Red Sea Trough Floods in the Negev, Israel (1964-2007)

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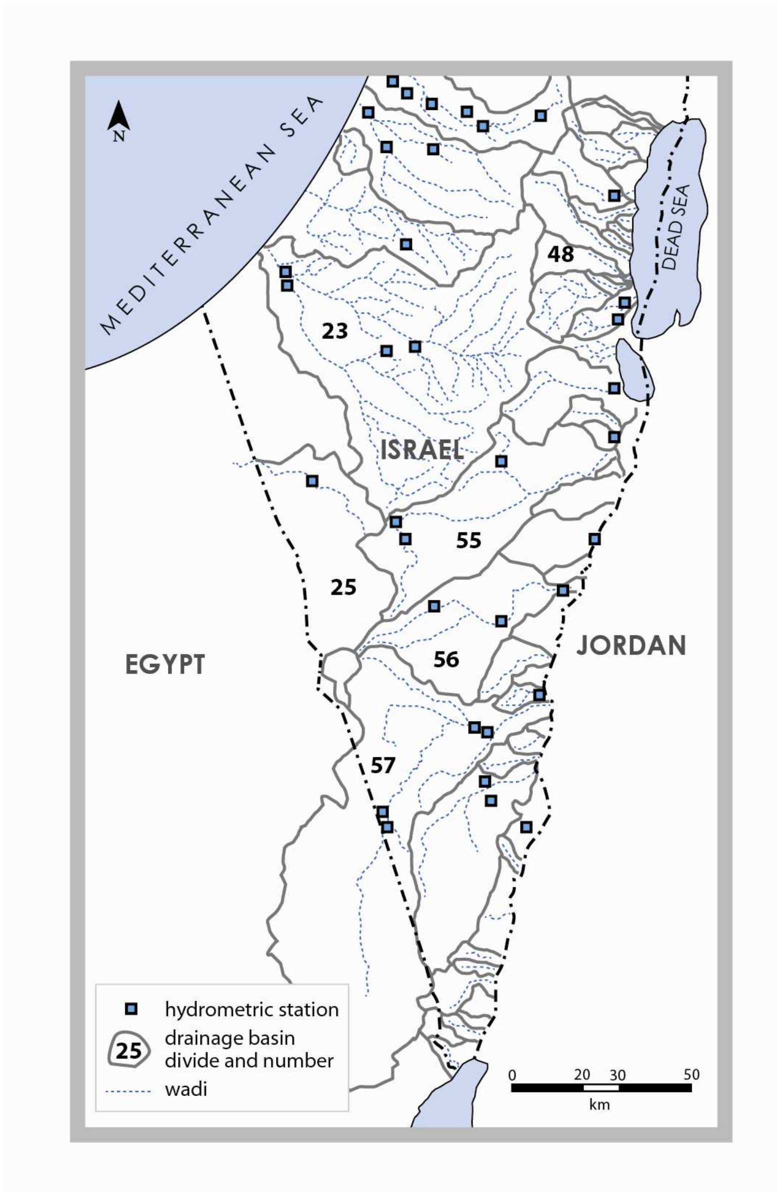

Fig. 1 Map of the drainage areas, basin numbers and location of gauging stations in the study area.
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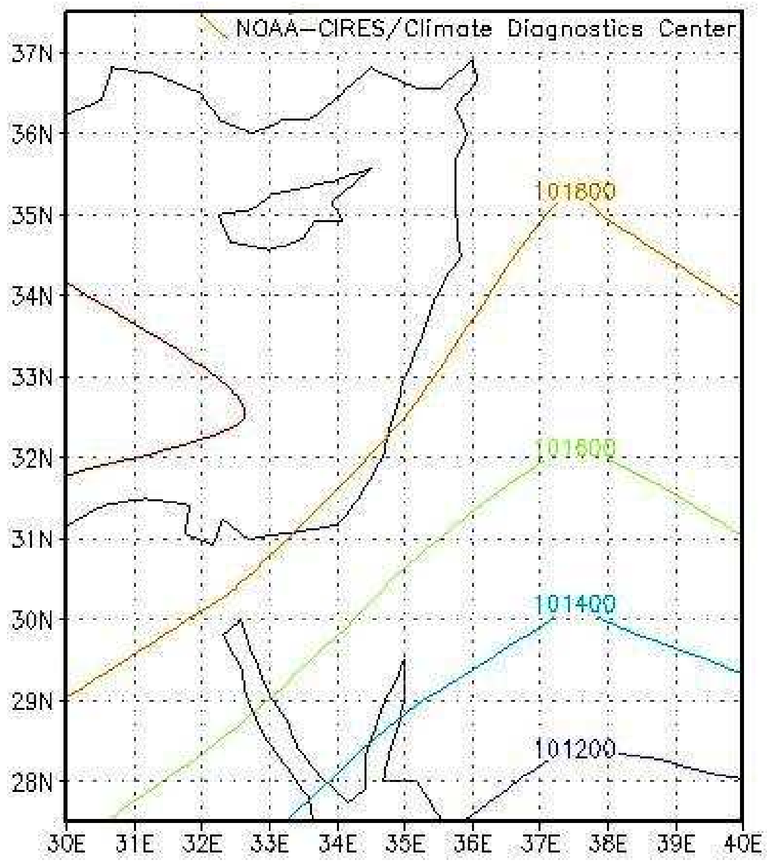

