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Growing Degree Day Climatology in Aydın, Türkiye

Ercan Yeşilırmak[1,a,*]

[1]*Aydın Adnan Menderes University, Faculty of Agriculture, Department of Biosystems Engineering, Division of Land and Water Resources, Aydın, Türkiye*
[*]*Corresponding author*

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ABSTRACT

Plants need to accumalate heat to complete a particular or whole growth period. This accumalation depends on temperature thresholds above or below which plant growth ceases, and on air temperature. It can be speculated that more heat accumulation is available for plants due to rapid warming within three or four decades. This study presents more recent heat accumulation for plants, quantified using a useful index called growing degree day (GDD), for five locations (Söke, Kuşadası, Aydın, Sultanhisar and Nazilli) in Aydın, Türkiye, during the latest climatic normal period from 1991 to 2020. GDD values were calculated both in monthly basis from March through October, and in daily basis from March 1st to October 31st. Monthly GDD averages, as expected, showed a pattern that increased from March to July or August, then decreased thereafter till October. Range and standart deviation showed approximately an opposite pattern, suggesting higher uncertainty in relatively colder months. The results are expected to provide farmers or agricultural practitioners with the latest averages of GDD to predict plant growth and development.

[a] *eyesilirmak@adu.edu.tr* *https://orcid.org/0000-0002-6054-4507*

Introduction

Growing degree days (GDD) concept, also known as “thermal time”, “heat units” or “growth units” (Anandhi, 2016), is a frequetly used proxy to assess crop development (Gordon & Bootsma, 1993). It is first postulated as early as 1735 by René-Antoine Ferchault de Réaumur, stating that “organisms need to accumulate a number of heat units unique to that organism in order to initiate growth and to develop or mature” (Mix et al., 2010). GDD is simply the sum of temperature, during growing season or a spesified period, above a spesific temperature threshold (i.e., base temperature, T_{base}), below which crop development ceases. There is also an upper temperature threshold (T_{upper}), above which crop is dormant. T_{base} and T_{upper} are spesific for each species. GDD is used to estimate or predict plant growth and development, occurrences of insects, plant maturity and harvest timing (Radzka, 2021; Kadıoğlu & Şaylan, 2001).

Global surface temperature increased from 1850–1900 to 2011–2020 by 1.09°C (Arias et al., 2021). Since the 1980s, each decade has been warmer than the previous one (Ansari & Landin, 2022), and the decade 2011-2020 was the warmest one on record (United Nations Climate Change, 2022). Particularly western Türkiye, along with other Mediterranean countries, is considered to be affected substantially from present and future warming (Caloiero & Guagliardi, 2021; Goubanova & Li, 2007). Previous studies have documented that substantial temperature increases have been observed in western Türkiye, including Aydın and environs (Hadi & Tombul, 2018; Çelebioğlu et al., 2021; Yeşilırmak & Atatanır, 2021). These results suggest that, if adverse impacts of extreme high temperatures are not accounted for, during the most recent decades more heat is available for crop development. Revealing the accumulated GDD during a specified period within a year provides insight into the latest status of heat accumulation. It is aimed in this study to document average GDD accumulation calculated for the latest climatic normal period from 1991 to 2020 in the province Aydın, western Türkiye. The results are expected to provide agricultural practitioners or farmers the latest averages of GDD to predict plant growth and development.

Materials and Methods

Daily maximum and minimum temperature (T_{max} and T_{min}, respectively) data recorded at five weather stations in Aydın, Türkiye, were used. Data were supplied from the State Meteorological Agency of Türkiye. The weather stations are shown on a map in Figure 1 and listed in Table 1. The stations are located within the administrative borders of the povince Aydın. Typical mediterranean climate prevails over the study area, characterized by hot and dry summers, and mild and rainy winters.

Table 1. Weather stations and their geographical coordinates (The State Meteorological Service of Türkiye, 2022)

No	Station No	Station name	Latitude (N)	Longitude (E)
1	17234	Aydın	37.8402	27.8379
2	17232	Kuşadası	37.8597	27.2652
3	17860	Nazilli	37.9135	28.3437
4	17850	Sultanhisar	37.8843	28.1504
5	17881	Söke	37.7049	27.3827

Figure 1. The locations of weather stations

T_{max} and T_{min} data used in the study cover the period from 1991 to 2020. The period 1991 – 2020 is the latest climatic normal period, based on the definition of World Metetorological Organization (Bonacci, 2022). The weather stations are operated by State Meteorological Agency of Türkiye.

