Theor. Appl. Climatol. 59, 61–77 (1998)

Theoretical and Applied Climatology

[1] Department of Geography, Tel-Aviv University, Ramat-Aviv, Israel
[2] Department of Geophysics and Planetary Sciences, Tel-Aviv University, Ramat-Aviv, Israel

Easterly Wind Storms over Israel

H. Saaroni[1], **B. Ziv**[2], **A. Bitan**[1], and **P. Alpert**[2]

With 12 Figures

Received September 9, 1996
Revised March 6, 1997

Summary

Continental wind storms are common along the Mediterranean coast. Along the northern coast they are mostly cold, similar to the Bora or the Mistral, and along the southern coast they are mostly warm, e.g., the Ghibli or the Shirocco. At the eastern Mediterranean basin and the Levant region, these storms are intermittently warm and cold during the same season and often even during the same event. Quasi-stationary systems, as well as moving disturbances, are the cause of such wind storms. Accordingly, the resulting weather conditions may be extremely converse due to the characteristics of the advected airmass. Specific regions in Israel, sensitive to easterly storms, are influenced by these wind storms for about 10% of the year (e.g., the westerly slopes of the mountains and valleys with west-east orientation). The frequency, however, of widespread storms covering the entire region is only approximately 1.4% of the entire year. These wind storms are therefore classified in the present study according to their climatological and synoptic characteristics; indicating that the dominant synoptic situation is the Red-Sea trough and the warm advections. These storms appear only from October-May and are most frequent during the cold season. The diurnal course is characterized by a strengthening in the morning hours and a weakening at noon and in the afternoon hours, due to the opposing effect of the westerly sea breeze, suppressing the easterly winds and the effect of katabatic winds. Nevertheless, synoptic conditions may contribute to this tendency as well. Accordingly, a significant increase in the frequencies of easterly storms, in relation to distance from the seashore has been identified. Although most of the stormy days are with westerly winds, the easterly wind storms has vast environmental implications, creating damage especially to agriculture and occasionally also to property and life; coastal flooding, potential air pollution, intensifying of forest fires and occasionally dust and sand storms.

1. Introduction

Easterly wind-storm episodes occurring in Israel during recent years and their extensive environmental implications are the cause for this study. The major influence of easterly wind storms is on agriculture. Hot and dry wind storms are increasing the evaporation rates, which is an acute problem in a region suffering from water shortage, while cold and dry wind storms are accompanied by advective frost (Saaroni et al., 1996). Several studies on synoptic conditions during forest fires in Israel indicated the dominance of easterly wind storms in enhancing the fires (Kutiel and Kutiel, 1991). Koch and Dayan (1992) indicated that easterly wind storms are creating high air pollution conditions, especially in Haifa bay area (The second great metropolitan area in Israel, see Fig. 1). Several strong storms caused severe damages to crop fields, trees, roofs and even death due to objects harm (Levy-Tokatly, 1960). The wind-storms have also caused flooding in the west bank of the Kinneret lake (Fig. 1), as well as widespread damage to the promenade, hotels and the marina.

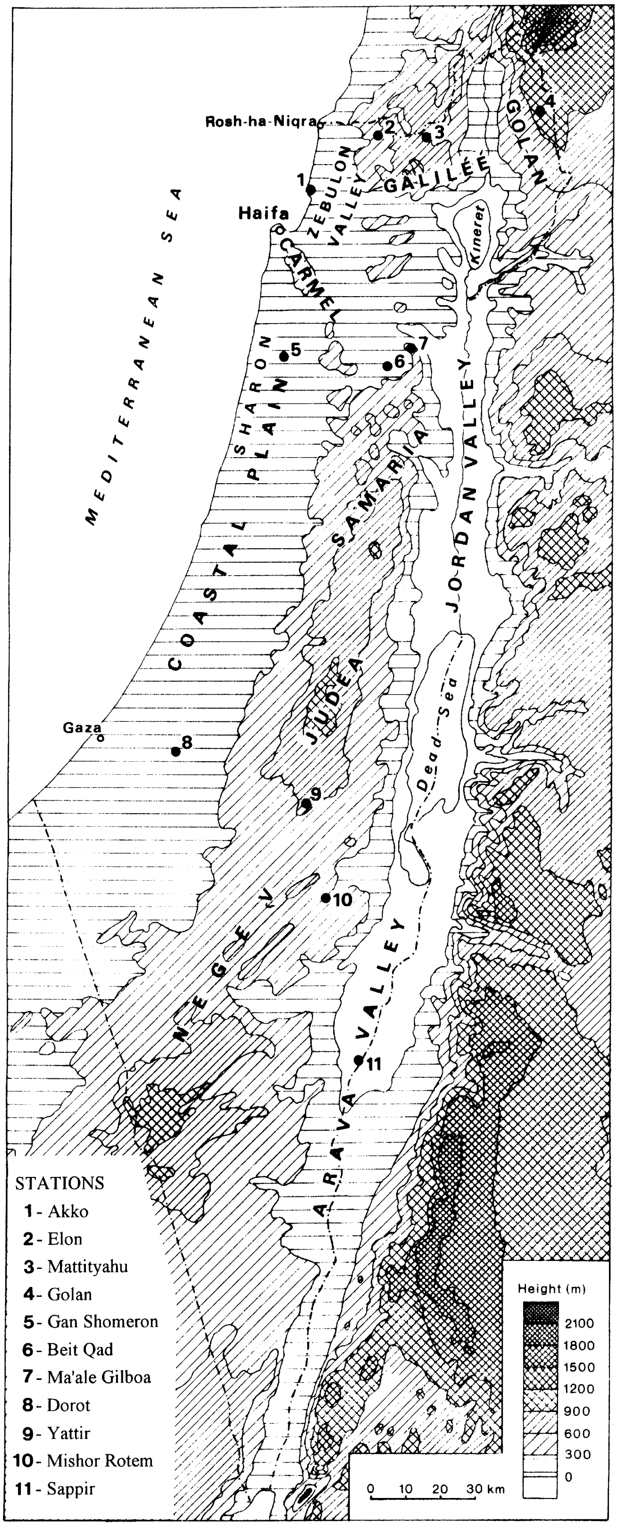


Fig. 1. The topography of Israel and the location of the stations

Most of the wind storms over Israel are westerly (Elbashan, 1981b; Bitan and Rubin, 1994). The dominant direction of wind storms is from the south-western to the north-western sector, associated with deep tropospheric disturbances. Most of them cover large areas of Israel and their intensities vary according to local conditions. Elbashan (1981b) found only 9 easterly wind storms of a total of 261 "stormy-days" over a studied 12 year period. His study was based on 14 stations for the years 1968–1979.

A comparison can be made between the easterly wind storms in Israel and the other known continental storms. The Bora and the Mistral are winds of continental polar or continental Arctic origin, usually penetrating gaps in the mountains along the northern coast of the Mediterranean, and are common during the cold season. The topographic factor is dominant in the formation of these winds (Air Ministry Meteorological Office, 1962; Barry, 1992). The Sirocco, Ghibli, Simoom, Khamsin etc. winds are of continental-tropical origin, causing warm and dry weather conditions (Air Ministry Meteorological Office, 1962; Winstanley, 1972; Alpert and Ziv, 1989). They are most common during the spring season and are associated with the warm front of the north African cyclones, which are known by the name 'Sharav' (Winstanley, 1972). Easterly winds characterize the warm fronts and the eastern portion of the warm sectors of frontal cyclones.

