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Article *in* Natural Hazards · June 1998

DOI: 10.1023/A:1008078920113

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Natural Hazards **18:** 1–25, 1998.

Analysis of Meteorological and Terrain Features Leading to the İzmir Flash Flood, 3–4 November 1995

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(Received: 23 December 1996; in final form: 3 March 1998)

Abstract. Flash floods associated with heavy precipitation has become a hazardous phenomenon along the Mediterranean coasts of Turkey in recent years. During 3 and 4 November 1995 heavy and intense rainstorm activity over the Aegean coast led to flash flooding in the city of İzmir. Damage exceeded $50 million and 61 people died as a result of the flood. The Karşıyaka district suffered the most severe damage. This study presents an analysis of the meteorological settings that led to the development of these intense storms and describes the role of the terrain features involved in the İzmir flood.

The important mesoscale features which initiated the severe weather outbreak included pronounced low-level advection, positive vorticity and strong upper level divergence. A surface low centered over the Aegean Sea enhanced the advection of warm and moist unstable air masses coming from the southwest over the Mediterranean Sea along a southwesterly low level jet (LLJ). A squall line oriented NE-SW over the Aegean Sea also contributed to the storm development, and intensity of the storms was further enhanced by the orographic effect. The presence of a frontal system, the stability indices associated with the event, and other meteorological features are all reminiscent of the synoptic type flash floods identified by Maddox. While the pressure and moisture patterns were favorable for severe storm activity, nonmeteorological factors including the topography, geompor-phology, and and land-use contributed to the flooding to a great extent. Settling in the flood-prone zone, insufficient floodwater structures, and the lack of channel improvements in the creeks enhanced flood damage to the city. Many of the deaths occurred in the settlements located in the flood-prone zone of the Ilıca and Dallık creeks.

Key words: flash flooding, low-level advection, orographic lifting, convective rainfall, flood-prone zone, İzmir, Aegean coast.

1. Introduction

Flash floods are usually produced by intense convective storms which cause very rapid runoff, and the damaging flood usually occurs within hours of the causative rainfall and affects very limited areas. Heavy rain events, with even hundreds of mm of precipitation in some hours, leading to damaging flash floods, have become a hazardous phenomenon along the coastal parts of Turkey. The coastal parts are particularly vulnerable to flooding in October and November, given rainfalls that would not be abnormal for this time of year. The Aegean coast alone was inundated by large-scale flooding several times in the last five years. The Marmaris flood on December 1992 and İzmir and Antalya floods on November 1995 are typical examples of such devastating floods.

A group of rainstorms swept through the Aegean and Mediterranean coasts of Turkey during 3–5 November 1995 and led to devastating flash floods. As much as 212 mm of rain fell within 24 hours in some parts of the Mediterranean coast (Figure 1). Settlements along the Aegean coasts suffered the greatest damage from the flood. Creeks draining the steep valleys rose quickly in the heavy rain and around midnight devastating floods swept through the settlements situated in the flood-prone zone of the creeks and where the creeks drain from the hills into the Aegean Sea. The heavy rains caused flooding in 27 creeks in the area (DSI, 1995). It has to be noted that most of the creeks in the area are simply winter torrents, only flowing after heavy rain. The flood associated with the heavy rains claimed the lives of 61 people and caused more than 50 million dollars of residential and commercial property damage in İzmir, which is a city of more than two million people (Figure 2). Cars, bridges and buildings were swept away by the raging floodwaters of creeks which had burst their banks (Figure 3). While 322 buildings were destroyed completely, nearly 10,000 houses suffered major damage as a result of the flooding in the city. Damage from the flood was greatest in the Karşıyaka district where most of the losses occurred in commercial and residential areas. The severe weather in the Aegean coast on 3–4 November 1995 was forecast quite well by the Turkish State Meteorological Service although the exact location of the heavy rainfall was not pinpointed. A severe weather warning was issued at 1200 LST on 3 November 1995, but it was too late for the local authorities to take the necessary precautions to avoid the adverse consequences of the flood. A factor which may have contributed to this lack of proper reaction is the fact that previous floods in the city of İzmir had not been nearly as severe as this event. Therefore, most residents did not have previous experience in dealing with such a dangerous flood event. The rapidity of the inundation coming during darkness at midnight when most people were asleep caused even greater confusion. As the damage and fatality associated with the flooding are significant, it has become important to document and understand the synoptic and mesoscale features and terrain conditions involved in the flood. The premise of this study is that floods are complex natural phenomena, but they are understandable when the producing mechanisms are identified and when we can explain how combination of meteorological extreme and terrain features act to create favorable flooding conditions. Moreover, any investigation of the processes by which heavy precipitation occurs can be of value to weather forecasters, provided the study focuses on the physical processes that lead to development of intense rainfall (Johns and Doswell, 1992).

The climate of the Aegean region is of the Mediterranean type with hot and dry summers and relatively cool winters. Most of the rainfall is concentrated between November and January. The climate of the coastal parts is less extreme than that

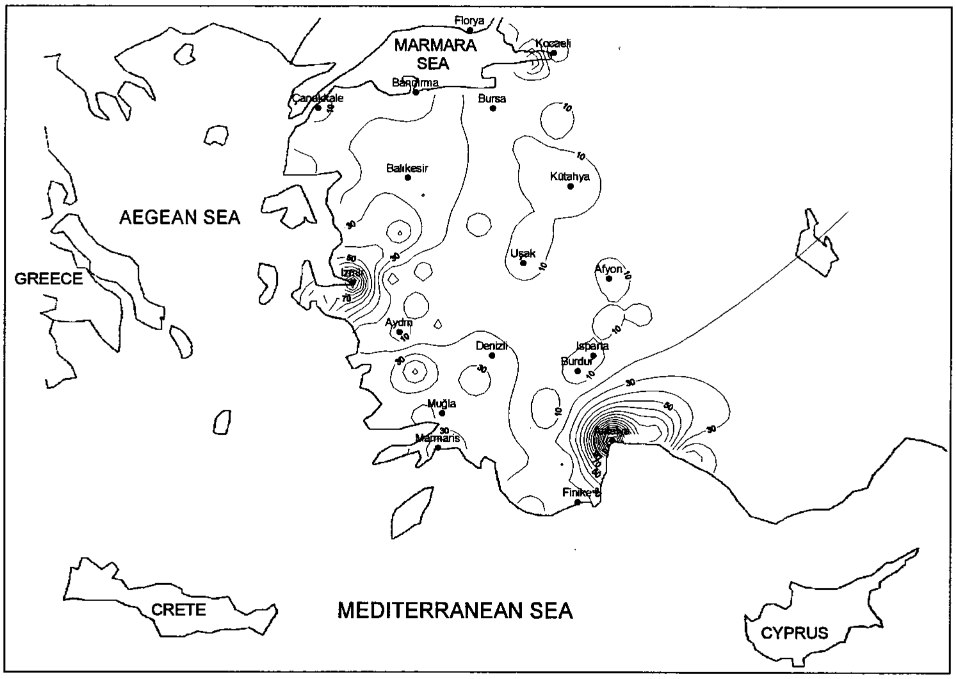

Figure 1. Geographical distribution of the 24-hour rainfall in the Mediterranean and Aegean regions during 3–4 November 1995.

of the inland, due to the fact that the effect of the sea-induced atmospheric humidities is always present there. Spring and autumn are short, typified by changeable weather, with occasional heavy storms battering the coast in spring and a westerly wind, called "meltem" carrying the influence of Atlantic depressions to this far eastern end of the Mediterranean. Short-lived stormy conditions resulting from fairly frequent small depressions prevail throughout the winter, with 60 per cent of rain falling between December and February. The chief rain-bearing air currents reach the area from the south-west, so that precipitation and atmospheric humidity is at its greatest on the western and south-western sides. Eastwards, precipitation and humidity are reduced by the partial rain-shadow effect of the mountains. Eastwards of the mountains where the land expands and the effect of sea influence decreases accordingly, humidity decreases progressively towards the inland. The synoptic and mesoscale patterns of the severe weather observed on the Aegean Sea during 3–4 November 1995 are very similar to those described by Jansa (1997) for a typical Mediterranean storm. On 3 November 1995, a surface low was centred over the Aegean Sea. The next day this deep low moved eastward, enhancing the advection of warm and moist unstable air masses toward the Aegean coast along the southwesterly low level jet (LLJ). Meanwhile, intrusion of the initially cold and moist air masses from the northwest over the Balkans being warmed from below and modified over the Aegean Sea, led to development of the intense storms

