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Delimitation of the warm and cold period of the year based on the variation of the Aegean sea surface temperature

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Abstract

Knowledge of the warm and cold season onset is important for the living conditions and the occupational activities of the inhabitants of a given area, and especially for agriculture and tourism. This paper presents a way to estimate the onset/end of the cold and warm period of the year, based on the sinusoidal annual variation of the Sea Surface Temperature. The method was applied on data from 8 stations of the Hellenic Navy Hydrographic Service, covering the period from 1965-1995. The results showed that the warm period starts sometime between April 28th and May 21st while it ends between October 27th and November 19th in accordance with the findings of other studies. Characteristic of the nature of the parameter used is the very low variance per station – 15 days at maximum. The average date of warm period onset is statistically the same for the largest part of the Aegean, with only one differentiation, that between Kavala and the southern stations (Thira and Heraklion).

Keywords: Season delimitation; Surface temperature; Statistical models.

Introduction

Several activities of the population of an area, especially those related to agriculture and tourism, depend on the date of the onset of the warm and cold season. Determining the dates of the interchange between the two seasons is also necessary for the planning of strategies for accidental pollution and the remedy for and handling of natural disasters. Therefore, a method able to determine, in an objective way, the onset of the warm and cold period of the year would be useful.

The obvious choice would be to use air temperature as the indicator parameter. Air temperature, however, presents intense spatial and temporal fluctuations, leading to results with significant variability that, moreover, cannot be considered as representative of wider regions. For this reason, it has been proposed to use parameters strongly related to air temperature, but with smoother spatial and temporal distributions (ARGIRIOU *et al.*, 2002). Such a parameter is the Sea Surface Temperature (SST). Atmosphere-sea interaction is well established and SST constitutes a decisive factor for the formation of the climatic characteristics of a coastal region. The correlation between SST and air temperature is strong while SST presents much smoother annual course (THEOHARATOS & TSELEPIDAKI, 1990; VLAHAKIS & POLLATOU, 1993).

Method

In the present study we used mean monthly values of SST, measured in 8 stations of Hellenic Navy Hydrographic Service, for the period 1965-1995. The period under investigation was not completely covered by all stations, while the type of the intended analysis imposed the exclusion of years with less than 10 available monthly values. The stations that were used and the corresponding time periods covered by the available data are presented in Table 1.

Fourier analysis of multiyear (1971-1985) mean monthly SST time series for 21 stations located in the Aegean Sea revealed that the annual course of mean monthly SST can be very well approximated by a simple sinusoidal function (VLAHAKIS & POLLATOU, 1993). The same was observed for mean monthly SSTs calculated over a 5x5 degrees grid covering the whole Mediterranean, over the period 1876-1988 (METAXAS & BARTZOKAS, 1990).

Results and Discussion

Based on the above the following expression was used to model the annual course of mean monthly SST:

$$SST_{ij} = A_i + B_i * \sin\left[\frac{2\pi}{365}\left(JD_j - C_i\right)\right] \quad (1)$$

where i denotes the year, j the month, and JD_j is the Julian Day corresponding to the 15th day of month j. Figure 1 presents the actual and modeled annual course of SST for a randomly selected station and year.

It is obvious that the model’s parameters have a physical meaning. More specifically, parameter A represents the annual mean value of SST and parameter B is the half of the annual SST range. Parameter C represents the Julian Day at which SST becomes equal to the annual mean. Since this parameter denotes the point of passage from SST values lower than the annual mean to values greater than this, we consider that it also indicates the passage from cold to warm season, for a specific station and year. Correspondingly we consider that the Julian Day C+365/2 indicates the reverse passage from warm to cold season.

Parameters A, B and C were calculated for each station and each year, applying non-linear

Table 1
Available SST data from the Hellenic Navy Hydrographic Service network.