Over the eastern Mediterranean basin and the Levant region, the name 'Sharqiya' represents the easterly wind storms. Definitions of the name 'Sharqiya' are antithetical. One definition refers to a continental polar storm (Levi, 1965; Bitan, 1983), while another refers to a continental tropical storm (Academy of the Hebrew Language and Israel Meteorological Service, 1971; Tokatly, 1994). A broader definition of 'Sharqiya' refers to all of the easterly wind storms, which are dry and warm during the winter season (Katsenelson, 1967).

This paper presents the climatology of easterly wind storms at the Levant region derived from analyses of station data taken in Israel. The methodology is presented, and the frequency, spatial distribution and magnitudes of the wind storms is analyzed. Specific discussion is devoted to the different synoptic systems responsible for these storms, associated weather conditions and the diurnal course related to the sea-land breeze.

2. The Topography of Israel

The topography of Israel (Fig. 1) has a dominant effect on storm distribution, frequency and magnitude. The topography consists of three strips running south (or southwest) to north: the costal plain, the hilly region and the Jordan valley. The coastal plain gradually narrows from south to north. Its width is approximately 30 kilometers (at Gaza) and about 10 kilometers at its center, the Sharon area. In the north, the coastal plain is interrupted twice by hills penetrating into the sea-the Carmel cape and the cape of Rosh ha-Niqra. The Haifa bay, interrupting the otherwise almost unbroken shoreline, and the adjoining Zebulon valley differ from the rest of the coastal plain in possessing features of a subsiding graben. The hilly region is divided into three sections. The southern sections (the Negev hills), differs from the northern section in the orientation of its ridges and valleys in a northeast-southwest direction, rather than north south as in the central section. The central section of the hilly region includes Judea and Samaria, and the northern section is the Galilee region including the Lower and Upper Galilee. The Lower Galilee is up to 500 meters in height while the Upper Galilee is up to 1000 meters in height. Transjordan (east of the Jordan river), the western part of the Golan, is distinguished by its thick cover of basaltic rock and soil, the result of which is a plateau sloping westward, which is open to the influence of the Mediterranean sea (Orni and Efrat, 1971).

3. Methodology

There are different definitions for the threshold of a storm (Linacre, 1992). According to Elbashan's research (1981a), a day is defined as "Stormy" over Israel if the daily maximum wind speed (10 minute average) is 14.3 ms^{-1} (28 kt) or more, in at least two stations ('Elbashan's definition'). The definition of a *gale* at any single station must demonstrate one of three criteria:

a. A 10 minute average: wind speed over 17.5 ms^{-1} (34 kt).
b. An upper gust: wind speed over 25.8 ms^{-1} (50 kt).
c. An hourly average: wind speed over 15.5 ms^{-1} (30 kt).

The definition used for 'gale' in this study is definition a.

Despite the above definitions, the Israel Meteorological service (IMS) refers to 10.2 ms^{-1} (20 kt) at a 10 minute average, as the threshold for a wind storm, due to the resulting environmental implications (Elbashan, 1981a). Accordingly, the present research focuses on days in which the wind speed exceeded this threshold at any single station and the wind direction was between 010°–170° (IMS definition).

The data are based on simultaneous measurements for the years 1983–1988, using Woelfle anemographs. Figure 1 shows the location of the 11 principal wind stations, representing the various regions of Israel.

For the purpose of case study analysis, data were collected from all wind stations in Israel, most of them equipped with Woelfle, and the remainder with Daynes or Monro anemographs.

The synoptic study (Chapter 5) refers to a day with an easterly wind lasted for at least 24 hours, if at least one, out of the 11 stations, experienced an easterly storm according to the IMS definition. The synoptic classification performed for 197 days out of the 215 recorded days. This criteria indicates clearly synoptic systems of easterly flow that dominated over mesoscale flows such as sea-land breeze (Saaroni et al., 1996).

The synoptic maps are produced by software, developed by Neeman and Alpert (1990), based on the European Center of Medium Weather Forecasting (ECMWF) initialized analysis. The maps show the 1000 hPa level isohypses in decameters (dam) with a 2 dam interval. The magnitude of the wind-vector arrows represent 7 hours displacement.

4. Frequency

Table 1 indicates that easterly wind storms were recorded at least in one station over Israel, on about 10% of the days and in about 5% of the days (16.8 days) at least in two stations. An easterly gale is relatively rare and its annual frequency at one stations was only 1.66 days (0.5%).

These situations do not necessarily relate to the existence of a respective pressure gradient over all of Israel, or even over most of its regions.

Table 1. *No. of Easterly Wind Storms and Gale Days (1983–1988)*

Year	Wind storms in at least one station ($V > 10.2\,\mathrm{ms}^{-1}$)	Wind storms in at least two stations ($V > 10.2\,\mathrm{ms}^{-1}$)	Wind storms in at least four stations ($V > 10.2\,\mathrm{ms}^{-1}$)	Wind storms in at least one station ($V > 14.3\,\mathrm{ms}^{-1}$)	Wind storms in at least two stations ($V > 14.3\,\mathrm{ms}^{-1}$)	No. of easterly gale days in at least one station ($V > 17.5\,\mathrm{ms}^{-1}$)
1983	27	7	2	5	1	1
1984	35	20	3	2	1	1
1985	48	25	9	7	5	2
1986	28	13	7	5	3	2
1987	33	16	2	10	4	1
1988	44	20	7	12	5	3
Total	215	101	30	41	19	10
Yearly Average	35.8	16.83	5	6.83	3.2	1.66
Yearly Average (%)	9.8	4.6	1.4	1.9	0.9	0.5

Table 2. *Monthly Distribution of Easterly Wind Storm Days (1983–1988)*

	Jan.	Feb.	Mar.	Apr.	May	Oct.	Nov.	Dec.	Total
No. of easterly wind storm days	33	31	29	25	11	14	33	39	215
% of easterly wind storm days	15.4	14.4	13.5	11.6	5.1	6.5	15.4	18.1	100

The measure of easterly wind storms (IMS definition), including most of the country regions (i.e. at least in four stations at different areas of the country), is low – 30 days over six years, namely 5 days/year (i.e. 1.4%).

Monthly distribution (Table 2), reveals that during the summer months (June-September), there were no easterly wind storms due to the prevalence of the Persian Gulf trough, causing continuous north-western Ethesian winds (Bitan and Saaroni, 1992; Alpert et al., 1992). Accordingly, the easterly wind storms blow only during October-May and are most frequent during the cold season, depending on different synoptic situations (see chapter 5).

When comparing the frequency of easterly storms with Elbashan's studies (1977, 1981b), a higher average frequency during the period 1983–1988 is noted; i.e. 3.2 days/year, compared to 0.75 days/year in Elbashan during 1968–1979. These difference can be a result of several reasons:

(a) Too small samples.
(b) Different stations used in each study; The 1983–1988 study includes several stations that supposed to be more sensitive to easterly wind storms, and therefore might influence the results.
(c) Differences in instrumentation.
(d) Potential global effects. However, since climate change could not be analyzed for a period less than 20–30 years, this hypothesis requires further research.

