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DYNAMIC CLIMATOLOGY OF LARGE-SCALE EUROPEAN CIRCULATION PATTERNS IN THE MEDITERRANEAN AREA

By

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With 4 figures in the text

1. Introduction

It has long been realized that synoptic conditions in the Mediterranean Basin largely reflect weather patterns in the main belt of the westerlies over the eastern Atlantic and continental Europe. Even though the overall circulation in the Mediterranean is dominated by the subtropical high pressure cells some four to five months a year, the not infrequent disturbances even of the summer season are invariably of westerly origin. During the winter half-year, October through March, 1950—59, some 87% and 12% of the disturbances penetrating the Basin entered across southwestern and southeastern Europe respectively, originating as surface or upper air lows or as frontal situations in the westerly drift. At the same time only 1% of the disturbances had their origin over the Sahara, and these could in almost every case be shown to be related to jet stream conditions, upper air troughs, or minor surface disturbances due to modified polar air.

The first succesful attempt to break down the major circulatory features dominating the westerlies into specific classes lasting a number of days was published by *Franz Baur* in 1937. This classification of large-scale weather patterns was of course limited to the European continent and its proximities. These *Großwetterlagen*, as they can be more precisely designated in German, in their turn reflect the overall structure of the upper air westerly circulation.

A succinct application of both of these concepts to a first synoptic study of Mediterranean weather conditons was made by staff members of the University of Chicago Institute of Meteorology in 1944 (*Riehl* et al, 1944). This valuable work long remained the only accessible consideration of synoptic and dynamic climatology of the Mediterranean, seen within the greater European perspective. A recent account of these dynamic aspects has been given by *G. T. Trewartha* (1960). Successful attempts to specifically apply the Großwetterlagen to synoptic, and in particular, rainfall conditions in the Mediterranean, have already been made by *E. Reichel* (1949) and *H. Flohn* (1948). These authors consider BM, HNz, N, S, and HFz as major rainbringers in the western basin, Ws, BM, HN, N, TM, TB and SE in the Adriatic and northern parts of the central Mediterranean. They do not, however, attempt any statistical or synoptic investigation. The older Großwetter classification employed by *Baur* was based in the main upon daily surface maps. After World War II the increasing number of upper air observations made a more rigorous and detailed classification necessary, as a result of which *Paul Hess* and *Helmuth Brezowsky* finally published their valuable reclassification in 1952. Simultaneously these authors presented a catalog of daily large-scale weather situations for Europe, valid for the area between 30° W to 45° E, 25° N to 70° N (see *Baur* 1948, p. 58—62), from 1881 to 1950. Admittedly all Großwetter classifications must need be somewhat arbitrary, and the *Hess-Brezowsky* system is in many aspects applied to local conditions in Central Europe[1].

[1] The Grosswetter classification of the Austrian Meteorological Institution (*F. Lauscher* 1954) is based upon more local conditions and does not possess a wide European applicability for general circulation classification as does that of *Hess-Brezowsky*. In recent years the Meteorological Service of the Italian Air Force has also attempted a classification of large-scale weather situations with particular application to the Mediterranean Basin (*Urbani* 1957). Despite overall correspondence with the 28 weather patterns of *Hess-Brezowsky*, there are a number of genetic difficulties in *Urbani's* synthesis, and it is preferable to limit this investigation to the more precisely outlined system of *Hess-Brezowsky*.

The present study attempts to sketch the outstanding upper air and surface characteristics associated with these European large-scale weather patterns in the Mediterranean, paying particular attention to frontal activity, cyclogenesis, storm tracks and precipitation. No detailed synoptic examples have been included, but the results are based both upon extensive statistical computations and a representative coverage of synoptic situations. As it is, the data have been derived from synoptic analyses employing materials from the Großwetterlagen Mitteleuropas, Bad Kissingen (since 1948) and the Tägliche Wetterbericht des deutschen Wetterdienstes, Hamburg (since 1950) and Bad Kissingen (since 1952), complemented by the tabular data of the Daily Series Synoptic Weather Maps (northern hemisphere), Washington, D. C. (since 1949). Unless otherwise stated, the treatment refers to the period October through March, which time represents the winter half-year sensu lato and the major rainy season of the Mediterranean Basin.

The frontal and cyclonic disturbances dominating Mediterranean weather during the winter are of three main genetic types: (1) originally mP air of Atlantic origin entering the basin across France or the Iberian Peninsula; (2) generally cP air masses (often modified mP) entering the eastern Mediterranean Basin over the Balkan Peninsula or Asia Minor from central or eastern Europe; and (3) disturbances having their origin over the Mediterranean proper, generally in association with upper air cut-off lows or troughs. Actually over 20% of the cold fronts encountered in the western Mediterranean are due to local cyclogenesis and frontogenesis. To delineate airmass penetration, higher level steering over the eastern Atlantic and southwestern Europe (i. e. France and Iberia), as well as over southeastern Europe and the Black Sea, must be determined. Frontal and cyclonic activities associated with each Großwetter type are also promoted to a large degree by upper air pressure fields and flow motion.

With these upper air prerequisitics it will be attempted to sketch the major dynamic climatological features of each large-scale weather pattern for the Mediterranean area in general. By so doing, it is hoped to further understanding of the dynamic climatology of that area, and likewise it may prove to be of use in short and middle-range forecasting. As a rule the patterns in question persist between about 3 and 5½ days and are in their turn part of the longer term fluctuations between zonal and meridional circulation. Another possible application is to the circulation anomalies of the recent climatic fluctuation and to palaeoclimatic problems per se.

2. Air Mass Supply and Cyclonic Routes

According to *Riehl, Allen* et al. (1944, p. 3 seq.) the air masses dominating Mediterranean weather during the winter half-year are cT^s, cP^s, cP^e, mP^a, mT^a, mP^m and mT^m. The super-scribed suffixes s, e, a, and m denote air of Saharan, European, Atlantic and Mediterranean characteristics respectively.

Saharan airmasses are generally only of synoptic importance outside of Africa when cT^s, cP^s or cP^e (from northern Algeria) air is drawn into the warm sector of a front moving over the central or eastern basin. Such airmasses leave the continent dry and stable aloft, but are rapidly modified in their lower levels over the warm water surface of the Mediterranean Sea. They develop a typical, uniform altostratus mass, often leading to frontal rainfall, and upon striking an elevated land surface their convective instability results in Cb development and possible showers.

More important for Mediterranean weather are the cP^e airmasses entering the Balkans or Asia Minor from eastern central Europe or southern Russia (the classical *Van Bebber* route IIIb). These frequently represent strongly modified mP^a air which has followed a long trajectory over land. Unless these thermal fronts are connected with distinct troughs aloft no appreciable rains fall during passage over the southern Balkans or Turkey. Only a limited proportion of these fronts have sufficient energy to move on into the eastern Mediterranean, fied to mP^m, which in its turn may be changed to mT^m after prolonged passage over increasingly warmer waters on moving eastward. The continued warming tends to maintain instability and clouds with vertical development.