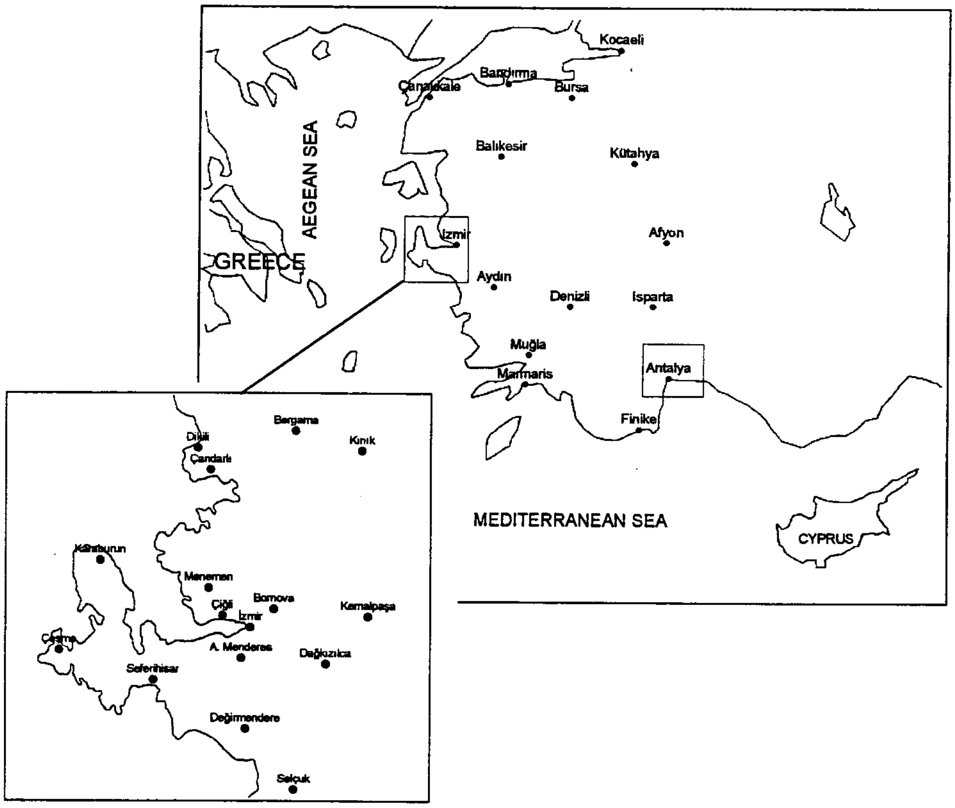

Figure 2. The areas affected by the flash floods occurred on 3–5 November 1995.

and caused anomalous rainfall amounts. The heaviest rain fell over the city of İzmir which remained on the frontal boundary zone leading to an extended period of convection. The intensity of the rainstorms further enhanced when the conditionally unstable and extremely moist air pushed upslope into higher terrain surrounding the city to the north. A maximum rainfall amount of 123.8 mm in a 24-hour period was reported, but the largest portion of that amount, however, was recorded in 4 to 6 hours. The wind speed reached 122 km per hour during the storm. Despite the fact that the meteorological setting was conducive for a heavy storm development and that the storms followed a dry period, nonmeteorological factors, such as the terrain features and land-use conditions, also contributed a great extent to the flood.

The İzmir flood once again emphasizes the importance of identifying and defining the important synoptic mechanisms that act to intensify heavy rainfall over a specific area and the terrain features that play significant roles in the occurrence of floods. Our analysis initially focuses on the synoptic and mesoscale conditions that favored heavy precipitation along the Aegean Sea coast. For that purpose, conventional weather analyses, including 200, 500, 700, and 850 mb, as well as surface charts, are carried out to document the meteorologic conditions involved

Figure 3. A scene from the Karşıyaka district immediately after the flood. Courtesy of the Posta newspaper.

in this two-day storm event. Particular emphasis in the analyses is placed on the development and evolution of the mesoscale and synoptic features and their interaction with low level processes acting on regional and local scales. The cross sections of vertical velocity and relative humidity data provided by the European Centre for Medium-range Weather Forecasting (ECMWF) are also analyzed to describe the convective instability of the atmosphere over the region. Then, the surface features including the topography and land-use conditions that contributed to the downstream extension of the flood are identified and their impacts on the flooding are examined.

It is hoped that the results of this study will be of use in improving severe weather forecasting for the settlements which suffer from flash flooding along the Aegean and Mediterranean Sea coasts. We believe that by analysis of surface and upper air data to identify the synoptic mechanisms peculiar to the region and the terrain features that act to produce flash flooding conditions, a better understanding of means of avoiding or minimizing the flood-related casualties and property damages in the region may be provided. This case study will hopefully heighten the awareness of the devastation and strife that the flooding imposes upon society and the environment across many locations along the Aegean and Mediterranean coasts.

2. Rainfall Analysis

Flash flood events associated with heavy precipitation are on the rise in recent years in many locations within the Mediterranean countries. Rainfalls of 200 mm in 24 hours have been recorded from time to time in many places around the Mediterranean (Jansa, 1997). Even extraordinary records of more than 800 mm in 24 hours have been observed in some locations (in eastern Spain and southern France). Consecutive storm activities badly affected Eastern Spain in 1994 (Corominas *et al*., 1995). Rainfall amounts of 300 mm were reached in some parts of the region and caused severe damage. Similarly, maximum rainfall amounts of 344 mm in 36 hours were recorded in the northern Pelopones peninsula in Greece and at least six people were killed as a direct consequence of the floods (Lanzinger, 1997).

Hazardous weather extremes resulting from cyclones cannot be over emphasized in the Mediterranean area which has the highest concentration of cyclogenesis in the world. Most of the precipitation in the Mediterranean basin is associated with cyclones forming in certain preferential areas such as the Gulf of Genoa and the Adriatic sea (Jansa, 1997). The Cyprus and Aegean regions are other areas with quite frequent true cyclogenesis. Some of the cyclones formed in the Mediterranean are very active and develop quickly to produce sudden periods of very disturbed weather. Even weak and small cyclones can organize limited warm and moist air streams within the Mediterranean that provide very effective surface forcings to trigger deep convection in an appropriate environment (Jansa et al., 1986; Jansa, 1987; and Jansa, 1994). Riosalido (1990), on the other hand, has shown that most of the heavy rainfall events in the western Mediterranean basin never fulfill the criteria for a Mesoscale Convective Complex (MCC) given by Maddox (1980) and argues that the majority of heavy rainfall in this region is convective in character. It has been observed by Jansa (1992) that the heaviest rainfall in the Mediterranean region is recorded from the end of autumn to the beginning of spring when significant cyclogenetic activity fundamentally determines the maximum rainfall. The seasonal distribution of this kind of events – with a maximum in late summer and autumn – suggests the relevance of the Mediterranean air-mass, for which the water content – being warm and wet air – is usually very large during this period of the year. Jansa (1997) argues that the presence of any Mediterranean low, even if it is not deep, organises differentiated air currents, as well as internal low frontal boundaries. The intersection of a warm-wet current with a thermal-humidity boundary, creates favorable conditions for a convective instability to be reached as both the feeding and the initial ascent are provided.

Flash floods associated with intense rainstorms have occurred in the Aegean and Mediterranean coasts of Turkey in the past many times, and the magnitude of these types of intense storms has risen in recent years. From a temporal perspective, the intense rainstorms that usually favor flooding in İzmir occur at night-time, usually starting around 2200 in late evening and ending after 0500 in early morning. On 3–4 November 1995, between approximately 1420 and 0500 LST, heavy rainstorm activity occurred over the city of İzmir. Rainfall amounts of 3.7–124 mm for a 24-hour period were reported at local stations (Figure 4). The extreme local nature of the heavy rainfall can be appreciated by looking at the variation in the recorded rainfall amounts for the towns close to each other. While İzmir (Güzelyalı) station was drenched with 108 mm, Kemalpaşa, only 28 km to the east, recorded only 3.7 mm rainfall. The heaviest rainfall amounts were reported from station of Çiğli, and the next highest maximum was reported as 108 mm in Güzelyalı station which is located in the centre of the city.

To acquire a proper perspective of the magnitude of the rainfall during the 3–4 November 1995 flooding, it is instructive to review past rainfall records. A tabulation of 24-hour record-rainfall amounts observed in the coastal parts of Turkey in recent years are given in Table I. At first glance, the rainfall magnitude of the 3–4 November 1995 İzmir flood does not seem to be extreme enough to cause a significant flooding when compared to the other rainfall events. Rainfall measurements in the Güzelyalı station have been taken since 1938, and the record-high 24-hour rainfall of 134 mm was observed in October 1976. It should, however, be remembered that 24-hour rainfall amounts received during flash floods may not always give a true indication of the magnitude of the event as the maximum rainfall is usually recorded at shorter time intervals. Although the figures tabulated here represent rainfall totals for the 24-hour period ending at 0700 LST, most of the damaging downpour occurred in a few hours after midnight on 4 November 1995. The rainfall amounts recorded for shorter durations during the event, therefore, were examined and it may be seen that, when the 6-hour duration is taken into account, the rainfall received during the 1995 flood was the most extreme of all the records (Table II). The extreme behavior of the rainfall is also reflected on the recurrence intervals computed for the maximum rainfall observed in İzmir-Güzelyalı station. The record high rainfalls and the associated recurrence intervals tabulated for varying durations are given in the bottom part of Table II. The recurrence intervals computed here are based on the distribution functions that best

