost exclusively over the land, and not over the adjacent seas, and show a marked increase in intensity with the elevation of the land. The rain begins most frequently near noontime, and ends most frequently in thc late afternoon, following the typical behavior of convective showers.

As the season advances, the entire Balkan region comes more and more under the influence of the monsoonal wind circulations of the great neighboring continents of Asia, and Africa, and a relatively dry, stable northeasterly wind, the Etesian, becomes prevalent, alternating with days when the Etesian circulation is weakened sufficiently for sea breezes to interrupt it locally. This pattern prevents rainfall except when the Etesian wind is subject to an unusual disturbance. Of the July climate, Mariolopoulos (1) says: «En effet, pendant ce mois prédomine dans prêsque toute la Grèce une secheresse absolue parfois interrompu seulement par quelques pluies dues a des orages de châleur». However, the intensity of the few rainfalls that do occur is the greatest of any season, reaching an average of 0,07 mm per minute (2). All but the few most favorable situations are eliminated as rain producers. The same situation prevails whithout substantial change throughout August and into September until weakening of the monsoon winds and intensification of Atlantic cyclonic disturbances combine to bring about a more or less abrupt change.

Beginning usually some time in late September or occasionally in early October, a rainfall pattern becomes established that is the antithesis of the spring rains. The season being one of prevailing cloudiness, with an average of only five or so clear days per month (3), and the sun being south of the equator, solar heating of the ground is greatly diminished and the nearby seas, which during the summer absorbed a great amount of solar heat, become the effective source of warmth. At this time the Mediterranean region becomes an area of low atmospheric pressure and the region is repeatedly invaded by cyclonic storms from the North Atlantic Ocean. The waters of the Maditerranean, energetically adding warmth and moisture to the chilly air passing over them, give rise to vigorous instability in the lower atmosphere, with the heaviest rainfall of the year resulting. This rainfall, however, has distinctly maritime characteristics; it falls over the sea as well as over the land, and is only moderately heavier over higher ground; the time of onset is most frequently during the latter part of the night, when the sea is warmest in comparison to the land. These influences reach the peak of their effectiveness in late November and early December.

Vith the further advance of the season another relatively adrupt change takes place, due also in part to the monsoonal wind system of the Asiatic continent, which at that season becomes an area of high pressure and cold, outflowing winds that spread over a wide region. This cold air, occasionally overspreading the eastern Mediterranean, brings periods of «halcyon days» that interrupt the trains of cyclonic storms. Furthermore, the Mediterranean waters by January have lost much of their warmth and are less effective than formerly in augmenting the supply of heat and moisture in the lower amosphere. Although cyclones from the North Atlantic continue to invade the Mediterranean until April or May, they develop less intensely there and bring less rainfall than during the autumn and early winter season. The latter part of this season coincides with a secondary minimum in the rainfall regime. The late winter and early spring is likewise the season of least frequent occurrence of thunderstorms (3), a further indication of the diminished instability.

With the further advance of spring, the ground again becomes warmer than the water and the continental-shower season returns.

The rainfall observations at Dekelia were combined with those at Tatoi to comprise a continuous series from 1933 to 1939 inclusive, and were used to characterize the climate of the Marathon watershed as these 2 stations were the nearest available to the area under consideration (4). In order to obtain a comparison with the longer period of observations at the National Observatory of Athens, the observations at Athens (Weather Bureau and Zappion) were likewise combined into a single series for the period 1933-1939, and tabulated along with the Dekelia-Tatoi observations.

Figure 1 presents, in summarized form, data relating the total rainfall to the frequency with which different intensities of rainfall occur. It