Although mP^a is normally associated with disturbances moving along the storm tracks Va and VIa, fronts passing well south of latitude 40° N across the warmer ocean south of the Azores tend to carry $mP^a \longrightarrow mT^a$ or even mT^a air with them. This is increasingly so the case with route VIb and almost generally so with VII. This air is as warm as or warmer than the Mediterranean waters, becoming cooled and stabilized in

Table I. *Frontal Entry into the Mediterranean Basin and major Zones of Frontal Passage* (October—March 1950—59). A — Mean daily frequency of fronts penetrating western Mediterranean Basin (via routes Va, VIa, VIb, VII). B — Mean daily frequency of fronts from central or eastern Europe penetrating the eastern Mediterranean Basin (routes $IIIb_1$, $IIIb_2$). C — Passage zones of Atlantic frontal disturbances in the central and eastern Mediterranean (in order of numerical importance) (cf. Fig. 1)

	A	Va	VIa	VIb	VII	B	$IIIb_1$	$IIIb_2$	C	No. of days of occurrence
Ws	.28	.08	.11	.09	—	.01	.01	—	5c	74
Wz	.20	.07	.12	.01	.01	.04	.03	.02		202
Wa	.11	.05	.05	.02	—	.10	.07	.03		60
BM	.03	.02	—	.01	—	.02	.01	.01		162
HM	.07	—	.01	.03	.03	.14	.06	.08	3 b_1	144
SWa	.20	—	—	.20	—	.07	.07	—		41
SWz	.22	.01	.09	.11	.01	.04	.01	.03		91
NWa	.14	.05	—	—	.10	.10	—	.10		21
NWz	.19	.15	.02	.02	—	.06	.06	—	3 b_1, 3 b_2	98
HNa	.17	—	—	.17	—	.06	.06	—	5c, 6	18
HNz	.45	.18	.06	.18	.03	.06	.06	—	5c, 3 b_1	34
HB	.12	.07	.01	.01	.03	.07	.05	.03	3 b_1, 3 b_2	83
Na	.36	.09	—	.27	—	—	—	—	5b, 5d, 5 d_2, 6	11
Nz	.32	.22	.04	—	.07	.02	.02	—	5c, 5d, 5 d_2	55
TrM	.28	.19	.09	—	—	—	—	—	5b, 5d, 6	74
TM	.24	.12	.08	.04	—	—	—	—	5b, 5c, 5d, 5 d_1, 6	49
TB	.38	.09	.21	.09	—	—	—	—	6, 5b	24
TrW	.31	.04	.17	.08	.02	—	—	—	5b, 6	47
Sa	.25	—	.05	.15	.05	.02	—	.02		54
Sz	.33	—	.10	.20	.03	—	—	—	6	30
SEa	.30	—	.11	.14	.05	.03	—	.03	6	36
SEz	.34	—	.17	.17	—	—	—	—	5c, 5d, 5 d_2, 6	29
HFa	.11	.02	.02	.06	.01	.04	.02	.02	5d, 5 d_2, 3 b_1, 3 b_2	92
HFz	.33	.10	.19	.05	—	—	—	—	5d, 5 d_2. 5b	21
HNFa	.21	.14	.04	—	.04	—	—	—	5b, 5d, 5 d_2, 5 d_1, 6	28
HNFz	.18	.07	—	.04	.07	—	—	—	5d, 5c, 6, 5 d_1	28
NE	.08	.08	—	—	—	.02	.02	—	5d, 5 d_1, 3 b_2	52
Ww	.26	.04	.21	.02	—	.03	—	.03	5c, 5d	69
Mean	.231	.06	.07	.07	.02	.033	.02	.02		62

where the associated airmasses are rapidly warmed at the surface and moistened from below. The resulting instability is characterized by widespread Cu and Cb, and showers or thundershowers may result. This type of disturbance is almost always associated with upper cut-off lows, surface convergence often only setting in after the upper lows are situated over the sea. The more seldom cP^e outbreaks over the Gulf of Lyons or the northern Adriatic are similar in character.

Although these moistened, modified continental airmasses can bring precipitation in the form of scattered showers, the greatest part of Mediterranean rainfall is associated with mP^a airmasses. Even though such air loses a part of its moisture on the land surfaces of France or Spain, surface warming over the western basin rapidly increases convective instability, with resulting widespread Cu and Cb. In pushing across the sea fresh mP^a may produce precipitation behind the front by lifting modified mP^m, or ahead of the front where there is convergence and overriding in the warmer air[1]. Orographic lifting over land surfaces enhances the instability. Over the western Mediterranean swelling cumulus persists in the rear for 24—36 hours after the passage of the front. In fact almost no visible surface minima enter the basin from without, so that the overwhelming majority of cyclones can be ascribed to local cyclogenesis associated with mP^a incursions. From 24—48 hours after entering over the sea surface mP^a has in almost all cases been modi-

[1] Quantitative observations complied by *Reichel* (1949) verify the repeated notices to the effect that the frequency or amount of rainfall ahead of fronts is less than that in the rear — as far as the Mediterranean area is concerned. For the route Gibraltar-Suez the ratio of rains ahead to rains in the rear of fronts is about 1: 1.25 east of longitude 5° E. Further west typical frontal rains predominate.

its lower layers. As a result such mT^a air is not responsible for cyclogenesis over the western basin and not favourable for precipitation.

In order to obtain a precise picture of airmass supply to the Mediterranean on the whole, and with regard to the 28 weather types in particular, Table I has been drawn up on the basis of an intensive study of the daily surface weather maps for the winter half-year from January 1950 to March 1959. The number of days of occurrence sampled is 1727, and the breakdown according to types is recorded in Table I. It was found that few minima pass over the continental parts of the classical[2] cyclonic routes V—VI—VII. Often enough a closed low is discernible at the 850 mb. or a higher level, but this again is not the rule. This necessitated the use of fronts rather than of surface lows for sampling cyclonic tracks. The procedure employed was to follow the progressive movement of the lowest pressure section of a front, and if none were present, the orientation of the front itself in the course of moving. Fronts moving southward over France and the Rhone gap with an orientation due W-E, were classified as following the Va route; if moving southeastward over the Garonne Basin, with an orientation SW-NE, as VIa; if moving eastward over the Iberian Peninsula, with an orientation N-S as VIb; if moving east-northeast

[2] It is not necessary to reconcile the various versions of the "classical" cyclonic routes which grew out of later additions supplementing the originally inadequate, single Va route. Thus VIa, VIb, VII (and another Ve route) were not defined in *Van Bebber*'s first publication. The revised criteria employed here and presented in Fig. 1 are intended to give a more realistic picture of zones of cyclonic travel. The belts so defined take care of the majority of so-called jumps from one path to the other, a point of controversy as regards the validity of any cyclonic routes in the Mediterranean.

to northeast over the Straits of Gibraltar and Marocco, as VII. Such fronts or lows were only considered to qualify for Mediterranean disturbances when they actually penetrated into the Western Mediterranean and persisted on the synoptic maps for at least 18 hours as such.

Table I records the mean daily frequency of fronts penetrating the western Mediterranean Basin in the area of southwestern Europe. The total frequency there is subdivided according to the routes Va, VIa, VIb and VII as defined above (see Fig. 1). The subsequent routes followed while travelling eastward of the focal point in the northern Tyrrhenian Sea (in Arabic numerals) have been separated from the original routes of ingression (in roman numerals) on the basis that there is no necessary sequence such as V—5 or VI—6. These routes are shown in Fig. 1 where it is clearly indicated that the pivot of most cyclonic routes lies in the general area of the northern Tyrrhenian Sea. The criteria used for following fronts, especially over continental Africa and Asia, are discussed in section 4. No attempt has been made to enter quantitative values in Table I although the routes over southeastern Europe are listed in order of numerical importance.