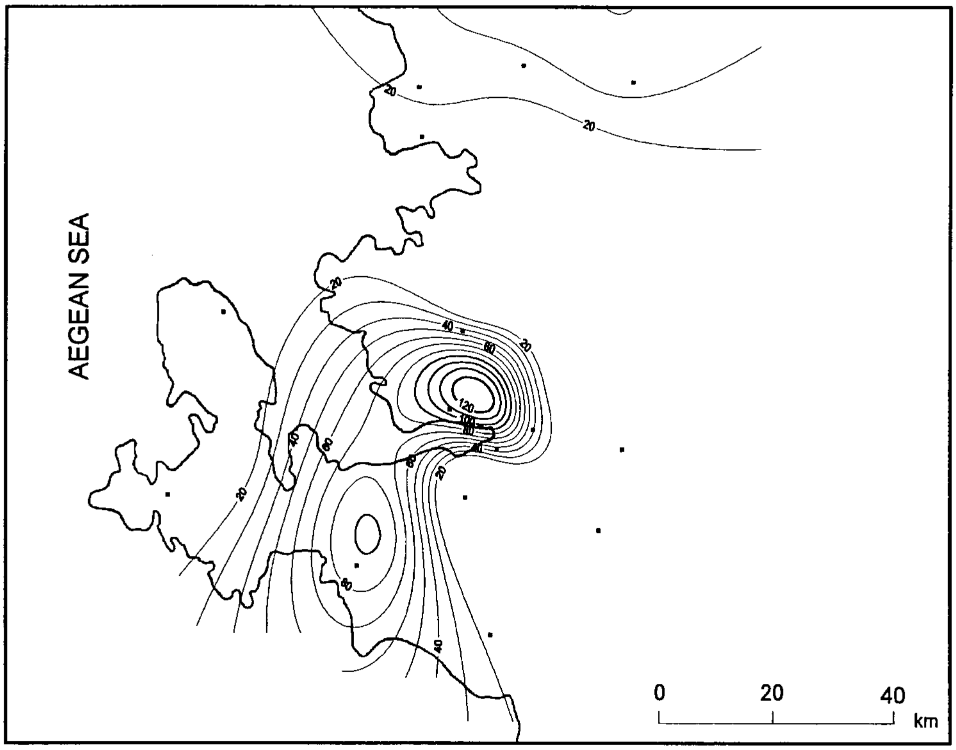

Figure 4. The 24-hour rainfall totals (mm) in İzmir and its surrounding on 3–4 November 1995.

represent the statistical character of the series. The recurrence intervals computed on a 24-hour base period indicate that the heavy rains that caused the flooding in İzmir in 3–4 November 1995 are expected to occur once every 50 years. On the other hand, the recurrence intervals of shorter durations such as 6- and 12-hours exceeded 100 years.

Meanwhile, no reliable discharge records were obtained during and after the flood due to a lack of recording gages in the streams in and around the city. There was only one observing station in the area, operated by the State Water Works (DSI) on Çamlı creek. But the DSI officials were unable to reach the station during the flood as it was swept away by the flood waters. After the floodwaters retreated, a team from the DSI surveyed the area and traced the floodwater levels along the major creeks (DSI, 1995). Based on their survey, the flood-crest elevations at some ungaged points along the streams were obtained by leveling to floodmarks identified immediately after the flood. Then, peak discharges in the streams were computed using empirical formulae (Table III). The numbers presented indicate that the peak discharges reached in most of the creeks in İzmir during the 3–4 November 1995 were twice as high as the average. The DSI survey also concluded

Table I. Extreme rainfall events observed in Turkey between 1985–1995

Duration (min)	Amount (mm)	Location/Region	Date
5	50.5	Hopa (Black Sea)	July 7, 1988
10	60.6	Hopa (Black Sea)	July 7, 1988
15	70.7	Hopa (Black Sea)	July 7, 1988
30	90.9	Hopa (Black Sea)	July 7, 1988
60	131.0	Antalya (Medit.)	April 11, 1995
120	180.5	Antalya (Medit.)	April 11, 1995
180	230.9	Marmaris (Aegean)	December 11, 1995
240	332.3	Antalya (Medit.)	November 4, 1995
300	374.3	Antalya (Medit.)	November 4, 1995
360	390.3	Antalya (Medit.)	November 4, 1995
480	410.4	Antalya (Medit.)	November 4, 1995
720	428.1	Antalya (Medit.)	November 4, 1995
1080	464.8	Marmaris (Aegean)	December 10–11, 1992
1440	466.3	Marmaris (Aegean)	December 10–11, 1992

that the highest level that the creeks reached during the flood was 4.10 m (DSI, 1995).

3. Meteorological Analysis

Synoptic and mesoscale aspects of flash flood events are described extensively by Maddox *et al.* (1979). They studied meteorological conditions associated with more than 150 intense convective precipitation events across the U.S. and found certain features common to almost all flash floods. These common features were; heavy rains produced by convective storms, high dewpoint temperatures, large moisture contents present through a deep troposphoric layer, and weak to moderate vertical wind shear through the cloud depth. They also classified flash flood events based on their meteorological patterns under four categories, namely synoptic, frontal, mesohigh, and western. The synoptic and mesoscale features of the 3–4 November 1995 İzmir flood have been analyzed on the basis of the classification developed by Maddox *et al.* (1979). Initially conventional weather analyses of the surface, 200, 500, 700, and 850 mb synoptic and mesoscale conditions that favored this two-day storm event are used (DMİ, 1995). The surface analysis for 4 November 1995 0000 GMT is shown in Figure 5. An important surface feature included in the surface chart is a deep low-pressure system over the Aegean Sea. The polar air mass over the Balkans and the warm and humid air mass originating from the central Mediterranean contributed to the formation of this low-pressure

Table II. Maximum rainfalls recorded at varying durations and their return periods for İzmir Güzelyalı station

Observations		Minute			Hour									
Year	5	10	15	30	1	2	3	4	5	6	8	12	18	24
1995	13.40	23.10	37.50	57.40	68.20	83.00	85.90	99.90	104.50	104.60	104.70	108.00	148.10	
1994	4.30	12.70	14.10	18.70	26.40	31.50	31.80	31.90	31.90	31.90	31.90	37.70	38.80	75.30
1993	2.50	3.10	4.30	7.20	10.50	14.30	16.90	19.90	24.60	27.30	31.80	34.80	37.90	66.70
1992	10.20	11.40	12.70	13.50	13.80	19.30	27.10	33.50	41.10	47.50	49.10	50.40	50.40	50.40
1991	8.20	14.40	20.8	22.40	27.50	26.40	27.80	27.90	27.90	27.90	27.90	27/90	30.40	40.80
1994	2.90	4.20	4.50	7.50	9.10	14.80	17.40	20.60	20.90	21.00	21.60	21.80	29.10	62.20
1989	9.10	13.00	16.80	26.40	31.80	35.30	35.30	35.38	35.30	35.30	35.30	35.30	35.30	83.00
1988	1.50	2.50	2.80	4.40	6.00	6.80	7.40	7.10	9.90	10.60	11.70	11.80	11.80	50.70
1987	5.60	9.50	13.10	19.20	27.80	34.10	38.40	40.00	44.50	52.30	58.20	73.00	79.70	85.60
1986	7.20	8.10	9.30	11.30	14.40	17.30	17.50	17.50	17.50	18.80	18.80	18.80	18.80	67.20
1985	9.90	13.50	15.40	16.00	29.80	32.00	34.40	40.30	43.40	44.40	44.40	44.50	44.50	44.50
1984	6.40	8.90	10.20	13.70	17.10	25.20	31.10	36.10	37.80	37.80	37.80	49.50	54.40	62.60
1983	4.50	7.00	8.60	12.30	15.20	21.70	24.70	35.00	38.40	39.80	47.00	56.10	72.40	77.20
1982	7.20	11.30	13.90	21.00	34.60	39.70	40.80	41.00	41.00	41.00	41.00	51.50	51.60	54.10
1981	7.30	10	13.00	21.80	32.30	47.80	58.20	58.40	58.60	58.60	62.70	81.80	92.60	112.00
1980	6.80	9.20	10.40	18.60	28.60	33.90	36.00	37.80	40.60	40.70	40.80	40.80	65.70	66.90
1979	18.40	29.70	37.40	52.30	60.80	62.80	63.10	63.10	63.10	63.10	64.20	72.24	72.60	72.80
1978	7.00	8.60	8.60	14.20	14.80	26.00	30.00	35.60	40.60	43.00	47.50	57.80	59.50	59.70
1977	3.30	3.60	4.40	6.00	9.50	11.20	16.70	18.64	21.80	24.30	26.60	37.10	38.90	46.00
1976	9.90	18.60	21.10	27.40	38.7	38.70	45.00	45.10	45.10	45.10	48.60	52.40	69.20	134.10
1975	14.50	17.80	20.20	23.04	24.30	24.90	28.10	35.90	39.90	42.10	47.10	56.90	57.40	58.10
1974	8.30	10.50	12.80	15.40	17.50	17.50	34.00	42.10	48.50	50.50	52.40	55.60	57.04	64.60
1973	10.50	14.40	15.80	18.60	20.30	34.20	32.80	34.30	35.00	38.80	47.70	50.20	75.60	76.20
1972	5.40	9.20	10.20	17.60	22.70	24.80	24.80	29.10	30.00	30.40	30.50	31.00	31.10	3,110
1971	6.40	8.10	10.40	12.70	16.30	26.20	43.80	51.60	58.20	63.20	66.80	84.90	93.90	93.94
1970	4.70	6.80	8.00	10.30	17.90	28.20	34.60	33.20	43.40	45.40	46.40	46.40	46.40	46.40
1969	5.40	7.20	8.70	13.60	23.40	30.90	30.90	30.90	34.60	37.50	45.80	55.10	57.90	58.30
1968	5.10	8.10	12.00	18.10	21.00	21.00	29.20	33.60	37.00	43.10	49.10	50.80	54.10	66.30
1967	10.00	11.00	12.30	16.50	20.00	23.80	26.64	34.20	38.20	41.80	49.10	52.84	55.10	59.70
1966	10.10	20.20	23.80	33.60	56.60	76.50	76.50	76.50	76.50	76.50	76.54	76.50	90.40	102.30
1965	9.30	9.30	12.40	17.70	19.50	21.50	25.80	33.00	38.50	43.20	50.60	62.70	6,420	66.20
1964	5.00	8.00	11.50	15.00	22.00	31.40	35.70	39.20	39.20	39.20	39.70	39.70	39.70	4,540
1963	8.10	970	11.90	11.90	21.70	35.60	35.60	35.60	35.60	35.60	35.60	42.20	48.00	48.0
1962	5.50	8.50	10.00	15.50	20.90	27.90	28.70	29.40	30.30	33.80	42.00	47.24	62.50	77.60
1961	6.50	8.00	10.00	13.90	22.30	27.10	27.80	28.00	28.20	28.20	28.20	28.20	2,820	31.40
1960	6.20	7.50	9.40	11.20	14.40	16.20	29.40	35.30	41.00	42.50	47.30	55.70	59.50	76.80
1959	5.70	10.00	10.00	12.50	14.50	20.90	24.50	27.50	30.40	33.10	36.00	42.80	43.90	46.20
1958	8.10	11.90	12.30	13.80	15.00	15.70	18.40	23.60	29.00	35.40	43.30	50.54	53.70	54.80
1957	7.20	9.00	14.70	16.20	17.70	17.70	18.00	18.00	18.30	21.90	27.70	32.60	33.80	33.80
1956	4.50	6.50	7.00	8.00	11.34	13.40	13.20	18.90	25.70	28.30	32.70	35.70	38.30	53.30
1955	3.90	6.00	7.70	11.80	14.80	19.90	20.60	23.44	24.60	27.00	27.10	43.40	61.40	63.30
1954	7.00	9.00	12.50	14.90	19.80	24.30	32.20	34.30	40.90	43.00	46.30	51.50	55.10	57.70
1953	9.9	11.90	14.04	15.60	17.64	25.30	29.54	34.10	38.10	42.70	48.40	52.70	53.70	55.80
1952	9.40	9.40	10.40	14.40	18.80	22.70	29.90	31.90	32.30	35.70	37.70	45.50	46.54	62.70
1951	6.20	6.20	6.50	9.00	14.00	22.20	22.20	22.20	27.20	29.30	32.70	37.20	43.80	74.94
1950	10.20	14.3	17.00	19.70	20.50	21.30	24.30	28.90	29.20	29.70	29.80	30.10	30.20	38.00
1949	5.80	6.00	6.20	8.70	13.00	22.40	23.90	26.3	29.10	31.80	33.40	33.50	33.50	44.90
1948	5.00	8.30	10.60	12.10	12.10	12.10	14.80	18.20	23.80	27.80	33.30	35.50	36.00	57.50
1947	3.80	5.90	6.30	12.50	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.50	25.50	50.30
1946	8.10	13.40	14.00	15.80	16.00	16.30	16.80	18.20	22.70	24.30	24.80	24.90	24.90	56.90
1945	7.40	12.80	15.00	16.80	18.00	18.50	18.50	18.50	18.50	18.50	18.50	18.50	18.50	84.20
1944	8.60	10.00	12.60	14.10	16.30	16.60	19.70	22.00	22.20	30.70	41.10	45.30	60.60	65.40
1943	14.10	17.10	19.50	27.30	35.40	37.00	37.40	37.00	37.00	37.40	37.40	37.00	37.00	52.10
1942	10.00	14.30	17.80	25.60	29.90	37.40	37.40	37.40	37.40	37.40	37.40	37.40	37.40	46.90
1941	8.90	12.20	12.80	14.00	14.00	15.00	18.50	24.00	25.70	26.00	26.00	26.40	26.00	33.20
1940	5.70	7.70	8.50	11.30	14.10	24.60	31.00	36.40	39.90	43.30	48.10	48.40	69.60	8,210
1939	5.00	8.00	10.40	12.10	12.10	13.00	16.70	16.70	18.30	19.30	21.50	31.14	48.20	49.50
1938	5.00	8.20	8.80	14.50	19.30	24.60	25.80	26.60	27.30	27.30	27.30	2,730	27.30	46.40
Dist. F.	G2P	LP3	LN3	LP3	LP3	LN2	LP3	LP3	LP3	LN3	LP3	G2P	LN3	LN2
2	7.08	9.65	11.55	15.09	19.07	24.76	28.26	32.02	34.70	36.73	40.60	45.51	51.65	57.34
5	9.89	13.48	16.45	21.31	27.38	36.56	39.42	43.28	46.78	49.15	53.31	60.59	68.55	72.37
10	11.79	16.37	20.11	26.16	35.13	44.81	48.19	51.51	55.68	58.45	62.18	70.56	78.88	85.20
25	14.16	20.43	25.18	33.20	46.50	55.70	60.98	62.83	68.00	71.34	73.89	82.95	91.21	98.49
50	15.90	23.78	29.25	39.14	56.70	64.07	71.85	71.97	77.98	81.69	83.02	91.95	99.94	108.15
100	17.62	27.41	33.56	45.73	68.55	72.69	83.95	81.71	88.68	92.67	92.49	100.78	108.39	117.66