Fig. 2 The two sea-level pressure (SLP) charts represent (a) the deep surface Cyprus low to the north of the E. Mediterranean see continuation in Fig 2b
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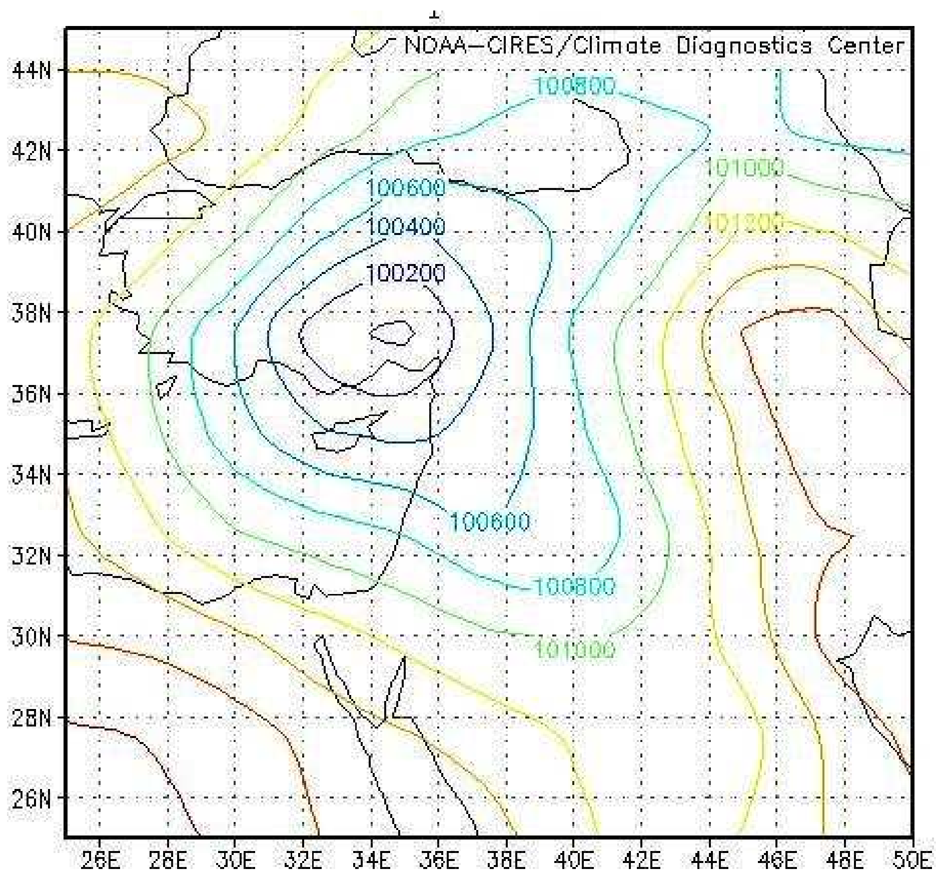

Fig. 2 The two sea-level pressure (SLP) charts represent (a) the deep surface Cyprus low to the north of the E. Mediterranean and (b) the Red-Sea Trough with an axis to the east of Israel, or to the EM coastline. The two maps represent actual maps at the centers of their clusters and are from the NOAA-CIRES reanalysis on the 27 Dec 1991 and 28 Oct 1985, both at 1200 UTC, respectively. Contour interval is 200 Pa. For further details on these two systems see Alpert et al (2004) and Osetinsky and Alpert (2006).
135x118mm (96 x 96 DPI)