5. Synoptic Conditions

Most continental storms around the Mediterranean basin are related to a typical synoptic system. The Bora and Mistral winds are associated with high pressure systems over Europe along with low pressure systems over the Mediterranean, the Aegean or the Adriatic seas. The Ghibli, Scirocco and Simoom winds are related to the warm front of the 'Sharav'

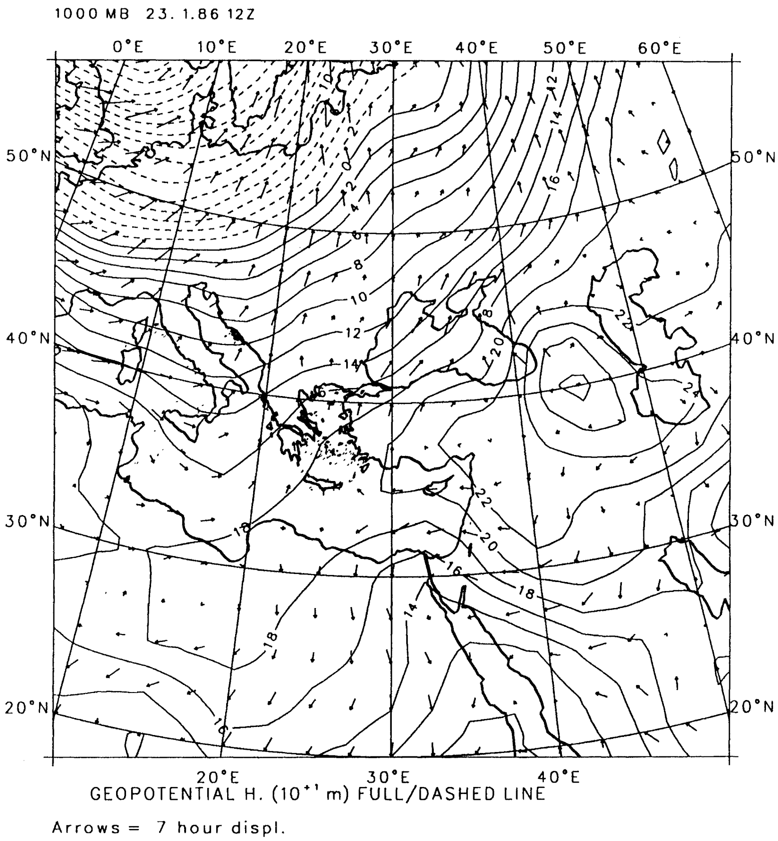


Fig. 2. 1000 hPa level for January 23, 1986

cyclone (Air Ministry Meteorological Office, 1962). The easterly wind storms over Israel and the Levant region are related both to the above mentioned systems and others. The synoptic situations were classified according to a manual generic classification (Yarnal, 1993). These days can generally be divided into two groups; 'quasi-stationary' synoptic situations and transient disturbances.

The 'quasi-stationary' situations include three types:

1. A lower level Red-Sea trough (e.g., January 23, 1986, Fig. 2), extending from the Red-Sea toward the north (Dayan 1983, Dayan 1986). A surface ridge is often located north of the trough, thus, an easterly flow develops over the Middle East (Fig. 2). It is combined with an upper level ridge extends from the sub-tropical anticyclone, causing air subsidence. The resulting weather conditions are hot, dry and stable due to the combined effect of the continental tropical advection and the air subsidence. Dust and sand storms are frequent east of the Levant, while haze often penetrates the region.
2. An 'active' Red-Sea trough (e.g. May 16, 1988, Fig. 3). The surface systems is quite similar to the former with a continental tropical outbreak (Fig. 3). But, the upper levels are characterized by a cyclonic southerly flow that cause an upward motion, resulting in an unstable conditions. These conditions are characterized by Altocumulus clouds in contrast with the clear skies characterizing the former. Heavy showers and thunderstorms in the eastern parts of Israel are occasionally characterizing this system. Downbursts from cumulonimbus clouds were created under this synoptic situation (Ziv and Yair, 1994).
3. A polar ridge, which causes a continental polar outbreak into Israel and the Levant region (Saaroni et al., 1996), e.g. January 22, 1986 (Fig. 4). The easterly wind storms then are the result of a pressure gradient which develops between the high pressure systems in the north (Lydolph, 1977), and the Red-Sea