Station	Available Period	Useful Period	# years
Kavala	1966-1995	1966-1995	29
Lesvos	1965-1991	1966-1991	14
Limnos	1965-1995	1966-1995	27
Samos	1971-1995	1972-1995	21
Milos	1971-1991	1972-1990	19
Thira	1971-1995	1972-1995	23
Rhodes	1971-1995	1972-1995	23
Heraklion	1971-1995	1972-1995	20

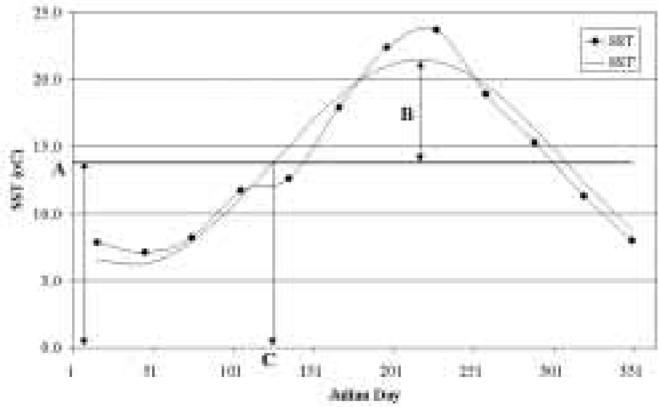

Fig. 1: Actual (SST) and modeled (SST') annual course of SST for the station of Kavala and the year 1989.

regression with SPSS statistical software (SPSS Inc., 1999). In all cases the true significance level of the modeled parameters was less than 5%. Long term average and standard deviation values were calculated from the resulting annual time series of the model parameters, namely A_i, B_i and C_i.

Even though the coefficients of linear correlation are high in all cases, a model cannot be characterized as successful unless it is demonstrated that it reproduces the main characteristics of the modeled parameter in an adequate way. In our case we consider the two main characteristics of SST, namely the annual mean SST -representing the baseline level - and the annual SST range - representing the magnitude of the annual variation - both calculated from monthly values. The respective annual time series, actual and modeled values, were compared using the root mean square difference (RMSE) while the long term mean values were compared using the paired t-test for means.

In order to obtain an overall impression Table 2 presents, for each station, the minimum coefficient of linear correlation, minR^2, the actual and modeled annual mean SST, $\overline{SST}$ and $\overline{A}$, the actual and modeled annual SST range, $\overline{SSTR}$ and $\overline{2B}$, the mean Julian Day of the warm season onset, $\overline{C}$, as well as the related root mean squared errors (RMSEs). The values in parentheses are 95% confidence intervals for the corresponding mean values, while values in bold correspond to cases for which the paired samples t - test indicates a statistically significant difference between actual and modeled long term mean values at 95% significance level.

The model appears to fit the data well, successfully reproducing the annual mean SST and its variation. Annual mean SST RMSEs are less than 2% and there is no case with a significant difference between the actual and the modeled long term mean SST. The success of the model is less when the parameter examined is the annual SSTR, with RMSEs sometimes exceeding 10%, and 3 out of 8 stations presenting a statistically significant difference between the actual and the modeled long term mean annual SST range. This is not unexpected since the sinusoidal form is unable to simulate the extreme values that determine SSTR. In general, however, SSTR variation is adequately modeled.

The transition day between the cold and warm seasons of the year appears to be fairly constant. The warm season variation ranges from 6 to 15 days around the mean value, with

Table 2
SST sinusoidal model fitting results.

	minR²	$\overline{SST}$ (°C)	$\overline{A}$ (°C)	RMSE / $\overline{SST}$	$\overline{SSTR}$ (°C)	$\overline{B}$ (°C)	RMSE / $\overline{SSTR}$	$\overline{C}$ (JD)
Kavala	0.94	15.9 (1.0)	15.9 (1.0)	1.4%	15.9 (1.4)	15.8 (1.2)	4.7%	126 (6)
Lesvos	0.87	17.0 (0.5)	17.1 (0.5)	1.0%	**9.4** (1.8)	**8.8** (1.6)	9.7%	127 (8)
Limnos	0.89	17.7 (0.5)	17.7 (0.5)	0.2%	11.4 (1.1)	11.3 (0.8)	5.6%	130 (7)
Samos	0.83	18.6 (0.7)	18.6 (0.6)	1.2%	**9.2** (1.8)	**8.7** (2.0)	10.3%	131 (11)
Thira	0.82	18.8 (0.5)	18.8 (0.5)	0.4%	8.1 (1.5)	8.0 (1.6)	6.3%	133 (7)
Milos	0.70	18.4 (1.0)	18.5 (0.9)	1.2%	**10.2** (1.7)	**9.8** (1.9)	8.2%	131 (11)
Rhodes	0.80	18.6 (1.1)	18.7 (1.0)	1.6%	**9.8** (1.4)	**9.1** (1.5)	10.7%	130 (15)
Heraklion	0.85	19.2 (0.5)	19.2 (0.5)	1.7%	10.9 (1.4)	10.6 (1.3)	7.1%	132 (7)

