



## Present and future responses of growing degree days for Crete Island in Greece

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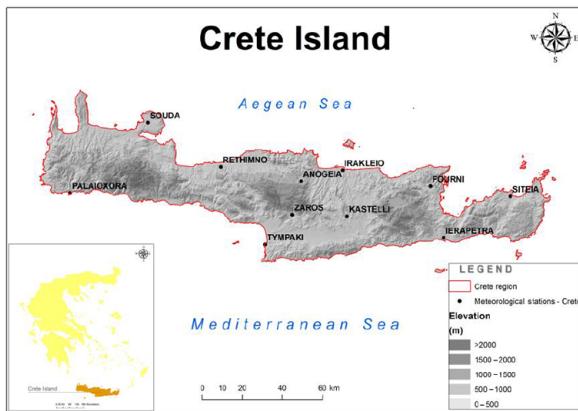
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**Abstract.** Climate affects practically all the physiological processes that determine plant life (IPCC, 2014). A major challenge and objective of the agricultural science is to predict the occurrences of specific physical or biological events. For this reason, flower phenology has been widely used to study the flowering in plant species of economic interest, and in this concept, temperature and heat units have been widely accepted as the most important factors affecting processes leading to flowering. The determination of heat requirements in the first developing phases of plants has been expressed as Growing Degree Days (GDD). Determination of GDD is useful for achieving a better understanding of the flowering season development in several plant species, and for forecasting when flowering will occur (Paparrizos and Matzarakis, 2017). Temperature and GDD represent two important spatially-dynamic climatic variables, as they both play vital roles in influencing forest development by directly affecting plant functions such as evapotranspiration, photosynthesis and plant transpiration. Understanding the spatial distribution of GDD is crucial to the practice of sustainable agricultural and forest management, as GDD relates to the integration of growth and provides precise point estimates (Hasan et al., 2007; Matzarakis et al., 2007). The aim of the current study was to estimate and map through downscaling spatial interpolation and multi-linear regression techniques, the future variation of GDD for the periods 2021–2050 and 2071–2100, under the A1B and B1 IPCC emission scenarios in relation with the reference periods for Crete Island in Greece. Future temperature data were obtained, validated and analysed from the ENSEMBLES European project. A combination of dynamical and statistical approach was conducted in order to downscale and perform the spatial interpolation of GDD through ArcGIS 10.2.1. The results indicated that in the future, GDD will be increased and the existing cultivations can reach maturity sooner. Nevertheless, rough topography will act as an inhibitor towards the expansion of the existing cultivations in higher altitudes.

### 1 Research area and methodology

Crete Island is located in the southern part of Greece. It has an area of 8342 km<sup>2</sup>, total population of 623 065 inhabitants and the local population is mainly employed in the primary section (Matzarakis and Nastos, 2011; Paparrizos et al., 2017a). The mean annual precipitation is 822 mm (Paparrizos et al., 2016a) and the mean annual  $T_{\text{mean}}$  is 17.2 °C. Figure 1 presents the general location, the meteorological stations and the characteristics of the study area, while Table 1 depicts the main cultivations, their characteristics, and

the GDD units that its cultivation needs in order to reach its maturity levels. Daily values of temperature data obtained from stations within to the study area for the years 1981–2000 were used in this study. Future climate change conditions were obtained by the output simulations of an ensemble of six regional climate models (RCMs), which were carried out within the European project ENSEMBLES (in parenthesis the Driven GCMs): METNO\_HIRHAM (BCCR-BCM2), CNRM\_RM4.5 (CNRM-CM3), HIRHAM5 (ECHAM/MPI-OM1), HADCM3C (METO-HC-HadCM3C), HADGEM2



**Figure 1.** Location and characteristics of the study area and the meteorological stations (reference period years: 1981–2000).

**Table 1.** Main cultivations and their characteristics (Paparrizos and Matzarakis, 2017).

Study area	Main cultivations	Latin name	GDD units to maturity
Crete Island	Olive	<i>Olea Europea</i>	900+
	Grape vine	<i>Vitis vinifera</i>	1210–1844
	Tomato	<i>Solanum lycopersicum</i>	1500–2000

(METO-HC-HadGEM2) and ETHZ-CLM (HadCMeQ0) for A1B and B1 scenarios, for the future periods 2021–2050 and 2071–2100. Prior to their use, future simulations were validated with the ground truth which constitutes a key point in future climate analysis. Validation results can be found in Paparrizos and Matzarakis (2017). The daily GDD units were calculated using the following equation (Eq. 1):

$$\text{GDD} = \left( \frac{T_{\max} + T_{\min}}{2} \right) - T_{\text{base}} \quad (1)$$

where  $T_{\max}$  represents the daily maximum temperature ( $^{\circ}\text{C}$ );  $T_{\min}$  is the daily minimum temperature ( $^{\circ}\text{C}$ ); and  $T_{\text{base}}$  is the temperature below which the process of growth does not progress (in the current research the threshold for  $T_{\text{base}}$  was set to  $10^{\circ}\text{C}$  for all existing cultivations in Crete Island).

