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A NEW SEASONS DEFINITION BASED ON CLASSIFIED DAILY SYNOPTIC SYSTEMS: AN EXAMPLE FOR THE EASTERN MEDITERRANEAN

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ABSTRACT

A new definition for seasons based on a synoptic classification is introduced. It uses the automatically classified daily synoptic systems. For the eastern Mediterranean (EM), the temporal distribution of the synoptic systems over 53 years enables a proper definition of the timing and duration of the cold rainy, warm dry and of the transition seasons. Comparisons with the astronomical, meteorological and the temperature-based seasons definitions following Trenberth is performed. According to the synoptic definition proposed here and applied to the EM, the winter and summer seasons each last about 4 months (3 months and 23 days). The EM 'synoptic summer' and 'synoptic winter' defined here begin at about the earliest starting date, i.e. the meteorological start, and they end at about the latest ending date, i.e. the astronomical end. Copyright © 2004 Royal Meteorological Society.

KEY WORDS: timing of the seasons; length of the seasons; synoptic system classification; eastern Mediterranean seasons; eastern Mediterranean climate

1. INTRODUCTION

Trenberth (1983), in his paper 'What are the seasons?', presents the following interesting problem: a severe snow storm occurs in an inland part of the USA in mid-December. The weather forecaster who describes this serious situation says that the winter has not yet actually begun, and that 10 days still remain before the winter begins. Of course, he referred to the astronomical definition of the winter season. The astronomical winter season (or summer in the Southern Hemisphere) is defined as the period from the winter solstice (22 December) to the vernal equinox (21 March). Spring ends at the summer solstice (22 June) and summer lasts from the summer solstice until the autumnal equinox (23 September). Autumn completes the annual cycle. Hence, the lengths of the astronomical seasons vary between 89 and 93 days, as a result of the noncircular orbit of the Earth around the Sun. Trenberth (1983) adds that, although the Earth–Sun geometry affects the seasons, there is no direct connection between the astronomical seasons and weather/temperatures variations.

In meteorology, however, the four seasons are defined as four equal-length periods of 3 months each (AMS, 2001). Trenberth (1983), therefore, suggested a more logical definition, which we will refer to as the 'temperature definition'. In the temperature method, the seasons are defined according to the observed annual surface temperature cycle. The beginning/ending dates of each season, corresponding to these two definitions, are shown in Figure 2(a) for summer and Figure 2(b) for winter (the temperature-defined seasons are shown for the eastern Mediterranean (EM); see below for explanation). Of course, there is a time lag between the astronomical and temperature cycles, and Trenberth (1983) showed this lag to be 27.5 days on average in the USA. While defining four seasons of equal length, Trenberth (1983) has also shown that, according to

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the 'temperature definition', every season begins in the USA about 17–20 days earlier than the 'astronomical definition'. Therefore, winter in the USA begins on 3 December on average, and summer on 4 June. This corresponds better to the 'meteorological definition', allocating 3 months for each season and pointing to 1 December as the beginning of winter and 1 June as the beginning of summer.

Following Trenberth (1983), Ovadiah and Goldreich (1997) applied this method based on the 'temperature definition' to defining the seasons in Israel. They analysed temperature cycles at 22 meteorological stations in Israel and found that, according to the temperature method, the winter in Israel begins on 12 December (on average) and ends on 14 March. The summer begins on 13 June and ends on 12 September.

Trenberth's temperature-defined seasons are obviously more closely associated with the weather variations than the astronomical and meteorological seasons. Nevertheless, its use is complicated because of the high spatial variability in temperature, i.e. the temperature cycle has a variable phase and amplitude, particularly in relation to distance from large water bodies. Therefore, seasons begin and end at different dates and have different lengths. This is a serious disadvantage when one defines the seasons for a given region for practical use, especially in regions like the EM, where different climatic regimes are very close to each other: maritime climate, desert climate, steppe climate, mountain climate. For example, the closer an area is to the sea, then the larger is the lag between the solar cycle (i.e. astronomical season) and the temperature variations that result from the tempering effect of the sea on surface temperatures. For instance, Ovadiah and Goldreich (1997) found that the time lag between the summer solstice and the hottest summer day is 42 days in Tel Aviv (the Mediterranean Sea coast), 37 days in Jerusalem (50 km from the coastline) and 30 days in Eilat (desert, about 200 km from the Mediterranean coast).