Previously disturbances penetrating the eastern basin from continental Europe have been poorly defined and hardly considered. Fronts passing eastward or southeastward along a route sometimes designated as III b often enough effect the Mediterranean, and depending upon the zone of incursion one may define two subroutes. Disturbances penetrating to the open Mediterranean Sea from eastern central Europe via Greece are here designated as $IIIb_1$; those entering from eastern Europe into central Anatolia via the Black Sea as $IIIb_2$. Table I lists these storm tracks as a whole and again subdivided. When such disturbances move into the Central or Eastern Mediterranean, or into the Levante area, they are again listed with arabic numerals in column C.

The general synoptic conditions related to the various Großwetter types are discussed in part II. At this point the airmass supply related to the various storm tracks can be summarized as follows:

Va: mP^a, cP^e; *VIa:* mP^a; *VIb:* mP^a, $mP^a \longrightarrow mT^a$; *VII:* $mP^a \longrightarrow mT^a$, mT^a; *$IIIb_1$:* cP^e, $mP^a \longrightarrow cP^e$; *$IIIb_2$:* cP^e.

During the period under study there was an average of some 30 outbreaks of mP^a air during the winter half-year, and only a quarter as many of cP^e. The bora winds of the Dalmatian coast are of course another source of cP^e surges, but the cyclogenesis possibly initiated thus is normally not of significance outside of the Adriatic area and adjacent Yugoslavia.

3. 500 mb Level Flow Components

Cool, moist airmasses may enter the Mediterranean Basin either from the eastern Atlantic or in modified form from eastern central Europe. To analyze the likelihood of airmass penetration at higher levels and in order to comprehend observed surface incursions, it is necessary to compute the net zonal and meridional transport of these gateway areas, the first of which can be localized between 15° W — 10° E, 35°— 50° N, the second 10°— 35° E, 35°— 50° N (Grids A and B respectively: Fig. 1). Net zonal transport is usually defined as

$$Z_N = \frac{1}{n+1} \sum_{k=0}^{n} \varrho_{(k)} V_{E(k)}$$

where $\varrho_{(k)}$ is the density, $V_{E(k)}$ the eastward component of the geostropic wind at the k—th point of observation and n the total number of observations. For two latitudes this value is directly proportional to the meridional decrease in pressure between these arcs. So

Z_N (Southwest Europe) = mean 500 mb geopotential of [(eastern Atlantic) — (western Europe)]

for which we employ the 5-degree latitudinal and 10-degree longitudinal intersections in the segments 15°— 5° W, 35°— 50° N, and 0°— 10° E, 35°— 50° N respectively (Fig. 1), the values being obtained from the 500 mb synoptic maps.

Similarly the net meridional transport M_N for southwestern Europe (Grid A in Fig. 1) is defined as the difference between the mean 500 mb geopotential of the grids 35° N — 40° N, 15° W—10° E and 45°— 50° N, 15° W—10° E. Z_N is counted positive to the east, M_N toward the south. The units are expressed in kg/m² sec.

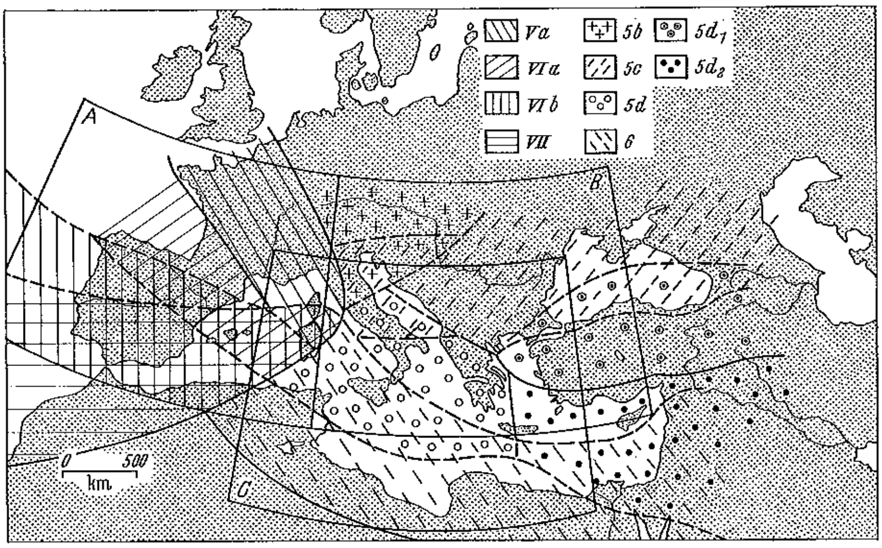

Fig. 1. Major Zones of Frontal Passage in the Mediterranean Area. Squares A, B and C delimit grids employed in text and tables. Roman and arabic numerals refer to zones of frontal passage, strongly modified after the original scheme of *van Bebber* and others.

Net zonal and meridional transport in southeastern Europe (Grid B in Fig. 1) is similarly calculated from the longitudinal segments 10°— 20° E to 25°— 35° for Z_N, and 35°—40° N to 45°— 55° N for M_N. Lastly net zonal and meridional transport in the Mediterranean (Grid C in Fig. 1) are obtained using segments 5°—15° E to 20—30° E for Z_N, 30°— 35° N to 40°— 45° N for M_N.

These zonal and meridional components of net upper air flow vectors over southwestern and southeastern Europe, and likewise the Mediterranean Basin have been computed for each large-scale weather pattern from specific weather situations during the period 1949—1958, which results are presented in Table II. These represent a mean of 14—21 day periods covering three long-term weather patterns of each type. The situations chosen to obtain this mean were (a) the two longest situations of each type occurring during the winter half-years of this period, and (b) a third situation of at least average duration specifically chosen for its similarity to the characteristic synoptic examples presented by *Hess* and *Brezowsky* (1952). Bearing in mind that *Baur* (1947) in presenting typical surface pressure distributions on the basis of prewar data, resorted to the use of one situation only, the considerably longer and equally discretely selected period employed here should enable one to give a fair picture of average 500 mb flow vectors for each of the European Großwetterlagen in the Mediterranean area. Exceptions are the Na situation, which only occurred once with average or longer duration during the said period (4 days total), and the SEa, which only occurred twice as such (13 days). It was assumed that single days would not present altogether typical development of the respective patterns.

The two components computed for these various grids describe the net upper air flow vectors for each of the weather patterns. Their significance for advection in the middle troposphere can be readily visualized. Air masses of northerly origin are favoured to enter the basin when the meridional component in areas A and B is positive, particularly when the vector proper is also of at least moderate strength, say at least 1 kg/m² sec. Strong upper advection of air with northerly components is most likely with Ws, Nz, TrM, TM, TB, TrW, SEz, HFz, HNFz and Ww over southwestern Europe. In actual practice it will be seen that the approximation given by calculating *net* transport for the said grid is not quite accurate. For the HNz, S and SEa situations, although the meridional type jet does take a course in a northeasterly direction over southwest Europe, it lies so far south, however that the main current still crosses the surface of the western Mediterranean. This exception would make use of a moving coordinate system desirable. In another case, the Na pattern, a strong meridional jet tends to move due south over the Alps or along their western foothills — despite strong anticyclonic circulation over most of the grid area A.

In other words it is necessary to apply the concept of *total* meridional transport

$$M_T = \frac{1}{n+1} \sum_{k=0}^{n} \varrho(k) \, |V_{M(k)}|$$

where n and $\varrho(k)$ are as above, and $|V_{M(k)}|$ denotes the absolute value of the meridional component $V_{M(k)}$ of the geostrophic wind at the k-th observation. The M_T so calculated from the synoptic map does bear out the northerly flow of the Na situation.