the southeastern stations presenting higher variations, while the mean onset date varies only 7 days across the Aegean. Moreover, the warm season onset seems to be earlier in the northern station with the remainder of the stations following in time as we move southwards. In order to check whether the warm season onset varies significantly across the Aegean, we applied a t - test for paired samples with a null hypothesis of equality between the mean onset dates of the various stations. All possible pairs were examined using only the data from years commonly available from both stations examined. The station of Kavala shows a statistically significant difference when it is compared to the southern stations of Thira and Heraklion as well as Limnos. Also differentiation is observed between the station of Heraklion and that of Lesvos. The statistical test used suggests that, on average, the warm season starts a little earlier in the northern part of the Aegean compared to its southern part. This is in agreement with ARGIRIOU *et al.* (2002) who detected similar behavior between Istanbul and Athens. The fact that both studies examined stations located around the Aegean does not support the direct extension of these conclusions to other areas such as the Ionian Sea.

Figure 2 presents a time series of the deduced dates of warm period onset for the examined stations. The northern stations appear to precede the southern ones, with the main volume of onset dates located between April 25th and May 20th and rather smaller variability from year to year. On the contrary, for the southern stations the onset dates extend till May 29th, while they also present some extreme cases with dates near the beginning of April.

Finally, the warm period onset time series was examined for the possibility of linear trend. The linear regression detected a statistically significant trend only in the case of Lesvos which, however, was not confirmed by the stricter Mann-Kendall test (SNEYERS, 1990).

Conclusions

According to the preceding analysis the following conclusions can be drawn:

1. The warm period of the year, in the stations which were examined, begins in early

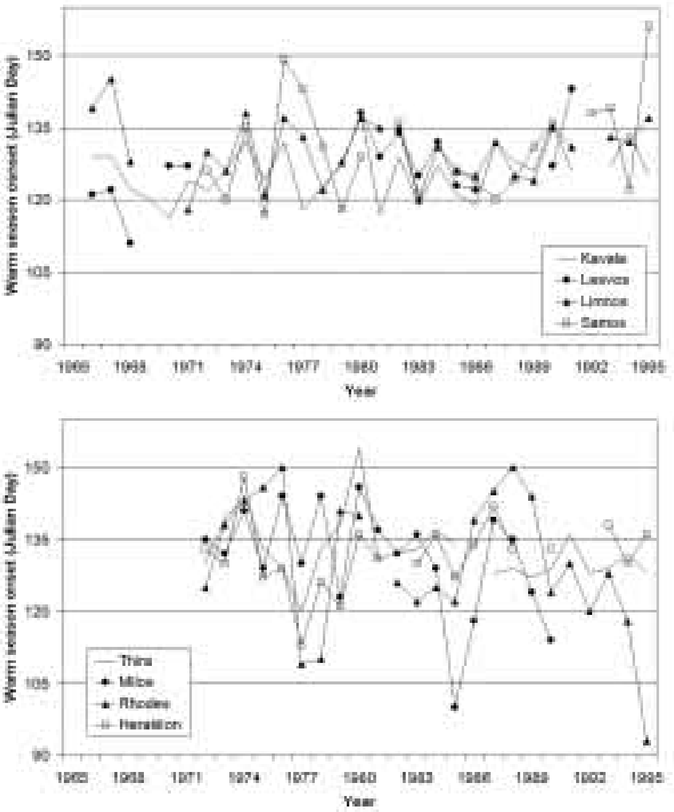

Fig. 2: Model derived warm period onset dates: a) northern stations b) southern stations.

May and more specifically between April 28th and of May 21st, while it ends between October 27th and of November 19th, consistent with the results of other studies (ARGIRIOU *et al.*, 2002).

2. The variation of the examined parameter is limited: 6 to 15 days, over a period of more than 20 years.

3. The warm period onset seems to happen earlier in the northern stations than in the southern ones, yet this conclusion should be considered with caution when extended to other regions.

4. No trend was detected regarding the warm season onset in the Aegean Sea.

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