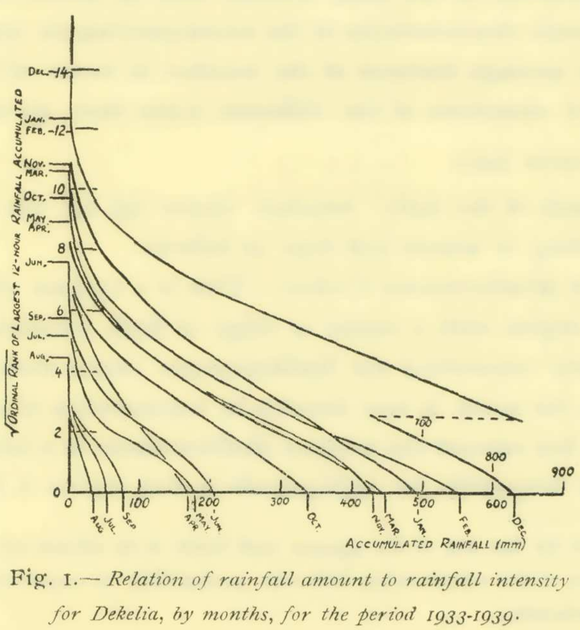

Fig. 1.— *Relation of rainfall amount to rainfall intensity for Dekelia, by months, for the period 1933-1939.*

was prepared by tabulating and grouping by months the individual amounts of rainfall occurring during each 12-hourly period of the 7 years studied, arranging the groups in ascending order of magnitude, and forming accumulated sub-totals corresponding to each ordinal rank.

The ordinate of the graph is the square root[1] of the ordinal rank of the sub-total, and the abscissa is the amount of that sub-total. For example, it shows that the ordinal rank zero (corresponding to the grand total of 12-hourly rainfall amounts) for the 7 Januaries at Dekelia amounted to 492 mm; the ordinal rank one, (corresponding to the grand total less the single heaviest 12-hourly rainfall amount) amounts to 438 mm, etc.

Storm Types

These climatic features express the average effect of the disturbances that pass over the Marathon watershed. Most of the storms that bring rain come from the North Atlantic Ocean, and their effect is determined by the influence that the Mediterrenean Sea and the Eurasian land mass exert on them. Although their variety in regard to detail is endless, certain typical sequences of weather events are distinguishable, corresponding to characteristic interactions between the principal weather determinants. For this study, several types of storm were distinguished, partly on the basis of characteristic patterns on the daily weather map (5), partly on the basis of the thermodynamic characteristics of the accompanying air masses, in order to interpret the average features of the weather in terms of the frequency of occurrence of situations of the different types that go to make it up.

Description of storm types

On the basis of the daily weather charts (4), (5), the storms were classified according to season and type as follows:

A. *Isolated Mediterranean Cyclone.*—This is a cyclone centered in the Mediterranean region with a center or ridge of high pressure over Middle Europe definitely separating the Mediterranean center from low pressure areas farther to the north. It may develop by regeneration of a North Atlantic cyclone that has entered the western Mediterranean in a late stage of dissipation, or, less frequently, by cyclogenesis in that region. A frontal system

[1] The reason for the use of the square root scale is to obtain an approximately linear presentation of the relationship between probability of occurrence and magnitude of rainfall intensity.

generally develops, the cold front moving southeastward past Malta and advancing rapidly into the southeastern Mediterranean, the warm front being held successively against the Appenines, the Dinaric Alps, and the Pindus ranges, where the cold front occludes it to form a warm-type occlusion. Although light rain generally occurs ahead of the warm front, the most intense rainfall and the largest amount takes place near and immediately behind the cold front aloft, originating in the unstable maritime air behind it. The rainfall from storms of this type averages about the same at Athens as at Dekelia. The storms generally dissipate in the eastern Mediterranean soon after occluding.

Type A storms are definitely a winter type, being common from November to March, and very rare at other times. They are most intense and yield the greatest rainfall during the first half of their season, when the Mediterranean water is warmer; and evaporation from the Mediterranean probably supplies most of the moisture for the rainfall. This type of storms, which rarely pass without yielding precipitation, yields the greatest anounts of rainfall of all the types classified, with an average of 20 mm per storm; and the probability of its yielding only sprinkles is smaller than with any other type, the lightest 5/8ths of the falls making up a quarter of the rainfall. About 5 type A storms occur in an average year, comprising 11% of all storms (14% of all winter storms) and bringing an average of 97 mm rainfall a year, 19% of the average annual rainfall.