From section 2 and Table I it will be seen that the above results correspond closely with actual observed airmass advection during 1950—59, all of the above weather types having above-average cold front penetration, with the exception of HNFz.

Gradients are appreciably weaker in the area of Grid B, which is reflected in part by the decreased frequency and intensity of frontal invasion (A:B = 7:1). Weather types with a positive resultant vector of M_N exceeding 0.5 kg/m²/sec are Wz, Wa, HM, SW, NW, HNa, HB, Sa, SE and HFa. There is an overall agreement with the actual observed IIIb disturbances (Table I). Sa and SEz do not register above-average frequency of IIIb disturbances or none respectively. It may be said that the Sa situation is characterized by an upper high or ridge over Russia, almost eliminating any practical application of the gradient further south to mP ⟶ cP air advection. The SEz type, on the other hand, is dominated by a jet stream over the Mediterranean with rapidly decreasing gradients to the north in eastern central Europe. Again the HNz is notable for IIIb incursions in the eastern Mediterranean, for which case the upper air gradients computed from the selected situations are not fully representative; surface cold fronts are thrust southeastward over southeastern Europe from the path of the jet recurving sharply around the meridional trough with its axis over Finland.

Table II. *Zonal* (Z) *and Meridional* (M) *Components of net Upper Air Flow Vectors* (V) over Southwest Europe (Grid A, Fig. 1), Southeast Europe (Grid B) and the Mediterranean Basin (Grid C) in kg/m²/sec. Winter season

	A		B		C			No. of days of occurrence
	M_1	Z_1	M_2	Z_2	M_3	Z_3	V_3	
Ws	0.09	1.88	—0.17	1.46	0.47	1.50	1.56	25
Wz	0.02	1.13	0.74	0.80	0.14	0.55	0.55	21
Wa	0.26	0.45	0.62	0.61	0.64	0.36	0.74	19
BM	0.66	—0.03	—0.12	0.29	0.11	0.61	0.62	22
HM	—0.02	0.04	1.05	0.21	0.15	0.29	0.55	22
SWa	—0.67	0.94	0.95	0.08	0.39	0.39	0.53	15
SWz	—1.08	1.61	0.59	0.66	0.36	0.84	0.91	24
NWa	0.08	—0.04	1.16	0.75	0.77	0.50	0.91	14
NWz	0.80	0.42	0.31	0.93	0.90	1.02	1.36	15
HNa	0.45	0.43	0.09	1.06	—0.28	1.28	—1.31	15
HNz	—0.27	1.08	—0.06	1.94	0.02	1.40	1.40	20
HB	1.01	—0.31	0.25	0.99	—0.34	1.37	—1.42	23
Na	—0.10	0.92	—0.09	0.61	0.62	1.00	1.18	4
Nz	1.08	0.96	—0.62	1.39	0.25	1.44	1.46	15
TrM	1.02	1.10	—0.55	1.13	—0.45	1.28	—1.35	16
TM	1.52	1.41	—1.12	1.46	—0.47	1.97	—2.02	15
TB	0.41	1.59	—0.24	0.83	—0.60	0.89	—1.07	14
TrW	0.23	1.23	—0.34	0.92	—0.64	1.15	—1.32	14
Sa	—0.72	1.17	0.39	0.46	0.19	0.89	0.91	23
Sz	—0.42	1.73	—0.05	0.67	—0.47	1.04	—1.17	16
SEa	—0.42	1.01	0.17	0.65	0.02	1.26	1.27	14
SEz	0.94	1.28	0.17	0.82	0.00	1.19	1.19	13
HFa	0.83	0.72	0.16	0.90	—0.10	1.20	—1.20	22
HFz	0.38	1.22	—0.38	0.54	—0.05	0.90	—0.91	14
HNFa	0.46	0.70	—0.28	0.65	0.10	0.93	0.93	17
HNFz	1.46	0.67	—1.19	0.91	—0.98	1.48	—1.79	19
NE	0.95	0.34	—0.34	0.73	0.31	1.36	1.40	18
Ww	1.03	1.07	—0.82	0.55	0.01	0.82	0.82	14

As a third major point in this discussion on mean upper air flow, the significance of the upper circulation over the Mediterranean proper may be referred to. Its components as well as the intensity of the resultant vector are listed in Table II. It will be readily seen that Großwetter types with net resultant vectors of over 1 kg/m²/sec represent strong upper air gradients. In effect such situations are limited to types where the yet stream proper, a periphery of it, or a jet branch cross the Mediterranean. The situation HFz is a borderline case, distinguished however be pronounced cyclonic circulation over the basin. Situations with net vectors of less than 0.95 kg/m²/sec are characterized by weak gradients, a greater tendency for airmass stagnation, or anti-cyclonic circulation with local high pressures. The zonal and 'mixed' types Wz, Wa, BM, HM, SW, NWa and the meridional types Sa, HNFa and Ww are characteristically so. On the basis of above-average frequency of both upper cut-off lows and closed surface lows during the winter half-years 1950—59 it is possible to select the areas of characteristically low pressure and hence stagnating airmasses from these weak gradient situations: the entire Mediterranean for BM and HNFa, local parts the basin for Wa, HM, SWz, Sa and Ww. The remaining areas or types are dominated by high pressures.

On the basis of Tables I and II and the synoptic material studied (compare also the surface and 500 mb-level type maps in *Hess* and *Brezowsky* 1952) one can subdivide the Großwetterlagen in the Mediterranean area according to *dynamic* types:

Major Jet Stream over the Mediterranean (Cyclonic circulation)
N, TrM, TM, TB, TrW, SEz, HNFz

Minor Jet Branch or Jet Periphery over Mediterranean
Cyclonic circulation: Ws, NWz, HNa, HB, HFa, HFz, NE
Anticyclonic or mixed circulation: HNz, Sz, SEa

Weak Gradients with Low Pressure and Cyclonic Circulation
BM, HNFa, Ww

Weak Gradients with Anticyclonic Circulation
Moderately high pressures: HM, SWz, Sa
Generally high pressures: Wz, Wa, SWa, NWa

The circulation pattern or form over the Mediterranean zone has been determined on the basis of the meridional components of the net upper air transport vectors in Table II and was found to compare favourably with the observed synoptic material.

Two last items related to net flow vectors over the Mediterranean Sea deserve mention. Contrary to expectation negative meridional components do not in practice imply a more northerly route for surface fronts and minima in the eastern parts of the Mediterranean. Similarly a comparison with Saharan depressions developing in the Atlas lee or over Libya-Egypt, and tending to move into the Mediterranean, showed no correlation whatever with negative meridional components. This necessitates a modification to the statement of *Riehl, Allen* et al. (1944, p. 65) that upper air trajectories veering northeastward would tend to draw cP or cT air from the Sahara into the central or eastern parts of the Mediterranean Sea. This is by no means generally applicable. It may be added that there is no statistical correlation between cyclone trajectories and 3 km isobar directions (cf. *T. A. Gleeson* 1954).

4. Regional Frequency of Surface Fronts and Closed Lows

A representative picture of average frequency of fronts and closed lows associated with specific large-scale weather patterns must necessarily be based upon a statistical examination of synoptic conditions over a longer period. The same sample of 1727 days over the 9½ year period January 1950 through March 1959 (excluding April through September) was employed as for Table I. This period should convey a relatively reliable impression of synoptic conditions distributed according to Großwetter situations identified in the Großwetterlagen Mitteleuropas, Bad Kissingen, Offenbach a. M., during this time. Patterns occurred with an average of 62 days, the most frequent being the Wz, BM and HM, least frequent the HFz, HNa and Na.