To overcome the inherent inconsistency of the above definitions with the actual weather, we suggest here a new definition of seasons, based on the synoptic systems dominating the region. The regional weather phenomena in every season are well defined by the synoptic system that is typical for a given season. We propose here a 'synoptic definition of seasons', based on a typical (dominant or specific) synoptic system over a given region and given season. The National Centers for Environmental Prediction (NCEP)–National Center for Atmospheric Research (NCAR) daily reanalysis data (http://www.cdc.noaa.gov/) for 1948–2000 were used to define the synoptic climatology over the EM and the associated EM seasons, as described next in brief, based on Alpert *et al*. (2004).

2. THE SYNOPTIC SEASONS DEFINITION

2.1. The dominant synoptic systems

Climatic records show that there are dominant synoptic systems over a given area in every season. Lamb (1950) introduced the term 'natural seasons' according to the beginning/end/duration (persistence) of the spells of a governing synoptic system in a certain season and defined five natural seasons in the course of the year in the British Isles, based on 1898–1947 data. Later, Lamb (1972) explained this term referring to the more detailed name of 'natural synoptic seasons' (Borisova and Rudičeva, 1968). Next, we will apply this idea for the EM. In contrast to Lamb, here, automatic synoptic classification (Alpert *et al*., 2004) will serve as a basis for the synoptic definitions of the EM seasons.

Meteorologists in every country know well what the dominant systems in their region are. Lamb (1972) noticed that there is a great regularity of occurrence in low latitudes compared with middle and higher latitudes. Ziv and Yair (1994) described the typical systems for the EM. For example, the dominant synoptic system in summer is the Persian trough (PT) that persists northeast of Israel, along with the subtropical high that borders the PT from the southwest (Alpert *et al*., 1990a). The most significant meteorological system in winter is the Cyprus low, which regularly penetrates the EM or is formed there in this season (Alpert *et al*., 1990b). In autumn, the Red Sea trough (RST) is most common (Kahana *et al*., 2002), whereas the Sharav lows are specific to spring (Alpert and Ziv, 1989). The assumption made for the synoptic definition is that the beginning and end of each season are characterized by noticeable changes (increase and decrease respectively) in the average frequency of the significant synoptic system.

2.2. Methodology of computation

First, we automatically classified every EM daily (at 1200 UTC) synoptic system since 1 January 1948 through to 31 December 2000 by our classification method (Alpert *et al.*, 2004). For the seasons definition, we considered only the big groups of synoptic systems and not their specific subdivision. For every synoptic group, we obtained the daily time series of its occurrence for the full study period. Every day was presented by 1 if that synoptic system took place and 0 if not. Then, we (i) computed for every day the total occurrence of each synoptic system in the period of 11 days (±5 days) straddling that specific day. (Thus, the first 5 days of the Julian year show the climatological frequency over 1949–2000, and last 5 days over 1948–1999.) Next, the results were (ii) 7-day-smoothed and (iii) averaged for every Julian day over 1948–2000. All the leap years have been fitted to a 365-day year by shifting the results since 1 March back by 1 day and cancelling the 366th-day results before executing step (iii). All the results for 29 February participate in computation at steps (i) and (ii) but do not appear explicitly in the final averaging.

