Climatic Change (2011) 105:455–468
DOI 10.1007/s10584-010-9892-8

Regional and local climatic effects on the Dead-Sea evaporation

Haim Shafir · Pinhas Alpert

Received: 22 December 2008 / Accepted: 14 June 2010 / Published online: 21 August 2010

Abstract The natural evaporation in the Dead-Sea is a very important meteorological parameter to the local industries at Sdom. It was found that the pan evaporation in Sdom has recently increased by 20–25%. In this paper we explore the reasons for this increase. It is found that both large-scale and local climatic changes have contributed to the evaporation increase in the Dead Sea Valley. The large-scale (global) change potentially associated with the global warming, resulted in changes of the frequencies of some synoptic systems in the region. The local change is a result of the recent Dead-Sea drying, which reduced the local Dead-Sea breeze while intensifying the Mediterranean-Sea breeze penetrating the Dead Sea Valley. It is suggested that while the local effect was the dominant climatic change factor in the Dead-Sea Valley in the 1970–1990, the global effect becomes the dominant one in the more recent evaporation increase in the Dead-Sea.

1 Introduction

The Dead-Sea has attracted the imagination of people from ancient times as it does today. It is a unique place in the world from several reasons. First, it is located at the lowest spot of the earth; about −425 m below sea level. Second, its water is very dense (about 1.3 gr/cm^3) and salty and rich with many kinds of minerals. Also, the climate of the Dead-Sea is very hot and dry with almost no precipitation throughout the year (20–50 mm/year). The Dead-Sea Works factory, located in the southern

H. Shafir · P. Alpert (✉)
Department of Geophysics and Planetary Sciences,
Tel Aviv University, Tel Aviv 69978, Israel
e-mail: pinhas@cyclone.tau.ac.il

H. Shafir
e-mail: chais@post.tau.ac.il, chai@cyclone.tau.ac.il

part of the lake (Sdom) makes use of the concentrated salts and the arid climate to manufacture potash, bromine and other minerals by the natural evaporation which makes the production process very efficient.

Therefore, the evaporation in the Dead-Sea is of much interest, and it is the focus of this paper. Alpert et al. (1997) investigated the dramatic pan evaporation increase at Sdom (Dead-Sea Works) in recent decades from about 350 cm/year in the 1960s to about 400 cm/year in the 1990s. They related this increase to a local climate change in the Dead-Sea Valley due to the drying of the lake. Steinhorn (1981), Klein (1982), Anati and Shasha (1989) and others investigated the drying of the lake from different points of view. The local climate change was noticed also by Stanhill (1994) and Cohen and Stanhill (1996). During the same period, Osetinsky (2006) and Alpert et al. (2004) have shown that a significant synoptic climate change has also occurred over the East Mediterranean (EM) in the last decades resulting in redistribution of some synoptic systems in the region.

In this paper we recheck the evaporation increase due to the local as well the synoptic or global climate changes. Section 2 describes the climate of the Dead-Sea and the local climate change which takes place in the region. Section 3 discusses the recent results of the pan evaporation increases in Sdom. Section 4 discusses the significance of the variation in the meteorological parameters in Sdom as compared to Eilat, while Section 5 describes the evaporation in Sdom in the different synoptic systems, and the increase of the evaporation due to the climatic change expressed in the redistribution of some synoptic systems in the EM. Section 6 summarizes and concludes the results.

2 The climate of the Dead-Sea and the local climate change

The pioneering studies of the Dead-Sea climate were those of Ashbel (1939, 1975). Bitan (1974, 1977) investigated the influence of the Dead-Sea on the climate in its neighboring regions. The climate of the Dead-Sea is very hot and dry. It is an arid zone having large differences in the diurnal temperature and humidity cycles, while the weak lake breeze of the Dead-Sea slightly tempers the hot and dry climate, Alpert et al. (1997). The two most dominant features in the daily wind cycle are the local Dead Sea breeze and the Mediterranean breeze. Alpert and Eppel (1985) suggested an index for mesoscale activity. This mesoscale activity is pronounced when this index is higher than one. The Dead-Sea valley winds are dominated by a very high index, particularly in summer (index of 2–4). This shows that the local winds are dominant compared to the large-scale wind component in the Dead-Sea Valley. The Dead-Sea breeze blows during the morning to noon hours with moderate speeds of up to 5–6 m/s and north-easterly direction in the southern Dead-Sea. The Mediterranean breeze originates at the Mediterranean coast and is very pronounced in spring and summer, Alpert et al. (1982). During the day the Mediterranean breeze flows up the Judean hills, then, it drops into the Dead-Sea valley in the early evening hours. Hence, this flow descends about 1200 m from the Judean Mountains to the Dead-Sea at about −420 m below MSL. This significant descent speeds up the wind, and the adiabatic heating warms and dries the Dead-Sea area.

The wind can reach a peak speed of over 15 m/s for short periods and has a dominant north-westerly direction at the Dead-Sea. These are the strongest and very consistent winds observed over the region in the summer season. Alpert et al. (2008) have shown that this strong, hot and dry wind significantly increases the evaporation in Sdom. During the late night and early morning hours the nocturnal winds prevail in the Dead Sea Valley.