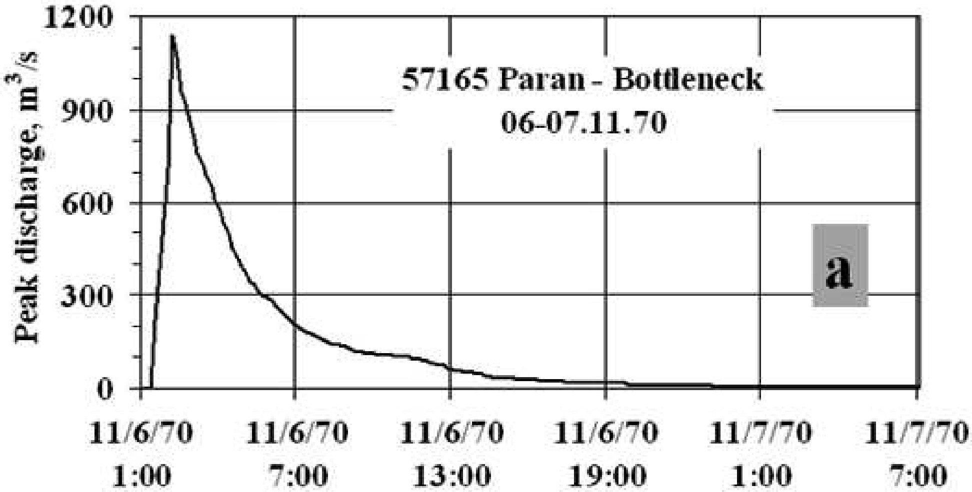

Fig. 3 Typical hydrographs of major flood events caused by RST (a), cyclones (b) and several successive RST systems (c).
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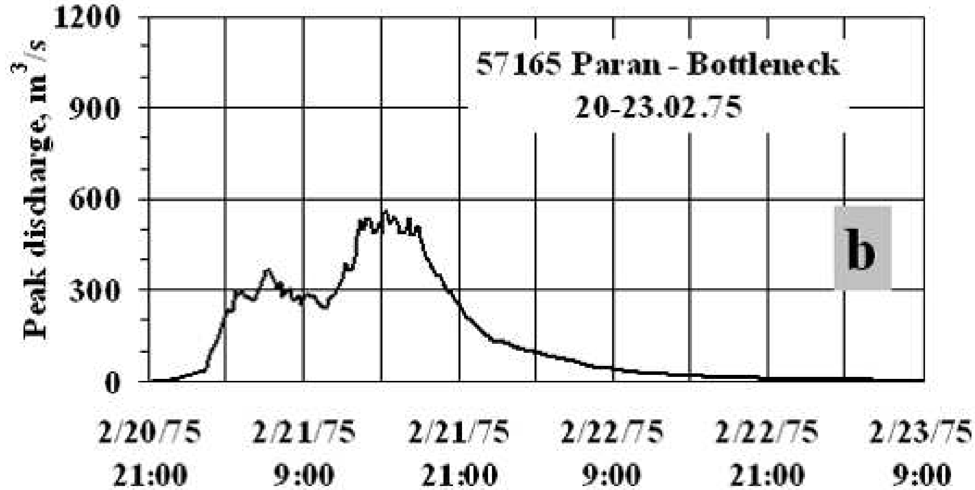

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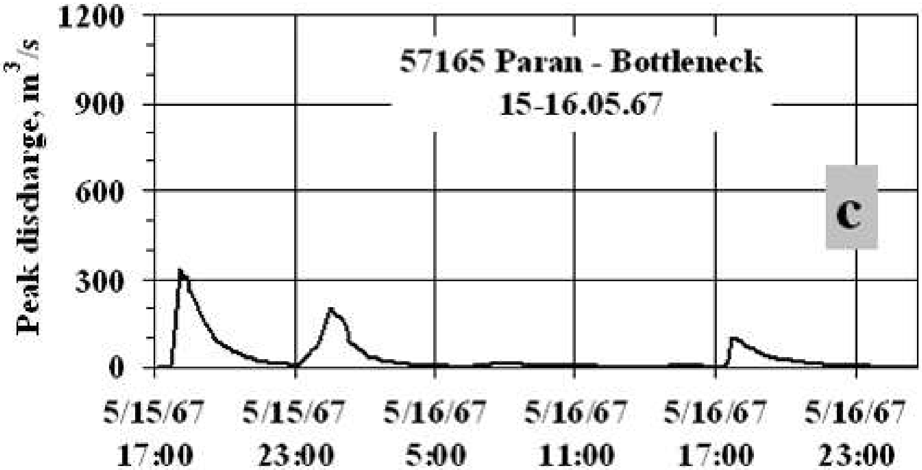

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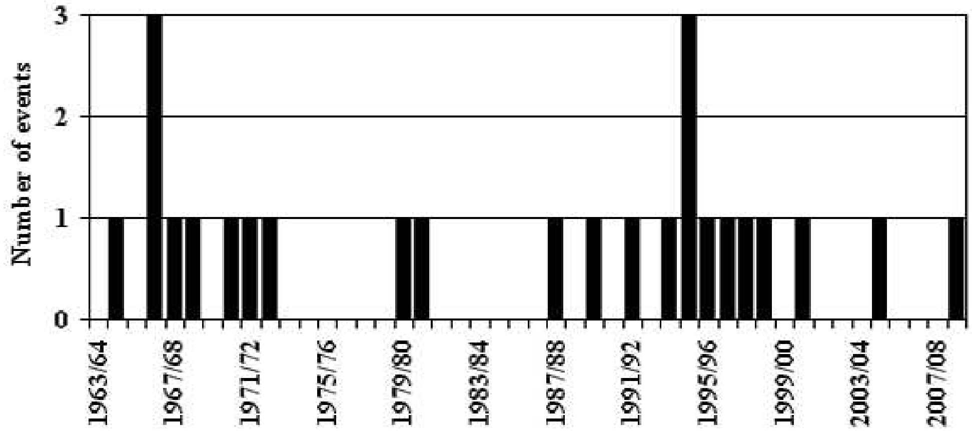

Fig. 5 Annual number of major RST flood events in the Negev, Arava and Dead Sea watersheds (1964-2007). Note: The next two years (2007/08-2008/09) are shown as added data.
208x97mm (72 x 72 DPI)

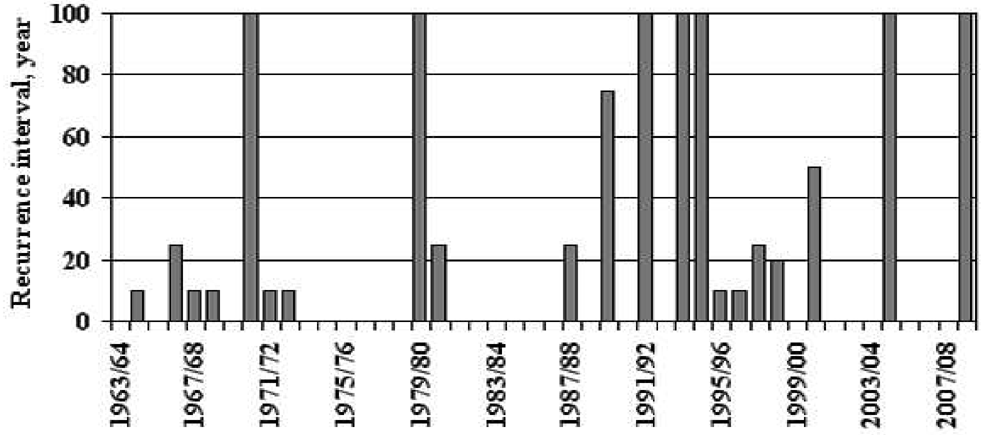

Fig. 6 Time series of the recurrence interval of peak discharge for major RST flood events in the Negev, Arava and Dead Sea watersheds during 1964-2007. See Note to Fig. 3.
208x97mm (72 x 72 DPI)