Hence, over every given 17 successive Julian days ($i = 1$ to 17), the weighted frequency of occurrence for the 9th day A_9 is eventually given by

$$A_9 = \frac{1}{7}\left(\sum_{i=1}^{i=11} a_i + \sum_{i=2}^{i=12} a_i + \sum_{i=3}^{i=13} a_i + \sum_{i=4}^{i=14} a_i + \sum_{i=5}^{i=15} a_i + \sum_{i=6}^{i=16} a_i + \sum_{i=7}^{i=17} a_i\right)$$

$$= \frac{1}{7} \times \left[7\left(\sum_{i=7}^{i=11} a_i\right) + 6(a_6 + a_{12}) + 5(a_5 + a_{13}) + 4(a_4 + a_{14})\right.$$

$$\left. + 3(a_3 + a_{15}) + 2(a_2 + a_{16}) + a_1 + a_{17}\right]$$

where a_i is the relative part of the years out of the 53 year period when a certain synoptic system took place on this ith (Julian) day. For instance, on 1 August, if a PT occurred in 20 years out of 53 years then the value of $a_{(\mathrm{Aug1})}$ would be 20/53. Similar time series were constructed for each synoptic system.

The period of 11 days for computation of a frequency of occurrence was chosen after comparison of a number of different periods. The use of longer periods obscured the main characteristics of the seasonal behaviour of the frequencies, whereas shorter periods led to a high level of noise. The optimal smoothing period of 7 days was chosen for similar arguments.

We have found, for example, that the occurrence of PT days reaches a value of 6 days on the 31 May for the first time in the course of the Julian year. This means that in the 11 day period centred on 31 May, 6 out of 11 days are defined, on average, as PT days (by synoptic classification over 53 years). Therefore, we defined 31 May as the first day of summer. Similarly, 25 June can be considered as the first day of high summer, because on this day a majority of nine PT days out of 11 are found for the first time in the year.

In a nearly bell-shaped plot the second derivative that denotes the maximum rate of increase and then decrease becomes equal to zero twice. Figure 1 demonstrates that, generally speaking, it is possible to define the beginning/end of a season as the date where the second derivative of the frequency becomes zero for the first/last time after/before getting over/below a half of its maximum value. The two zero-points defined in such a way fit quite well to the beginning/ending dates of the EM summer (when the PT frequencies are above 6 days/11 days) and winter (when the Winter-low (WL) frequencies are above 3 days/11 days) (Figure 1 and Table I).

3. DEFINITION OF THE SEASONS

3.1. Summer

Figure 1 shows the frequency (number of days) of the dominant synoptic system in the four seasons as outlined above. The dominance of the PT during the summer is clearly noticed, and enables us to define the summer accurately. The summer season definition based on 6 days out of 11 days fits the period of 31

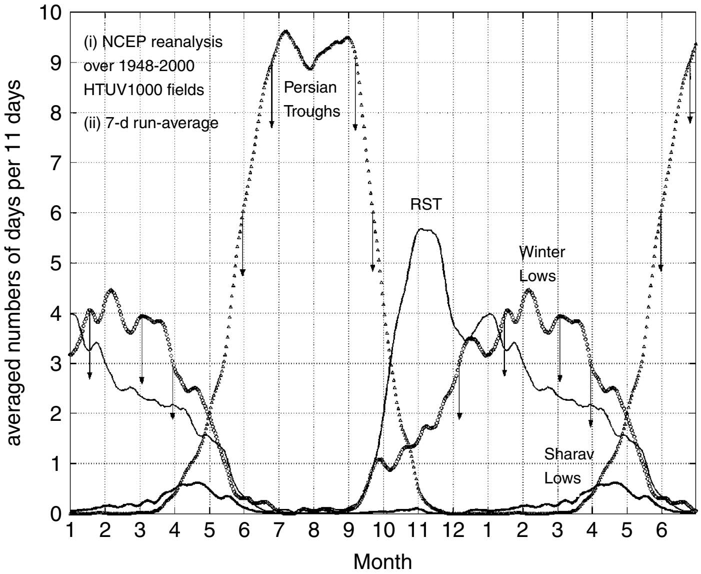

Figure 1. Climatological seasonal distribution of the typical EM synoptic systems' frequencies. The typical systems are: PT in summer, RST in autumn, WLs in winter and Sharav lows (SL) in spring. The frequency for every synoptic system for every Julian day was calculated as follows. (i) The number of days of occurrence of a given synoptic system in ±5 days intervals centred on a given day was calculated from 6 January 1948 through to 26 December 2000. (ii) The results obtained in (i) were smoothed by 7-day running means (see Section 2.2). (iii) The results from (ii) were averaged over 53 years (1948–2000) for every Julian day from 1 January till 31 December. Arrows indicate the starting/ending dates of the seasons (Table I)