B. *Blocked Atlantic cyclone.* – This is a cyclone that reaches the Mediterranean from the eastern North Atlantic, usually across France into the western Mediterranean but occasionally across Spain or Germany, its normal path toward the Baltic being blocked by a large anticyclone over Siberia or Middle Europe. It usually reaches the Mediterranean in the form of a warm-type occlusion, ahead of which a warm front forms between Mediterranean and continental air. The cyclone regenerates more or less strongly in the central Mediterranean, tending to dissipate at the east end but often proceeding onward toward the Black Sea. In structure it resembles the Type A storm, but air-mass contrasts in it are generally less marked and the path of the center often passes somewhat farther north across the central part of the Balkan peninsula.

Type B storms have a more extended season than Type A, occurring from October to April on an average of 8 times a year. The average storm rainfall is 14 mm, totalling an average of 112 mm annually. They comprise 18% of all storms (23% of winter storms), and produce 22% of the mean annual rainfall. During the winter season there is comparatively little difference in yield between Athens and Dekelia, but in spring the yield is greater at Dekelia. The proportion of sprinkles is higher than with type A storms.

These Type B storms occasionally pass the Marathon watershed without causing precipitation, but the lack of rainfall is then probably due to the structure of the storm rather than to a lack of ice-forming nuclei.

C. *Middle-European Trough.*—When cyclones pass eastward across Germany and Poland, a secondary cyclone often forms in the Ligurian or Adriatic seas and moves eastward in tempo with the primary disturbance, the two being connected by a trough of low pressure oriented roughly north-south or northwest-southeast. To the west of the trough, modified polar maritime air generally enters the Mediterranean region by way of France or Germany, while east of the trough southerly winds transport Mediterranean air northward. It is these storms that most commonly cause Foehn winds in the Alps. The structure of the low in the Mediterranean is largely dictated by the conditions of its origin, high-level divergence that causes low temperatures aloft and a steep lapse rate in middle levels. The main precipitation system accompanies the pressure trough, but because of the instability aloft showers frequently break out considerable ahead of the trough where mountains favor local lifting, and orographic effects in general find greater expression than in Types A and B. Storms of this type often diverge considerably from the ideal pattern, according to the relative strengths and positions of the two associated low pressure areas, the prevailing air masses, and seasonal influences. The moisture supply comes mostly from the Maditerranean, but often polar maritime air moving southward behind the trough contributes materially to the rainfall.

Type C storms occur 9 times a year on the average, from October to May but mostly in the winter, and account for the greatest annual precipitation of any type, 130 mm a year with an average of 15 mm per storm. They consitute 20% of all storms (25% of winter storms), and account for 25% of the annual rainfall. Sprinkles are somewhat more probable than with Types A and B, the lightest 2/3rds of the storms accounting for a quarter of the total rain.

D. *Winter Etesian.*—This type of rainfall situation is characterized by the absence of a closed cyclonic circulation over Greece, but the presence of a pressure trough in the lee of the mountain chain of Asia Minor and the Balkans. The air flow is from the north or northeast across the mountains, and the source of the moisture is the polar maritime air flowing southward across Gernany and Poland by way of Yugoslavia. Occasionally continental air crossing the Black Sea and the Aegean contributes some moisture. Weather of this type frequently follows the passage of a Type B or C storm, or ensues upon the passage of a disturbance across Poland or into the Baltic that had no primary consequences in the Mediterranean.

Type D storms have the highest frequency of occurrence of any type, just over 9 times in an average year. It is a late-winter type, with half of its occurrences coming in January, February and the other half distributed from October to June. The rainfall is not noticeably altitude-dependent, about as much falling at Athens as at Dekelia. The average rainfall per occurrence is 11 mm, the type accounting for 97 mm annually on the average, the same as for Type A storms. The rain is frequently light and sprinkly, the lightest 3/4ths of the storms accounting for one quarter of the rainfall. The precipitation is somewhat diurnal in character, with a maximum in the daytime.

E. *Cold front passage.*—When cyclones pass to the north of Greece without the formation of secondary disturbances in the Mediterranean, showers nevertheless sometimes break out along the front of the cold air as it pushes southward in the rear of the cyclones. The showers are restricted to the immediate vicinity of the front and do not persist within the cold air mass, as they do in the winter Etesian.