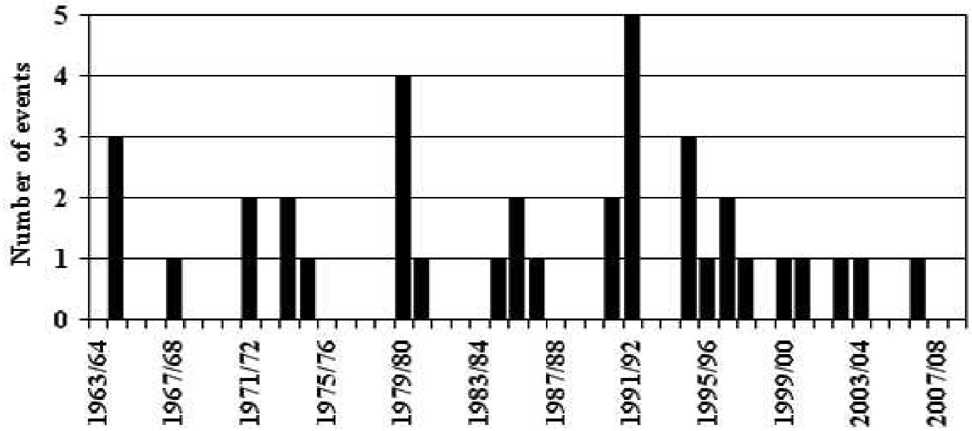

Fig. 7 Annual number of major cyclone flood events in the Negev, Arava and Dead Sea watersheds (1964-2007). See Note to Fig. 3.
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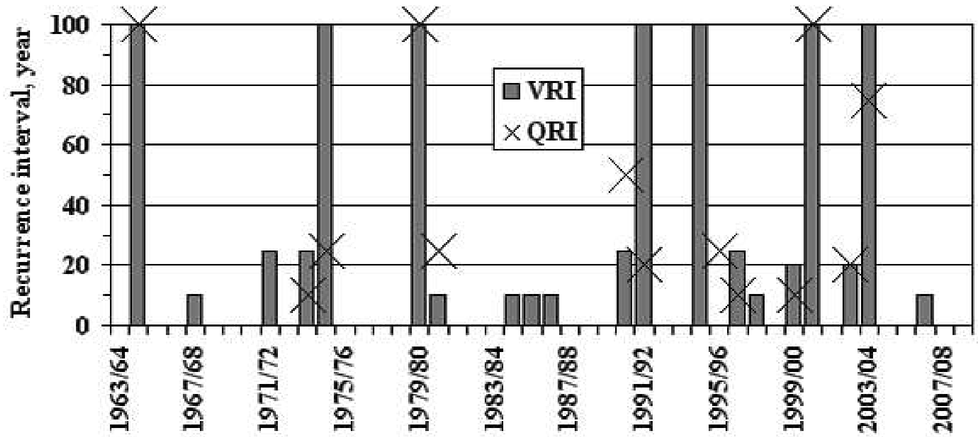

Fig. 8 Time series of the recurrence interval of peak discharge (QRI) and of volume (VRI) for major cyclone flood events during 1964-2007. See Note to Fig. 3.
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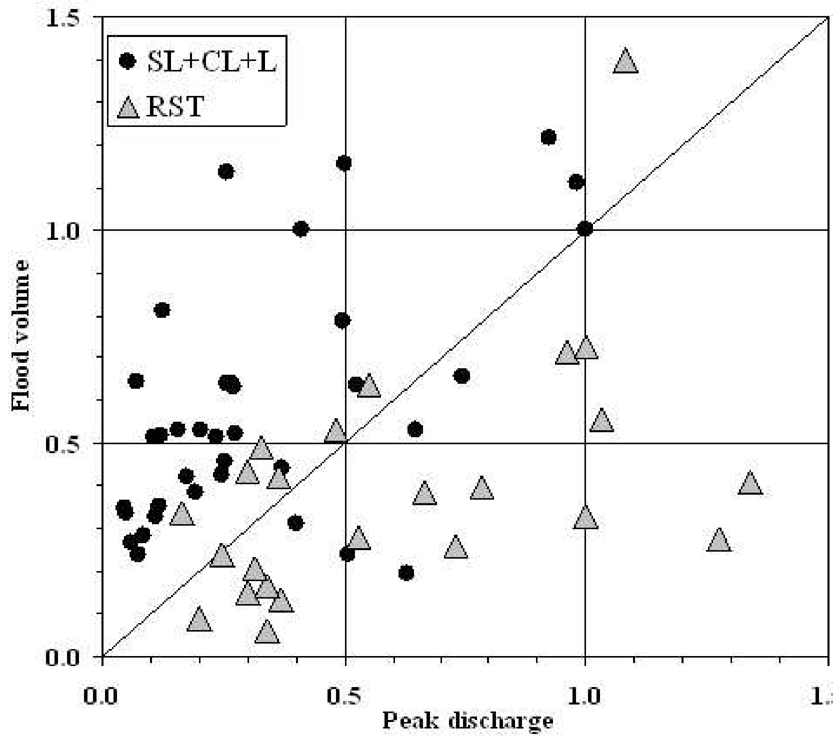

Fig. 4 Ratios of flood volume to peak discharge for major flood events with regard to causal synoptic systems. Note: To be comparable, flood characteristics (on the abscissa and ordinate) are related for every hydrometric station to the magnitude of the 100 year recurrence interval (the Negev and Arava) or to the historical hydrometric maximum (Dead Sea western watersheds). SL, CL and L are winter cyclones (Syrian Low, Cyprus Low and other, respectively).
152x121mm (96 x 96 DPI)

Red Sea Trough Floods in the Negev, Israel (1964-2007)

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Abstract

Results of a comprehensive synoptic-hydrological analysis of major flood events in the Negev (1964-2007) are presented. A low threshold for major flood data was set to be the 10 year recurrence interval of peak discharge and/or flood volume magnitude. Altogether 75 major flood events - or 133 hydrometrically monitored floods - were extracted. These events were categorized according to synoptic oriented classes by verification of the paired databases of (1) floods in the study area and (2) synoptic systems over the Eastern Mediterranean (Alpert et al., 2004).