Table I. New definition of seasons in the EM

Season	Full period	High season	Duration of full period
Dates and lengths			
Summer	31 May–22 Sep	25 Jun–7 Sep	3 months 23 days (115 days)
Autumn	23 Sep–6 Dec	8 Oct–28 Nov	2 months 14 days (75 days)
Winter	7 Dec–30 Mar	17 Jan–2 Mar	3 months 23 days (114 days)
Spring	31 Mar–30 May	2 Apr–30 Apr	2 months (61 days)
Suggested rules			
Summer	PT dominates; above 6 days/11 days	PT dominates; above 9 days/11 days	
Autumn	Between summer and winter (RST dominates)	RST dominates; above 4 days/11 days	
Winter	WLs above 3 days/11 days	WLs dominate; above 4 days/11 days	
Spring	Between winter and summer (SL are typical)	SLs above 0.6 days/11 days (see text)	

May–22 September (115 days). In a similar way, a frequency of 9 days out of 11 days (about 82%) naturally defines the high summer season, because nine is the highest integer value obtained for the PT frequency when using an 11 day period. This corresponds to the period of 25 June–7 September (72 days) for high summer. The high summer in the EM region is characterized by the most northward position of the Subtropical high so that it covers much of the region. Therefore, in the middle of high summer, the PT is moved slightly to the northeast and is partially replaced by the Subtropical high from the southwest. This shows as a secondary minimum in the frequency of the PT in mid-summer (Figure 1). It is worth noting that the 'temperature definition' of seasons by Ovadiah and Goldreich (1997), following Trenberth (1983), yields for summer the period 13 June–12 September with 91.25 days on average; these beginning/ending dates and duration fall between our suggested synoptic definitions for summer and high summer (see Figure 2 and Table I). It is also