Cold front passages occur rather frequently without causing rainfall. They do, however, bring rain, on the average, 4 to 5 times a year, mostly in autumn and winter but occasionally in spring. The showers are generally of brief duration and small yield, the average rainfall being only 4 mm, accumulating an average of 19 mm in a year. Their seasonal distribution corresponds to that of cyclonic activity in general, running from October to June with a maximum in winter.

F. *Summer Etesian.*—The general features of the Etesian wind that characterizes the summer climate of Greece have been described above as one of the outstanding general features of the climate. It was pointed out that in general the Etesian period is one of absolute dryness punctuated by a few relatively heavy showers. The showers occur during episodes of unusual disturbance of the Etesian wind, usually when the semi-permanent lee trough south of Asia Minor and the Balkans is deepened by an upward surge in the strength of the stream. Thus, it happens that the day of showers is likely to be a day when the Etesian vind is stronger than usual, or a day when it resumes sway at Athens after a period of diurnal sea breezes. There is strong evidence that these surges in the Etesian wind are coupled with changes in the westerly airstream farther to the north, and summer showers over the Marathon watershed are strongly related to the arrival of North Atlantic cyclones in the region of the White Sea.

Summer Etesian rainfall is limited to the period from late May or early June to early October, occurring on the average 8 times a year. Etesian showers are less regular in their occurrence than any other rainfall situation, and their number varies widely from year to year. The average rainfall with each occurrence is 7 mm, for a total of 57 mm per year. They constitute 18% of the annual rainfall occasions and produce 11% of the precipitation. The rainfall is diurnal in character, with a strong daytime maximum, and it is markedly increased with elevation, Dekelia receiving 5 mm for every 3 mm received at Athens.

U. *Unclassified.*—There were 10 occasions of rainfall during the 7 years studied that did not correspond closely enough to any of the types described to be classified with them. However, these 10 occasions yielded a total of only 17 mm of rainfall, or less than 3 mm per year, and they have therefore been disregarded in the analysis of the climate.

Summary.—Summarizations of the number of storms and the rainfall amounts at Dekelia by season and storm type for the entire 7-year period are shown in Tab. I. Figure 2 shows the relationship of intensity to frequency of occurrence for each type summarized without regard to season, using the same form of presentation as for Fig. 1.

Adjustment to long-period mean.—Since the 7-year period covered by the analysis of storm types is too short for an accurate determination of mean values, the monthly mean rainfall amounts at Athens during this 7-year period were compared with the means of the period from 1857 to 1939

TABLE I.—*Rainfall amounts and Number of storms by season and storm tupe at Dekelia (1933-39)*

Type		January February March	April May June	July August September	October November December	7-years
A.	Rainfall (mm)	346	9	17	306	678
	No. of storms	20	1	1	12	34
	Average rain	17.3	9.0	17.1	25.4	20.0
B.	Rainfall (mm)	323	58	0	401	782
	No. of storms	20	9	0	29	58
	Average rain	16.2	6.4	—	14.8	13.5
C.	Rainfall (mm)	426	72	0	407	905
	No. of storms	30	14	0	18	62
	Average rain	14.2	5.1	—	22.5	14.6
D.	Rainfall (mm)	332	129	0	217	678
	No. of storms	32	13	0	19	64
	Average rain	10.1	9.9	—	11.4	10.6
E.	Rainfall (mm)	22	1	0	109	132
	No. of storms	15	4	0	13	32
	Average rain	1.5	0.2	—	8.4	4.1
F.	Rainfall (mm)	0	268	127	3	398
	No. of storms	0	24	31	2	57
	Average rain	—	11.2	4.1	1.5	7.0
Sum	Rainfall (mm)	1449	537	144	1443	3573
	No. of storms	117	65	32	93	307
	Average rain	12.4	8.3	4.5	15.5	11.6

at the same staton to determine to what degree the 7-year period was representative. Figure 3 shows these values compared with the corresponding 7-year monthly means and an estimate of the probable long-period means at Dekelia. The comparison shows that the winter rainfall during the period studied was somewhat greater than normal, and the summer rainfall somewhat less, the annual means being virtually identical. The indication is therefore that the frequency of summer rainfall, especially the summer Etesian type, is somewhat under-estimated by the figures given, while winter types are correspondingly over-estimated. It is not likely, however, that the order of magnitude is different from that given.