T_{max} and T_{min} records were subjected to a basic quality control procedure: $T_{min}>T_{max}$ and non-existent days (Klein Tank et al., 2002). Detected miscodings were set to a missing value. Overall, missing data were no more than 0.15% at any station. Missing data were filled by using data of neighboring stations with simple linear regression (Hu et al., 2012). Annual mean series of T_{max} and T_{min} were examined for homogeneity using the double mass curve method and no apparent breakpoint was detected (Hu et al., 2012).

For a specified period, accumulated GDD is calculated using the equation 1 (Anandhi, 2016):

$$GDD = \sum \left[\frac{(T_{max}-T_{min})}{2} - T_{base}\right] \quad (1)$$

where T_{base} is the base temperature (or, lower threshold temperature) below which crop growth does not occur. Furthermore, an upper temperature threshold (T_{upper}) above which crop growth ceases is also considered. In cases of T_{max} or T_{min} being above T_{upper} or below T_{base}, T_{max} or T_{min} is set to T_{base} or T_{upper} if they are below T_{base} or above T_{upper}, respectively (Paparrizos & Matzarakis, 2017). Five T_{base} (0, 5, 7, 10 and 15°C) and two T_{upper} (30 and 35°C) were selected. Accumulated GDDs were calculated on montly basis from March through October, and in daily basis from March 1st to October 31st.

Results and Discussion

Mean monthly GDD from March to October are shown in Figure 2 as bars, with the respective GDD values being presented at tips of bars, which makes the results more easily readable. The most prominent pattern is that mean GDDs have an increasing tendency from March till mid-summer, with peak values in July or August, then decreasing toward October. This pattern is, with no exception, the same for all T_{base} and T_{upper} combinations, and consistent with temperature evolution throughout year, also with expectation that heat accumulation of a colder period is fewer than that of a warmer period. March is the month with the lowest heat accumulation, varying roughly from 44 to 406°C, depending on thresholds and station. March is followed by april and october. The highest heat accumulations (i.e., GDD values) take place in july or august, which ranges roughly from 300 to 900°C depending on station and threshold. One can find or calculate, in terms of averages over the latest normal climatic period from 1991 to 2020, accumulated heat for a desired crop when a particular growth stage is attained.

As shown in Figure 2 for a given T_{base} and station, GDD values for both T_{upper} are the same or very close to each other in relatively colder months, namely in march, april and october at Kuşadası and Söke, and in march and april at other stations. On ther other hand, as time progresses and weather becomes hot, the two diverges and the difference between them becomes more evident in warmer months particularly in july or august. Up to 20% more heat accumulation is recorded in case of T_{upper}=35°C compared to T_{upper}=30°C. The reason, as expected, is that T_{max} exceeds rarely lower upper threshold (T_{upper}=30°C) in relatively colder months, but frequently higher upper threshold (T_{upper}=35°C) in warmer months.

For a given T_{upper}, GDD values decrease as the base temperature increases. This is the direct consequence of shrinking temperature extent between T_{base} and T_{mean}. As an example, for the station Nazilli, the month October and T_{upper}= 30°C, GDD values are 597.1, 442.5, 381.7, 294.1 and 177.5°C for T_{base} values of 0, 5, 7, 10 and 15°C, respectively. This decrease is more notable in relatively colder months, particularly in March in which there is up to ten-fold decrease. For example, in Kuşadası and for T_{upper}=35°C, GDD is 400.2°C for T_{base}=0°C, but 44.3°C for T_{base}=15°C. However, in summer months, particularly in July or August, the decrease is about 50%.