Recently, Israel, Jordan and Syria have made extensive use of the water previously flowing into the Dead-Sea. The national water carrier of Israel and the Ruhr canal in Jordan began to utilize the Jordan River water in the 1960–1970. As a result parts of the Dead-Sea have dried. The water level which was −390 m in the 1960s now reaches a level of −425 m. Alpert et al. (1997) claimed that the local Dead-Sea breeze has weakened as a result of this drying. Since this breeze tempers the Dead-Sea climate, its weakening has caused the air temperature to increase, the relative humidity to decrease and thus the pan evaporation at Sdom has increased.

Alpert et al. (1997) and Alpert et al. (2006b) suggested also that another local climate change has occurred in recent years. They suggested that the Mediterranean breeze intensity in the Dead-Sea Valley has become stronger in the last decades. The Dead-Sea breeze is pronounced in the Dead-Sea even in the early evening hours when the Mediterranean breeze penetrates the region. This two winds are opposed each other. Therefore, in the past, when the Dead-Sea breeze was stronger it delayed the penetration of the Mediterranean breeze. Due to the recent weakening of the Dead-Sea breeze, the Mediterranean breeze penetrates stronger and earlier into the Dead-Sea Valley. The strong, hot and dry wind further increases the evaporation in Sdom.

3 The annual evaporation at stations in the Jordan Valley and the Arava

Figure 1 shows the study area and the stations locations discussed next. Figure 2 shows the time-series of the annual evaporation in the Jordan Valley and the Arava stations. Polynomial trend lines were added to the stations with available data till 2008. It is clearly seen that the pan evaporation at Sdom that Alpert et al. (1997) showed its increasing till 1994, accelerated its rise at the two Sdoms' stations (second Sdom station is not shown, although it shows the same trend as the main Sdom station). The evaporation reached a very high value of 442 cm/year in 2002. It is noticed in Fig. 2 also that this evaporation increase at Sdom is the highest in respect to the other stations in the Jordan Valley and the Arava that have a similar climate. This suggests that a local climate change in the Dead-Sea Valley has caused this evaporation rise in Sdom. Some other stations in the Jordan Valley and the Arava like Tirat Zvi and Jericho show even slight decreasing trends. Eilat, Yotveta and Massada show decreasing trends from the 1960s to the 1990s. However, an increasing trend is noticed from the 1990s to the 2000s. The polynomial trend lines for these long-recorded stations have changed their sign in the 1990–1995 (Fig. 2). This behavior of reducing evaporation in those stations till the 1990–1995, while increasing evaporation in Sdom strengthens our point that a local climate change is noticed in the Dead-Sea area. While the increasing trend from the 1990–1995 at all the stations

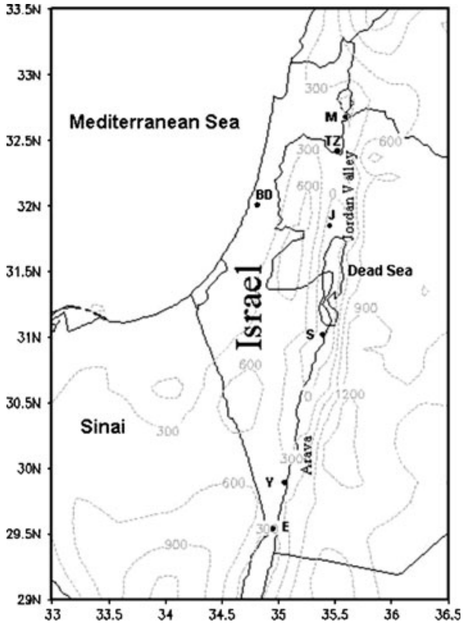

Fig. 1 Area of the study domain. Topography contours are dashed with 300 m interval. The letters *M*, *TZ*, *J*, *BD*, *S*, *Y* and *E* represent the stations' locations of Massada, Tirat-Zvi, Jericho, Bet-Dagan, Sdom, Yotveta and Eilat, respectively