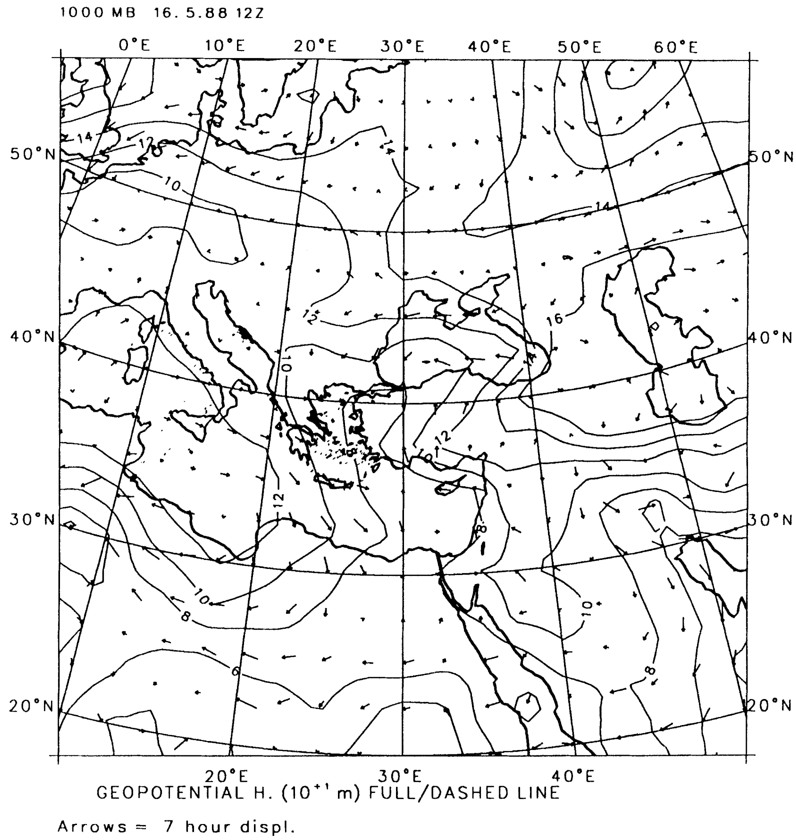


Fig. 3. 1000 hPa level for May 16, 1988

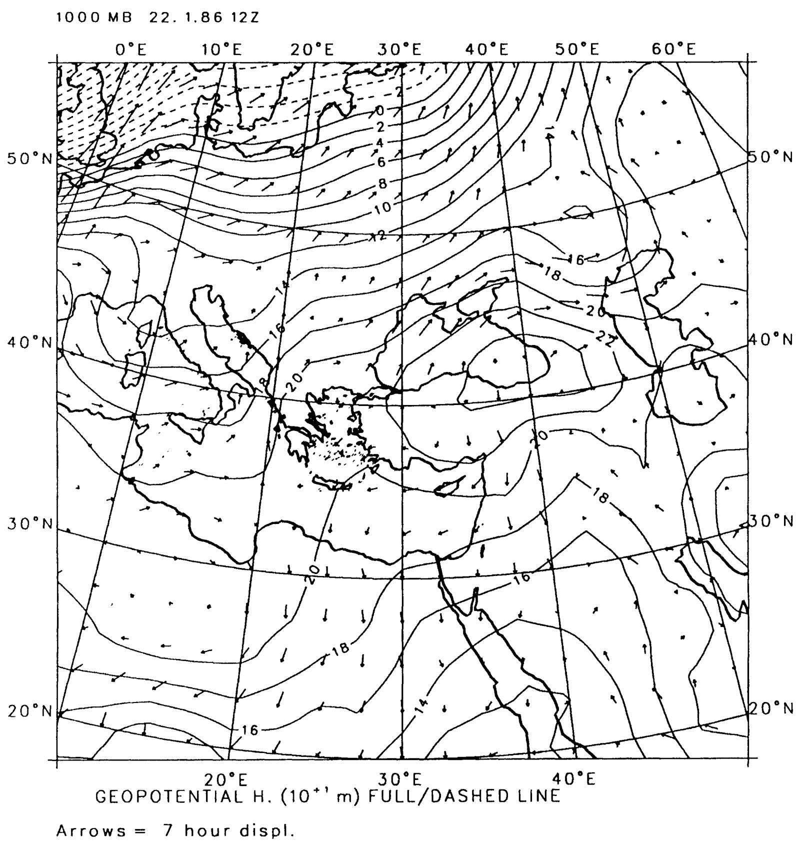


Fig. 4. 1000 hPa level for January 22, 1986

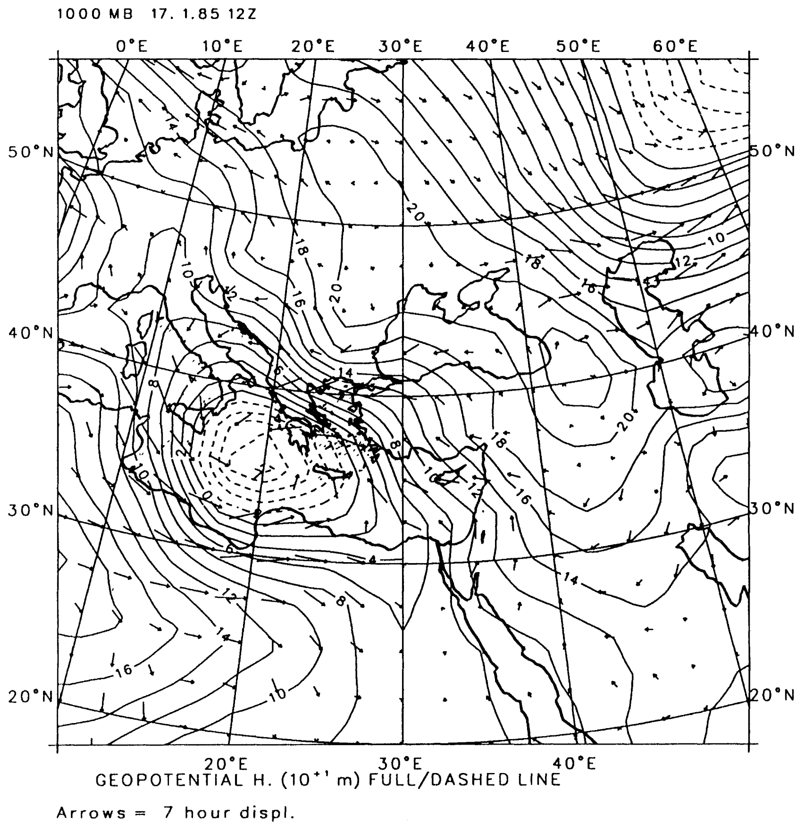


Fig. 5. 1000 hPa level for January 17, 1985

trough located further to the south. It must be emphasized that the continental polar outbreak, known as a 'Siberian anticyclone' over the Levant (Elbashan, 1977; Ronberg, 1984; Lieman, 1993; Shafir et al., 1994), was found to be generated over different locations such as, Turkey, the Caucasian region, western Asia and eastern Europe. Thus, it became known as a "Polar ridge" (Saaroni et al., 1996). Nevertheless, weather conditions during these outbreaks are similar; cold, clear, dry and stable (Saaroni et al., 1996).

Transient tropospheric disturbances include two apparently similar synoptic situations:

1. A warm sector of a Cyprus cyclone (Alpert et al., 1995), e.g. January 17, 1985 (Fig. 5). An easterly storm develops at the warm forefront and during the first stages of the warm sector passage. The center of the cyclone is located between Crete and Cyprus, while Israel is influenced temporarily by a Red-Sea trough from the south and high barometric pressure to the north. The winds are mostly south-easterly, causing continental tropical advection, with a tendency to warming and dryness. Easterly wind storms are not typical to every cyclone crossing the region. Dust and sand storms are correlated to wind speed. Further advance of the cyclone causes the wind to veer into the southern and southwestern sectors.
2. A warm sector from the 'Sharav' cyclone (e.g. May 26, 1988, Fig. 6). The easterly wind storm usually starts while the cyclone is crossing eastern Libya. Nevertheless, easterly wind storms associated with the 'Sharav' cyclones are shorter in duration and more intense than in a warm sector of a Cyprus cyclone. The characteristic period of time whereby the Sharav cyclone is active is about half of that of the Cyprus Cyclone. The weather conditions are characterized by an acute warming and dryness accompanied by dust and sand storms (Alpert and Ziv, 1989).

Table 3 demonstrates the distribution of easterly stormy days in Israel according to the

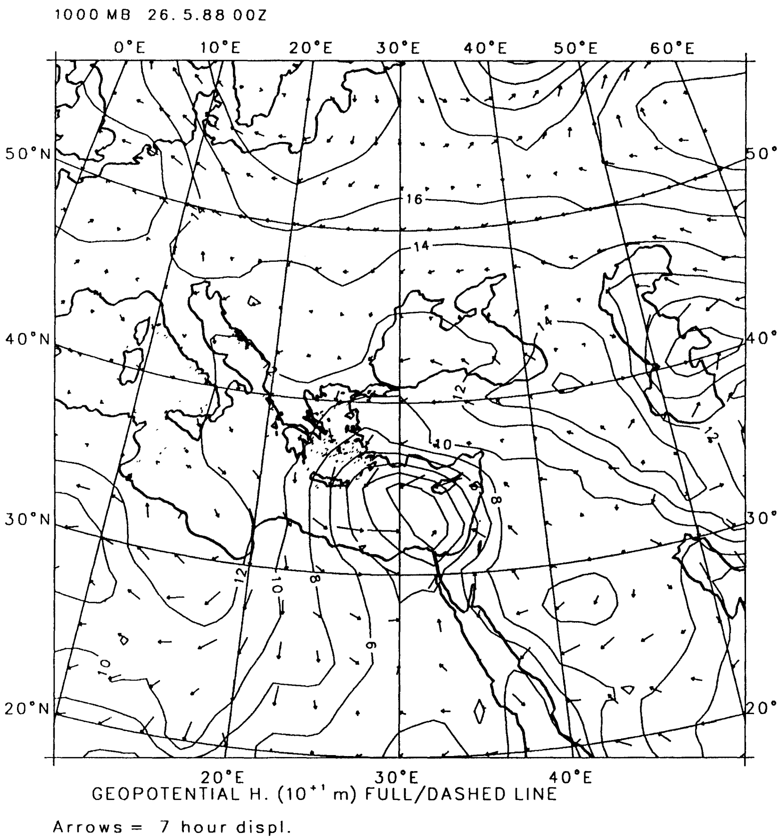


Fig. 6. 1000 hPa level for May 26, 1988

Table 3. *Synoptic Distribution of Easterly Storm Days (1983–1988)*

Synoptic condition	No. of stormy days ($V > 10.2\,\mathrm{ms}^{-1}$)	% of all synoptic conditions
a. Red-Sea trough with a surface ridge	96	49
b. "Active" Red-Sea trough	22	11
c. Polar outbreak	20	10
d. Warm front of cold cyclone	25	13
e. Warm front of 'Sharav' cyclone	34	17
Total of defined situations	197	100
Undefined	18	
Total	215	

relevant synoptic systems. Most systems are 'quasi-stationary' (70%), the most dominant being the situations of the Red-Sea trough, with ground ridge. The tropospheric disturbances are less frequent (30%). It should be noted that the quasi-stationary situations were found to last for several days, while transient disturbances, influencing the region for short periods, lasted typically only 1 day.