Following that, the daily GDD units were accumulated into monthly, seasonal, and annual averages.

A coupling of dynamical and statistical downscaling approach was performed combining a multi-linear regression technique to interpolate the point data from the stations into a  $1\text{km} \times 1\text{km}$  resolution grid. Through the statistical approach, the following equation was created (Eq. 2) for each chronological period and scenario:

$$\text{GDD}_{\text{value}} = b_0 + b_1 h + b_2 \text{slp} + b_3 X + b_4 Y + b_5 \text{DistWat} \quad (2)$$

where  $\text{GDD}_{\text{value}}$  represents the dependent variable at a certain point;  $b_0$  is constant;  $b_1 \dots b_5$  represent the coefficients

**Table 2.** Accumulated mean GDD ( $^{\circ}\text{C}$ ) for the reference (1981–2000), 2021–2050 and 2071–2100 periods.

Period	GDD	2021–2050		2071–2100	
		current	A1B	B1	A1B
Apr–Sep	2196.3	1946.9	1939.9	2230.5	2126.3
Apr–Oct	2496.6	2268.9	2260.4	2602.0	2476.4
Apr–Nov	2663.0	2487.7	2478.7	2856.8	2708.0

obtained for each independent variable from the multi-linear regression;  $h$  is the altitude (m); “slp” is the slope (%);  $X$  is longitude ( $^{\circ}$ );  $Y$  is latitude ( $^{\circ}$ ); and “DistWat” is the distance from a water body (sea or lake – km).

In the dynamical approach through ArcGIS 10.2.1, the Ordinary Kriging analysis was performed by creating automatic points ( $\text{GDD}_{\text{point}}$ ) within a  $1\text{ km} \times 1\text{ km}$  resolution grid and each point was given a unique value through the equations. For the spatial interpretation of the results, the existing cultivation period of April–October was used. A more detailed description of the methodological approach can be found in Paparrizos et al. (2016b).

## 2 Results

Figure 2 depicts the spatial interpolation and mapping of GDD for the reference, 2021–2050 and 2071–2100 periods for the month from April to October under the A1B and B1 scenarios, respectively. Table 2 presents the results of the accumulated mean GDD ( $^{\circ}\text{C}$ ).

## 3 Discussion

The results indicated that present and future analysis of GDD in Crete Island is presented with differentiations. Specifically, Growing Degree Days are expected to face minor decreases during the first examined period of 2021–2050, while