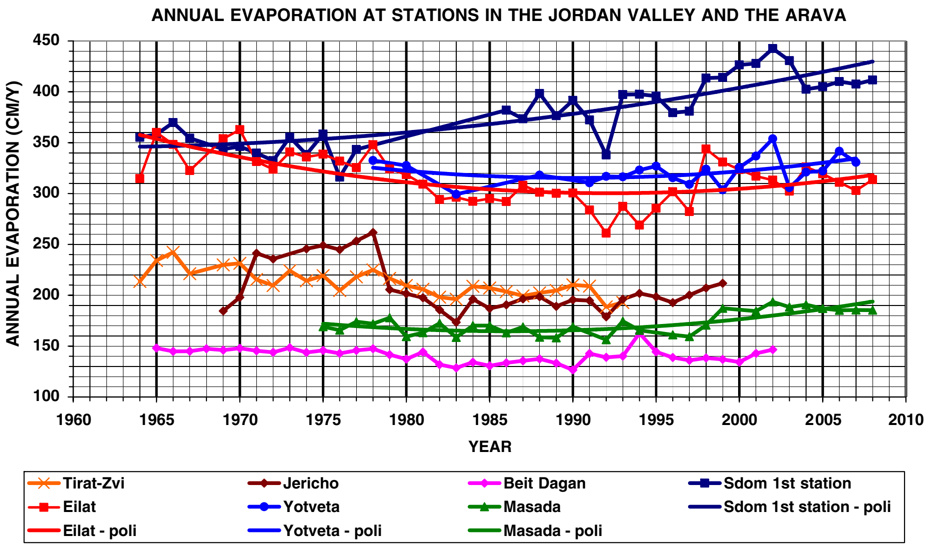

Fig. 2 The course of annual evaporation (cm/year) at several stations in the Jordan Valley and the Arava, during 1960–2008. Polynomial trend lines were added to the longest series

in the Arava means that a larger-scale or perhaps a global effect which increases the evaporation has impacted the region.

4 Climatic changes of the meteorological variables in the Jordan Valley

In order to find the causes for the increased evaporation in Sdom we checked the meteorological data averaged for all months at the hours 8, 14 and 20 (local times). We try to find the statistically significant changes comparing the averaged parameters for the recent 1995–2004 averages as compared to the 1970–1994 periods. The pan evaporation, temperature, relative humidity and wind speed were checked. Based on the T-test the significance of the changes in those average parameters was found. Table 1 shows the results in Sdom. Table 2 shows the same test results in Eilat. The Eilat station has a similar climate as Sdom, but it is not affected by the local change of the Dead-Sea, and certainly might be affected by the global change.

From these tables the following results are noticed:

1. The evaporation has very significantly increased in Sdom during all months (about 2.5 cm/month rise in winter and up to 5.8 cm/month in spring and summer). Notice the high rise in November (4.6 cm/month). While in Eilat there are no increases in the pan evaporation.
2. The temperature has significantly increased especially in summer and in the evening both in Sdom and Eilat. This rise is higher in Sdom as compared to Eilat.
3. There are insignificant changes in the relative humidity. It has increased in Eilat and reduced in Sdom. This reduction in Sdom although insignificant is noticed along the entire year.
4. The wind speed has intensified in the evening in the new period both in Sdom and Eilat.

From these results it is clearly seen that the pan evaporation in Sdom shows highly significant increases (as we noticed in Fig. 2), while in Eilat the evaporation increases are only from the 1990s. Therefore, while comparing the 1995–2004 to the 1970–1994 there are no significant changes in the evaporation in Eilat. It seems that there are several reasons for this course of evaporation:

1. The temperature rise in the new period exists both in Sdom and Eilat. It might be a result of the global warming known as the “greenhouse effect”, particularly observed to be strong over the Mediterranean region (Saaroni et al. 2003). Indeed, 2002 was globally a very hot year, and in 2002 the evaporation in Sdom reached its highest in record value of 442 cm/year. The temperature rise seems not to influence the evaporation in Eilat. This might be explained by the fact that the evaporation rise in Sdom is primary a local phenomenon (Alpert et al. 1997). However, a closer look on Fig. 2 shows that the evaporation in Eilat has begun to rise in the 1990–1995. The evaporation means for Eilat for 1964–1970, 1992–1996 and 2000–2008 are 343.7, 280.9 and 314.4 cm/year, respectively. Hence, there is an evaporation rise in Eilat of about 35 cm/year from the 1990s to the 2000s, and it might be associated with the acceleration in the global warming since 1980 (Ziv et al. 2005).

Table 1 Significant changes of the average hourly meteorological parameters at Sdom

Param.	Hour month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
T (C)	08	_+1.1_***	_+1.0_***	=	=	=	_+0.4_**	_+0.7_***	_+0.6_**	=	=	_+1.1_***	_+1.4_***
	14	=	=	=	=	+0.8*	=	_+1.0_***	=	+0.4*	=	=	+0.9*
	20	_+1.3_***	+1.0*	=	=	_+1.2_***	_+0.9_***	_+1.5_***	_+1.0_***	_+0.6_**	=	_+1.2_***	_+1.6_***
RH (%)	08	=	=	=	=	=	=	=	+1.2*	=	=	=	=
	14	=	=	=	=	=	=	−1.8*	=	=	=	=	=
	20	=	=	=	=	=	=	_−2.7_**	=	_−3.0_***	=	_−4.4_**	=
WS (m/s)	08	+0.9*	=	+0.9*	=	=	=	=	_+0.5_**	=	=	=	=
	14	=	=	_+1.1_**	+1.0*	=	=	=	=	=	=	=	=
	20	=	_+1.3_***	+1.0*	+0.9*	+0.7*	_+1.5_**	=	=	=	_+0.9_**	_+0.9_***	+0.7*
EVAP (cm)	Monthly	_+1.9_***	_+2.8_***	_+3.8_***	_+5.8_***	_+5.0_***	_+4.3_***	_+5.5_***	_+5.8_***	_+4.6_***	_+2.7_***	_+4.6_***	_+2.1_***