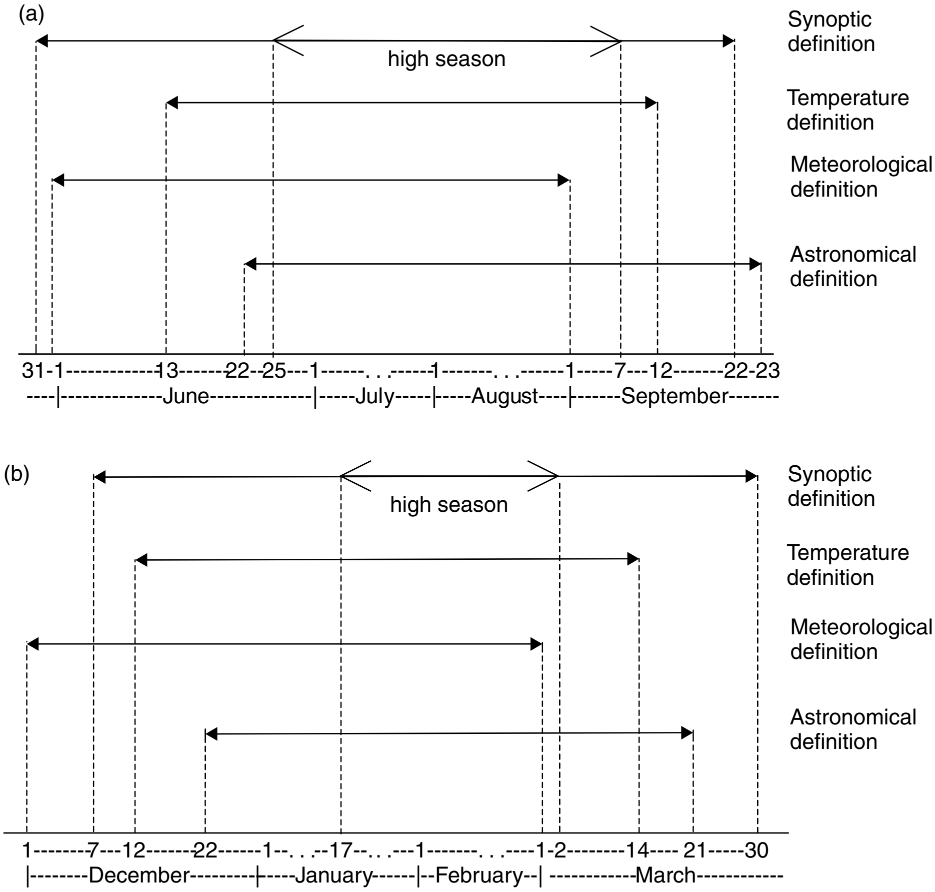

Figure 2. Comparison of the lengths of summer (a) and winter (b) by the four different methods: astronomical, meteorological, temperature and synoptic. The high seasons are marked by winged arrows

interesting to note that the meteorological definition, i.e. terminating the summer by the end of August, is in contrast to all the other definitions, which extend the summer into September (12 September: 'temperature'; 22 September: 'synoptic'; 23 September: 'astronomical') and is also contrary to the common meteorological experience over the region.

3.2. Winter

In winter, the rain-bearing Mediterranean cyclones are the most significant systems. Their frequency is obviously smaller than the summer PT. The EM winter is defined as the period when the WL frequencies of occurrence exceed 3 days/11 days (see Section 2.2). From 31 January till mid-February the WL frequencies also exceed the value of 4 out of 11 days (37%). Therefore, this highest integer value of four is kept for the EM high winter-season definition (Figure 1 and Table I).

3.3. Autumn

The transition seasons are also characterized by their typical synoptic systems, but they are more naturally defined as filling the gaps between winter and summer.

According to our synoptic definition, the autumn season is shorter than the winter and summer, and is dominated by the RST. The RST frequencies have two modes (Figure 1). The highest peak (5.7 days/11 days) is in the middle of the autumn, in the first 10 days of November, and the secondary peak (4 days/11 days) is at 1 January, i.e. about 3 weeks after the beginning date of the synoptically defined winter. However, clearly all the RST values above 4 days/11 days belong to the autumn season (Figure 1) and, therefore, are kept for the high autumn definition. The secondary RST peak in late December–beginning January is indeed slightly exceeding the number of WLs, but the EM weather is clearly dominated in that period by the WL. Some regression of WL out of the EM region in late December–beginning January is one of the characteristic features of the EM winter season bimodality. The RST moved back to its origin (i.e. southward) at the beginning of winter, but it then returns to its more northern position when the WLs are slightly less frequent.

3.4. Spring

The spring season is very short, and the Sharav lows reach their peak in April (0.6 days out of 11 days, i.e. 5%). There are several reasons for such a low average frequency of the Sharav lows, besides its low natural frequency of about once a week in high spring (Alpert and Ziv, 1989). The first reason is related to the automatic classification. Sharav lows move quickly eastward along the North African coastline. They often cross the EM in 1–2 days, and sometimes within a period of less than 1 day (Alpert and Ziv, 1989). Hence, the moment of appearance of the Sharav low over the EM may fall between the classification sampling times, which are currently only once daily at 1200 UTC. We have estimated that at least about a third of the Sharav lows pass over the EM at non-sampling times. Also, since the Sharav lows are relatively small (200–500 km), no part of them may remain over the EM area for the automatic classification. The second reason for the lower long-term frequency is the averaging process. Averaging is performed over 53 years and includes the years with the maximum of Sharav-low cases (high spring) in slightly different periods. But this slight difference also results in a smoother maximum of Sharav-low cases on the averaged curve (Figure 1) that characterizes spring very well. The Sharav lows' weather, with very high temperatures, very low humidity, strong winds, dust storms, low visibility and sometimes mid and high clouds with light rains, clearly defines the spring over the EM in spite of their relatively low frequencies.