For the study area two most frequent flood-generating synoptic systems are the autumn Red Sea Trough (RST), 31%, and winter cyclones, 49%. The entire RST series consists of 24 major flood events (55 floods). The synoptic definition was corroborated by analyzing the specific form of flood hydrographs and the ratio of flood volume to peak discharge. Regional analysis shows increased contribution of RST events southwards from 30% to 90% with a respective decreased number of cyclone events.

By comparing two 22 year sub-periods (1964-1985 and 1986-2007), a positive trend in the frequency and magnitudes of RST flood events is discerned. There is also an increased tendency for the occurrence of cyclone floods.

Key words: floods, synoptic system, climate change, Negev, Arava, Dead Sea, Mediterranean

Introduction

The question "Are there changes with respect to the magnitude and frequency of flood events in drylands during the last years?" is important and more than once discussed by hydrologists as well as by weather forecasters weary of a potential climate change in Mediterranean regions (Reid et al., 1999; Murray-Hudson et al., 2006; NWB Group, 2008). This theme is particularly relevant to extreme floods caused by the Red Sea Trough (RST) system over the Eastern Mediterranean. To attempt answering this question, major flood events in the Negev have been examined by a synoptic-hydrologic analysis.

The study area (Fig. 1) includes the four regions in the southern half of Israel (wadi names are given parenthetically): North-Western Negev (Besor, Beer Sheva and Lavan), Central Negev (Zin and Neqarot), Arava (Paran and tributaries) and the Dead Sea watersheds (western tributaries). The north-western part of the region is characterized by a dry Mediterranean climate whereas the rest has a semiarid to hyper-arid climate, with typical ephemeral flow regimes (e.g., Ben-Zvi, 1982; Reid et al., 1999; Cohen and Laronne, 2005).

Previous research has largely relied on 'case studies' to point out the atmospheric circulation systems associated with a specific flood, analysis of flood mesoscale characteristics and examination of extreme flood-producing rainstorms (e.g., Dayan and Abramski, 1983; Inbar, 1987; Schick and Lekach, 1987; Greenbaum *et al.*, 1998; Krichak and Alpert, 1998; Ben David-Novak *et al.*, 2004; Ziv *et al.*, 2004; Dayan and Morin, 2006).

The first experience on systematic synoptic climatology of major floods in the Negev was undertaken by Kahana *et al*. (2002). The present synoptic-hydrologic flood analysis differs from the latter study by a longer flood series, more informative samples of major events and using a classification of synoptic systems over the Eastern Mediterranean (Alpert et al., 2004) as a tool for categorizing floods to synoptic oriented classes.

Data and methods

Categorizing flood events to synoptic oriented classes was based on data verification for the paired databases of (1) floods in the research area (Israel Hydrological Service) and (2) synoptic systems over the Eastern Mediterranean (Alpert et al., 2004, updated to 2007). SLP charts of the major synoptic systems are depicted in Fig. 2 (further details on the systems can be found also in Osetinsky and Alpert, 2006). The study period is 1963/64-2006/07; hydrological years start on October 1.

Major flood events were extracted from hydrometric data on condition that at least in one hydrometric station peak discharge and/or flood volume reached a magnitude of a 10 year recurrence interval (10% annual probability). Due to lack of sufficient data for Dead Sea tributaries, 25% of the historic hydrometric maximum was considered as a low threshold for major floods.

A total series of 75 major flood events (measured as 133 floods in hydrometric stations) were selected and thereafter classified by synoptic systems. Every flood event was related to a defined daily synoptic system (beginning in the afternoon) with regard to the times of flood start, end and especially the time of peak discharge. In the indeterminate cases, the preceding situation was taken into consideration with a lag time of 3-6 h for medium catchments and 12-24 h for areas larger than 1000 km^2 (Kahana et al., 2002).

The major floods

The two most frequent synoptic types causing major floods in the study area are the Red Sea Trough in the autumn (31%) and winter cyclones (49%), including the Syrian Low, Cyprus Low and other lows. The rest of the synoptic cases (20%) are either related to winter-spring RST or to autumn-spring cyclones. The synoptic classification of the major flood events was corroborated by analyses of the specific form of the flood hydrograph and the ratio between flood volume and peak discharge.

The major floods caused by the RST systems in most cases represent pointed, single-peaked hydrographs with relative high peak discharge and short duration. In contradistinction, major floods caused by cyclone systems represent complex, multi-peaked hydrographs with relatively low peak discharges and long durations. Typical hydrographs of major floods are shown in Fig. 3. These results confirm the known specific characteristics of RST rain events, concerning more local convective precipitating element as compared to winter cyclones generated rather widespread rain and also differences in rain depth, duration and intensity (e.g., Dayan & Morin, 2006).