New period (1995–2004) against previous period (1970–1994). For the evaporation the corresponding periods are, (1995–2005) and (1964–1994). Empty box with the sign = represent no significant change. When there is a significant change: + represents increase, while − represents decrease in the parameter in last period, following with the average difference of the parameter between the two periods, and the significance level of the change, where three stars (***) corresponds significant level of more than 99%, two stars (**) to more than 97.5% and one star (*) to more than 95%. Italicized entries represent significant level change of more than 97.5%

Table 2 As Table 1 but for the station of Eilat

Param.	Hour month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
T (C)	08	+0.8*	=	=	=	=	=	*+1.0****	+0.6*	=	=	+0.8*	*+0.9***
	14	+0.9*	=	=	=	=	=	*+0.8****	=	=	=	+0.8*	*+1.2****
	20	*+1.3****	=	=	=	*+1.1****	*+1.0****	*+1.7****	*+1.2****	*+0.8****	*+0.7***	*+1.2****	*+1.4****
RH (%)	08	=	=	=	+2.3*	=	*+2.9****	=	*+2.0***	=	+2.1*	=	=
	14	=	=	=	=	=	*+1.6****	=	+1.5*	=	*+2.8****	=	=
	20	=	=	=	=	=	=	−1.6*	=	=	=	=	−3.0*
WS (m/s)	08	=	=	=	=	=	=	=	=	=	=	=	=
	14	=	=	=	=	=	=	=	=	=	=	=	=
	20	=	+0.7*	=	+0.6*	=	*+0.9****	*+1.0****	*+1.0****	*+0.8****	+0.6*	=	=
EVAP (cm)	Monthly	=	=	=	=	=	=	=	=	=	=	=	=

2. The reduction in the relative humidity is noticed in Sdom, while in Eilat the humidity is increasing. This suggests that the evaporation rise in Sdom is partly due to a local phenomenon of the lake drying.
3. Tables 1, 2 show that in the evening the wind becomes stronger in Sdom and Eilat. It seems that the Mediterranean Sea breeze, which reaches South Israel in the early evening hours, has become stronger recently and resulted in the temperature rise in the evening. In Sdom the Mediterranean breeze could have become stronger due to the weakening of the Dead-Sea breeze as explained in Ch. 2. Another potential contributor for this might be that due to the temperature rise in the evening at the Dead-Sea, the valley becomes warmer compared to the Judean Hilles to its west. This leads to a stronger hill-valley pressure gradient and stronger winds. Also, the intensifying breeze in the Dead Sea Valley can explain the higher evaporation in Sdom as discussed in Ch. 2.

In general, when we compare Alpert et al. (1997 Ch. 3.2 and Tab. 1, 2) results to the current results it seems that two following factors are causing the pan evaporation increases in Sdom; the local effect of the lake drying on the one hand and the large-scale global warming effect on the other. It seems that till the 1990s the local effect was the dominant one. However, from the 1990s the global effect has become stronger.

5 Evaporation in Sdom under different synoptic systems

5.1 The relative contribution of the different synoptic systems to the Sdom evaporation

Alpert et al. (2004) suggested a semi-objective classification of the daily synoptic systems in the EM. Every day from 1948 to 2006 was classified to one of the 19 synoptic systems typical to the EM. Table 3 shows the characteristics of these 19 systems as related to the Sdom evaporation. Based on this classification Alpert et al. (2004) and Osetinsky (2006) have shown that some synoptic systems have redistributed due to the climatic change. For instance, they have found that the annual frequencies of the hot and dry systems entitled the Red-Sea Trough (RST), nearly doubled since the 1960s from 50 to almost 100 day/year. They also noticed that the frequency of the summer hottest system of the Weak Persian Trough (WPT) has increased on the account of the other cooler summer systems of the Medium Persian Trough (MPT) and Deep Persian Trough (DPT). The frequency of the WPT has increased from 35 days per year in the 1964–1974 to 49 in the 1996–2005. While the frequencies of the MPT and DPT have reduced from 56 to 43 and from 13 to 5 day/year respectively.

Computing the daily pan evaporation in Sdom from 1960s to 2000s for each synoptic system, Fig. 3 shows the average daily evaporation in Sdom for the 19 different synoptic systems during 1964–2006. As expected, the evaporation is highest in the summer synoptic systems of the WPT, MPT and DPT, the highest being for the hotter WPT. Also, the evaporation is the lowest in the coolest winter systems of the Cyprus lows. The RST systems are typical to the transition seasons, and consequently the evaporation in the RST systems shows intermediate values.