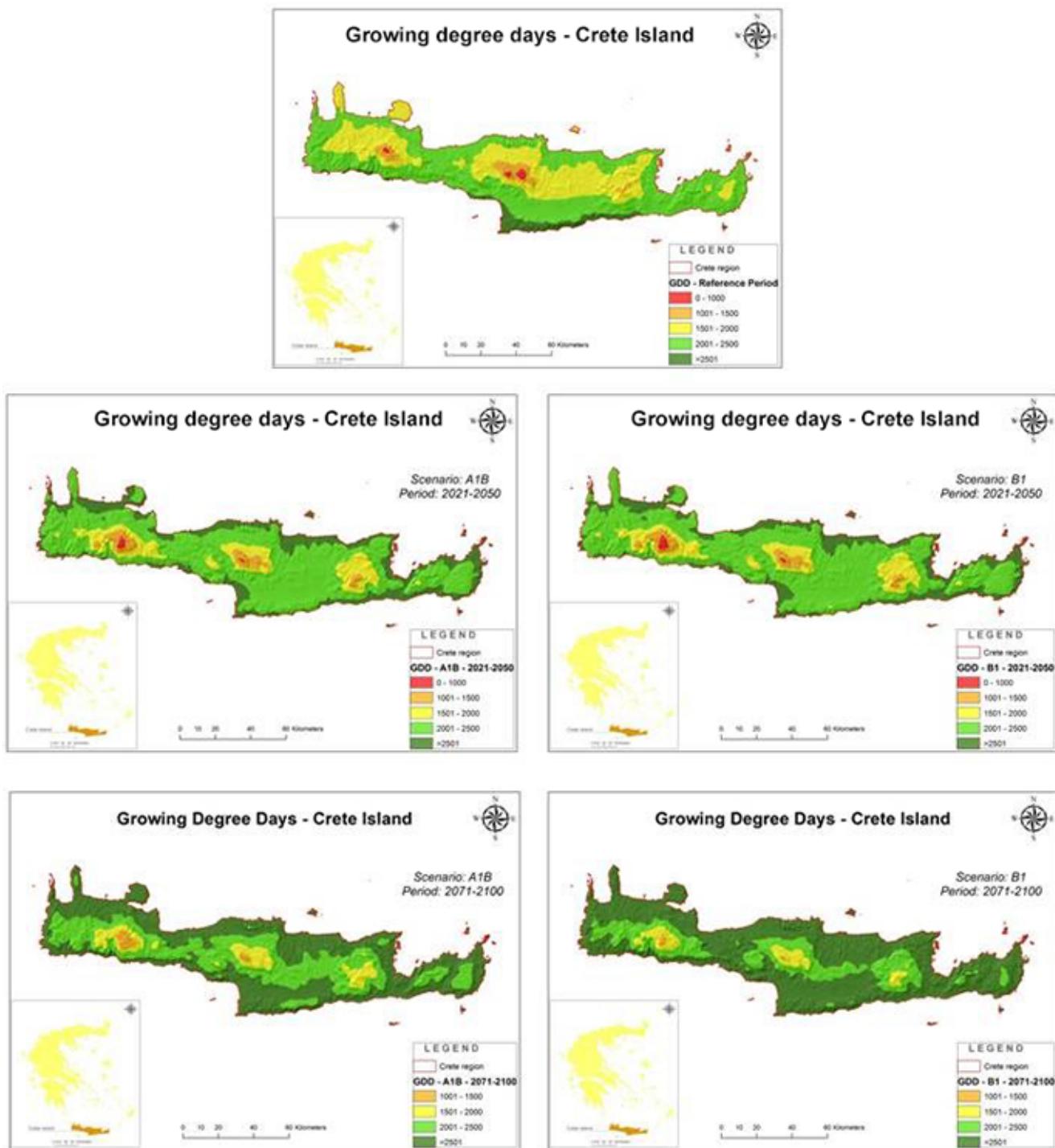


Figure 2. Growing Degree Days analysis – Crete Island.

by the end of the century (2071–2100) are expected to increase for both examined IPCC emission scenarios and cover the needs in terms of GDD units of the existing cultivations. Spatial interpolation of GDD is driven mainly by the elevation and indicates that by the end of the 21st century in the largest percentage of the study area higher GDD values will

be presented; even in higher altitudes. According to Fig. 2, in areas where high altitudes exist, the spatial interpolation of GDD indicated that even by the end of the century the GDD units will not exceed the 2000. Nevertheless, these areas are mainly dominated by abrupt slopes and there are very few possibilities for cultivations (at least not extensive cul-

tivations). According to a previous research of Matzarakis et al. (2007), Greece is characterized by favourable thermal conditions for the cultivation of high productivity crops. This is validated by the current research which adds the fact that these favourable thermal conditions will increase in the future. In summary, the main cultivation period could be reduced and shifted from April–October to April–September, especially in the 1-year cultivations of the current study. This fact could directly affect (and reduce) the production costs, which in combination with the new technologies and innovations that occur every day will further decrease the expenses. Additionally, the potential reduction of the cultivation period can lead to the mitigation of the amount of energy required to provide products and services and contribute towards the efficient energy use. The water resources management could benefit from that fact, as well as the quality of the ground and the underground aquifers. On the other hand, the shortening of the growing period or the impact of various extreme events such as droughts, heat waves, extreme rainfall, etc. (Eitzinger et al., 2013), or variations in available soil water (Eitzinger et al., 2003, 2004) could vary and reduce the potential crop yield as well. Since the latest studies indicate that there will be a water shortage in the upcoming years, and the certain study area will exhibit water scarcity problems due to irrigation and furthermore due to drought phenomena (Paparrizos et al., 2017b) or decreased land precipitation (Paparrizos et al., 2016a), even the smallest diminution of water use can act towards the preservation and the sustainable development of the water resources, especially in areas where water is essential for agriculture. Finally, potential future increase of GDD units can lead to the introduction of more demanding but also more profitable and efficient cultivations. Nevertheless, the harsh topography that exists in Crete Island, as well as the possible reduction of the potential crop yield due to reduction of the cultivation period that described above can act as inhibitors towards the sustainable development and expansion of agriculture in Crete Island.

#### 4 Conclusions

In the current research, an assessment of the spatial distribution of the Growing Degree Days for the periods 2021–2050 and 2071–2100 under the A1B and B1 IPCC emissions scenarios using data from several RCMs was performed for Crete Island in southern Greece. The combination of the dynamical and statistical approach in order to downscale and map the GDD units with the highest resolution within a 1 km × 1 km grid renders the current research an innovative one and of great contribution towards the accurate interpolation and thus representation of various variables over certain areas in the mesoscale. The results indicated that the upcoming years the GDD units will be increased and overcome the needs of the existing cultivations. Maturity of the existing cultivations in Crete Island can be achieved in a shorter pe-

riod of time and this could have a direct effect on the reduction of cultivation costs and contribute towards the mitigation of the negative impacts of the existing economical crisis in Greece. On the other hand, reduced growing period can produce a much lower crop yield and the economical balance might not be positive. The farmer can mitigate this effect by introducing new and more profitable cultivations that require more GDD units to maturity but then the concept of the GDD needs to be re-evaluated in order to determine the productivity of the newly introduced cultivations. Additionally, the potential crop yield depends also on cultivar characteristics, interactions with seasonal water balance changes, etc. Thus, in order to reach a conclusion regarding the general improvement of the economic income through the concept of GDD, multiple parameters need to be evaluated. In any case, the results of the current research must be taken into account as they can be a helping hand for all the farmers and various stakeholders, as they can obtain significant and accurate information so they can further adjust their adaptation systems and manage their agricultural procedures in order to prevail against the upcoming climate change.

**Competing interests.** The authors declare that they have no conflict of interest.

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