Regional analysis of the RST-generated floods shows not only (i) increased contribution of RST events southwards from 30% to 90% with a respective decreased contribution of the cyclone events, but also (ii) increased frequency of successive daily RST systems generating multi-peak hydrographs.

Floods associated with RST systems differ from the cyclone-generated floods by the ratio between flood volume and peak discharge (Fig. 4). The synoptic classification is based on a total series of 61 major floods, presented maximal ones measured within the large flood events in the study area (1964-2007). Every point on this graph presents a flood. Point coordinates are flood volume and peak discharge related to the 100 year recurrence interval (or to historical maximum) for every hydrometric station. For the RST-generated flood group characterized by a higher peak discharge with a relatively low volume, the majority of points (71%) are below the line of equal values. In contrast, for the cyclone-generated flood group characterized by a lower peak discharge and a relatively high volume, the majority of points (86%) are above the line of equal values. The RST and the cyclone groups include floods with outstanding peak discharge and exceptionally large volume, respectively.

As a synoptic system is very strong but not the only causative factor with reference to flood magnitude, the proposed hydrograph classification is not all definitive. In addition to the influence of local and regional factors, reasons of uncertainty include accuracy of used method and errors of hydrometric data. Deviating points concern several indeterminate events (due to complexity of synoptic system) and successive daily RST systems, generated multi-peaked hydrographs with relatively high flood volume with respect to peak discharge. The deviating upper RST datapoint is an example of an unreliable hydrometric datum (reconstructed hydrograph of the partly measured flood on 13-14.10.1991, Tsin-Waterfall station).

Analysis of major RST-generated floods

The series consist of 24 major RST events (monitored as 55 floods), from which 9 were measured at one station, 6 at two stations within 1-2 regions and 9 at 3-6 stations within 1-3 regions. The complete series is shown in Table 1, where each event is presented by the most considerable measured flood. Of these events, 67% relate to RST with an Eastern axis (class 1), 25% with a Central axis (class 3) and 8% with a Western axis (class 2). RST-generated floods are most frequent during October and November (7 and 11 events respectively). In December-January and April-May the number of RST events decreases respectively to 2 and 1 per month.

Fig. 5 shows the number of the major RST floods in the Negev, Arava and Dead Sea watershed for each year during the study period (1964-2007). Major RST-generated floods occurred in 20 of 44 years; only 2 years experienced 3 events and others at most one. The time series contains eleven gaps without major RST floods (seven of 1 year, one of 2 years, one of 3 years and two of 6 years). The distribution indicates the existence of two periods in which major RST floods were relatively frequent: 1965-1973 (nine events for 9 years, two 1-yr gaps) and 1988-2001 (twelve events for 14 years, four 1-year gaps).

Peak discharge magnitudes are represented by the recurrence interval (QRI) in Fig. 6. If an event was observed at more than one station, it is the most considerable measured flood. A sample includes 7 large events with QRI = 75-100 yr.

During the last 6 hydrological years (2001/02-2006/07) only one major RST-generated flood was observed (at Mamshit, left tributary Zin, 29.10.2004). However, this was a maximal historical peak discharge at this station (138 m^3/s, with a 100-yr return interval), whereas the previous maximum was 99 m^3/s on 6.11.89 (with 75-yr RI). Two gaps of 2-3 years are not exceptional. The last two years (2008-2009) are added to the study series (1964-2007) as independent data (Fig. 5 and Fig. 6): one RST (class 1) major flood event (24-25.10.2008) was measured at the stations Mamshit (peak discharge 120 m^3/s, almost 100-yr RI) and Hemar (peak discharge 185 m^3/s; 20-yr RI).

RST floods and climate change

Generally, the inter-annual distribution of RST major events in 1964-2009 (Fig. 4), as well as magnitudes of peak discharge (Fig. 6), does not give sufficient support to assert a negative trend evolving under climate change in the Eastern Mediterranean. Conversely, by comparing two sub-periods (1964-1985 and 1986-2007), a positive trend for RST flood events is discerned (Tables 2-3). For the last 22 years (as compared with the previous 22-yr sub-period) the following tendencies are revealed: (i) the number of years without RST events decreased whereas the number of years with one event increased, (ii) the number of medium (20-50 yr RI) and large (75-100 yr RI) events doubled, but (iii) the number of relative small events (10 yr IR) decreased by half.

The changes in the frequency of occurrence and the magnitude of major RST-generated floods in the Negev, Arava and Dead Sea western watersheds stand in good agreement with previous conclusions (Alpert et al., 2004) concerning (i) the trend in the annual frequencies of the Red Sea trough (RST) systems in the Eastern Mediterranean (EM) region for 1948-2000 which has nearly doubled since the 1960s from 50 to about 100 days per year, and (ii) a dominant decreasing trend of rainfall in most of the EM, along with an increase in the southern part of the EM region (when the RST is deep enough to bring tropical moisture over this area), both of which are explained by the increase in the active and stormy types of RST situations.

Cyclone floods and climate change

Major cyclone events were also extracted from the flood data by a lower threshold of a 10 yr recurrence interval for peak discharge and/or flood volume. The total series consists of 37 flood events monitored as 59 floods at one to five stations within 1-3 regions. Some major cyclone floods are presented in Table 4.

Among a total 37 major cyclone events, 51% were generated by a Syrian Low system, 33% - Low system and 16% - Cyprus Low. Cyclone flood events are most frequent during December, January and February (10-12 per month) and only one month event was observed in November and March to May.