Table 3 The characteristics of the 19 synoptic systems in Israel as found by the semi-objective classification made by Osetinsky (2006)

No.	System	Most typical season	Mean daily evaporation in Sdom (mm/day)	Temp	RH	Wind intensity
1	Weak Persian Trough	Summer	14.5	High	High	Low
2	Medium Persian Trough	Summer	14.5	High	High	Low
3	Deep Persian Trough	Summer	13.3	Mild	Mild	Mild
4	Sharav Low Over Israel	Transient	11.6	High	Low	High
5	High to the West	Winter	11.0	Mild	Mild	Low
6	Shallow North Cyprus Low	Winter	9.6	Low	Mild	High
7	High over Israel	Winter	8.8	Mild	High	Low
8	West Sharav Low	Transient	8.2	High	Low	High
9	RST—Eastern Axis	Transient	7.9	High	Low	High
10	RST—Central Axis	Transient	7.8	Mild	Low	Mild
11	Deep North Cyprus Low	Winter	7.7	Low	Mild	High
12	High to the North	Winter	7.1	Mild	Low	Low
13	RST—Western Axis	Transient	7.0	Mild	Mild	Mild
14	Shallow East Low	Winter	6.6	Low	Mild	Mild
15	Deep Low to the East	Winter	6.4	Low	Mild	High
16	West Cold Low	Winter	5.9	Low	Mild	High
17	High to the East	Winter	5.8	Mild	Low	Low
18	Shallow South Cyprus Low	Winter	5.6	Low	Mild	Mild
19	Deep South Cyprus Low	Winter	5.3	Low	High	High

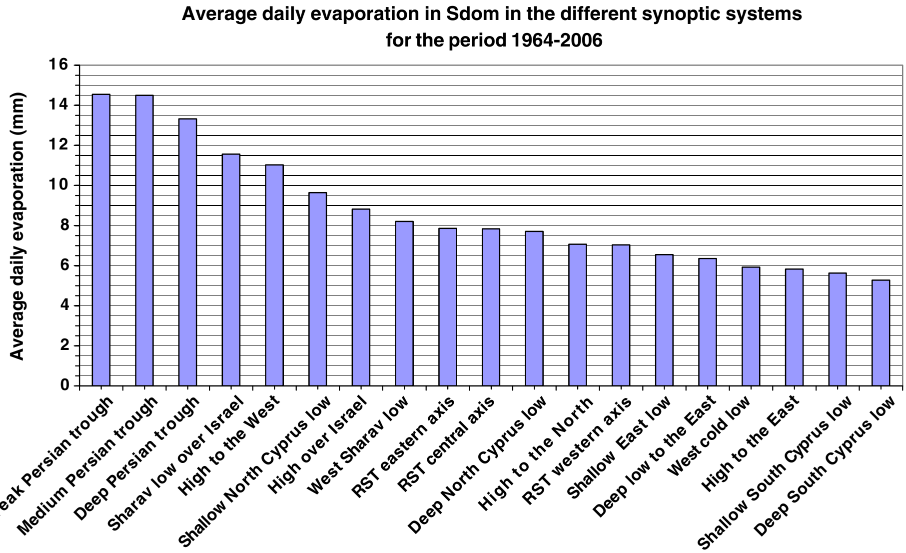

Fig. 3 The average daily evaporation (mm/day) in Sdom in the different synoptic systems for the period 1964–2006

5.2 Time-series of the synoptic contributions

Figure 4 shows the 1964–2006 course of the relative contribution to the annual evaporation of two systems; The RST-eastern axis, and the WPT. Figure 4 shows that the relative contribution of the RST-eastern axis to the annual evaporation has increased from 7% in the 1960s to 12% in the 2000s. This fits the significant increase of this system pointed by Alpert et al. (2004). The contribution of the WPT system also increased from 15% to 24%. On the other hand, the contribution of the MPT has reduced from 22% to 18%, and also the HW shows a decreasing trend from 24% to 18%.

5.3 Which synoptic systems contributed to the evaporation increases?

Since there is a rise of the pan evaporation in Sdom from 350 cm/year in the 1960s to about 420 cm/year in the 2000s, it is of interest to quantify the contribution of each synoptic system to this 70 cm/year increase. Figure 5 shows each contribution to this 70 cm/year rise by every individual synoptic system. This was done by subtraction of the 1964–1974 averages from the 1996–2005 showing that the WPT and the RSTs are the primary contributors. Note also that November shows a peak evaporation increase in the Sdom evaporation (Table 1), and in this month the RSTs are also the most dominant (Alpert et al. 2006a). Therefore, it can be concluded that the global climate change in the EM resulting in the redistribution of some hot and dry systems is manifested by the 70 cm/year evaporation rise in Sdom.