Surface fronts and closed lows as observed on the daily synoptic sea-level maps of the German Weather Service were enumerated for specific geographical areas. Both cold and warm fronts were distinguished, and lows were classified according to central pressures a) less than 1000 mb, b) 1000—1004 mb, c) 1005—1009 mb, d) 1010—1014 mb. In order to judge the validity of the fronts entered on the German maps, a selection of fronts was redrawn with the ample daily station data provided by the U.S. Weather Bureau daily series for the northern hemisphere. In almost all cases the fronts on the German weather maps could be accepted as valid. On the other hand it was found that the fronts on the U.S. daily series were drawn in large, closed arcs in a fully schematic, and for such purposes, unusable way. For example cold fronts were regularly drawn from Turkey all through the Sahara to join up with others over the southern North Atlantic. Precaution had to be employed when evaluating the German map data for North Africa and Asia. Unless distinct windshifts, rapid thermal jumps, isobaric discontinuities and at least $^3/_4$ cloud cover either behind or ahead of the front could be verified, designated fronts were not accepted as such. This has almost entirely eliminated the extrapolated and quasi-imaginary fronts so often extended into the Sahara. For unless such minimum conditions are fulfilled a front loses its synoptic implications, in particular for potential precipitation development. Saharan depressions and closed lows developed over the African continent and not maintaining a visible connection with Mediterranean disturbances were not included in the data presented below, but were considered separately.

The geographical areas employed for the analysis are delimited as follows (see Fig. 2): 1) [I] Iberian Peninsula; 2) [W] Western Basin, subdivided into (a) Gulf of Lions, (b) southern Western Basin, (c) Gulf of Genoa, (d) Tyrrhenian Sea; 3) [Ad] Adriatic and Yugoslavia; 4) [G] Albania, Greece and Aegean; 5) [An] Anatolia (Turkey); 6) [M] Morocco; 7) [Al] Algeria and Tunisia; 8) [C] Central basin (to 25° E); 9) [E] Eastern Basin; 10) [NE] Levante and Iraq; 11) [L] Libya; 12) [Eg] Egypt; 13) [BS] Black Sea area. These geographical divisions are intended to provide a clear picture of centers of cyclogenesis or cyclonic activity of frontal passages, and overall areal distributions. Barometric minima were in each case only counted in one zone, whereas fronts extending over several such areas were counted in the plural.

The results of the statistical analysis are presented in Tables III and IV. A further table of mean daily expectancy of warm fronts was also prepared but has not been included. The simple arithmetic mean of total (cold and warm) fronts experienced per geographical unit has been multiplied by 180 to give a figure of average frontal passage during the winter half-year. The same has been done for closed surface lows, both sets of values being entered in Fig. 2. This then provides a visualization of the local intensity of cyclonic and frontal activity. Several features can be presumed from these distributions, which can be affirmed on the basis of the underlying synoptic study:

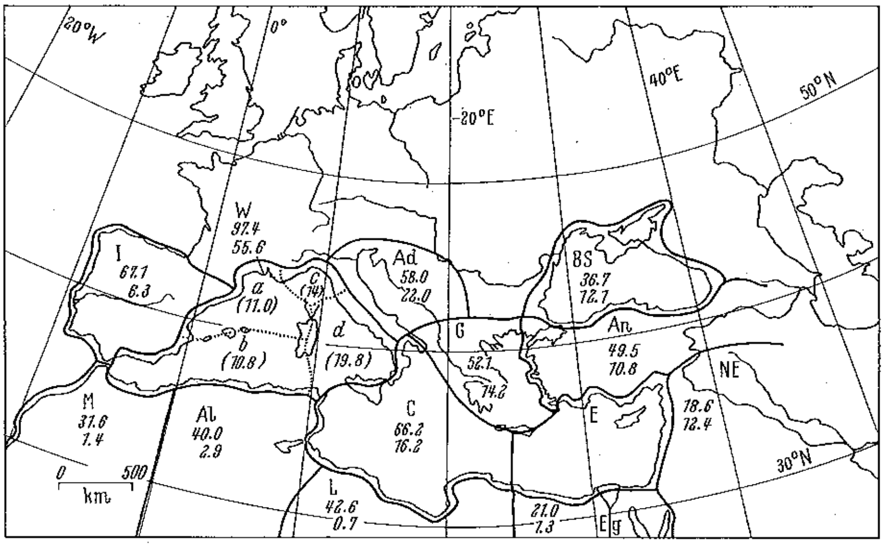

Fig. 2. Geographic Regions employed in the Synoptic Analysis. Letters (with subdivisions of western Mediterranean) refer to text description. Numbers refer to total number of surface fronts (upper figure) and closed surface lows with minima less than 1015 mb (lower figure) occurring October through March 1950—1959, based on an 180-day average

(1) The western Mediterranean and Adriatic are a primary center of cyclogenesis, more particularly the Tyrrhenian Sea — not the Gulf of Genoa as commonly considered.

(2) The number of surface lows over the Iberian Peninsula (and the southern half of France as well) is insignificantly small, indicating infrequent passage of surface lows over these lands.

(3) The eastern Mediterranean clearly represents a secondary center of cyclogenesis.

(4) Contrary to expectation, the contrast of cold land and open sea in winter does not single out the Black Sea as an important zone of cyclogenesis.

(5) The ratio of fronts to lows in the various zones expresses certain climatological characteristics.[1] Three classes can be distinguished: (a) The Iberian Peninsula (11:1) and the African mainland (Morocco 22:1, Algeria-Tunisia 14:1, Libya 61:1; Egypt 16:1) where the ratio of fronts to lows is over 10 to 1. This indicates extremely continental and generally anticyclonic conditions, and that these are characteristic areas of cyclonic filling. (b) The Adriatic (5:2), Black Sea (3:1), Greece (4:1), Central Mediterranean (4:1) and Anatolia (5:1) occupy an intermediate position showing an overall dominance of more maritime or cyclonic characteristics. (c) The western (1.7:1) and eastern (1.5:1) Mediterranean and the Levante-Mesopotamian area (1.5:1) show an almost 1:1 relationship, indicating that the barometric minima are out of proportion to the number of fronts. In other words, these are characteristic areas of cyclogenesis. This was already obvious for the two former regions, but it is a novel realization as far as the Fertile Crescent is concerned. Although the overall number of disturbances is not exceptional, the synoptic studies accompanying this statistical analysis verified a center of cyclogenesis over eastern Syria, between the middle reaches of the Euphrates and Tigris. Although often associated with

Table III. *Mean Daily Expectancy of Cold Fronts in the Mediterranean Area* (according to regions in Fig. 2)
(October through March 1950—59)