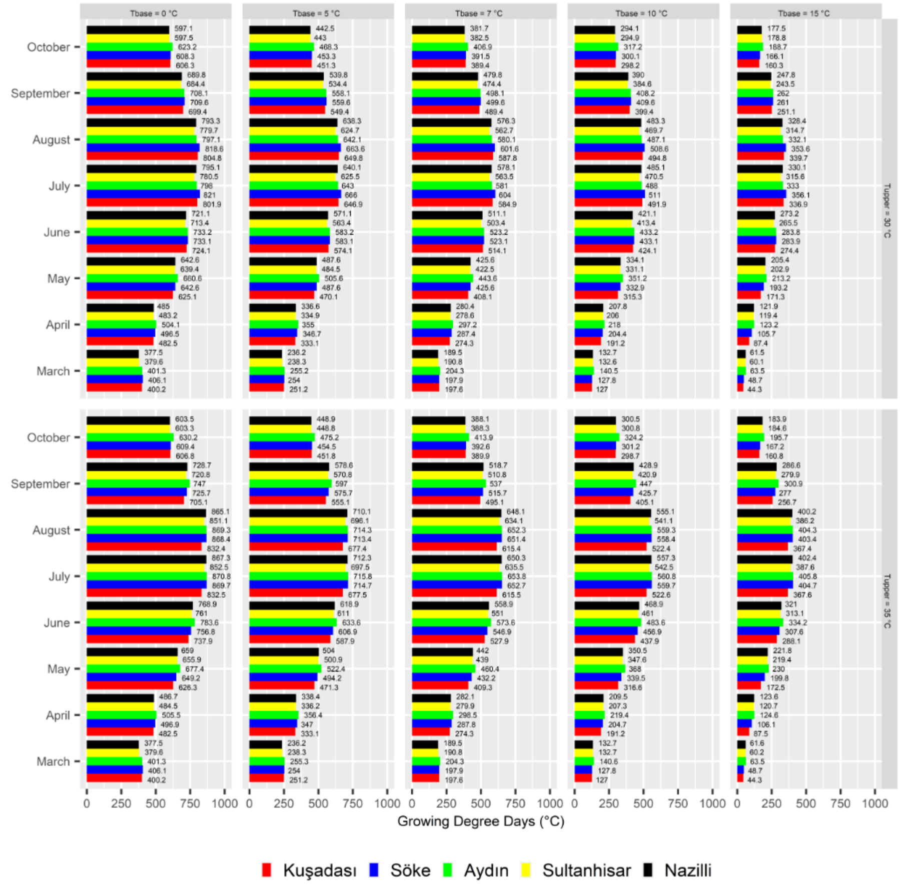

Figure 2. Monthly GDD values by month and station

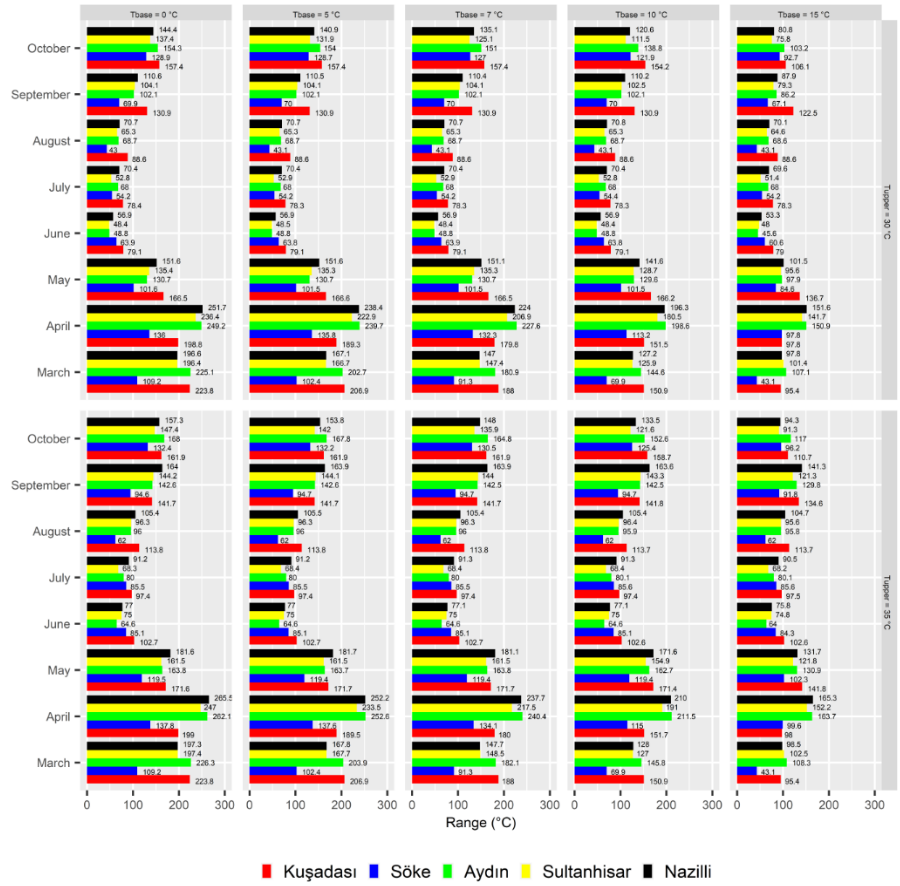

Figure 3. Ranges of monthly GDD values

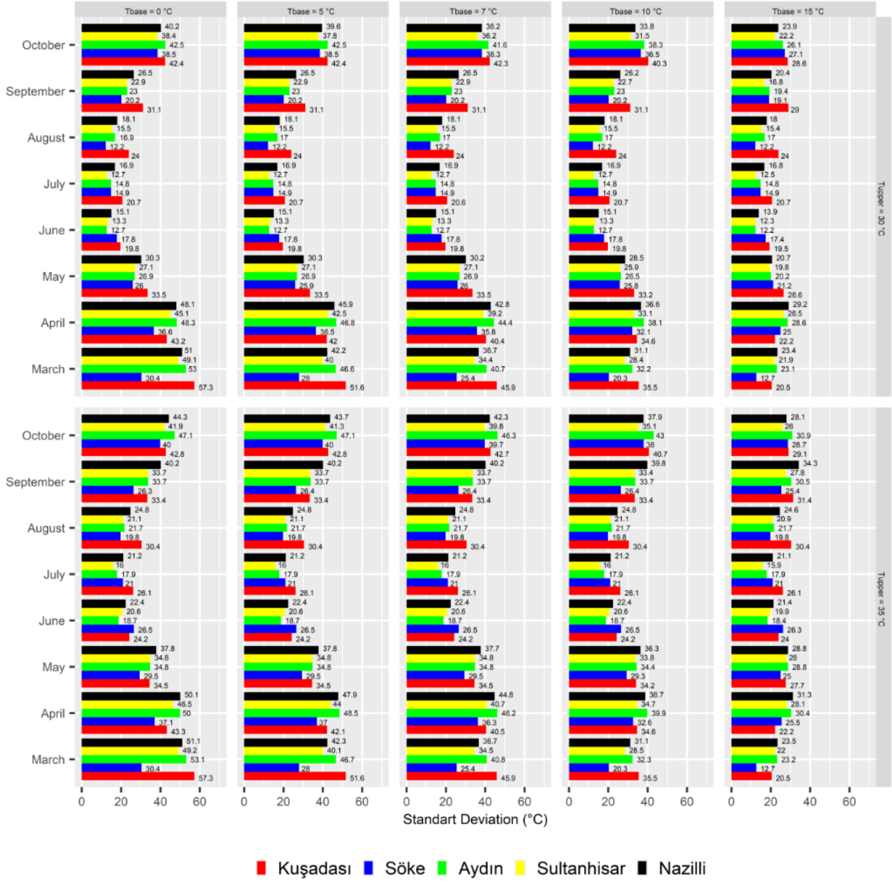

Figure 4. Standart deviations of monthly GDD values

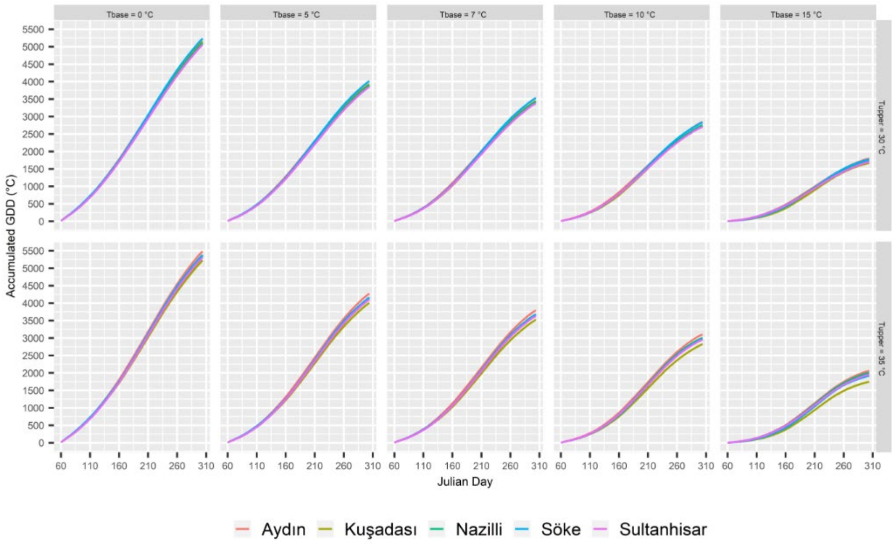

Figure 5. Accumulated GDD from March 1st (Julian day 60) through October 31st (Julian day 304)

For given T_{base}, station and month, GDD is higher for the case with higher T_{upper} than that the case with lower T_{upper}, particularly in warmer months, due to the fact that the temperature interval between T_{base} and T_{upper} is higher in the case that the higher T_{upper} (i.e., 35°C) is used. As an example, for T_{base}=0°C, August and Nazilli, GDD values are 793.3 and 865.1 C for T_{upper} of 30 and 35°C, respectively. However, this may not be the case in colder months, yet they are equal or differ very slightly, because T_{max} exceeding T_{upper} (30 or 35°C, in this study) does not occur in these months. For again Nazilli and T_{base}=0°C, GDD (377.5°C) is the same in March for both T_{upper}=30°C and T_{upper}=35°C. On the other hand, in April, which is warmer than March, the corresponding values in Nazilli for T_{base}=0°C are 485 and 486.7°C, representing a slight increase between them.

Variabilities of GDD values over the study period can be evaluated through their ranges and standart deviations, as shown in Figures 3 and 4, respectively. There exist in general decreasing tendencies from spring months toward mid-summer, and then increasing tendencies afterwards. In other words, the