Harmonic analysis of precipitation, pressure and temperature over Turkey

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Summary. — Monthly averages of temperature, precipitation and pressure values from ground-based measurements for long-term data observed in different geographical regions in Turkey have been investigated. The main purpose of this study is to define the role of small- and large-scale phenomena (local and synoptic fluctuations) on precipitation, pressure and temperature variations and their periods. Hence, the Fourier transformation analysis of the monthly average value of meteorological parameters has been considered, and phase angles and amplitudes have been calculated. The first-order harmonics of temperature, precipitation and pressure values show large-scale effects, while higher-order harmonics show the effects of small-scale variations. The variations of first–sixth-order harmonic amplitudes and phases provide a useful means of understanding the large- and local-scale effects on meteorological parameters. The phase angle can be used to determine the time of the year when the maximum or minimum of a given harmonic occurs. The analysis helps us distinguish different precipitation, pressure and temperature regimes and transition regions. Local- and large-scale phenomena and some unusual seasonal patterns are also defined. This analysis also shows strong annual variations of precipitation in the Southern and Western part of Anatolia and that strong semi-annual fluctuations are predominant in the eastern part of Turkey. Strong annual influence on pressure variations is mostly observed in the coastal part of Turkey. The dominance of the first three harmonics of pressure is smaller over most of the terrestrial stations. Temperature variations are mostly influenced by the annual fluctuations in eastern and south-eastern Anatolia. The urban heat island caused by developing metropolitan areas refers to local warming effects and heat islands. The local effects are observed in the western part of Turkey.

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1. – Introduction

Non-random scatter of climate element is a regular or quasi-regular fluctuation. Daily and annual variations of temperature and radiation are obvious and are usually

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linked with similar fluctuations of rainfall (Linacre, 1991). There may be more subtle rhythms including the 26-month quasi-biennal oscillation, the El Niño Southern oscillation or a fluctuation associated with the 11-year cycle of sun-spots, which are discussed in long-term, annual and seasonal rainfalls. A surrogate for the global climate change must consider climate changes averaged over major circulation systems (Lindzen *et al.*, 1995). North Atlantic Oscillation (NAO) is a predominant teleconnection pattern in all seasons (Philips, 1995). After the winter of 1987/1988, seven consecutive winters have recorded positive NAO patterns. The positive NAO is generally accompanied by an abnormally intense low-pressure level height centre over Iceland. The positive NAO is also associated with enhanced westerlies across the North Atlantic in middle and high latitudes, below normal temperatures in the Greenland-Labrador area and in the Middle East and above normal temperature in the eastern USA and Europe. The negative phase of the NAO reflects circulation, temperature and precipitation anomalies of the opposite sign. The Eurasian teleconnection pattern (EU) reflects wave-like pattern circulation anomalies that extend across western Europe and much of central Russia. Positive phases of this pattern are associated with above-normal-pressure level heights throughout Europe and below-normal-pressure level heights over the Caspian Sea sector.

In recent years, harmonic analysis has emerged as a useful tool in studying annual patterns of some meteorological parameters (Aslan and Topçu, 1994; Okçu, Kartal and Aslan, 1995). The spatial distributions of temperature, precipitation and pressure have been examined by Kirkyla and Hameed (1989), and Currie and Hameed (1990). The results of harmonic analysis enable to distinguish different precipitation regimes and transition regions. The first- and higher-order harmonics, in other words harmonics of 6, 4, 3, 2.4 and 2 months, show the local- and large-scale effects on meteorological parameters in this study. The amplitude and phase values are calculated and analysed for each harmonics by using the long-term temperature, precipitation and pressure data from Turkey.

2. – Material and method

Harmonic analysis is based on the series of trigonometric functions given in the following equation, Kirkyla and Hameed (1989):

$$X = X_0 + \sum_{i=1}^{N/2} A_i \cos(360 \quad it/p + \Phi_i)\,, \tag{1}$$

where

X: value at time t,
A_i: amplitude of the harmonics,
Φ_i: phase angles,
N: number of observations,
p: period of observation,
X_0: arithmetic mean,
t: time.