	I	W	Ad	G	An	M	Al	C	E	NE	L	Eg	BS
Ws	.36	.50	.24	.23	.23	.05	.20	.27	.15	.05	.13	.07	.25
Wz	.26	.32	.18	.14	.13	.04	.10	.21	.14	.05	.12	.11	.14
Wa	.11	.11	.05	.10	.17	.02	.02	.10	.10	.05	.12	.07	.17
BM	.08	.17	.11	.13	.17	.03	.06	.23	.13	.05	.17	.07	.12
HM	.15	.18	.08	.14	.25	.06	.08	.17	.15	.11	.10	.06	.18
SWa	.32	.22	.08	.02	.08	.13	.15	.13	.05	.05	.06	.02	—
SWz	.41	.37	.04	.09	.12	.10	.12	.13	.13	.07	.07	.04	.10
NWa	.14	.10	.05	.05	.10	.14	—	—	—	.10	—	—	.19
NWz	.19	.34	.19	.25	.27	.03	.07	.23	.25	.14	.16	.14	.18
HNa	.28	.61	.44	.11	.17	.22	.33	.44	.06	—	.22	.11	.22
HNz	.26	.61	.29	.18	.32	.23	.35	.18	.20	.06	.09	.15	.29
HB	.12	.26	.15	.19	.21	.07	.08	.30	.15	.11	.20	.12	.16
Na	.36	.45	.27	.27	.09	.27	.27	.27	.18	.27	.45	.18	—
Nz	.31	.41	.22	.23	.25	.13	.13	.31	.23	.09	.23	.16	.18
TrM	.30	.48	.36	.36	.11	.15	.23	.37	.16	.04	.24	.12	.05
TM	.26	.50	.38	.30	.20	.12	.26	.44	.24	.10	.28	.14	.20
TB	.63	.59	.21	.12	.08	.17	.25	.29	.08	.04	.25	.08	.08
TrW	.41	.54	.29	.17	.08	.17	.25	.38	.02	—	.21	—	.02
Sa	.46	.29	.13	.09	.18	.20	.22	.20	.13	.09	.11	.09	.11
Sz	.62	.76	.20	.13	.03	.33	.30	.36	.03	.03	.23	.03	.20
SEa	.54	.46	.19	.13	.11	.27	.27	.30	.08	.08	.22	.03	.16
SEz	.40	.82	.34	.21	.10	.31	.40	.47	.24	.10	.44	.21	.07
HFa	.18	.32	.22	.24	.21	.13	.10	.27	.23	.08	.20	.19	.10
HFz	.38	.48	.19	.29	.29	.10	.14	.52	.33	.10	.33	.10	.10
HNFa	.25	.56	.35	.25	.39	.32	.32	.42	.32	.11	.32	.32	.11
HNFz	.21	.42	.21	.49	.39	.25	.18	.56	.28	.11	.39	.32	.18
NE	.12	.36	.17	.25	.25	.04	.12	.33	.15	.10	.25	.10	.10
Ww	.27	.38	.23	.20	.17	.10	.16	.27	.25	.13	.23	.14	.21
Mean	.300	.415	.209	.192	.184	.149	.184	.291	.159	.083	.208	.113	.139

Table IV. *Mean daily Frequency of Closed Surface Lows in the Mediterranean Area* (according to regions in Fig. 2)
(October through March 1950—59)

	I	W	a	b	c	d	Ad	G	An	M	Al	C	E	NE	L	Eg	BS
Ws	—	.29	.03	.05	.21	—	.13	.03	.04	—	—	.03	.07	.03	—	—	.11
Wz	.01	.20	.01	.03	.09	.07	.10	.08	.03	—	.01	.11	.10	.06	—	—	.06
Wa	—	.10	—	.05	.03	.02	.05	.05	.03	—	.02	.08	.12	.07	.01	—	.03
BM	.03	.35	.03	.09	.02	.21	.06	.08	.07	.02	.02	.19	.12	.05	—	—	.08
HM	.05	.14	.03	.08	.01	.02	.02	.03	.08	.02	.05	.06	.10	.09	—	—	.05
SWa	.07	.08	.03	.03	—	.03	—	—	.05	.04	—	.05	.05	.07	—	.02	.02
SWz	.01	.16	.04	.03	.04	.05	.03	.04	.03	.01	.01	.07	.19	.10	—	—	.03
NWa	.10	—	—	—	—	—	—	.05	—	—	—	.10	.43	.19	—	—	.05
NWz	.02	.17	.01	—	.08	.08	.10	.21	.08	—	—	.12	.10	.07	—	—	.09
HNa	—	.72	.22	.17	.11	.22	.22	.06	—	—	—	.17	.11	.17	—	.06	.11
HNz	—	.32	.06	.09	.12	.06	.15	.15	.09	.03	.03	.06	.09	—	—	.03	.09
HB	.07	.31	.01	.08	.08	.14	.11	.09	.07	—	.01	.14	.20	.08	—	—	.07
Na	.09	.27	—	—	.09	.18	.18	.09	—	—	—	.27	.18	.18	—	—	—
Nz	.04	.29	—	—	.20	.09	.22	.22	.04	—	—	.04	.13	.05	—	—	.16
TrM	.01	.46	.03	.05	.25	.12	.23	.12	.04	—	—	.04	.07	.03	—	—	.01
TM	—	.36	.06	.08	.10	.12	.30	.06	.06	.02	.02	.04	.04	.02	—	—	.06
TB	—	.33	.04	—	.21	.08	.08	.08	.04	—	—	.12	.21	—	—	—	.04
TrW	.12	.31	.10	.04	.12	.06	.17	.08	.02	.02	.04	.04	.06	.06	—	—	.02
Sa	—	.16	.07	.02	.02	.05	.03	.07	.13	—	.05	.05	.22	.09	—	—	.05
Sz	.07	.33	.13	.07	.10	.03	—	—	—	—	—	.03	.03	.03	—	—	.07
SEa	.05	.27	.03	.11	—	.13	.05	.03	.05	.03	—	.08	.11	.08	—	—	.05
SEz	.03	.62	.21	.13	.07	.21	.13	.10	.07	—	.07	.07	.13	.03	—	—	.07
HFa	.02	.32	.09	.07	.03	.13	.11	.19	.16	.03	.02	.12	.20	.05	—	—	.09
HFz	—	.33	.14	.05	—	.14	.29	.24	.05	—	—	.10	.10	.10	—	—	.05
HNFa	.11	.43	.11	.07	—	.25	.21	.04	.14	—	.07	.07	.11	.07	—	—	.07
HNFz	—	.56	.14	.14	.07	.21	.18	.28	.11	—	.04	.14	—	—	—	—	.11
NE	.04	.49	.04	.12	.06	.27	.12	.19	.10	—	—	.06	.06	.12	—	—	.14
Ww	.03	.29	.04	.02	.12	.12	.14	.07	.10	—	—	.12	.13	.03	—	—	.10
Mean	.035	.309	.061	.060	.080	.110	.122	.079	.060	.008	.016	.092	.124	.069	.000	.004	.067

[1] Ratios of fronts to lows compared between different geographical units can be of considerable significance. It is a known fact that barometric minima passing from the sea onto a land surface generally tend to fill in, at least at the surface. In the Mediterranean this contrast of cyclogenesis or cyclonic deepening over the warm waters of the sea, and rapid filling over the dry, cooler land surfaces, is particularly important. Fronts associated with such lows filling in over the land persist and often continue to remain noticeable for several days. It can be reasoned that a high ratio of fronts to lows is typical for such continental surfaces with a dominance of anticyclonic circulation. Over the sea surface this ratio will be more equalized and in areas of pronounced cyclonic activity or cyclogenesis — where fronts just begin to develop in growing depressions and most fronts accompany surface lows — this ratio will be almost 1:1. Comparison of such ratios in an area can then express a) the degree of anticyclonic circulation characterizing continental areas, b) whether smaller land masses are fully under the dominance of cyclonic circulation or whether they generally behave as areas of cyclone filling, c) the significance of cyclonic activity and the likelihood of an area to qualify as a zone of cyclogenesis.

upper troughs, a number of these Mesopotamian lows can only be explained as dynamic cyclonic vortices in the lee of the Taurus Mountains.[1]

Continuing with the general evaluation of the statistical data, one may combine the average daily expectancy of lows and fronts to obtain some kind of synoptic index bearing on the likelihood of cloud development or precipitation. In order to obtain such an index of cyclonic activity (e) the following formula is employed:

$$e = \frac{f + 2\,L}{3}$$

Zonal circulation situations	0.104
Mixed type situations	0.087
Meridional circulation situations	0.177

— High over North Atlantic 0.176; High over Russia 0.159; High over Fennoscandia 0.196.