Table III. Maximum streamflow discharge reached in some creeks during the 3–4 November 1995 İzmir flood (m^3/s)

Creeks	Average discharge (m^3/s)	Manning's formula (m^3/s)	Mockus triangle (m^3/s)
Yamanlar	40.5	92.6	69.0
Bostanlı	67.5	262.7	267.0
Kavak	21.8	44.9	51.0
Büyük Çiğli	36.4	80.2	76.0
Çamlı	110.0	295.0	284.0

system. The surface analysis further indicates that the pressure gradients are highest over the Aegean, Marmara, and western Mediterranean Seas, and the surface isobaric field seems to be conducive to rapid northeastward transport of moisture from the Mediterranean Sea. In addition, wind shifts and pressure decreases in the warm sector area are other significant features portrayed in the surface chart. The atmospheric pressure is measured as low as 1000.8 mb in the warm sector, which is not typical for the area.

At 850 mb, the presence of a positive vorticity and warm air advection extending from the Aegean costs to the Marmara Sea is evident (Figure 6). At this level wind is continuous at 40–50 knots over the Crete-İzmir line indicating the presence of a low-level jet (LLJ) stream. An initial outbreak of severe weather was most likely along the southwesterly low level jet which enhanced the advection of warm and moist air from the Mediterranean Sea. The surface dewpoint temperatures here also help to identify regions of significant moisture content. The dew point temperatures reach their maximum over the Crete-izmir line. These low-level synoptic features are similar to many other severe weather outbreaks observed in the U.S. (Maddox *et al*., 1979 and Maddox and Doswell, 1982). As noted in Doswell *et al*. (1996), heavy rainfall requires the rapid ascent of moist air and parameters like low-level moisture convergence have demonstrated their utility in diagnosing synoptic scale regions favoring convection. At the 700 mb map, a 0 °C isotherm extends over the Crete-İzmir-İstanbul line and represents warmer air than its surroundings (Figure 7). The wind speed reaches its maximum along the same line. In addition, an increase in wind speed with height is evident at this level over İzmir (65 knots), which favours the formation of a squall line. The 500 mb synoptic map indicates that a deep trough is located over the western coasts of Greece and that band of warm air lies along an axis that extends over Crete-İzmir-İstanbul line (Figure 8). Also, strong winds are noted over the same axis. At the 500 mb level the temperature is −16 °C and the temperature difference between the surface and the 500 mb level reaches

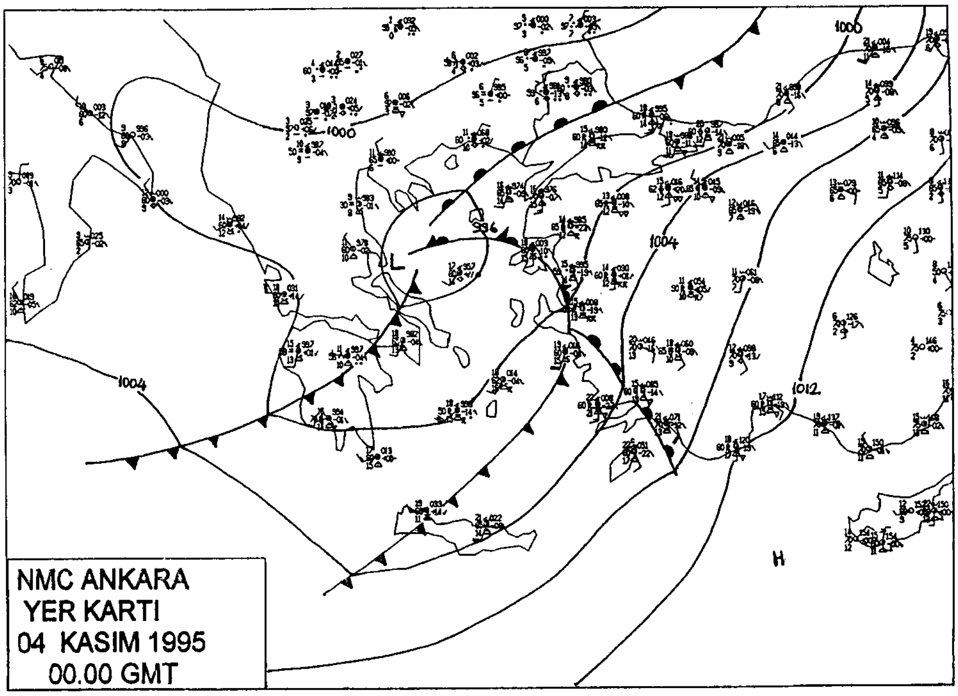

Figure 5. Surface analysis for 0000 GMT, 4 November 1995.