In this study, p is 12 months. A large first harmonic indicates strong annual variation, a comparatively large second-harmonic amplitude points to a strong semi-annual variation. The phase angle determines the time of the year when the maximum or minimum of a given harmonic occurs. Short-period harmonics indicate influences of local phenomena. Amplitudes and phases determine various boundaries and areas of transition. In this study long-term (between 1940 and 1990) precipitation, pressure and temperature data have been analysed. Monthly average of precipitation, pressure and temperature values has been recorded at 28 stations in different geographical regions of Turkey.

3. – Results and conclusions

3˙1. *Analysis of precipitation.* – The annual amount of precipitation depends chiefly on the geography, *i.e.* latitude, distance from the sea, elevation and shape of terrain. In the Mediterranean climate, particularly dry summers and wet winters have been observed. The circulation of pressure systems highly affects precipitations.

Figure 1a) shows the variation of the first-harmonic amplitude of precipitation. Strong annual variations are observed in south-western and south-eastern Anatolia. The 2500 mm isoline extends through the whole southern region of Turkey, from West to East. Their effects decrease in the central and eastern part of Turkey.

The seasonal variation of the fourth-harmonic amplitude of precipitation data is presented in fig. 1b). The meso-scale variations of precipitation mostly affect the southern region of Turkey.

The maximum amplitude of short-period harmonics which shows the influences of local phenomena is important in the southern and western part of Turkey, fig. 1c). The small-scale effects play a less important role with respect to total precipitation in central and eastern Anatolia. The patterns in figs. 1a), b) and c) look almost similar, except in the central part of Turkey.

The phase angles of first-, fourth- and sixth-order harmonics of precipitation data are presented in table I. The analysis of the phase angles shows that the annual circulation had an effective influence on precipitation in January (winter) and in February in the Aegean Sea region (Izmir, Afyon). Their influences are important in the eastern Black Sea region (Rize, Trabzon) in October and November.

3˙2. *Analysis of pressure.* – Figure 2a) shows the annual cycle of pressure variations. Pressure variations over the Mediterranean region, southern Anatolia, eastern Black Sea region and northern Aegean Sea are very much influenced by the large-scale fluctuations. These effects are observed in central Anatolia (Ankara, Kayseri, Konya) in November, over the eastern part of Turkey (Elazığ, Erzurum, Van) between October and November, and over the other regions in January, respectively, (table II). Small-scale phenomena play an important role in all coastal areas in January, fig. 2b).

3˙3. *Analysis of temperature.* – Large-scale atmospheric and oceanic patterns cause temperature anomalies. Seasonal predictions have been generally carried out by using ECMWF and COLA Models (Shukla, 1993).

The spatial variation of first-order harmonics of temperature data are shown in fig. 3. The large-scale phenomena play an important role on temperature variations over the eastern and south-eastern part of Turkey. Their influence decreases over the coastal areas. The maximum effects of synoptic scale variation on temperature fluctuation have been observed in July (in the first part of July in central Anatolia and in the second part of July in the Black Sea region) as shown in table III.