Annual number of the major cyclone-generated flood events in the Negev, Arava and Dead Sea watersheds (1964-2007) is shown in Fig. 7: events occurred in 21 of 44 years; only 2 years experienced 4-5 events, 7 years experienced 2-3 events and others no more than one event. The time series contains eleven gaps (1-4 years) without major cyclone floods. The distribution indicates the existence of a period (1979/80-1997/98) with higher frequency of cyclone-generated flood events (twenty three events during 19 years).

Fig. 8 shows time series of peak discharge and volume recurrence interval (QRI and VRI) for major flood events caused by cyclone synoptic systems. A sample includes 7 events with 100 year RI for flood volume, among which only 4 events are also characterized by 75-100 RI for peak discharge. The RST sample includes 7 events with 75-100 year RI for peak discharge but with lower flood volumes. In the last 10 hydrological years (1997/98-2006/07) major cyclone-generated events were observed in six years, the annual number did not exceed 1 and two events were considerable (100 yr RI for volume and 75-100 yr RI for peak discharge).

By division of the study period to two sub-periods (every 22 years) it is apparent that the number of years without cyclone events decreased by a third for the last sub-period in comparison to the previous one, whereas the number of years with 1-2 cyclone events nearly doubled (Table 5). More frequent appearance of cyclone events occurred in the last 22 years of the study period (Table 6). No major cyclone flood events were observed during last two years (2008-2009), but the general increased dynamics of major cyclone-generated flood events is revealed for the study period. It does not conform to the slightly negative trend of the Cyprus Low systems (1967-1998) in the EM region (Alpert et al., 2004).

Discussion

The seasonal, monthly and spatial distribution of major flood events, classified synoptically, was derived for the Negev and generally in agreement with earlier findings (Kahana et al., 2002). However, the present results are more comprehensive because of (a) a more complete database, i.e. 75 major flood events measured as 133 floods in hydrometric stations for 1964-2007 against a former study of 42 major flood events for 1965-1994; (b) complex flood characteristics (peak discharge, volume, duration and hydrograph) based on a region-season model in contrast to the traditional analysis regarding only peak discharge, thereby disregarding the large majority of winter flood events; and (c) a more informative sample of major flood events selected by 10 yr recurrence interval threshold whereas the former was a 5 yr. Increasing the threshold to 10 yr reduced the Kahana et al. (2002) data series from 42 to 18 events. Hence, the current study covers a quadruple number of heavy floods (RI>10), i.e. 75 compared 18. Observe that the classification of synoptic systems over the Eastern Mediterranean (Alpert et al., 2004) was used as a tool for categorizing floods to synoptic-oriented classes, whereas previously (Kahana et al., 2002) each synoptic type was initially identified by analysis of atmospheric data.

The question is large flood events - rare extreme floods with magnitudes represented by a recurrence interval of 100 years. Every such flood case is a subject of much research and the topic of a large number of publications (see reference list). For RST flood events (Table 1), a sample of 44 years includes 6 large events (with historical maximal peak discharge in every station). Among them (Table 3), 2 events occurred in the first sub-period (1964-1985) and 4 – in the second period (1986-2007). Indeed, these are small numbers, but considering the rareness of such events and based on available data series it seems reasonable and quite interesting to point out that these extreme events doubled in the more recent period, especially within evidence of an increased common tendency in the frequency and magnitude for both RST and cyclone events.

A trend to higher frequency of RST-generated flood events, with lower volumes for given discharges or, conversely, larger peak discharges for given flood volumes is revealed for the last period. This may have direct effect on several fluvial aspects, particularly to soil erosion, central to which is the response of sediment transport. Most of the fluvial sediment in drylands (and particularly so in Mediterranean regions) are transported in suspension (e.g., Powell et al., 1996). Also, it is the large volume of floods which accounts for most of the suspended sediment yield (Alexandrov et al., 2009). However, it is the high discharges associated with high peak discharges, which give rise to exceptionally large fluxes of bed load (Laronne and Reid, 1993). A shift to more frequent and larger major RST-generated flood events may, therefore, bring rise to an increase of the bed load fraction in Mediterranean and semiarid systems, thereby the response becoming more typical of that in arid to hyper-arid systems (Laronne and Wilhelm, 2001).

Summary

This study deals with changes in magnitude and frequency of flood events in EM drylands during recent years. Results of a synoptic-hydrological analysis of major flood events in the Negev, Arava and Dead Sea watershed and comparison of two sub-periods (1964-1985 and 1986-2007) may be summarized as follows:

- for RST floods number of years without major flood events decreased, number of years with 1-2 major flood events increased, number of large (75-100 yr RI) and medium (20-50 yr RI) flood events doubled where as number of small ones (10 yr RI) decreased by half;
- for cyclone floods number of years without major flood events decreased by a third, number of years with 1-2 major flood events doubled, number of large (75-100 yr RI) and medium (20-50 yr RI) flood events, at least, did not decreased where as number of small ones (10 yr RI) doubled.

Analysis of the inter-annual distribution of major flood events in the study area and its magnitudes show evidence of an increase tendency for both RST and cyclone events during the last 22 sub-period (1986-2007). Revealed dynamics of major flood events in the Negev, Arava and Dead Sea watershed during the last 44 years conform to an increase in the trend of the annual frequency of

RST synoptic systems in the EM region (since the 1960s), but do not corroborate a slight drop in the annual frequency of the Cyprus lows (Alpert et al., 2004).

Categorizing major flood events to synoptic-oriented classes and detection of the main features of flood events through analysis of synoptic conditions may enable prediction of future flood dynamics in drylands under climate change scenarios. For this purpose, scenarios should be formulated in terms of classification for daily synoptic systems (e.g., over the Eastern Mediterranean; Alpert et al., 2004).