36 °C. Finally, the vertical rise of the warm and humid air ends at the 200 mb level and divergence in the jet streams in northerly and easterly directions occurs (Figure 9). While the wind direction was in south and southeasterly with 180° on the surface, direction of the flow in the upper level jets is southwesterly with 220°. The differences, both in direction and angle of the jet stream flows, indicate how strong the divergence is in the upper atmosphere.

The meteorologic conditions of the heavy rains are illustrated from another perspective in Figure 10 which shows the temporal relationship between the temperature, atmospheric pressure, and precipitation at İzmir-Güzelyalı station on 3–4 November 1995. In the afternoon of November 3, the air temperatures tend to rise gradually and the air pressure drops when the warm front passes through the area. The decrease in the pressure becomes even more evident with the increasing precipitation. Meanwhile, a stationary warm and humid air mass originating from the Mediterranean Sea is located over the Gulf of İzmir. The first development of the devastating rainstorms is initiated when a rapidly advancing cold front penetrates the Gulf of İzmir from the northwest around 2300. The atmospheric pressure begins to increase again after the cold front passes through and the rainfall intensity decreases concurrently.

Unstable behavior of the atmospheric conditions over the region also exhibits itself in the stability indices obtained from upper-air soundings for 0000 GMT

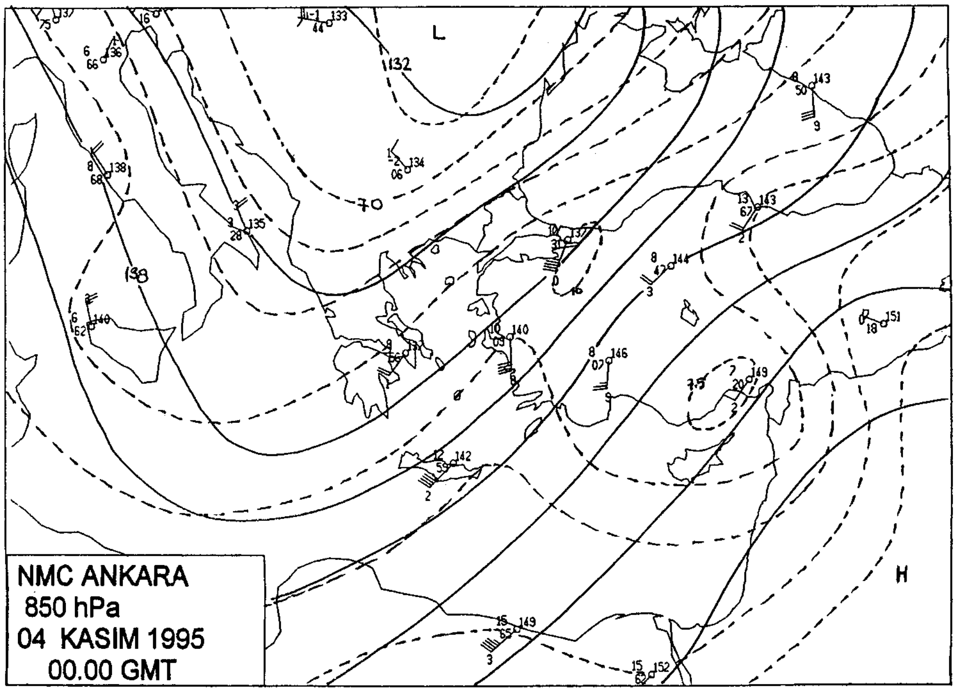

Figure 6. 850 mb analysis for 0000 GMT, 4 November 1995.

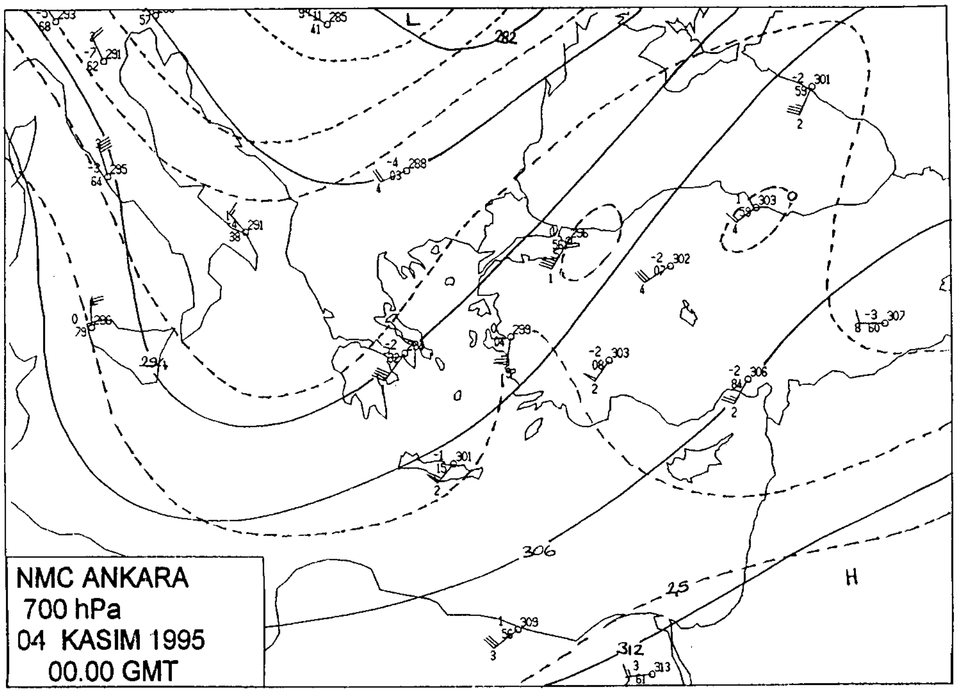

Figure 7. 700 mb analysis for 0000 GMT, 4 November 1995.

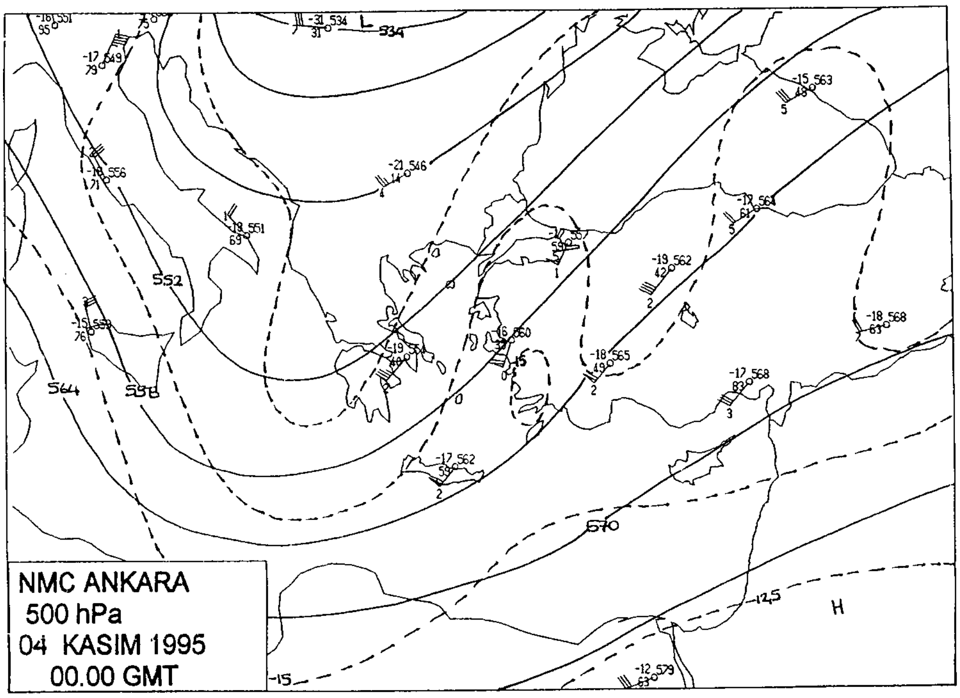

Figure 8. 500 mb analysis for 0000 GMT, 4 November 1995.

November 3–4 1995 for İzmir (Table IV). The changes in the indices are dramatic from November 3 to November 4. Almost all the indices exceed the marginal values. The increase in K index is particularly significant, exceeding the marginal value of 30 given by Maddox *et al.* (1979). Precipitable water (PW) in the surface to 500 mb level totals 31.4 mm and exceeds the marginal values for a heavy rain event (Doswell, 1982). The convective instability of the atmosphere is revealed through the relative humidity and vertical velocity data as well. The relative humidity depressions observed in the Tripoli-Ankara cross section demonstrate the moisture-laden atmosphere over the region. The relative humidity exceeded 80 percent in the heavy rain area (Figure 11). The upward vertical motion gained great momentum over the Aegean Sea and acted further to destabilize the atmosphere and trigger deep convection during the night of 4 November 1995 (Figure 12). It has to be noted that, although the convective instability was an important factor for the storm development, the most important key for this type of heavy rainfall was a large feeding current of warm and wet air from low levels, replacing the large amount of water continuously removed by the heavy rain.