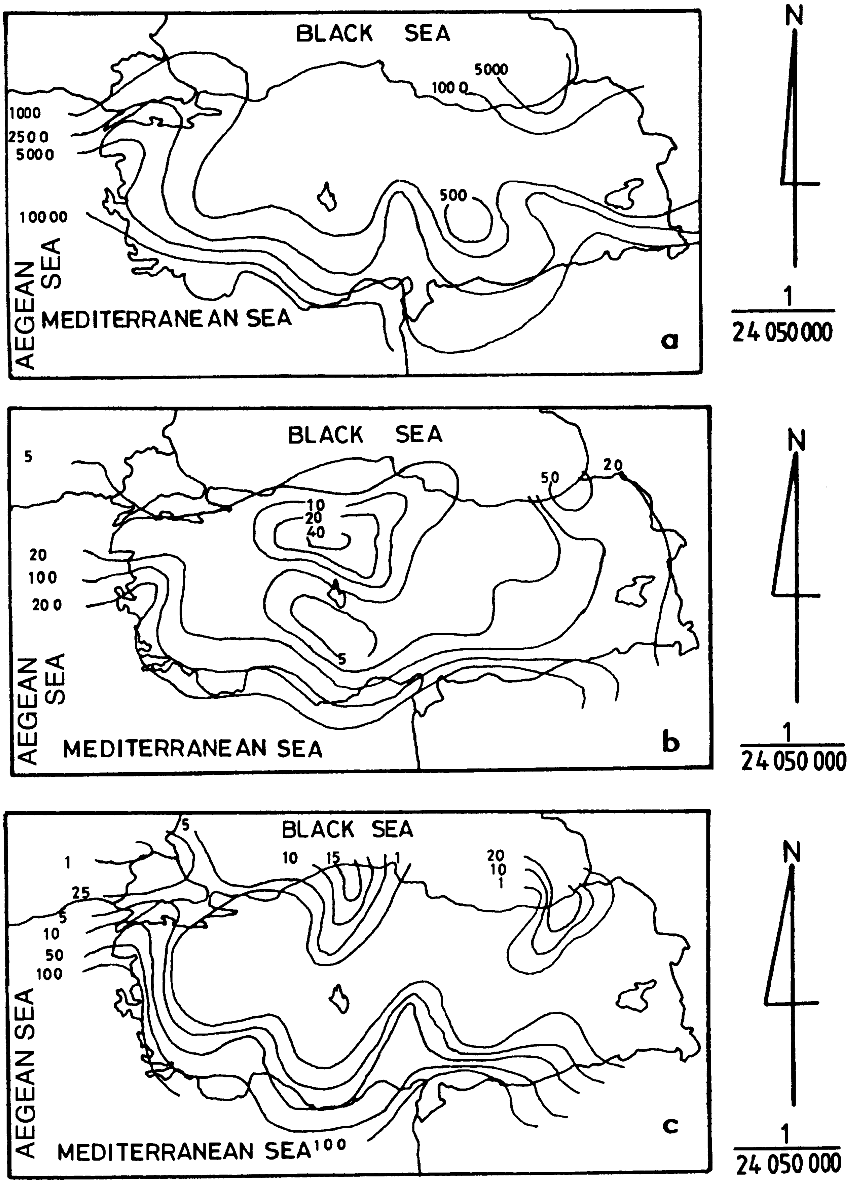

Fig. 1. – a) Spatial variation of the first-harmonic amplitude (in mm) of precipitation data. b) Spatial variation of the fourth-harmonic amplitude (in mm) of precipitation. c) Spatial variation of the sixth-harmonic amplitude (in mm) of precipitation.

3·4. *The ratio charts.* – The ratio of the amplitudes of the first and second harmonics determines the relative importance of the two harmonic components.

A strong semi-annual influence is observed on precipitation in eastern Anatolia, fig. 4. Over several local areas such as Erzincan, Erzurum and Van, a dominant semi-annual

TABLE I. – *Phase angles of first-, fourth- and sixth-order harmonics of precipitation data (indicated by the month).*

Station	First harmonic	Fourth harmonic	Sixth harmonic
Afyon	2.570	0.560	0.070
Ankara	2.290	11.730	0.030
Antalya	0.830	0.390	0.060
Bursa	0.934	0.229	0.254
Çanakkale	0.802	0.365	0.983
Diyarbakır	1.730	1.330	0.060
Edirne	0.842	0.257	0.071
Elazığ	2.004	1.494	0.798
Erzurum	2.885	10.563	0.040
Gaziantep	0.903	10.995	0.019
Isparta	1.509	0.293	0.039
İstanbul	0.627	0.360	0.951
İzmir	0.971	0.085	0.022
Kastamonu	4.891	0.053	0.018
Kayseri	2.924	0.002	0.017
Kırşehir	2.109	11.948	0.088
Konya	1.858	11.130	0.881
Malatya	2.143	1.247	0.892
Muğla	0.910	0.250	0.008
Rize	10.717	0.009	0.957
Samsun	0.255	0.486	0.833
Siirt	1.823	1.293	0.692
Sivas	2.501	11.005	0.802
Trabzon	11.435	1.112	0.118
Van	1.982	1.416	0.126

influence ($A2/A1 > 1$) is observed. Strong annual influence ($A2/A1 < 0.25$) is observed over western and south-eastern Anatolia.