3.5. Summary of the synoptic definition

Table I presents a summary of the synoptic definition of the EM seasons based on the synoptic classification (corresponding to the arrows in Figure 1). According to this synoptic definition, the winter and the summer each last about 4 months (3 months and 23 days), and the autumn and spring each last nearly a half of this period, about only 2 months (75 days and 61 days respectively). High-pressure systems like the Siberian high in the cold period and Subtropical high in the warm period have not been included into the seasons definition because they do not govern the weather features in any specific EM season. The Siberian high is found over the EM region from autumn through to winter on all the days without a low-pressure system, and the Subtropical high is frequent from spring, through summer, till the autumn on all such days.

4. RESULTS AND DISCUSSION

Trenberth (1983) argued the need for updating the seasons definition due to the fact that the astronomical and meteorological definitions do not consider the real weather. Trenberth (1983), therefore, proposed to analyse the annual surface temperature cycles and checked them for the USA, noticing that the average lag between the temperature cycle and the sun radiation cycle is about 27.5 days. However, the temperature is only one meteorological parameter among all the weather phenomena that characterize a season. Weather phenomena are determined much better by the typical synoptic systems.

For example, over the EM the passage of rainy Mediterranean lows define the winter weather, and the hot and dusty Sharav lows characterize the spring. Following this, we propose here an alternative definition for the seasons based on the automatically classified synoptic systems. The EM synoptic winter and summer are of lengths 114 days and 115 days respectively, i.e. of about 4 months each (Table I). Indeed, it was pointed out earlier by Zangvil and Shemer (1986) that the winter and summer in southern Israel should each be of about 4–4.5 months based on precipitation. They also suggested that the seasons may be redefined based on synoptic considerations. This is the first advantage.

The second advantage of the synoptic definition is its sensitivity to climatic changes. The typical synoptic system of a season is generated depending on temperature differences (spatial and temporal) rather than on the temperature value itself and its annual cycle. This holds especially for areas with sharp climatic gradients like the EM. A classic example is the baroclinic instability, which is believed to be responsible for the generation of most of the winter lows. Baroclinic instability results from horizontal temperature gradients that cross some threshold (Holton, 1992). Also, according to some researchers (Menzel and Fabian, 1999), climate changes caused by global warming are responsible for the changes in duration of seasons, e.g. expansion of the summer season and a delay of the end of winter toward the spring. This holds for the EM as well.

The seasons definition here is based on some rules given in Table I. Some subjectivity is incorporated in our definition, such as the choice of 3 days/11 days for the winter at the time when RST is still more frequent at the beginning of the winter, i.e. 7 December.

An alternative, fully objective definition based on crossing-points of the typical synoptic systems' frequencies is problematic, as discussed in the Appendix.

Figure 2 compares the season lengths for (a) summer and (b) winter, according to the aforementioned definitions: astronomical, meteorological, temperature and synoptic (the two latter are for the EM). The main conclusions are as follows:

1. According to the astronomical and meteorological methods, the length of each of the four seasons is equal to 3 months. The meteorological seasons precede the astronomical seasons by about 3 weeks.
2. According to the temperature method proposed by Trenberth (1983) and applied, for example, to Israel by Ovadiah and Goldreich (1997), the seasons each last for about 3 months and start and end exactly between the astronomical and meteorological seasons. This might well fit the entire EM region due to the geographic position of Israel in the southeastern Mediterranean corner.
3. According to the synoptic definition proposed here and applied to the EM, the winter and summer seasons each last for about 4 months (3 months and 23 days). The synoptic season in the EM begins at about the earliest start date as in the 'meteorological' start, and ends at about the latest end date as in the 'astronomical' definition.
4. The synoptic high season in the EM begins at about the latest start date (astronomical start) and ends at about the earliest end date (meteorological end).