In conclusion, both the surface and upper air synoptic features indicate the presence of the meteorological conditions that are favorable for severe weather. Particularly, low level and upper level jets appeared to play a major role in focusing the differential temperature and moisture advection. The meteorological features

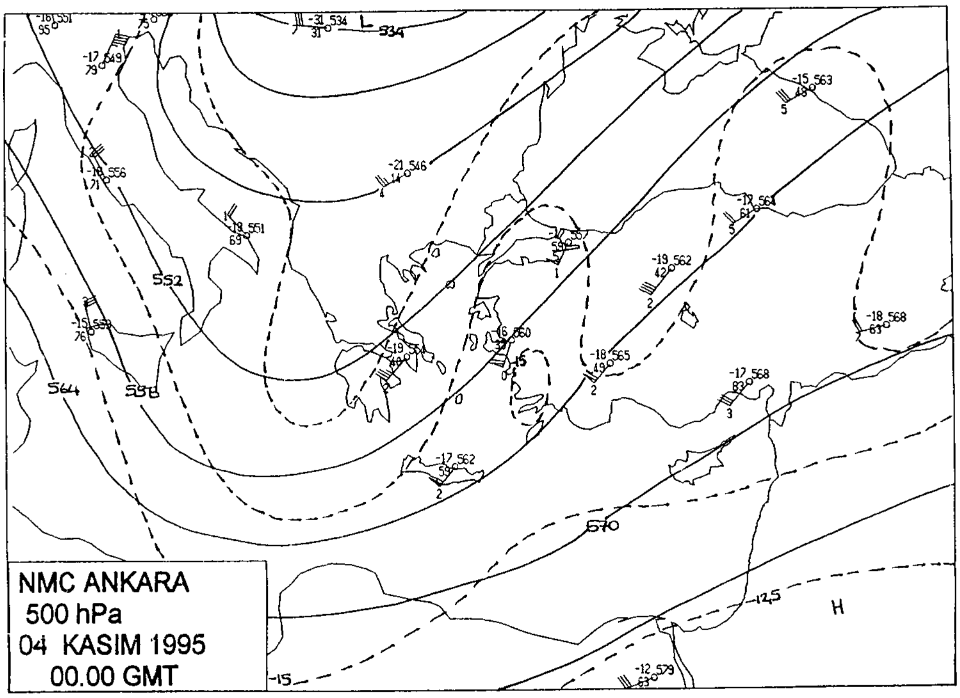

Figure 9. 200 mb analysis for 0000 GMT, 4 November 1995. Position and divergence of the jet streams are indicated.

associated with this flash flood event are reminiscent of a Maddox ‘synoptic type’ heavy rain event (Maddox *et al*., 1979). In particular, the presence of a large scale frontal system, a warm air sector with high moisture content, and a convective instability in the surface and upper air charts support this argument.

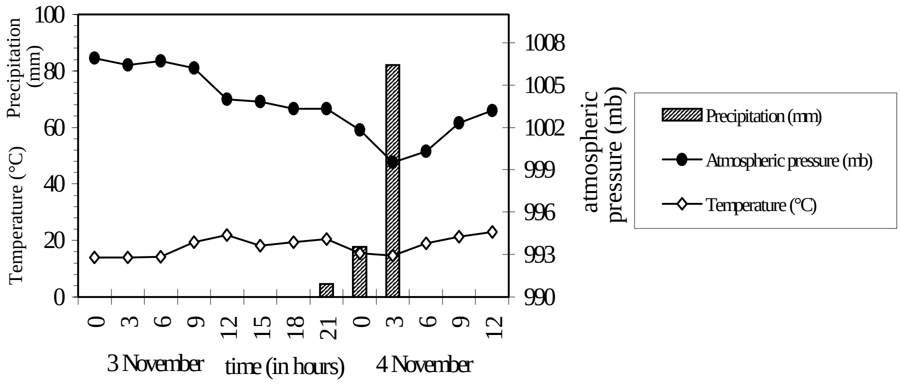

Figure 10. Temporal variations of air temperature, precipitation, and atmospheric pressure on 3–4 November 1995 for İzmir (Güzelyalı) station.

Table IV. Results of stability indexes and precipitable water (PW) obtained from radiosonde for 0000 GMT November 3–4 1995 in İzmir(Güzelyalı) station

Index/date	3 November 1995	4 November 1995	Marginal values
Lifted index	6.6	−0.6	0
Sweat index	179.0	290.8	300
K index	18.3	34.6	25
T totals	45.4	51.3	49
V totals	24.5	26.1	26
C totals	20.9	25.2	23
Precipitable water (PW)	18.2	31.4	20

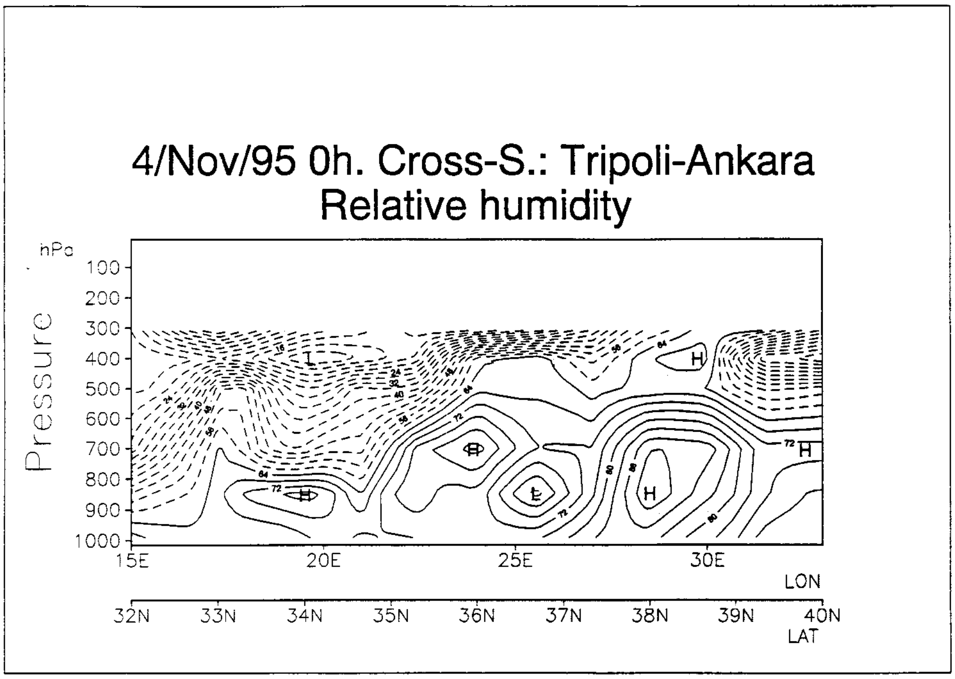

Figure 11. 4 November 1995 0000 GMT Tripoli-Ankara cross section of relative humidity (For İzmir the longitude is 27.1°E and the latitude is 38.2°N).

4. Terrain Conditions

The preceding section described the meteorological conditions that led the 3–4 November 1995 İzmir flood. Despite the fact that the rainfall received during the flood did not seem to be significant as compared to heavy rain events observed in other parts of the country (e.g. December 1992, Marmaris, and December 1988, Hopa), the consequences were devastating in terms of the casualties and number of

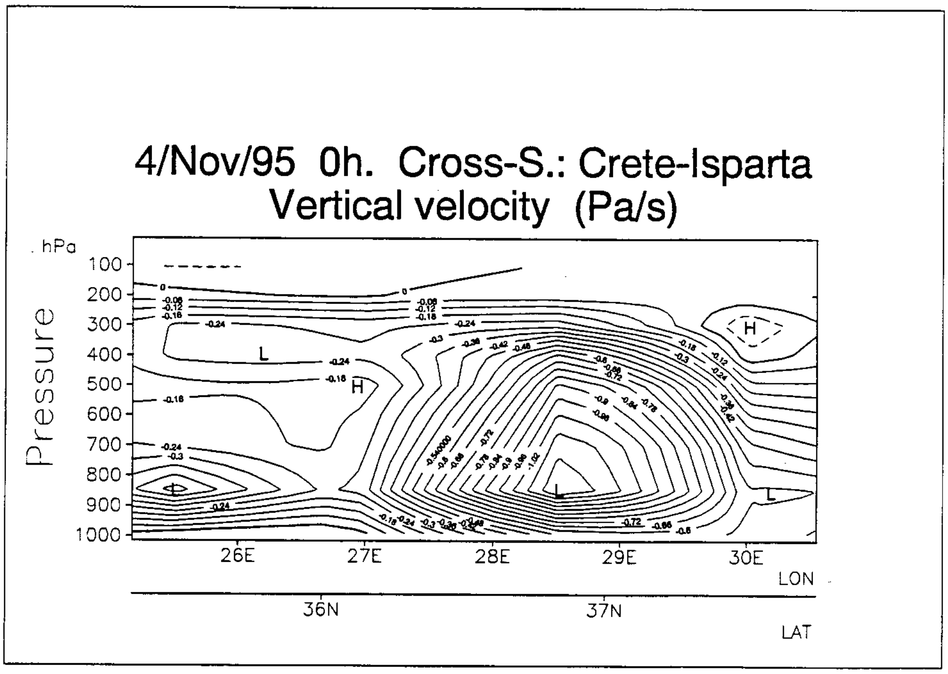

Figure 12. 4 November 1995 0000 GMT Crete-Isparta cross section of vertical velocity (For İzmir the longitude is 27.1°E and the latitude is 38.2°N).

properties and buildings damaged. The antecedent moisture conditions also were not favorable for such storm runoff to cause severe flooding. These facts led us to examine the terrain features of the area more closely in order to determine how they contributed to the flooding. In this respect, we found that three main factors had considerable impact on downstream extension of the flood and aggravated the consequences of the flood to a great extent in the area; (i) topography, (ii) geomorphology, and (iii) land-use.