The ratio chart of the amplitudes of pressure is given in fig. 5. The influence of semi-annual variations on pressure data is smaller than the influence of annual variations over Turkey. Strong annual influence ($A2/A1 < 0.25$) is observed in the coastal part of Turkey.

From the analysis of the distribution of the ratio of temperature which is not given here the strong annual influence ($A2/A1 < 0.015$) is dominant over Turkey.

3˙5. *Contribution of the first three harmonics.* – The relative contribution of the first three harmonics to the seasonal variance is given by the ratio of the sum of squares of their amplitudes to the sum of squares of all six amplitudes. Hence, a ratio value close to unity suggests that the first three harmonics account for most or all of the seasonal variation in the curve; on the other hand, a smaller fraction implies a more complex annual curve with a greater amount of variability contained by the high-frequency harmonics (Kirkyla and Hameed, 1989).

Figure 6 illustrates the fraction of total variance contained in the first three harmonics as calculated from measurements of precipitation. The figure shows that the total variability in the seasonal cycle is explained by the first three harmonics over

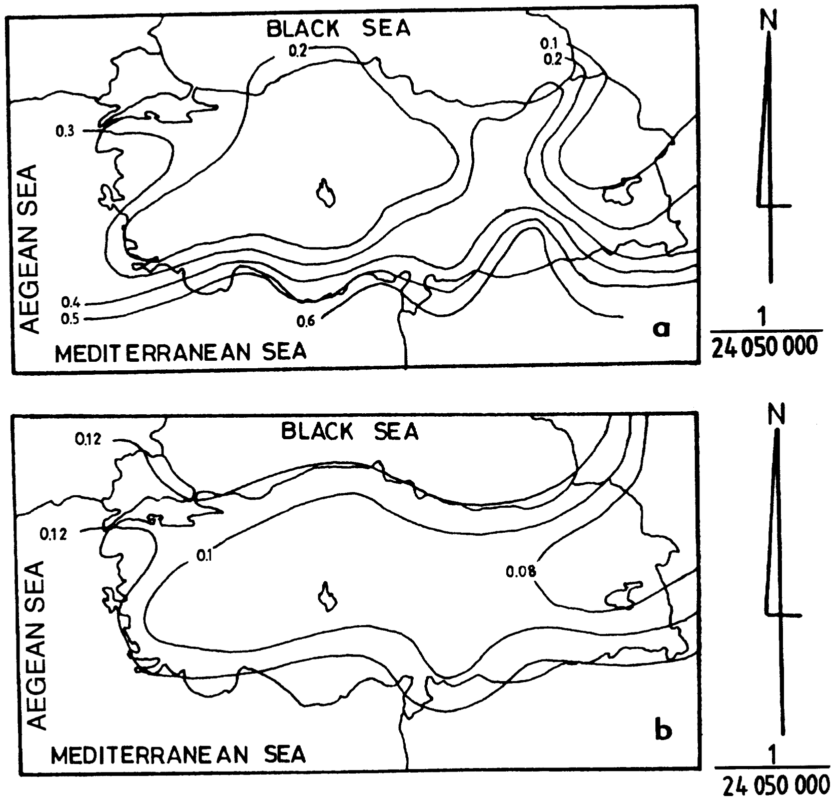

Fig. 2. – a) Spatial variation of first-harmonic amplitude (in hPa) of pressure data. b) Spatial variation of sixth-harmonic amplitude (in hPa) of pressure data.

Turkey. Dominance of the first three harmonics decreases slightly over the central part of the Black Sea and the Mediterranean Coast.