It is striking that the meridional situations have a value of almost twice as great as that of the combined zonal and mixed situations. Another interesting application can be made to the meridional circulation classes delineated by *C. C. Wallén* (1953):

Table V. *Index of Cyclonic Activity in the Mediterranean Area. e:* overall expectancy for the Mediterranean area (arithmetic mean of 12 regions Fig. 2). *f:* percent frequency of weather situations during October through March 1881—1950 (data from *Hess* and *Brezowsky* 1952)

	I	W	Ad	G	An	M	Al	C	E	NE	L	Eg	e	f
Ws	.16	.44	.24	.13	.16	.02	.07	.17	.10	.03	.05	.02	0.133	5.1
Wz	.11	.28	.19	.14	.10	.02	.05	.14	.11	.06	.04	.04	0.107	14.1
Wa	.04	.10	.07	.08	.10	.01	.01	.10	.11	.06	.05	.02	0.063	5.2
BM	.05	.36	.11	.14	.12	.02	.03	.24	.12	.05	.07	.02	0.111	6.1
HM	.09	.17	.05	.08	.19	.03	.07	.12	.15	.12	.05	.02	0.095	12.0
SWa	.14	.11	.03	.01	.04	.06	.06	.08	.04	.05	.02	.01	0.054	2.8
SWz	.16	.21	.04	.06	.09	.04	.06	.10	.17	.10	.03	.01	0.090	1.6
NWa	.10	.04	.02	.05	.07	.05	—	.05	.27	.15	—	—	0.066	4.0
NWz	.08	.26	.19	.29	.17	.01	.02	.18	.15	.10	.06	.05	0.130	3.9
HNa	.11	.92	.41	.15	.08	.07	.13	.24	.13	.11	.09	.08	0.210	2.5
HNz	.13	.64	.35	.26	.21	.11	.15	.13	.12	.03	.03	.07	0.187	1.1
HB	.11	.33	.16	.18	.18	.03	.03	.23	.15	.09	.09	.04	0.135	3.0
Na	.21	.33	.27	.21	.03	.09	.09	.42	.15	.21	.18	.06	0.188	0.6
Nz	.13	.45	.31	.27	.17	.05	.05	.13	.15	.08	.08	.05	0.160	2.1
TrM	.14	.63	.36	.24	.07	.05	.09	.17	.11	.03	.08	.04	0.168	4.0
TM	.12	.52	.49	.19	.16	.05	.12	.21	.12	.05	.10	.05	0.182	2.9
TB	.28	.63	.22	.12	.09	.07	.08	.19	.18	.01	.08	.03	0.165	2.0
TrW	.29	.49	.26	.12	.03	.08	.14	.22	.03	.03	.10	—	0.149	1.9
Sa	.18	.33	.06	.09	.13	.07	.12	.10	.18	.09	.05	.04	0.120	3.2
Sz	.24	.71	.07	.04	.01	.12	.11	.17	.03	.02	.10	.01	0.136	1.4
SEa	.23	.41	.10	.09	.08	.14	.12	.17	.08	.10	.08	.01	0.134	2.9
SEz	.21	.97	.30	.23	.11	.10	.21	.31	.23	.10	.16	.07	0.250	2.4
HFa	.10	.39	.18	.28	.26	.06	.05	.23	.21	.08	.07	.06	0.164	4.6
HFz	.22	.49	.41	.34	.19	.03	.08	.22	.16	.10	.14	.03	0.201	1.0
HNFa	.25	.72	.35	.21	.33	.12	.21	.27	.22	.14	.11	.11	0.254	0.8
HNFz	.08	.81	.38	.51	.20	.10	.18	.40	.09	.04	.13	.11	0.253	1.3
NE	.07	.59	.18	.26	.20	.02	.04	.20	.11	.11	.09	.03	0.158	3.7
Ww	.13	.39	.22	.17	.18	.03	.05	.19	.20	.07	.09	.06	0.148	3.1
Mean	.15	.46	.22	.17	.13	.06	.09	.19	.14	.08	.08	.04	0.150	

where f is the total frequency of cold and warm fronts and

$$L = 2\,l_1 + l_2 + 0.5\,l_3$$

where l_1 is the average frequency of closed lows with central pressures below 1000 mb, l_2 with central pressures between 1000 and 1009 mb, l_3 between 1010 and 1014 mb. These formulas are based on the assumption that over water at least cold and warm fronts are equally likely to favour precipitation, but that, on the whole, fronts associated with cyclones are considerably more effective for precipitation. In view of heavy, prolonged precipitation being overwhelmingly associated with deep lows the importance of surface minima for possible precipitation required the use of proportionality constants. The results are again listed in Table 5 along with the percent frequency f of the respective Großwetter types during the months October through March (1881—1950), derived from *Hess* and *Brezowsky* (1952, Table 1). The regional climatological significance of these statistical analyses will be discussed in a later publication.

Instructive syntheses can be provided by computing further averages, namely the arithmetic mean of the 12 regions involved for each large-scale weather type. This overall index of cyclonic activity is of course only of very limited relation to actual precipitation. It does nevertheless permit an easier assessment of the weather characteristic of the various Großwetter and even index-pattern types. If we group the zonal and meridional situations arithmetically we get the following overall values of e, namely ε:

	ε	CV	f
Zonal and Mixed	0.094	28%	54.8%
North Meridional (HN, HB, N, SEa)	0.169	17%	12.2%
South Meridional (TrM, TM, TB, S, SEz, Ww)	0.165	22%	20.9%
Warm Meridional (HF, HNF, NE)	0.206	20%	11.4%

where CV is the coefficient of variation defined as $100\,\sigma/\bar{x}$ expressed in percent, where σ is the standard deviation, $\bar{x}$ the mean. The situation HM has been left in the group of zonal and mixed types as the corresponding winter circulation over Scandinavia is generally more or less zonal, while the anticyclonic and cyclonic SE cases have been divided among the north and south meridional classes respectively. Although the number of samples is in each case very small, the coefficients of variation do give an indication that the north and warm meridional types are relatively uniform and similar in overall e, whereas the zonal-mixed and the south meridional types are more variable. Regarding the latter it is possible and practical to sub-divide into two further groups, a moist and a dry or indifferent class:

	ε	CV	f
Moist South Meridional (TrM, TM, TB, SEz)	0.191	18%	11.3%
Dry South Meridional (TrW, S, Ww)	0.138	8%	9.6%

on account of the sharp contrasts of the synoptic index in the Mediterranean area.

In the accompanying 28 diagrams of Fig. 3—4 surface pressure anomalies are given for the various large-scale weather patterns. The data have been compiled by semi-

[1] If the desert depressions forming over the Sahara or the Syrian Desert are included in the above ratios, the situation for Morocco becomes 20:1, for Algeria 5:1, Libya 9:1, Egypt 6:1 and the Near East (Fertile Crescent) 1.3:1.