highest ranges and standart deviations are observed in spring or early autumn months, which are relatively colder, while the lowest ones occur in summer months. This pattern is almost valid at all stations for all T_{base} and T_{upper} combinations, and can be easily discernable by the lengths of bars in which the corresponding range and SD values are located at the tip of bars. The highest range and SD values are observed in spring months, particularly in March or April. However, the lowest ones exist in summer months. Those in September and October lie in between those of spring and summer months. This pattern of monthly variability in range and SD values is just opposite of averages. While spring months have the lowest averages, they have the highest range and SD values. Similarly, summer months have the highest averages and the lowest range and SD values. All these results imply that uncertainty is the highest in spring months, and that larger departures from averages can be expected in these months. Failure in an attempt to estimate crop growth in early stages in spring is more likely. Conversely, this is not the case in summer months.

Figure 5 depicts average accumulated GDDs from March 1st through October 31st at all stations for all T_{base} and T_{upper} combinations. X-axes in each panel represent day from Julian day 60 (March 1st) to Julian day 304 (October 31st), ignoring leap day (February 29th). In each panel, all curves are S-like. All lines are steeper in mid-season (i.e., Julian day 152 through Julian day 243, or June through August) than in begining or end. This indicates more heat accumulation in mid-season due to higher temperatures. For a given T_{upper}, accumulated GDD decreases as T_{base} increases. This pattern, as an example, can be shown by tracking the values of Aydın for T_{upper}= 30°C during the whole study period from March 1st to October 21st. The accumulated GDDs in Aydın for T_{upper}=30°C are 5226.6, 4011.5, 3535.3, 2844.2 and 1800.3°C for T_{base} values of 0, 5, 7, 10 and 15°C, respectively.

A few studies were conducted to determine heat requirements of various major crops in Aydın. Serter (2003) grew six corn varieties as main and second crop in 2001 and 2002, and determined accumulated GDD values during specific phenophases and whole growth period. For example, GDD for whole growth period changed for from 1042°C to 1869°C depending on year, variety and planting time. Serter (2003) assumed 10°C as T_{base} and 30°C as T_{upper}, and replaced T_{min} by 10°C if T_{min} is less than T_{base}, and T_{max} by 30°C if T_{max} is greater than T_{upper}. Özkan and Kaynak (2009) determined heat accumulations of four cotton varieties during specific phenophases and whole growth period in 1997, 1998 and 1999 in Aydın, assuming 15.6°C as T_{base}. For whole growth period, accumulated GDD values ranged from 1310°C to 1386°C. A farmer or agricultural practitioner can estimate timing of a specific phenophase or whole growth period for corn or cotton by using the results of this study together with that found by Serter (2003), and Özkan and Kaynak (2009) in Aydın, or for any other crop provided that its heat requirements and the threshold temperatures are available.