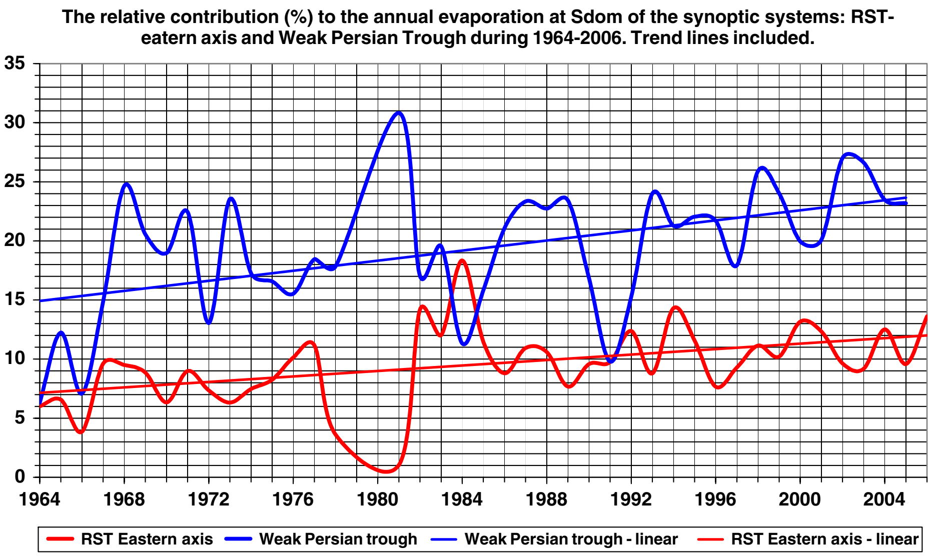

Fig. 4 The relative contribution (%) to the annual evaporation at Sdom of the synoptic system: RST–Eastern axis and Weak Persian Trough during 1964–2006. Trend lines included

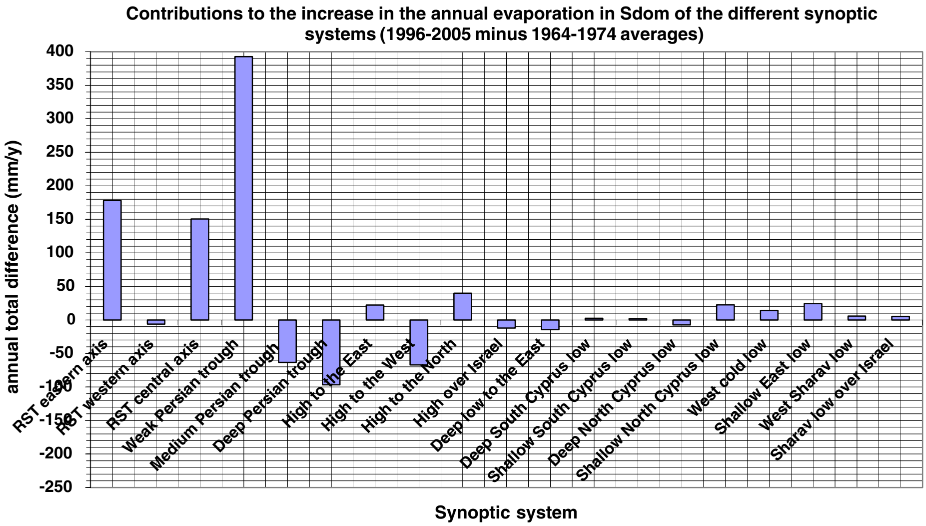

Fig. 5 Contributions to the increase in the annual evaporation (mm/year) in Sdom for the 19 different synoptic systems (1996–2005 minus 1964–1974 averages)

5.4 Separating the evaporation increase in Sdom to two parts: the intrinsic daily change and the synoptic systems changes

The 70 cm/year evaporation increase in Sdom can be a result of two factors: it can be the outcome of increased evaporation per day in the different synoptic systems, or the result in the changing frequencies of the synoptic system. These two factors were quantified for each system. This was done the following way.

The total change in the average annual $\Delta\overline{E}$ can be written as:

$$\begin{aligned}\Delta\overline{E} &= \overline{E}_{2000s} - \overline{E}_{60s} = \sum_i \left(\overline{E}_{i2000}\overline{f}_{i2000} - \overline{E}_{i60}\overline{f}_{i60}\right)\\ &= \sum_i \left[\left(\overline{E}_{i60} + \Delta E_i\right)\left(\overline{f}_{i60} + \Delta f_i\right) - \overline{E}_{i60}\overline{f}_{i60}\right]\\ &== \sum_i \left[\overline{E}_{i60}\Delta f_i + \Delta E_i\overline{f}_{i60} + \Delta E_i\Delta f_i\right] \cong \sum_i \left[\Delta f_i\overline{E}_{i60} + \Delta E_i\overline{f}_{i60}\right] \qquad (1)\end{aligned}$$

where:

$\overline{E}_{i2000}, \overline{E}_{i60}$ represent the mean evaporation for synoptic system (i) in the 2000s and 1960s, respectively,

$\overline{f}_{i2000}, \overline{f}_{i60}$ represent the mean frequency of synoptic system (i) in the 2000s and 1960s, respectively, and:

$\Delta E_i, \Delta f_i$ represent the changes of the intrinsic evaporation and frequency respectively from the 1960s to the 2000s for each synoptic system i.

The term $\Delta E_i \Delta f_i$ was found very small and negligible (order of 10^{-1} and lower) compared to the other two terms (This term is the highest in the WPT with a value of 42 mm/year as compared to a value of 393 mm/year of the full term).

Equation 1 can be rewritten as;

$$\Delta \overline{E} \cong \sum_i (Fr_i + Ev_i) \quad (2)$$

Where $Fr_i = \Delta f_i \overline{E}_{i60}$ is the frequency change contribution, and $Ev_i = \Delta E_i \overline{f}_{i60}$ the intrinsic evaporation change contribution for the *ith* synoptic system.