The last two conclusions confirm that the synoptic seasons definition, best fitted to the weather phenomena, corresponds very well to the other definitions. Such a synoptic season definition may be adopted over other regions in the world with some of the aforementioned advantages.

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APPENDIX

An alternative, more objective definition for seasons is based on crossing-points of the frequencies of the typical synoptic systems. However, there are serious disadvantages.

Table A.I shows the results for such an alternative definition. In such a case, the spring completely disappears, since the Sharav-lows' frequencies are too low even at the peak period of April. This does

Table A.I. Alternative definition of seasons in the EM based on crossing points of dominant synoptic systems

Season	Full period	High season	Duration of full period
Summer	1 May–7 Oct	31 May–22 Sep	5 months 7 days (160 days)
Autumn	8 Oct–14 Dec	15 Oct–28 Nov	2 months 6 days (68 days)
Winter	15 Dec–30 Apr	17 Jan–2 Mar	4 months 15 days (137 days)
Spring	—	—	—

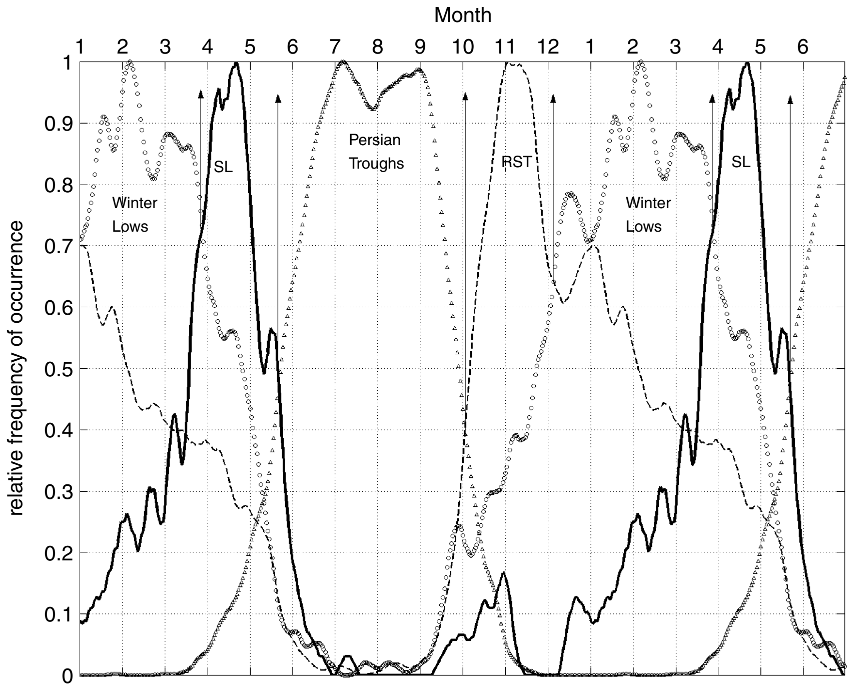

Figure A.1. Normalized crossing-points approach to the seasons definition

not seem the right choice, since Sharav lows dominate the EM spring weather with their unique intensive features even though the RST or WLs are more frequent at this time (Figure 1). With regard to the latter, the desert-borne Sharav lows sometimes shift slightly northward, to the Mediterranean, before approaching the EM coast and are, therefore, automatically classified as WLs. This may also explain the subtle peak of WLs' frequencies in mid-April which coincides with the peak of the Sharav lows (Figure 1).

We also examined crossing-points of normalized (by their maximum values) frequency distributions, and the results of this approach are quite close to what is suggested elsewhere in this paper (Figure A.1). In the normalized approach, the chosen spring, i.e. the Sharav lows, does not disappear. However, this approach is also problematic because it ignores the relative intensities of the synoptic systems frequency distribution.

Since, however, this 'normalized crossing-point' approach yields similar results to our proposition, we therefore preferred not to adopt this normalized approach.

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