Conclusions

This study presents average GDD values for various base and upper threshold temperature combinations, calculated over the latest climatic normal period from 1991 to 2020 at five sites in Aydın, Türkiye, to determine the time a specific growth phase of a crop is attained. Monthly averages show a pattern that increases from March to July or August, then decreases thereafter till October. Range and standart deviation show approximately an opposite pattern, suggesting higher uncertainity in relatively colder months. Therefore, more caution is needed when incorporating GDDs in month with higher range and SD values into heat accumulation.

Declarations

Conflict of Interest

The author declares no conflict of interest.

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References

Anandhi, A. (2016). Growing degree days – Ecosystem indicator for changing diurnal temperatures and their impact on corn growth stages in Kansas. *Ecological Indicators,* 61, 149–158. https://doi.org/10.1016/j.ecolind.2015.08.023

Ansari, R.A., & Landin, J.M. (2022). Coverage of climate change in introductory biology textbooks, 1970–2019. *PLoS ONE* 17(12), Article e0278532. https://doi.org/10.1371/journal.pone.0278532

Arias, P.A., Bellouin, N., Coppola, E., Jones, R.G., Krinner, G., Marotzke, J., Naik, V., Palmer, M.D., Plattner, G.-K., Rogelj, J., Rojas, M., Sillmann, J., Storelvmo, T., Thorne, P.W., Trewin, B., Achuta Rao, K., Adhikary, B., Allan, R.P., Armour, K., Bala, G., Barimalala, R., Berger, S., Canadell, J.G., Cassou, C., Cherchi, A., Collins, W., Collins, W.D., Connors, S.L., Corti, S., Cruz, F., Dentener, F.J., Dereczynski, C., Di Luca, A., Diongue Niang, A., Doblas-Reyes, F.J., Dosio, A., Douville, H., Engelbrecht, F., Eyring, V., Fischer, E., Forster, P., Fox-Kemper, B., Fuglestvedt, J.S., Fyfe, J.C., Gillett, N.P., Goldfarb, L., Gorodetskaya, I., Gutierrez, J.M., Hamdi, R., Hawkins, E., Hewitt, H.T., Hope, P., Islam, A.S., Jones, C., Kaufman, D.S., Kopp, R.E., Kosaka, Y., Kossin, J., Krakovska, S., Lee, J.-Y., Li, J., Mauritsen, T., Maycock, T.K., Meinshausen, M., Min, S.-K., Monteiro, P.M.S., Ngo-Duc, T., Otto, F., Pinto, I., Pirani, A., Raghavan, K., Ranasinghe, R., Ruane, A.C., Ruiz, L., Sallée, J.-B., Samset, B.H., Sathyendranath, S., Seneviratne, S.I. , Sörensson, A.A., Szopa, S., Takayabu, I., Tréguier, A.-M., van den Hurk, B., Vautard, R., von Schuckmann, K., Zaehle, S., Zhang, X., & Zickfeld, K. (2021). Technical Summary. In V. Masson-Delmotte, P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou (eds.), *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 33−144). https://doi.org/10.1017/9781009157896.002

Bonacci, O. (2022). What is above average air temperature!? *Theoretical and Applied Climatology,* 150, 85-101. https://doi.org/10.1007/s00704-022-04144-y

Caloiero, T., & Guagliardi, I. (2021). Climate change assessment: seasonal and annual temperature analysis trends in the Sardinia region (Italy). *Arabion Journal of Geosciences,* 14, Article 2149. https://doi.org/10.1007/s12517-021-08527-9

Çelebioğlu, T., Tayanç, M., & Oruç, H.N. (2021). Determination of temperature variabilities and trends in Turkey. *Bursa Uludağ University Journal of The Faculty of Engineering*, 26(3), 1003–1020. https://doi.org/10.17482/uumfd.881416

Gordon, R., & Bootsma, A. (1993). Analyses of growing degree-days for agriculture in Atlantic Canada. *Climate Research*, 3, 169-176.