Acknowledgements

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Table 1 Major flood events caused by Red Sea Trough (RST) in the Negev, Arava and Dead Sea watershed (western tributaries) during 1964-2007

station		area km^2	hydrol year	flood event date	Q m^3/s	V $10^6 m^3$	RI year
ID	name						
N 23106	Besor - Nizzana Rd.	185	1964/65	17/11/64	66.8	0.750	10
N 23134	Beqa	96	1966/67	9-10/11/66	63.7	0.652	10
N 23106	Besor - Nizzana Rd.	185	1966/67	11-12/11/66	101	0.366	25
A 57165	Paran - Bottleneck	3350	1966/67	15-18/05/67	338	3.90	10
N 25190	Lavan - Nizzana	220	1967/68	15-16/11/67	128	0.538	10
A 57165	Paran - Bottleneck	3350	1968/69	23-28/11/68	183	8.75	10
A 57165	Paran - Bottleneck	3350	1970/71	6-8/11/70	**1150**	14.4	100
C 55180	Zin - Aqrabim	1130	1971/72	1/04/72	94.3	0.986	10
A 57160	Arod	161	1972/73	24-25/11/72	44.8	0.402	10
N 25190	Lavan - Nizzana	221	1979/80	22-23/10/79	**440**	1.09	100
C 55110	Zin - Waterfall	233	1980/81	26-27/12/80	272	3.65	25
N 23137	Beer Sheva - Hazerim	1220	1987/88	18-20/10/87	872	9.69	25
C 55165	Mamshit	64	1989/90	6-7/11/89	99.0	0.586	75
C 55110	Zin - Waterfall	233	1991/92	13-14/10/91	**551**	8.05	100
C 56150	Neqarot Upper	697	1993/94	22-23/12/93	**708**	2.59	100
C 55110	Zin - Waterfall	233	1994/95	10-11/10/94	122	1.38	10
A 57165	Paran - Bottleneck	3350	1994/95	2-6/11/94	371	12.7	10
D 48130	Teqoa	142	1994/95	5/11/94	**74***	0.270	*~100*
D 48125	Darga	70	1995/96	2/11/95	12.4	0.036	*~10*
D 48130	Teqoa	142	1996/97	23-24/01/97	23.5	0.169	*~10*
D 48130	Teqoa	142	1997/98	17-18/10/97	39.3	0.229	*~25*
D 48125	Darga	70	1998/99	24/01/99	20.7	0.024	*~20*
C 55165	Mamshit	64	2000/01	15/10/00	80.6	0.325	50
C 55165	Mamshit	64	2004/05	29/10/04	**138**	0.337	100

Note: Q is peak discharge, V is flood volume, hydrol year is hydrological year, RI is recurrence interval for peak discharge, bold type denotes historical peak discharge, sign ~ denotes rough indirect estimate RI for Dead Sea tributaries, letter in first column (ID) refers to region: N - North-western Negev, C - Central Negev, A - Arava and D - Dead Sea watershed; each event is presented by the most considerable measured flood.

Table 2 Comparison of two sub-periods by the inter-annual distribution of RST major flood events in the Negev, Arava and Dead Sea watersheds

annual number of RST flood events	number of years in sub-period	
	1964-1985	1986-2007
0	13	11
1	8	10
2	-	-
3	1	1
total	22	22

Table 3 Comparison of two sub-periods by the recurrence of peak discharge of RST major flood events in the Negev, Arava and the Dead Sea watersheds

recurrence interval year	number of RST flood events in sub-period	
	1964-1985	1986-2007
10	7	4
20-50	2	4
75	-	1
100 and more	2	4
total	11	13

Table 4 Some major floods caused by cyclone systems in the study area (1964-2007)

station		area	date of event	Q	V	RI	
ID	name	km^2		m^3/s	10^6 m^3	Q year	V year
N 23150	Besor - Reim	2630	*Peak 19/01/65*	**1000**	**33.0**	100	100
A 57165	Paran – Bottleneck	3350	20-24/02/75	562	**30.0**	25	100
D 48155	Arugot	235	*Peak 21/02/80*	**528**	**3.01**	~100	~100
D 48130	Teqoa	142	2-4/12/91	30.5	**0.820**	~20	~100
D 48155	Arugot	235	4-7/02/92	65.8	2.44		~75
N 23150	Besor - Reim	2630	28/11-9/12/94	264	**33.7**		100
D 48125	Darga	70	02/05/01	**61.2**	**0.399**	~100	~100
C 55165	Mamshit	64	15/12/03	95.0	**0.997**	75	100

Note: Q is peak discharge, V is flood volume, RI is recurrence interval for peak discharge or volume, bold type denotes historical peak discharge, sign ~ denotes rough indirect estimate RI for Dead Sea tributaries, letter in first column (ID) refers to region as N - North-western Negev, C - Central Negev, A - Arava and D - Dead Sea watershed.

Table 5 Comparison of two sub-periods by the inter-annual distribution of cyclone major flood events

annual number of cyclone flood events	number of years in sub-period	
	1964-1985	1986-2007
0	14	9
1	4	8
2	2	3
3-5	2	2
Total	22	22

Table 6 Comparison of two sub-periods by the recurrence of major cyclone flood events

recurrence interval, year	number of cyclone flood events in sub-period	
	1964-1985	1986-2007
10	5 / 2	9 / 4
20-50	6 / 2	5 / 4
75	-	2 / 1
100 and more	3 / 2	4 / 1
Total	14/6	20 / 10

Note: Volume and peak discharge estimate is presented in numerator and denominator, respectively; events of RI<10 yr are excluded.

List of figures