Topographic influences can play a large role in the structure and evolution of the weather systems associated with heavy precipitation (Smith *et al.*, 1995). Topographic features may provide the convection necessary to initiate mountain storms. This convective activity can be due to a number of mechanisms such as orographic lifting and channeling. The main topographic and geomorphic features of the area are Yamanlar Mountain and Yamanlar Depression, Upper Karşıyaka Plain, and Lower Karşıyaka Plain (Figures 13 and 14). The low-lying plains of Karşıyaka extend nearly 3 km around the Gulf of izmir and are surrounded by high terrain to the north of the city. The Yamanlar Depression lies in SSW-NNE with a length of 8 km and width of 5 km and is a catchment area for the Dallık, Örnekköy, and Yamanlar creeks which drain to the Gulf of İzmir (drainage area and return flows of the major creeks of the area are given in Table V). The depression have deep valleys which are characterized with steep slopes. The northern slopes

Table V. Drainage area and return flows of the major creeks in İzmir (DSI, 1995)

Creek	Drainage area (km^2)	Q_{100} (m^3/s)	Q_{500} (m^3/s)
Bostanlı	27.3	67.5	100
Dallık	2.5	14.4	21.3
Ilıca	15	40.5	51.5
Çamlı	62.5	152.2	223.1
Tahtacı	6.5	33	49
Büyükçiğli	13.7	51.2	72.6
Alionbaşı	16.4	101	146

of the depression have a highly dissected topography which are formed by small creeks. In the evening of 3 November 1995, the frontal air masses originating from the Mediterranean Sea advanced to the area from the southwest, moved along the Yamanlar depression, and lifted orographically when they hit the high terrain to the north of the city. This caused rain to be effective in a very localized area along the depression which became very conducive for rapid runoff. Interestingly, the antecedent moisture conditions were not favorable for rapid runoff as the storms followed a dry period. The main reason for the localized runoff was not just the intense rainfall, but the fact that the terrain over which runoff moved had steep slopes and lacked vegetative cover (Staff, 1996). It should also be noted that while the Yamanlar depression is orientated NE-SW, the main axis of the high intensity rainfall is orientated E-W. Thus, we can not explain the intensity of the rainfall by orographic lifting alone. It is possible to argue that the Yamanlar mountain had some effect to increase the intensity of the rainfall, but the synoptic patterns also were favorable for such intense rains. The depression also has several creeks that drain the floodwaters to the Gulf of İzmir (Figure 13). These creeks rose quickly in the heavy rain and spilled out of their banks. As a result, considerable damage occurred in the houses near to the creeks.

The Upper Karşıyaka Plain is a depositional area for the sediments and alluvial materials carried through by the Dallık and Örnekköy creeks that cut through the Yamanlar Depression (Figure 14). However, it lacks appearance of a typical accumulation fan mainly because of the narrowing between the Cumhuriyet and Gümüşpala ridges. At the initial stage of the heavy rains, water levels in the creeks rose significantly and occupied the properties and houses in the Küçük Yamanlar district which is the main settlement located in the plain. In upper reaches of the creeks, the steep bed slope led to bed scouring and mobilization of large boulders. The alluvial materials and large boulders brought by the creeks during floods were deposited in that narrow zone behind the ridges in the mouth of the plain and blocked the passage to the Lower Karşıyaka plain. The impounded water

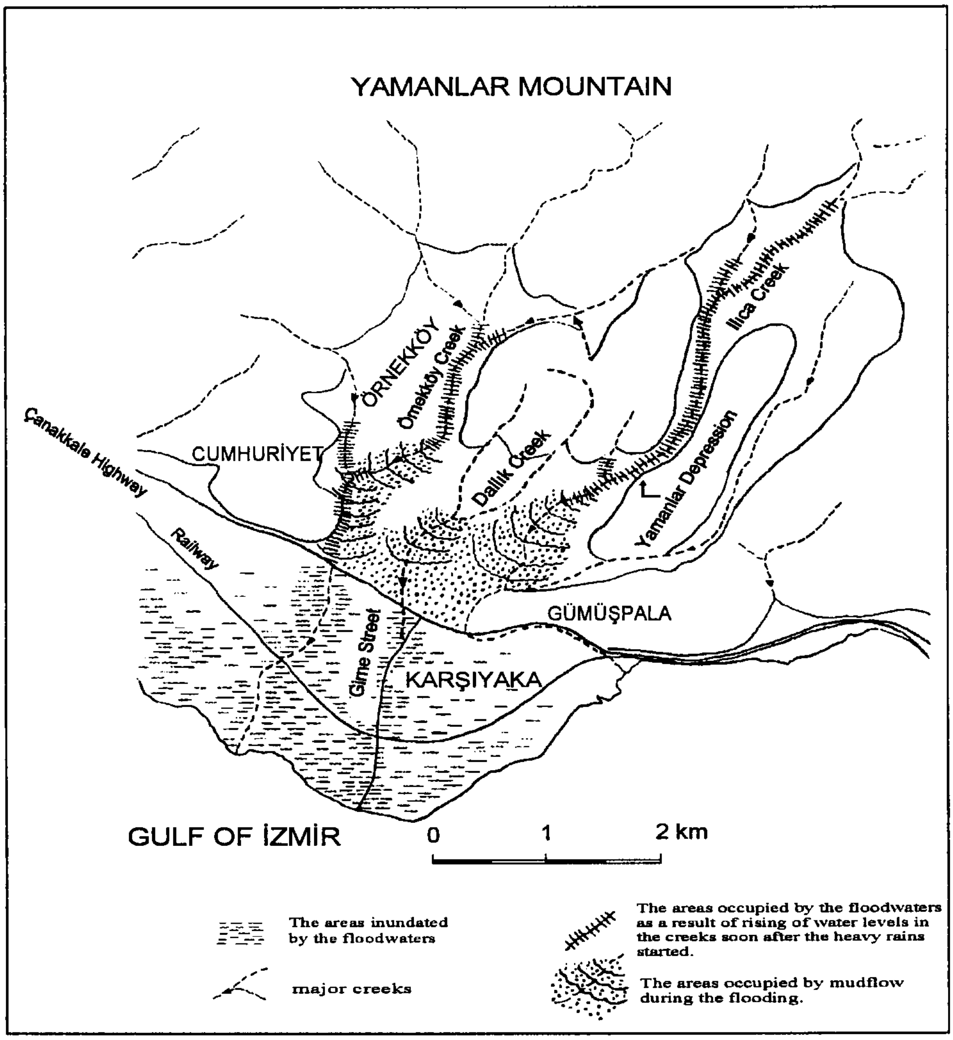

Figure 13. The areas affected by the 3–4 November 1995 İzmir flood (Adapted from Staff, 1996).

eventually overtopped the alluvial blocks, and the floodwaters swept through the Lower Karşıyaka plain which provides access to the Gulf of İzmir. The plain is formed by fine-grained alluvial deposits brought by the creeks cutting through the Yamanlar depression (Figure 14). It lacks steep slopes and the water table in the area is very high. The Karşıyaka district, which is the commercial centre of the city, is located in the plain and it suffered the greatest damage from the flood. There were several factors that worsened the flooding conditions in the district. Most of the streets in the district are parallel to the hillslope, and that eased the movement and channeling of the storm runoff along the streets. It also has to

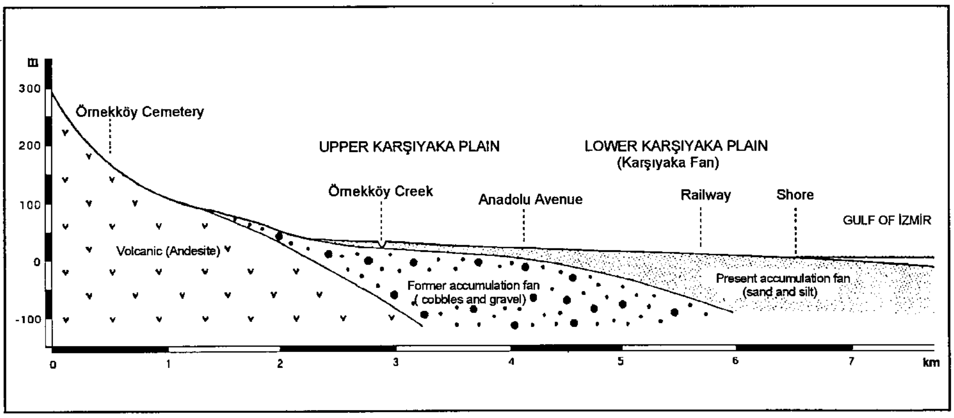

Figure 14. Cross-sectional representation of major geomorphic features of the area in N–S direction (Adapted from Staff, 1996).

be noted that construction activities have increased in the area in recent years in response to the increasing population and urbanization of the city of İzmir. The population of the city has been rising steadily and has already exceeded 2 million people due to migration from other parts of the country. More than 250,000 people migrated to the city in 1990 alone (State Institute of Statistics 1994 and 1995). While the ratio of the city population to the total population was 54 percent in 1980, that figure went up to 78 percent in 1985 (State Institute of Statistics, 1995). The city attracted people particularly from the rural parts of İzmir province, and as a result the village population in İzmir province declined sharply after the 1980s (Figure 15). In order to absorb the increasing population, new settlements were constructed in the Karşıyaka and Yamanlar districts. Between 1987 and 1995 more than 47,000 new buildings were constructed in the Karşıyaka district alone (İzmir Municipality, 1998). In 1995, housing units made up more than 80 percent of the land-use in the district. As the low-lying areas surrounding the Gulf of İzmir where the Karşıyaka district is located was already over-urbanized, the city began to expand particularly toward the Yamanlar District after 1985, but most of the housing units in the district were illegal and were not constructed in accordance with the construction standards set by the İzmir municipality. Meanwhile, more than 200 km of roads were asphalted in the Karşıyaka district between 1990 and 1995 and that added a great percentage to the impervious surface area in the district. As a result of the increased construction activities in the parts of the Yamanlar and Karṡıyaka District, more soil became vulnerable to the storm runoff due to the excavation. Also, those areas without lack vegetative cover were eroded very quickly with the intense rains and turned into mudflows during the flood. The streets in the Karşıyaka district also follow the path of the drainage network, and that helped the floodwaters to cover the district easily. Girne street, which is set on the natural course of Dallık creek, is a typical example of this. Moreover, the district lacks