Goubanova, K., & Li, L. (2007). Extremes in temperature and precipitation around the Mediterranean basin in an ensemble of future climate scenario simulations. *Global and Planetary Change,* 57, 27–42. https://doi.org/10.1016/j.gloplacha.2006.11.012

Hadi, S.J., & Tombul, M. (2018). Long-term spatiotemporal trend analysis of precipitation and temperature over Turkey. *Meteorological Applications,* 25, 445–455. https://doi.org/10.1002/met.1712

Hu, Y., Maskey. S., & Uhlenbrook, S. (2012). Trends in temperature and rainfall extremes in the Yellow River source region, China. *Climatic Change,* 110, 403–429. https://doi.org/10.1007/s10584-011-0056-2

Kadioğlu, M., & Şaylan, L. (2001). Trends of growing degree-days in Turkey. *Water, Air, and Soil Pollution,* 126(1), 83–96. https://doi.org/10.1023/A:1005299619084

Klein Tank, A.M.G., Wijngaard, J.B., Können, G.P., Böhm, R., Demarée, G., Gocheva, A., Mileta, M., Pashiardis, S., Hejkrlik, L., Kern-Hansen, C., Heino, R., Bessemoulin, P., Müller-Westermeier, G., Tzanakou, M., Szalai, S., Pálsdóttir, T., Fitzgerald, D., Rubin, S., Capaldo, M., Maugeri, M., Leitass, A., Bukantis, A., Aberfeld, R., van Engelen, A.F.V., Forland, E., Mietus, M., Coelho, F., Mares, C., Razuvaev, V., Nieplova, E., Cegnar, T., Antonio López, J., Dahlström, B., Moberg, A., Kirchhofer, W., Ceylan, A., Pachaliuk, O., Alexander, L.V., & Petrovic, P. (2002). Daily dataset of 20th-century surface air temperature and precipitation series for the European Climate Assessment. *International Journal of Climatology, 22*, 1441–1453. https://doi.org/10.1002/joc.773

Mix. K., Rast, W., & Lopes, V.L. (2010). Increases in growing degree days in the Alpine Desert of the San Luis Valley, Colorado. *Water Air and Soil Pollution, 205,* 289–304. https://doi.org/10.1007/s11270-009-0074-0

Özkan, İ., & Kaynak, M.A. (2009). Farklı pamuk çeşitlerinde (*Gossypium hirsutum L.*) gün-derece değerlerinin, verim, verim unsurları ve lif kalite özelliklerine etkisinin saptanması. *ADÜ Ziraat Fakültesi Dergisi*, 6(2), 39 – 46.

Paparrizos, S., & Matzarakis, A. (2017). Present and future assessment of growing degree days over selected Greek areas with different climate conditions. *Meteorology and Atmospheric Physics,* 129, 453–467. https://doi.org/10.1007/s00703-016-0475-8

Radzka, E. (2021). Variation in growing season thermal resources in Central-East Poland. *Journal of Ecological Engineering,* 22(6), 145–150. https://doi.org/10.12911/22998993/137439

Serter, E. (2003). Farklı mısır gruplarında büyüme derece gün, sıcaklık parametreleri ve verim komponentlerinin saptanması. [*Doctoral dissertation, Aydın Adnan Menderes University]*. YÖK Ulusal Tez Merkezi.

The State Meteorological Service of Türkiyeurkey. (2022, August 21). *İstasyon Bilgileri Veritabanı*. https://www.mgm.gov.tr/kurumsal/istasyonlarimiz.aspx?il=Aydın

United Nations Climate Change. (2022, August 21). *2020 was one of three warmest years on record*. United Nations Climate Change, External Press Release. https://unfccc.int/news/2020-was-one-of-three-warmest-years-on-record

Yeşilırmak, E., & Atatanır, L. (2021). Variations in erosion risk in Western Anatolia (Turkey): Modified Fournier Approach. *COMU Journal of Agriculture Faculty,* 9 (1). 179–188. https://doi.org/10.33202/comuagri.866697