Only 18 (8%) days, out of the 215 recorded days, remained undefined because these days were characterized by rapid change in the synoptic situation throughout the day and the easterly flow lasted only for few hours. Most of these days belong to the category of transient tropospheric disturbances, particularly the warm fronts of the 'Sharav' cyclones. They are characterized by rapid movement, in particular, in the case of the 'Sharav' cyclones (Alpert and Ziv, 1989). This picture indicates that 92% of the days of easterly winds storms are part of a synoptic pattern which causes easterly winds, for at least 24 hours, and not a single short gust wind.

6. Spatial Distribution

Table 4 presents the spatial distribution of the above mentioned storms for the 11 research stations. These results indicate the following:

Table 4. *No. of Easterly Wind Storm Days and Percentage of Total Measured Days at 11 Stations, 1983–1988*

No. of Station	Station	Height (m a.s.l)	No. of easterly storm days	No. of measured days	% days with easterly storms
1	Akko	15	71	908	7.8
2	Elon	300	74	1080	6.9
3	Mattityahu	700	23	1317	1.8
4	Golan	940	54	1381	3.9
5	Gan Shomeron	50	1	1455	0.1
6	Beit Qad	150	13	1362	1.0
7	Ma'ale Gilboa	500	92	1028	9.0
8	Dorot	110	14	1346	1.0
9	Yattir	650	70	1322	5.3
10	Mishor Rotem	387	22	1435	1.5
11	Sappir	10	2	1221	0.2

There are specific regions less sensitive to easterly wind storms:

- The central and southern sections of the coastal plain have relatively low frequencies of easterly wind storms. This seems to reflect both synoptic, mesometeorological and micrometeorological factors: western regions which are further from the regions where the pressure gradient is maximum, the influence of the sea breeze and the absence of a topographical effect (height and slope) in contrast to the northern section of the coastal plain (Fig. 1).
- The Arava valley, represented by Sappir (station 11) has the lowest frequency due to the topography, i.e., north-south orientation of the valley channels the flow into a dominant northern flow.

The following regions were found to be most sensitive to easterly wind storms:

- The western slopes of the mountains, e.g. Elon (station 2), at the western Galilee mountains, as indicated by Elbashan (1977). The same tendency characterizes the eastern part of the Hula valley and the coastal plain along the Carmel mountain.
- The east-west valleys, where channeling effect intensifies easterly flow, exemplified by Akko (station 1) and characterizing the Galilee valleys. The location of Akko at the foot of the western Galilee mountains is an additional factor for enhancing the easterly flow.
- The summits of mountains and high regions. The main causes can be attributed to reduced friction, wind strengthening with height and the weakening effect of the sea breeze. It must be emphasized that the micro-climatic conditions in these elevated regions have a dominant effect on the frequency and distribution of the easterly wind storms, e.g. plateau regions [Mattityahu (station 3) and Golan (station 4)] have lower frequency than the mountains' summits [Yattir (station 9) or Ma'ale Gilboa (station 7)].

Skibin (1985) indicated that strong downslope acceleration occurs in special cases where there is an inflection point in the wind profile, most typical of easterly wind storms (Sharqiya) in Israel.

Although local conditions, in microscale terms, are dominant for the storm's frequency and distribution, it should be noted that higher frequency was noticed over the northern parts of Israel. This tendency may be explained by synoptic conditions. During 'quasi-stationary' synoptic situations the pressure gradient is typically higher in the north of Israel.

7. Diurnal Effects

In order to study the diurnal variations of easterly wind storms in Israel, we selected 15 days out of the sample. They were taken from the middle period of the prolonged events at the stage when

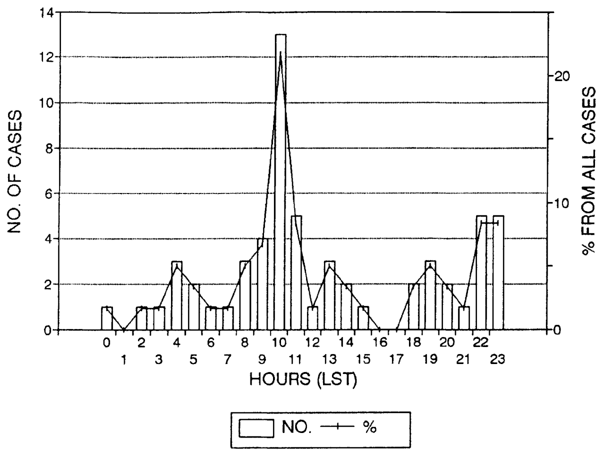


Fig. 7. The time distribution of maximum wind speed, for all stations over central and northern Israel, during the representative days

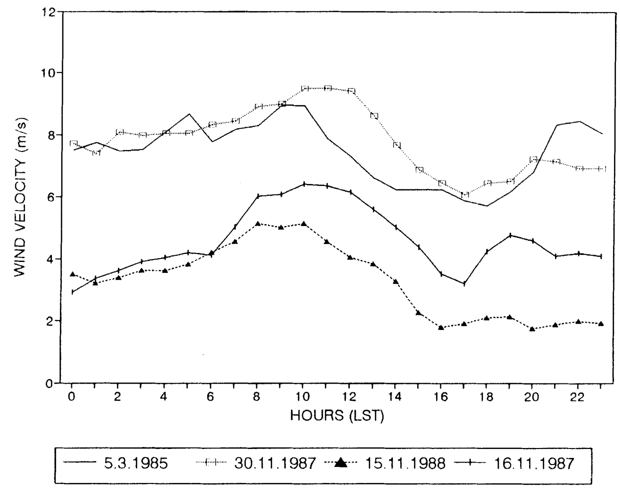


Fig. 8. The hourly average wind speed, during four representative days, of easterly wind storms from all measuring stations

the synoptic-scale pressure gradient was relatively constant. For these days, we examined the time of maximum wind speed for stations having easterly strong wind (from the 11 research stations). Figure 7 shows the time distribution of the maximum wind speed during these days. It indicates that the maximum wind speed may appear at any hour of the day, but that there is a distinct preference for the morning hours. Between 0800–1200 L.S.T, where 52% of the daily maximum wind measurements were recorded, two third of them between 1000–1200. In comparison, during the hours 1300–2000 L.S.T, the frequency was only 1.5% of the measurements,

Figure 8 shows the hourly average wind speed for the research stations during four representative days. Two days, November 30, 1987 and November 15, 1988, represent warm days, while March 5, 1985 and November 16, 1987, represent cold days, These days represent different synoptic systems. It indicates a maximum in wind speed during the morning hours and a decrease during the afternoon hours. These results are consistent with those presented in Fig. 7 and indicate significant diurnal variation in time for the maximum wind.

This finding differs from the nocturnal maxima found by Atkinson (1981) for downslope winds. For most stations included in our study, easterly winds are actually downslope winds (Fig. 1). Therefore, the diurnal variation found here can be explained as a combination between the diurnal wind course of the synoptic flow itself together with the effects of sea-land breeze circulation and katabatic winds. The former is expressed by an increase in wind speed during day hours due to the vertical convection that transports momentum from upper levels downwards. In other words, the friction is deeper and the winds near the ground strengthen (Lamb, 1972; Sutton, 1953). The sea breeze, is effective all over Israel (Alpert et al., 1988a, 1988b) and suppresses the easterly wind during the afternoon hours. Lieman and Alpert (1993) has shown a distinct sea breeze along the eastern Mediterranean coastal strip during synoptic conditions of prevailing easterly flow. Alpert et al. (1988b), applying a model for simulating a continental polar outbreak, obtained a decrease in the easterly wind speed during the afternoon hours. They explained it as the result of the contribution of the pressure gradient related to the sea breeze. Venkatesh and Danard (1978) found a similar tendency along Ontario lake. This mesometeorological factors favours the decrease in the occurrence of maximum easterly wind during the afternoon hours. Two other factors that has to be taken into account are the nocturnal land breeze and katabatic winds at the foots of mountains. They contribute to the increasing of easterly winds during the night hours. For the above arguments, easterly winds in Israel are, indeed, expected to strengthen during the morning hours as demonstrated above.