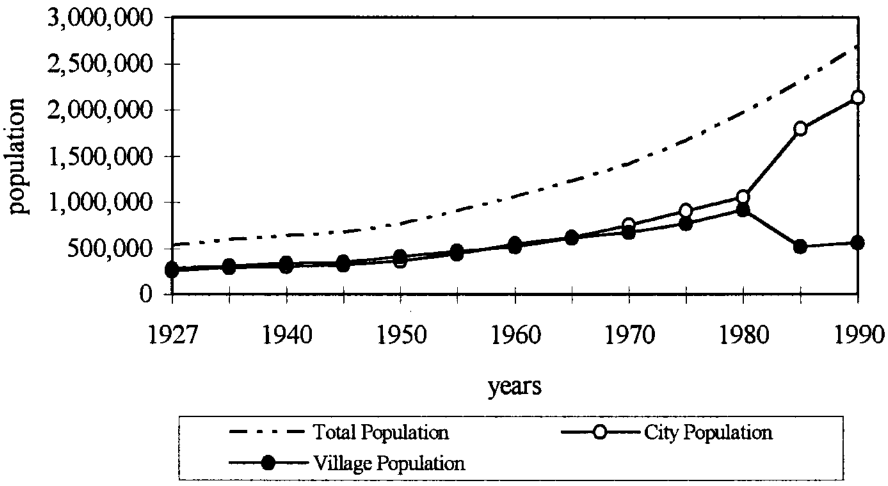

Figure 15. Census statistics for the city of İzmir.

efficient retention and recharge infrastructures to drain floodwaters quickly. Large wind-driven waves moving in from the sea also contributed to the raising of the downstream levels of the creeks. During the heavy rains the wind speed reached a maximum of 120 km per hour. As a result of these gusty winds, flow of the creeks discharging into the Gulf of İzmir was impeded for a short period of time. Another factor that contributed to the impeding of discharging of floodwaters into the Gulf of İzmir was the interruption of the natural drainage along the coast by constructing recreational facilities. The İzmir municipality aimed to use the coast as a recreational area for public, mainly for hiking and jogging.

5. Conclusion

The meteorological settings associated with the flood of İzmir on 3–4 November 1995 are analyzed, and the role of the terrain features are described, to explain the devastating consequences of the flood. It has been shown that certain synoptic weather patterns were favorable to the development of intense storms, which in turn interacted with the topography to produce heavy rains in small time intervals over a specified area. The intensity of the storms was enhanced further by the orographic effect. Despite the fact that the meteorological settings were conducive for heavy rains, the 24-hour rainfall received from this event was not high enough to cause significant flooding. However, the rainfalls recorded at shorter durations during the event were extreme enough to lead to flash flooding. Meanwhile, the terrain features and land-use of the area had considerable impact on the flooding in various ways. First was the orographic effect of Yamanlar mountain which enhanced the severity of the storms by providing a continuous lifting mechanism for the warm and moist air on the warm sector of the front. Second was detention of the floodwater in the upper Karşıyaka plain which acted as a reservoir during the flood (Staff, 1996). The mud flows which were left by the debris flow occupied the bottom and first floors of the homes and shops located in the plain. The floodwaters detained in the upper Karşıyaka plain at the initial outbreak of the heavy rains overtopped the alluvial blocks eventually, moved rapidly toward the Karşıyaka fan, and finally inundated the Karşıyaka district which is the most urbanized part of the city. Finally, to describe the consequences of the flooding further, it was also necessary to examine the role of the commercial development and urbanization that the district has experienced in recent years. Details of the matter are beyond the scope of this paper, but we identified several potential factors that had some impact on the flooding in the Karşıyaka district and city in general. The first was the change in the land-use as a result of the growing population and urbanization of the city of İzmir. In order to absorb the increasing population, new settlements have been built in and around the city. The property values in the commercially developed parts of the city, mainly in the Karşıyaka district, have increased significantly in recent years (Staff, 1996). The increasing property values have made the risk of flood hazard worth taking and encouraged people to settle in the flood-prone zone despite its known danger. In parallel to the urbanization, there has been a substantial increase in the construction of asphalt roads, parking lots, and pavements in the city. It should also be noted that insufficient flood control structures and lack of channel improvements in the creeks enhanced the flood damage further. The capacity of the storm sewers and flood detention structures in the city is inadequate to control a large scale flood. The conveyance capacity of the creeks was greatly reduced during the flood by the walls of the houses built in the stream beds (Staff, 1996). The report prepared by the DSI officials based on their field survey immediately after the flood, also supports our arguments in explaining the devastating consequences of the 1995 İzmir flood. The DSI officials listed several factors in their report that worsened the flood conditions in the area. Their findings indicate that non-meteorological factors, such as housing in the flood-prone zone, reducing the conveyance capacity of the creeks by building houses in the stream beds, constructing roads on the stream beds, throwing garbage and construction materials into the creeks, and lack of channel improvements in the creeks, aggravated the consequences of the flood to a great extent (DSI, 1995).

6. Concluding Remarks

The results of this study indicate that the meteorological conditions were favorable for the severe weather development, but the consequences of the flood were considerably aggravated by improper urbanization, housing in flood-prone zone, and lack of adequate floodwater control structures. In order to avoid or minimize future flood damages in the area, we suggest some strategies that need to be developed immediately. These strategies can be classified under four categories, namely (i) structural measures, (ii) land-use control, (iii) channel improvements, and (iv) installing early warning systems. Land-use practices, such as planting trees, terracing, and strip cropping, may control small floods in the area but would be ineffective to control larger floods in the city as industrial and residential development keeps growing along with the steadily rising population. Thus, we believe that the land-use control would be the least effective of all the strategies for controlling a large flood in the area as the urbanization is very resistant to that type of measures. The land-use control measures, however, would be beneficial to reducing soil erosion in the upstream zone which has the largest contributing area to the flood, and therefore the deposition of silt and sand within the channels and flood-protection structures would be minimized (Dunne and Leopold, 1978). The land-use controls can be effective only if new regulations are enforced forbidding certain activities or by specifying standards of construction for buildings occupying the flood-prone zone in the area. It should also be reminded that land-use control activities may not bring solutions on a short-term basis, and they should rather be planned as long-term measures. We believe that the structural measures would probably be the most effective way of controlling the flood and minimizing its damages in the residential and commercial sites of the city. Many successful applications of reservoirs for flood control exist in many European countries and the U.S.A. (Valdes and Marco, 1995). Levees and floodwalls may be built along the banks of Örnekköy, and Ilıca and Dallık creeks which drain the valleys of Yamanlar depression. Another structural solution should be taken in the Upper Karşıyaka Plain which detained the floodwaters during the flood. A flood-detention reservoir may be constructed in the plain so that storm waters can be controlled before they reach dangerous peaks and volumes. This, however, in turn may cause higher flood levels in downstream where the Karşıyaka district is located. Experiences in some countries indicate that when floodwaters are not allowed to spill over and are stored in channels, the water level will be higher for the same discharge than it was before floodwaters are confined (Dunne and Leopold, 1978). In addition, a drainage project might thus be necessary to discharge storm waters detained in the plain into the channels during floods. Therefore, floodwaters impounded in the Upper Karşıyaka Plain may be drained out slowly during and after the flood through a reservoir. Channel improvements in the major creeks of the area are necessary to increase their conveyance capacity. Channel improvements that can be done in the creeks, however, should not only be in the form of deepening, widening, lining or straightening the channels. The attempts should be directed toward taking flood-plain protection measures that would prohibit building houses in the flood-prone zone. Finally, we believe that installing flood-warning systems in and around the city may help to reduce the flood losses by providing meteorological information and flood forecasting prior to storms. People can be moved to safer areas before the floodwaters invade the heavily populated parts of the city if the warning is given in time. Real-time flood forecasting supported by a continuous storm rainfall information through the extensive radar coverage along the Aegean coast and dissemination of the flood information through an efficient network of public officials and news media can provide a considerable flood damage reduction in the area. We should, however, believe that structural modifications to the riverine environment and flood proofing of flood prone areas may not always produce viable solutions to the problem of flooding. Therefore, as society continues to experience population growth and people choose to live by the water, we have an ever increasing need to educate the public on flood related hazards and to improve our predictions to support flood mitigation activities. A final point that has to be emphasized is that the government agencies that are involved in severe weather and flood management in the country urgently need to develop a methodology for forecasting heavy precipitation and flash flooding based on the synoptic and mesoscale features of the severe weather events that threaten the coastal parts of Turkey. Once that kind of a methodology is developed it will be much easier for the forecasters to delineate specific regions where the flash flood threat may be the greatest.

Acknowledgments

The authors wish to thank the Division of Weather Forecasting of the Turkish State Meteorological Service for supplying the synoptic charts and ECMWF products and the Division of Agricultural Meteorology for providing the rainfall information. We also express our thanks to the General Directorate of the State Water Works for their assistance in providing us with the hydrologic information about the flood.

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