Figure 7 presents the spatial variation of the contribution of the first three harmonics of pressure over Turkey. The dominance of the first three harmonics is smaller over most of the terrestrial stations. The minimum contributions of the first three harmonics are observed in Bolu, Erzurum, Afyon, Kastamonu, Isparta and Ankara. The maximum contributions are observed over the south-eastern part of Turkey. The percentage of total variability is within the 80%-90% range. Over the eastern Mediterranean region, the first three harmonics explain more than 85% of the total variance of the seasonal cycle. In eastern Anatolia and western Black Sea, a decrease in the percent of total variability occurs, and values fall between 40% and 50%.

The temperature analysis showed that the first three harmonics explain more than 95% of the total variance of the seasonal cycle in all regions in Turkey. (The map of percent variability obtained from the first three harmonics of the annual temperature value is not given in this paper).

3˙6. *Conclusions.* – Because of the complex topography, land and sea effects cause complexity of precipitation, pressure and temperature in the climatology of Turkey.

TABLE II. – *Phase angles of first-, fourth- and sixth-order harmonics of pressure data (indicated by the month).*

Station	First harmonic	Fourth harmonic	Sixth harmonic
Adana	0.725	0.467	0.499
Afyon	11.430	0.453	0.515
Ankara	11.698	0.464	0.517
Antalya	0.668	0.457	0.502
Bolu	11.493	0.498	0.530
Bursa	0.213	0.479	0.511
Çanakkale	0.232	0.465	0.529
Diyarbakır	0.624	0.465	0.500
Edirne	0.123	0.474	0.516
Elazığ	0.246	0.473	0.482
Erzurum	10.862	0.480	0.501
Gaziantep	0.383	0.462	0.493
İstanbul	0.236	0.473	0.520
İzmir	0.477	0.474	0.513
Kastamonu	11.486	0.476	0.527
Kayseri	11.784	0.459	0.510
Kırşehir	11.668	0.488	0.500
Konya	11.675	0.489	0.508
Malatya	0.299	0.463	0.515
Muğla	0.165	0.463	0.516
Rize	0.427	0.467	0.517
Samsun	0.316	0.477	0.525
Sivas	11.530	0.469	0.510
Trabzon	0.234	0.489	0.499
Urfa	0.638	0.457	0.495
Van	11.577	0.473	0.512

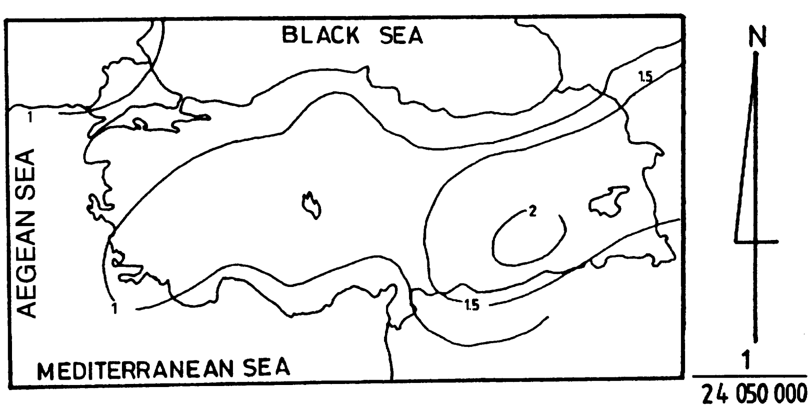

Fig. 3. – Spatial variation of first-harmonic amplitude (in °C) of temperature data.

TABLE III. – *Phase angles of first-, fourth- and sixth-order harmonics of temperature data (indicated by the month).*