Synoptic factors may also influence these diurnal variations mainly during the 'quasi-stationary' situations. Continental polar highs, being thermal systems, tend to build-up and intensify during the colder night hours, thus, the maximum pressure gradient and the easterly wind tends to be maximum in the morning hours accordingly (Saaroni et al., 1996).

Where intense synoptic systems are concerned, the wind course and the timing of the strongest winds are not expected to reflect diurnal variations along wind storms. Nevertheless, Alpert et al. (1990) detected diurnal variations even when intense cyclones affected the region.

In conclusion, although the maximum wind speed appeared at different hours, due to the course of the synoptic evolution, diurnal variations were found in easterly wind storms, mostly due to the contribution of the sea breeze, to the general diurnal variation of wind speed and partly due to the contribution of the sea breeze to the general diurnal variation of wind speed, and partly due to the synoptic conditions.

8. Wind Speed

The wind speed regime of the easterly wind storms in Israel can be expressed in the following two forms: monthly average of maximum speeds, expressing the average magnitude of these storms (Table 5), and absolute maximum speed (Table 6), all refers to 10 minutes average. A typical maximum of 10–14 ms^{-1} characterizes these storms in Israel, while the absolute maximum speed for the period 1983–1988, 21.6 ms^{-1}, was measured on November 30 1987, at Akko (station 1). The maximum wind speed recorded in Israel during the same day was 28 ms^{-1} in Dammon (a station which is not included in the 11 principal stations), at the western slope of the Carmel mountain.

Most extreme wind events in Israel were characterized by westerly winds (Rubin et al., 1997). The absolute maximum westerly wind, 44 ms^{-1}, was recorded in Stella Marris, located at the top of the Carmel mountain, on January 1968. Several events of strong westerly winds up to 36 ms^{-1} were measured at mountains tops in Israel. Along the coastal plain the absolute maximum westerly winds, 31 ms^{-1}, were recorded in Tel Aviv in 1946. The absolute maximum easterly wind ever recorded in Israel was 38 ms^{-1}, at the western slope of the Samaria mountains, near Ma'ale Gilboa, on February 1981 (Rubin et al., 1997).

These results indicate that Israel is not subject to violent easterly wind storms, although in some events the damage was significant. The significant differences in wind velocity between the stations are associated with the locations of these stations. The topographic height is not the dominant feature for determining wind speed. For example, Mattityahu (station 3), located in the upper Galilee mountains at a height of 800 meters, has lower velocities compared with Elon (station 2), located in the western Galilee mountains at a height of 500 meters only, or Akko (station 1), located in the Zebulon valley, at a height of 50 meters only. The differences seem

Table 5. *Monthly Distribution of Easterly Storms, Average Velocities (ms^{-1})*

No. of Station	Station	Jan.	Feb.	Mar.	Apr.	May	Oct.	Nov.	Dec.	Monthly Average
1	Akko	11.8	13.4	13.4	13.4	13.9	–	13.4	13.4	13.3
2	Elon	12.4	11.8	12.4	11.3	11.3	12.9	11.8	11.8	12.0
3	Mattityahu	11.8	11.3	9.8	10.3	–	–	10.3	10.8	10.8
4	Golan	12.4	11.3	11.3	12.4	–	10.8	11.3	11.3	11.5
5	Gan Shomeron	10.8	–	–	10.8	–	–	–	9.8	10.5
6	Beit Qad	9.8	–	12.4	11.6	10.8	12.4	–	11.8	11.7
7	Ma'ale Gilboa	12.4	12.4	12.9	13.9	–	11.8	11.3	12.4	12.5
8	Dorot	11.6	9.8	14.4	11.6	9.8	–	10.6	10.8	11.2
9	Yattir	12.7	10.8	11.8	11.6	10.8	12.4	11.8	12.4	11.9
10	Mishor Rotem	12.1	11.8	12.9	11.8	13.9	11.3	11.3	11.3	11.9
11	Sappir	–	–	–	10.8	–	–	–	9.8	10.3

Table 6. *Monthly Distribution of Maximum Easterly Storm Velocities* (ms^{-1})

No. of Station	Station	Jan.	Feb.	Mar.	Apr.	May	Oct.	Nov.	Dec.	Average maximum
1	Akko	12.9	20.6	15.4	17.0	17.0	–	21.6	18.0	17.5
2	Elon	18.0	17.0	13.4	13.9	12.4	12.9	15.4	15.4	14.8
3	Mattityahu	15.4	11.3	9.8	10.8	–	–	10.8	10.8	11.3
4	Golan	14.9	12.9	12.4	16.0	–	11.3	12.4	12.4	15.3
5	Gan Shomeron	10.8	–	–	10.8	–	–	–	9.8	10.5
6	Beit Qad	9.8	–	16.0	13.4	10.8	12.4	–	13.9	12.8
7	Ma'ale Gilboa	14.4	17.0	18.0	18.5	–	13.4	13.9	14.9	15.7
8	Dorot	12.4	9.8	14.4	12.4	9.8	–	11.3	10.8	11.5
9	Yattir	20.6	11.8	14.9	17.0	11.3	13.9	14.4	13.9	14.7
10	Mishor Rotem	12.9	12.4	13.4	13.4	13.9	11.3	11.8	11.3	12.6
11	Sappir	–	–	–	10.8	–	–	–	9.8	10.3

to result from the local conditions engendered by the downslope acceleration in Elon (station 2) and the channeling effect of the Beit Hakerem valley in Akko (station 1). Land breeze and katabatic winds during night time are also contributing to this process.

There is a significant correlation between the frequency of stormy days and the velocity. Figure 9a illustrates the correlation between the number of easterly wind-storm days (x) for the years 1983–1988, and the average maximum speed at the 11 stations (y), while Fig. 9b illustrates this correlation with the maximum wind speed during the month of April (y). The r^2 has been calculated according to the following formula:

$$r^2 = (\Sigma xy)^2/(\Sigma x^2)(\Sigma y^2)$$

where: $x = x - x_{\text{average}}$ and $y = y - y_{\text{average}}$

Both have an r^2 of ~ 0.8. Accordingly, the stations that are more sensitive to easterly wind storms (i.e. having higher frequency of this storms), are also subject to stronger wind velocities.