Figure 6 shows the Ev_i term, which is the contribution to the evaporation rise as a result from the higher daily evaporation in each system. Figure 6 shows that a daily evaporation rise is noticed in all the systems. Note especially the rise for the HW, WPT and the RSTs. It shows that besides the contributions due to higher frequencies of these systems there is also a consistent rise in the daily evaporation of these systems, which can be either a result of local effects, or due to radiative contribution by the greenhouse gases increases.

Figure 7 shows the frequency change contribution, the Fr_i term, which is the contribution to the evaporation rise as a result from the changing frequency in each synoptic system, and thus represents large-scale factors or even global effect. As we noticed that there are higher frequencies of the RSTs and WPT which contribute to the increased evaporation. There are also reductions of the frequencies in some synoptic systems such as the MPT, DPT and HW.

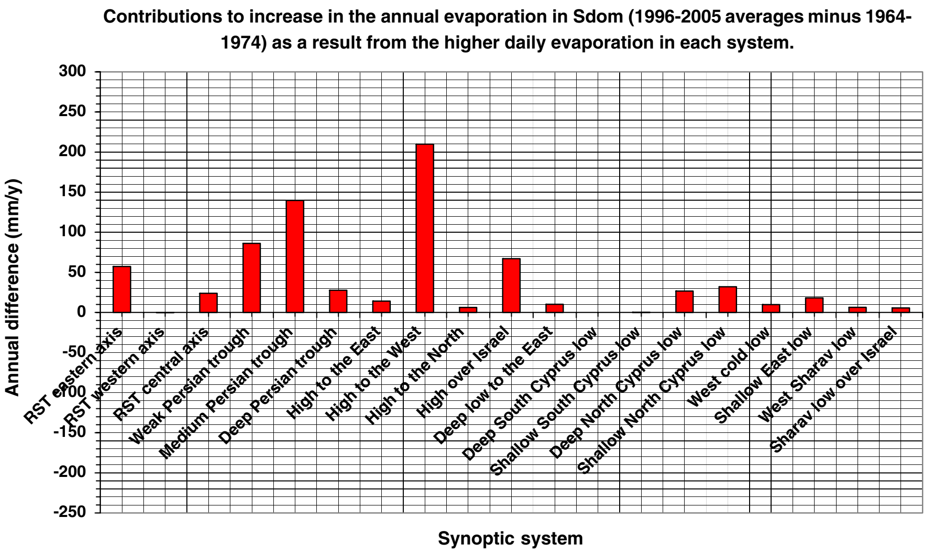

Fig. 6 Contributions to increase in the annual evaporation in Sdom (1996–2005 averages minus 1964–1974) in (mm/year) as a result from the higher daily evaporation in each system, i.e. term Ev_i in text

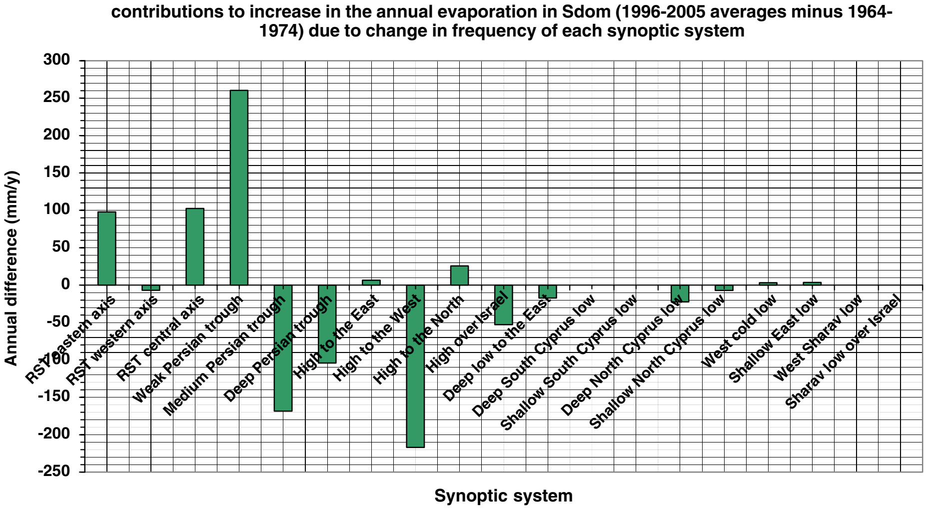

Fig. 7 Contributions to increase in the annual evaporation in Sdom (1996–2005 averages minus 1964–1974) in (mm/year) as a result from each synoptic system changing frequency, i.e. term Fr_i in text

6 Summary and conclusions

The evaporation from the Dead-Sea is very important to the local industries. It was found that the pan evaporation in Sdom has increased by about 70 cm/year from the 1960s to the 2000s. In this paper we explore the reasons for this increase. Several explanations were suggested. One explanation is that the rise is a local phenomenon because of the drying of the lake. This drying has caused the local Dead-Sea breeze intensity to reduce. This breeze uses to temper the Dead-Sea climate and its weakening causes the temperature to increase, the relative humidity to decrease, and hence the Sdom pan evaporation to increase. Another local climate change is the intensification of the Mediterranean breeze entering the Dead-Sea as a result of the reduced interference of this wind with the opposing but weakened Dead-Sea breeze. The Mediterranean breeze reaches the Dead-Sea during the evening hours in spring and summer. The Mediterranean Sea breeze intensifies as it adiabatically descends into the Dead Sea Valley, warms and dries significantly which is another contributor to the Dead-Sea evaporation increase.