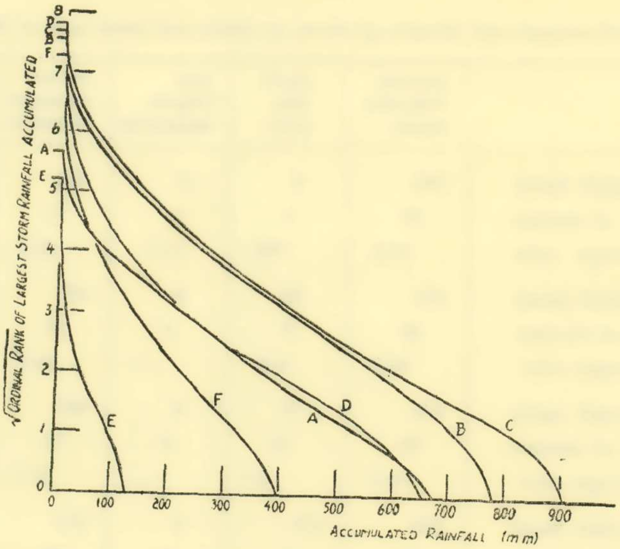

Fig. 2.– *Relation of rainfall amount to rainfall intensity for Dekelia, by storm types, for the period 1933-1939.*

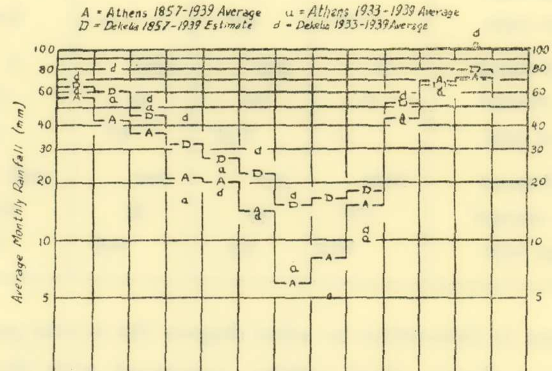

Fig. 3.– *Estimate of long-period monthly mean rainfalls at Dekelia based on the 1933 - 39 means compared with the long - period and 1933-39 means at Athens.*

ΠΕΡΙΛΗΨΙΣ

Ἐν τῇ παρούσῃ ἐργασίᾳ, ἥτις σχετίζεται γενικῶς μὲ τὴν πρόκλησιν τεχνητῆς βροχῆς, παρέχονται ἐν πρώτοις τὰ κύρια χαρακτηριστικὰ τοῦ κλίματος τῆς περιοχῆς τοῦ Μαραθῶνος ἀπὸ βροχομετρικῆς ἀπόψεως, διακρινομένων τεσσάρων περιόδων βροχοπτώσεως, αἵτινες λεπτομερῶς διερευνῶνται. Περαιτέρω, βάσει ἀναλύσεως τῶν ἡμερησίων χαρτῶν καιροῦ τοῦ Β. Ἡμισφαιρίου, αἱ ἐπηρεάζουσαι τὴν περιοχὴν τοῦ Μαραθῶνος βροχοπτώσεις κατατάσσονται εἰς τύπους, τῶν ὁποίων λεπτομερῶς περιγράφονται τὰ δυναμικὰ χαρακτηριστικά, παρέχονται δὲ καὶ αἱ πιθαναὶ συχνότητες τοιούτων βροχοπτώσεων.

REFERENCES

1. MARIOLOPOULOS, E. G., Régimes Pluviométriques de la Grèce. *Annales de l'Observatoire Nationale d'Athènes*, 12 (1932), 81-93.
2. LIVATHINOS, A. N., Étude sur la pluie à Athènes. *Annales de l'Observatoire Nationale d'Athènes*. 12 (1932), 121-132.
3. Climate of Athens. General Climatic Information Guide No. 17 (revised). *Weather Division, Headquarters, Army Air Forces, Washington (May 1944)*.
4. Bulletin Quotidien du Temps. Royaume de Grèce, Ministère de l'Aeronautique, Service Météorologique Nationale. (1933-1939).
5. Historical Weather Maps, Daily Synoptic Series, Northern Hemisphere Sea Level. *U. S. Weather Bureau*, Washington. (1933-1939).