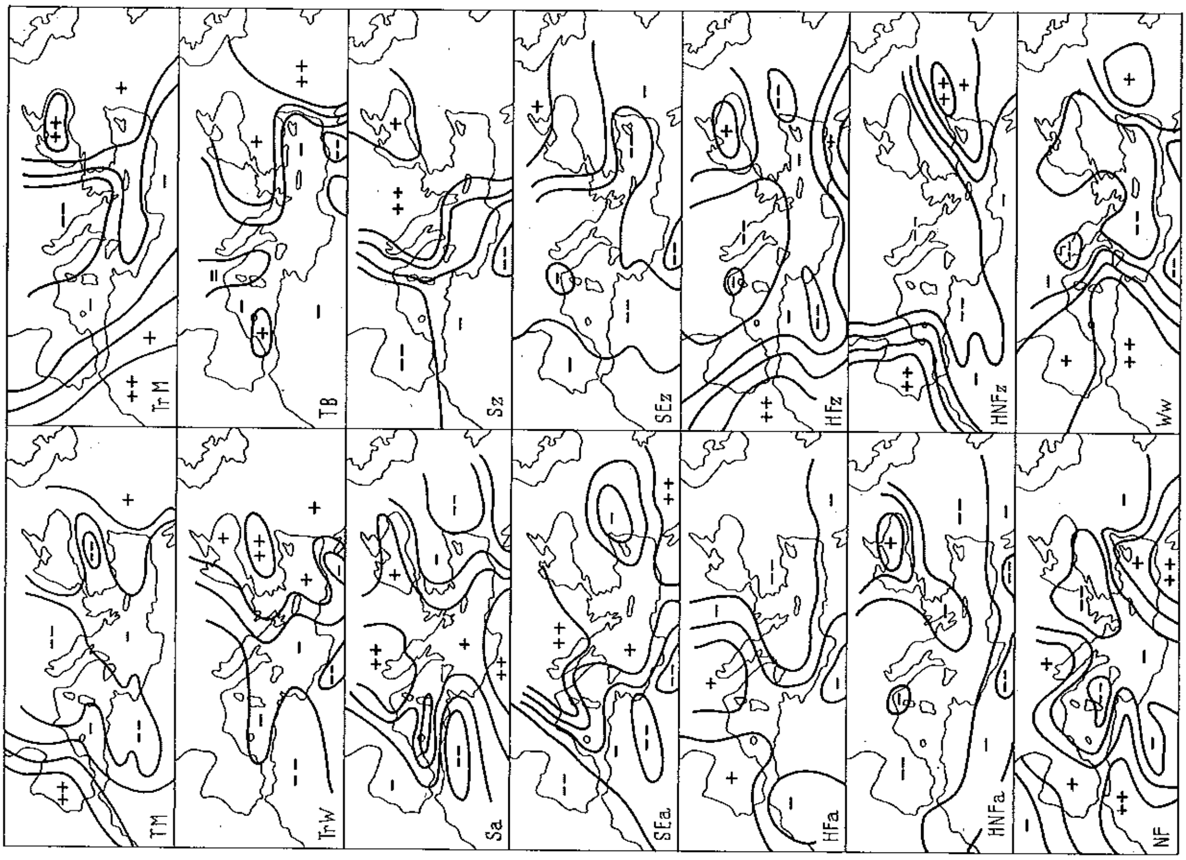

Fig. 4

Fig. 3

Fig. 3—4. Surface Pressure Anomalies associated with large-scale Circulation patterns (Winter half-year)

quantitative methods[1] from the analysis of the winter half-years 1950—59, and has therefore been presented in the form of relative and not numerical anomalies. The "Saharan" depressions and those similar cyclonic storms of shallow

[1] Relative pressure anomalies were obtained by averaging the four classes of closed lows considered earlier, cases of open low pressures, and conditions of anticyclonic circulation. The pictures so obtained compared well with situations computed from mean daily pressure deviations at 5° intersections, although no numerical values in millibars are allowable.

profile originating in northern Arabia are of course conspicuous among pressure anomalies over the southerly continents. Their individuality has been preserved on Fig. 3—4 by the use of closed anomalies limited to the land and more schematically applied to their peculiar localities: the lee of the Anti-Atlas between 5° W and the Gulf of Gabes, Tripolitania, the Libyan Desert and the Syrian Desert. In this way it is easy to distinguish between the Saharan depressions and those of other origin. The former will be treated in a subsequent paper.

The individual outlines have made it clear that there are some weather situations characterized by cyclonic control of Atlantic origin, others by cP^c outbursts from southeastern Europe. The two do not coincide in the majority of cases. We can further fully support the work of *M. G. El Fandy* (1946) on the primary importance of local cyclogenesis over the eastern Basin for precipitation development in the Fertile Crescent and Egypt. Both the writer's and *El Fandy*'s opinions are not quite compatible with the simple, classical presentation that Atlantic disturbances inevitably travel straight through the Mediterranean to the Near East, and often on to Iraq and even India. During the period of investigation the majority of the depressions in the southeastern Mediterranean developed independently through local cyclogenesis east of 25° E. Approximately a half of these showed obviously that they were the product of regeneration of shallow lows by the approach of cold, labilized cP^c air from northerly quadrants. Yet these are no longer strictly Atlantic disturbances.

In order to single out these important *genetic* distinctions the various types can be grouped as follows:

A. Generally High Pressures (25.4% frequency in winter half-year) Wz, Wa, (BM)

B. Generally High Pressures, Cyclonic Control in East (22.9%) HM, NW, HB

C. Cyclonic Control limited to both western and eastern Peripheries (11.9%) SW, S, SEa

D. Full Cyclonic Control of combined Atlantic (mP^a) and Continental (cP^e) Origin (9.4%)
HNz, HFa, NE

E. Full Cyclonic Control of Atlantic Origin (29.7%)
Ws, HNa, N, TrM, TM, TB, TrW, SEz, HFz, HNF, Ww

This division stresses the broad regional contrasts of the area under consideration solely on a basis of cyclonic origins. Phases of pronounced cyclonic activity in the Near East may take place quite independently of conditions for example, in the western Mediterranean. This accounts for a total dissimilarity of precipitation and temperature trends between the eastern and western basins on an annual, five or ten year basis (cf. *Butzer* 1960). As the writer (*Butzer* 1957) was able to show, only anomalies between 30-year means indicate a uniformity of climatic fluctuation through the greater part of the Mediterranean. There are two major centers of cyclogenesis in the Mediterranean area.[1] The first is located in the quadrangle Montpellier-Venice-Naples-Sardinia, and centered in the northern Tyrrhenian Sea west of Rome (not in the Gulf of Genoa). The other is located in the belt between Rhodos, Cyprus and the upper Tigris — south of the Taurus Ranges. To the classical „Cyprus lows" one should add a subdivision of „Mesopotamian lows", purely orographic lows situated along the Syro-Turkish border and induced by northerly currents.[2] These are just as distinct from the mixed or purely thermodynamic lows of the eastern Mediterranean as are the „Genoa lows" from those developing over the Gulf of Lions or the Tyrrhenian Sea. The Genoa lows are created dynamically when northerly currents move down the Rhone gap (route Va) and then swerve strongly so that fronts assume a north-south orientation over the Mediterranean. The dynamic vortices for which we have here suggested the name "Mesopotamian lows" form under somewhat analogous circumstances, and will be considered in a later paper.

[1] See also the useful map in *G. T. Trewartha* (1960).

[2] These "Mesopotamian lows" do not appear on the maps of Mediterranean cyclogenesis given by *Gleeson* (1954), or very barely so. However the synoptic material he employed (period 1929—1939) has a very poor coverage for Southwest Asia and the Sahara, so that one cannot consider these data as fully adequate for those areas.

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