A very different contribution to the evaporation rise is the increasing effect of the global warming known as the "greenhouse effect". The Red-Sea Trough which is often a hot and dry system has nearly doubled in frequency during last 50 years. Also, the hottest system of the year-the Weak Persian Trough has increased frequencies. It was also found that most of the 70 cm/year evaporation increase were due to the intrinsic evaporation rise in the Red-Sea Trough (about 30 cm/year) and the Weak Persian Trough systems (about 40 cm/year).

Based on the significant results it was found that both the global as well as the primarily local effect are contributing to the evaporation increases. It seems that till the 1990s the local effect was the dominant one, while since the 90s it seems that the large-scale effect due to the global warming becomes a dominant factor of the evaporation increase at the Dead-Sea.

Acknowledgements We wish to thank the Dead-Sea Works that supported this research. Partial support was also given by the GLOWA—Jordan River Project funded by the German Ministry of Science and Education (BMBF), in collaboration with the Israeli Ministry of Science and Technology (MOST) and by the EU-CIRCE project. We are thankful also to the Water Authority for partly supporting this research. Special thanks to Marco Cohen, Yosi Lati, Moti Aharoni, Ofir Cohen and the entire Dead-Sea Works team for their help with the research. We also thank Isabella Osetinsky for the synoptic systems classification data, and Fengjun Jin for plotting Fig. 1.

References

Alpert P, Eppel A (1985) A proposed index for mesoscale activity. J Clim Appl Meteorol 24:472–480
Alpert P, Cohen A, Neumann J, Doron E (1982) A model simulation of the summer circulation from the Eastern Mediterranean past Lake Kinneret in the Jordan Valley. Mon Weather Rev 100:994–1006
Alpert P, Shafir H, Issahary D (1997) Recent changes in the climate of the Dead Sea Valley. Clim Change 7:1–25
Alpert P, Osetinsky I, Ziv B, Shafir H (2004) Semi-objective classification for daily synoptic systems: application to the Eastern Mediterranean climate change. Int J Climatol 24:1001–1011
Alpert P, Price C, Krichak S, Ziv B, Saaroni H, Osetinsky I (2006a) Mediterranean climate and some tropical teleconnections. Nuovo Cimento Soc Ital Fis C Geophys Space Phys 29(1):89–97
Alpert P, Krichak S, Shafir H, Jin F, Kalmikov A, Sharon A, Dayan M, Cohen M, Lati Y (2006b) The impact of the sea canal on the Dead-Sea evaporation. A First Year Report to the Dead-Sea Works. Tel-Aviv University, 25p (in Hebrew)
Alpert P, Krichak S, Shafir H, Jin F, Potchter O, Yaakov Y, Cohen M, Lati Y, Aharoni M, Cohen O (2008) The impact of the sea canal on the Dead-Sea evaporation. A Third Year Report to the Dead-Sea Works. Tel-Aviv University, 26p (in Hebrew)
Anati DA, Shasha S (1989) Dead Sea surface level changes. Isr J Earth Sci 38:29–32
Ashbel D (1939) The influence of the Dead Sea on the climate of its neighborhood. Q J R Meteorol Soc 115:185–194
Ashbel D (1975) Forty five years of observations in the climate and hydrology of the Dead Sea. The Hebrew Univ. of Jerusalem, p 183 (in Hebrew)
Bitan A (1974) The wind regime in the north-west section of the Dead Sea. Arch Meteorol Geophys Bioklimatol 22(Ser. B):313–335
Bitan A (1977) The influence of the special shape of the Dead Sea and its environment on the local wind system. Arch Meteorol Geophys Bioklimatol 24(Ser. B):283–301
Cohen S, Stanhill G (1996) Contemporary climate change in the Jordan Valley. J Appl Meteorol 35:1051–1058
Klein C (1982) Morphological evidence of lake level changes, Western Shore of the Dead Sea. Isr J Earth Sci 31:67–94
Osetinsky I (2006) Climate changes over the E. Mediterranean—a synoptic systems classification approach. Ph. D. Thesis, University of Tel-Aviv, pp 138
Saaroni H, Ziv B, Edelson J, Alpert P (2003) Long-term variations in summer temperatures over the Eastern Mediterranean. Geophys Res Lett 30(18):1946. doi:10.1029/2003GL017742. 8 pp
Stanhill G (1994) Changes in the rate of evaporation from the Dead Sea. Int J Climatol 14:465–471
Steinhorn I (1981) A hydro-graphical and physical study of the Dead Sea during the destruction of its long-term meromictic stratification. Ph.D. Thesis, Weizmann Institute of Science, Rehovot, pp 323
Ziv B, Saaroni H, Baharad A, Yekutieli D, Alpert P (2005) Indications for aggravation in summer heat conditions over the Mediterranean basin. Geophys Res Lett 32:L12706. doi:10.1029/2005GL022796