Station	First harmonic	Fourth harmonic	Sixth harmonic
Adana	7.408	10.705	0.352
Afyon	7.229	10.784	0.508
Akhisar	7.261	0.607	0.054
Ankara	7.229	10.651	0.509
Antalya	7.428	1.048	0.651
Balikesir	7.284	0.616	0.031
Bandırma	7.413	0.560	0.035
Bolu	7.299	10.858	0.015
Bursa	7.305	11.011	0.029
Çanakkale	7.418	11.081	0.057
Çankırı	7.097	1.333	0.949
Dikili	7.347	0.679	0.122
Diyarbakir	7.285	0.987	0.507
Edirne	7.190	10.984	0.026
Elazığ	7.283	1.326	11.992
Erzincan	7.202	10.604	11.951
Erzurum	7.328	10.651	11.244
Eskişehir	7.184	0.751	0.012
Gaziantep	7.273	1.465	0.065
Gölcük	7.353	0.409	0.032
Isparta	7.270	1.498	0.976
İnebolu	7.311	0.366	0.049
İstanbul	7.495	10.838	0.101
İzmir	7.339	10.831	0.174
Kastamonu	7.153	10.897	11.996
Kayseri	7.142	1.486	11.991
Kırşehir	7.188	1.265	0.017
Konya	7.158	1.437	11.006
Malatya	7.225	1.088	11.506
Merzifon	7.221	0.830	0.015
Muğla	7.358	11.055	0.889
Rize	7.580	10.839	0.199
Samsun	7.630	10.953	0.053
Siirt	7.345	1.112	0.013
Sinop	7.660	0.551	0.044
Sivas	7.240	10.626	11.946
Tekirdağ	7.616	0.230	0.018
Trabzon	7.662	11.114	0.112
Urfa	7.321	1.311	0.856
Uşak	7.320	0.591	0.052
Van	7.317	1.233	11.046
Zonguldak	7.488	0.504	0.033

These three parameters have been affected by local and regional regimes. The harmonics analysis of monthly averages of meteorological parameters shows the long- and short-term variations. The regional and local characteristics can be determined by

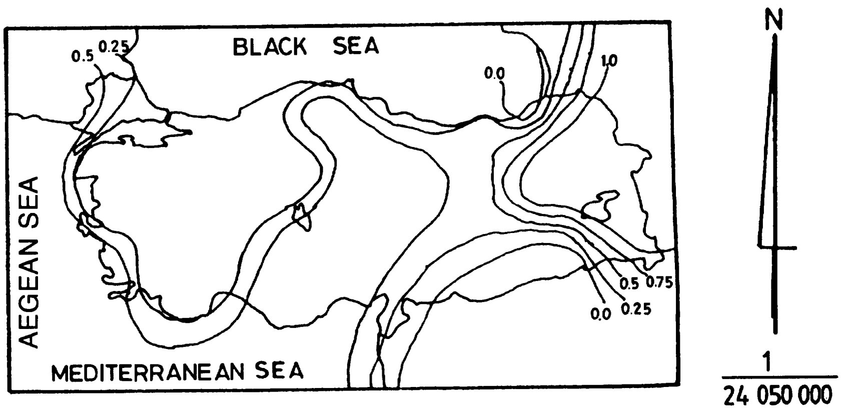

Fig. 4. – Distribution of the ratio of precipitation data of the second-harmonic amplitude to the first-harmonic amplitude ($A2/A1$).

seasonal-variation analysis. The regions have been distinguished where annual and semi-annual fluctuations are dominant.

The analysis allows us to determine different precipitation, pressure and temperature regimes and transition regions. Local- and large-scale phenomena and some unusual seasonal patterns are defined. Annual variations of precipitation are observed in the southern, western and central part of Anatolia, but semi-annual fluctuations are predominant in the eastern part of Turkey. Pressure variations are mostly influenced by strong annual fluctuations in the coastal part of Turkey. The first three harmonics of precipitation play an important role in the eastern and western part of Turkey. But the effects of the first three harmonics of pressure data increase over south-eastern Anatolia. Temperature variations are mostly influenced by the annual fluctuations in eastern and southern Anatolia. The urban heat island caused by the developing metropolitan areas refers to local warming effects and heat islands (Tarleton and Katz, 1994). The local effects are observed in the western part of Turkey.