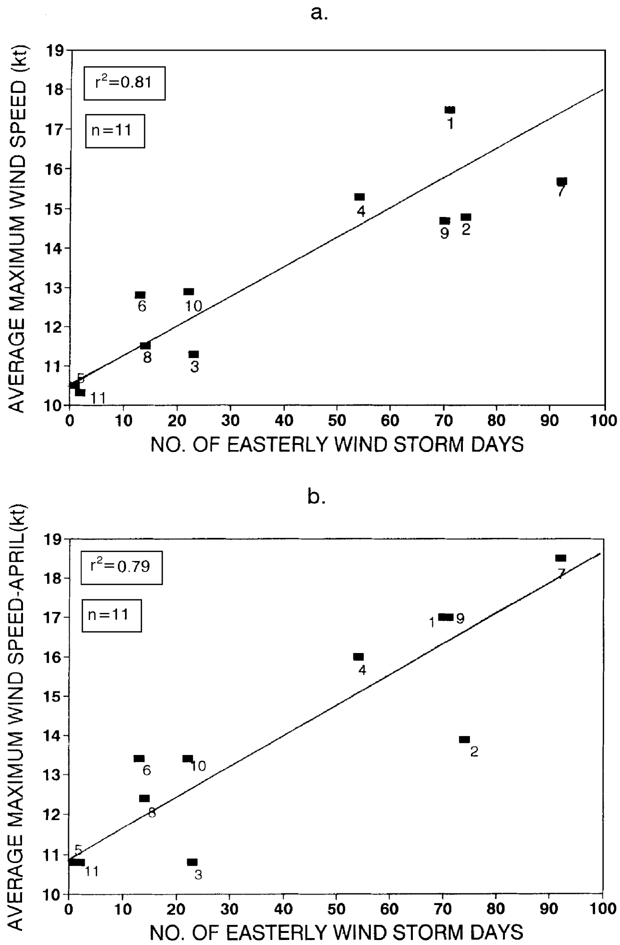
In contrast, no correlation was found between the monthly distribution of easterly wind storm days and maximum wind velocities. The storms are more frequent during the cold season (Table 2), whereas maximum velocities occur mainly during the transitional seasons, especially spring (Tables 5 and 6). Violent easterly wind storms characterize the warm front of the 'Sharav' cyclones, which may last for only a few hours due to their quick passage.

9. A Case Study: March, 11–12, 1992

The easterly wind storm of March 11–12 1992, was one of the most violent and widespread storms in the region. It caused extensive environmental damage, including flooding at the western shore of the Kinneret lake and destruction caused by roof destruction in Akko (station 1), at the western part of Bet Hakerem valley.

This storm was characterized by a sharp change in the synoptic situation during its course. The synoptic map from March, 11, 1992 (Fig. 10) shows a steep pressure gradient over the eastern Mediterranean and Israel due to the combined effect of a polar ridge from the north and the Red-Sea trough from the south. This caused a continental polar outbreak with low temperatures and low relative humidity. The 850 hPa temperature at Bet Dagan, located at the center of the Israeli coastal shore, was significantly below the monthly average. A sharp change occurred during the second day of the storm, March 12, 1992 (Fig. 11) while a 'Sharav' cyclone developed over Egypt, causing a continental tropical outbreak and rapid warming, with dust penetrating from the south-east due to a change in the origin of the airmass.

Wind speed was monitored during this two day event at all stations in the central and northern part of Israel. Figure 12a illustrates the location of these stations. Figure 12b demonstrates the course of the wind speed. It indicates a diurnal variation of wind speed and differences between individual stations.



1 - Akko
2 - Elon
3 - Matityahu
4 - Golan
5 - Gan Shomeron
6 - Beit Qad
7 - Ma'ale Gilboa
8 - Dorot
9 - Yattir
10 - Mishor Rotem
11 - Merkaz Sappir

Fig. 9a. The correlation between the number of easterly windstorm days, (1983–1988) and the average maximum speed at the 11 stations ($r^2 = (\Sigma xy)^2/(\Sigma x^2)(\Sigma y^2)$) b. As in Fig. 9a, this correlation is for the maximum wind speed in April

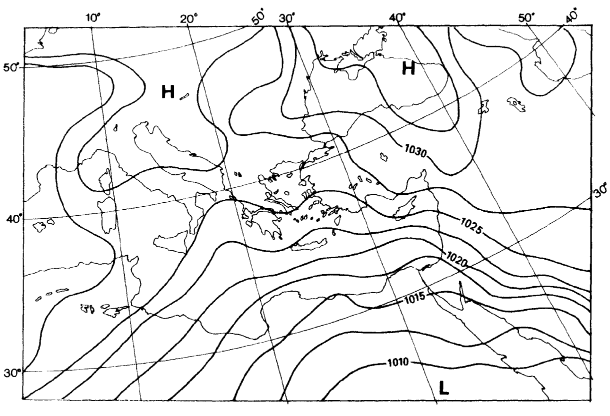


Fig. 10. Sea level pressure for March 11, 1992

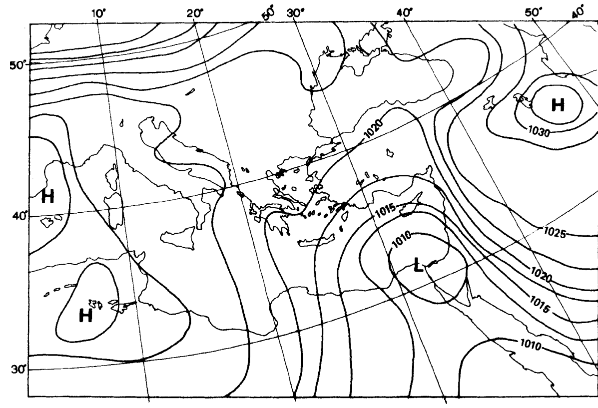


Fig. 11. As in Fig. 10, for March 12, 1992

It could be possible that there might have been an earlier timing of the maximum wind speed at the eastern stations compared with the western ones. It can be observed from Fig. 12b that the maximum wind speed in Haifa and Akko (station 1), the western stations located at the Mediterranean seashore, occurred later than at the eastern stations, e.g. Hachula and Karei-Deshe. It is interesting to point out that at the easterly stations, Avney-Eitan, Dafna, Yavniel and Karei-Deshe the maximum wind speed was measured on the first day of the event, March 11, while at the other 14 stations (all located westward), the maximum wind speed was measured on the second day of the event, March 12. It is proposed that this tendency is due to an advance of a secondary disturbance (or wave) superimposed upon the synoptic system, a subject justifying further investigation.

10. Summary and Conclusions

From the global point of view, the eastern Mediterranean, the Levant region and Israel are located between the planetary westerly wind belt and the subtropical anticyclone. Easterly winds over the region deserve a special explanation. They may be attributed to three different factors: (1) Continental polar outbreaks, which are manifestations of the winter Asiatic monsoon. (2) Northward extension of the trade winds associated with the Red-Sea trough, or (3) Incidental approaches of moving atmospheric disturbances. These synoptic conditions occur between October and May, and are most frequent during

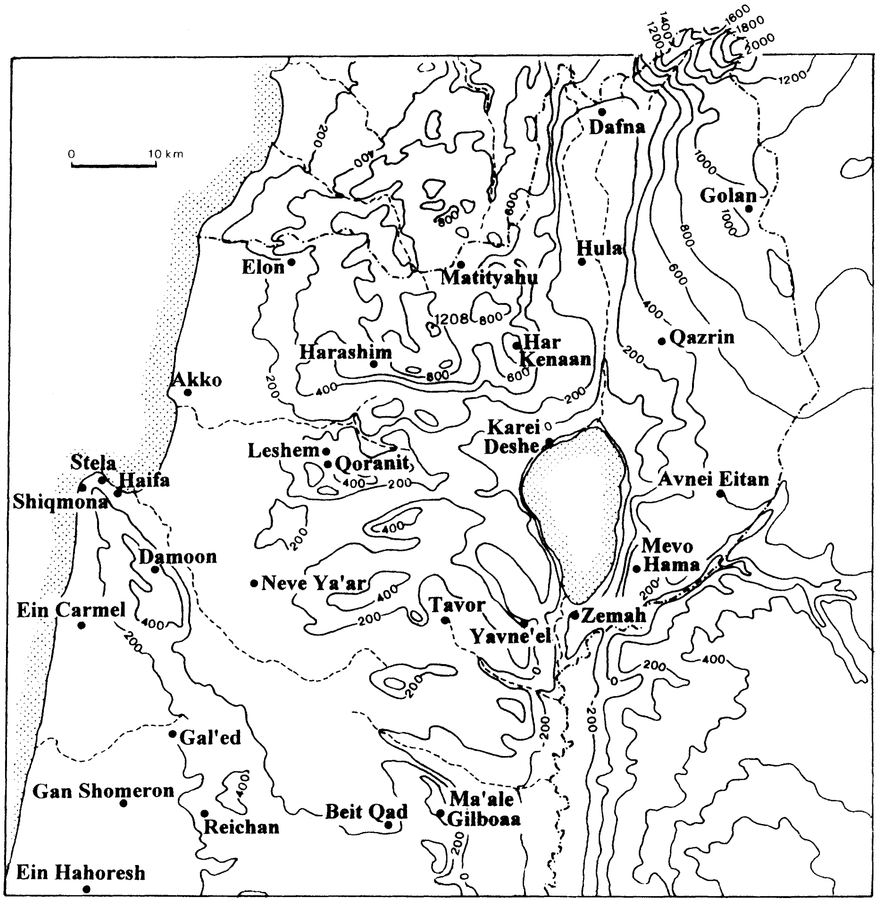


Fig. 12a. The location of wind measurement stations in the center and northern parts of Israel during March 11–12, 1992

the winter months (December–February), due to the increase in frequency of both the polar anticyclone and the tropospheric disturbances. The prevailing Ethesian winds during June–September, eliminate easterly flow during the summer.

These easterly wind storms are far less frequent than the westerly wind storms over the region, with an average of 6–7 days/year. Nevertheless, as demonstrated above, the region of Akko (station 1) was subject to over 35 days/year. Easterly gales, i.e. $V > 17.5\,\mathrm{ms}^{-1}$, are quite rare, 1–2 days per year, and are restricted to sensitive regions. However, the absolute maximum speed ever recorded with easterly wind in Israel was $38\,\mathrm{ms}^{-1}$.

The spatial distribution of the easterly wind storms has a diurnal variance due to the meso- and micro-scales. The sea breeze is a dominant factor for the decrease in velocities and frequencies along the coastal strip. Land breeze is a supportive factor for the easterly wind speeds. Special topographic postings over westerly mountain slopes and valleys with a west-east orientation, strongly favor the easterly storm. The synoptic factor has less influence on the spatial distribution, mostly causing a decrease in the storm's frequency, from north to south, due to a stronger pressure gradient in the northern part of the region. The antithetical origin of the airmasses of different synoptic systems, is the cause of the extreme penetration of continental airmasses into Israel, i.e. the warmest as well as the coldest episodes. Change in the penetrating airmass may occur during one event, while the easterly wind storm continues to blow. Relative humidities for the easterly wind storms are mostly far below the monthly averages.

There is a tendency for wind to strengthen at specific hours during the storms, as illustrated.

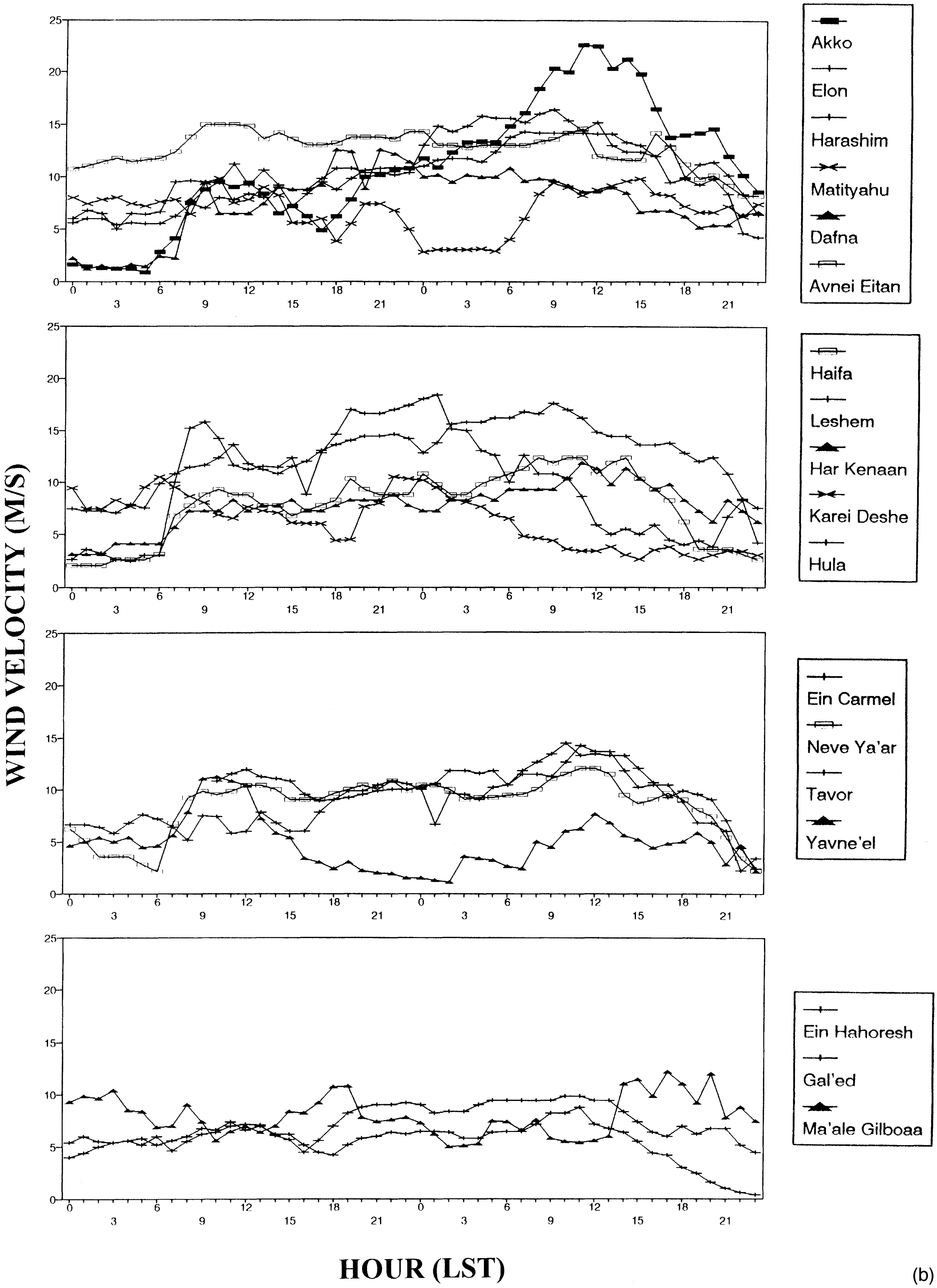


Fig. 12b. The wind speed according to Fig. 12a

Although the maximum wind speed occurred at various different times during the day, a tendency was also found for the morning hours to be most favored for the easterly wind to strengthen, while wind speed decreased typically during the afternoon hours, due to the contribution of the sea breeze and other synoptic factors.

Due to the resulting influence on agriculture, forest fires, air pollution, dust and sand storms and occasionally severe damage, caused by the easterly wind storms, it is important to further study their climatological and synoptic characteristics in order to enhance our knowledge and to improve the forecasting of their occurrence, timing and intensity.

Acknowledgments

The authors would like to thank the Israel Meteorological Service for providing Meteorological data, and Dr. Yaakov Dorfman who prepared the drawings.

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Authors' addresses: Hadas Saaroni and Arieh Bitan, Department of Geography, Tel-Aviv University, Ramat-Aviv, Tel-Aviv 69978, Israel; Baruch Ziv and Pinhas Alpert, Department of Geophysics and Planetary Sciences, Tel-Aviv University, Ramat-Aviv, Tel-Aviv, 69978, Israel.