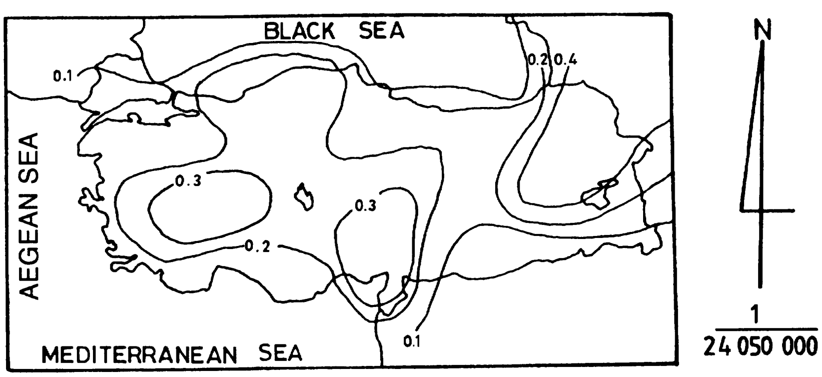

Fig. 5. – Distribution of the ratio of the pressure data of second-harmonic amplitude to the first-harmonic amplitude ($A2/A1$).

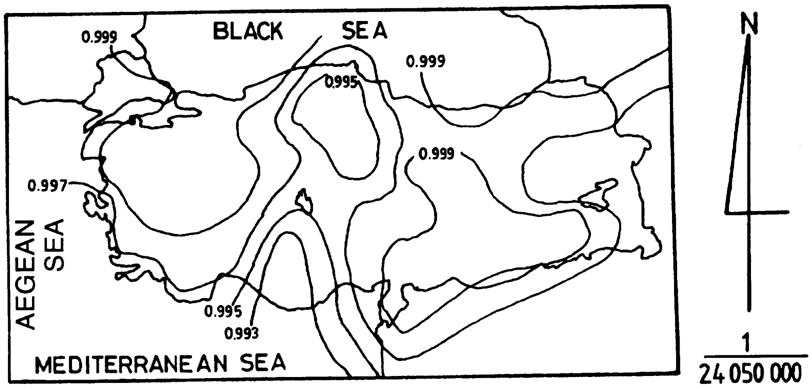

Fig. 6. – Percent variability obtained from the first three harmonics of the annual precipitation.

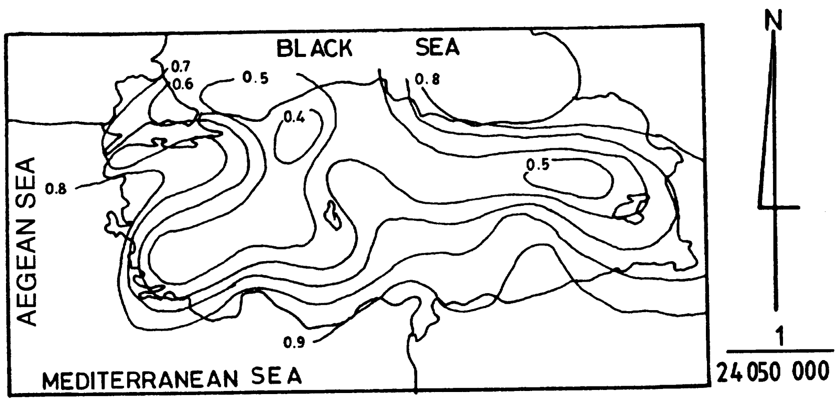

Fig. 7. – Percent variability obtained from the first three harmonics of the annual pressure.

The month of maximum or minimum of a given harmonic is also defined by using the phase angle where annual and semi-annual fluctuations are dominant.

During 1993, droughts occurred in every region of the world, (Philips, 1995). The warm phase of ENSO was associated with droughts in many parts of the globe. Precipitation anomalies (10% of lower rainfall rate than the climatological occurrences) were observed in the Aegean Sea and western Mediterranean Sea coasts of Anatolia in 1992. Similar precipitation values were recorded in Marmara, terrestrial part of Aegean Sea and Mediterranean Sea region in Turkey in 1993. These results are in good agreement with fig. 1 which shows the dominance of large-scale effects on precipitation variation over the western and the southern part of Turkey. The analysis of climatological data recorded between 1991 and 1996 will be compared with these results in a forthcoming study.

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