Impact of Climate Variability on Agricultural Growing Season: A Review

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Abstract:

Over the previous century, the global mean surface air temperature has risen, and this trend is anticipated to continue in the next decades. This has an impact on the global water deficit's temporal distribution, where these meteorological variables have substantial influence on the growing season parameters (start, end and length). In most parts of the world there has been a change in the length of the growing season, damaging and benefiting according to the changes in temperature and precipitation in specified locations. The increase in temperature elongates the growing season across the mid- and high-latitude areas of the Northern Hemisphere benefiting crop growth, where as in equatorial and Southern Hemispheric areas, it shortens the growing season having damaging effect on the crop growth. The onset and end of the growing season can be difficult to be determined since there are different definitions depending on the meteorological variable that the area is constrained by. Because they are designed to account for soil moisture availability, threshold-based definitions are suited for local agronomic research based on station data. Thresholds, on the other hand, are difficult to predict consistently. They are especially vulnerable to bias and resolution, which is a key issue for climate models. The rainy season can be defined as a period of consistent precipitation above a reference value that can be changed to an Agronomic ally relevant value using methods like the Anomalous Accumulation technique. Such methods are distinguished by the fact that they do not require any external parameters, i.e., they are unaffected by the study's environment.

Keywords: Growing Season, Climate Variability, Model Definitions, Land Surface Phenology.

1 Introduction:

The global mean surface air temperature has risen over the previous century, with a 0.74 °C warming trend from 1906 to 2005, with the majority of the warming occurring in the last 50 years (UNFCCC, 2011). This trend is likely to continue in the next decades (UNFCCC, 2017), as are the observed greater trends in hot and dry years, which will be driven by fast rising temperatures (Coffel et al., 2019). This has an impact on the global distribution of water deficit throughout time. It also poses a threat to agricultural development rates, as well as the temporal dynamics of crop water requirement and supplementation over the last few decades, posing a serious risk to food security (Wu et al., 2014). Temperature is the primary determinant of crop development rate, has an impact on the ecosystem, and is a key factor in the occurrence and severity of agricultural droughts (Schwartz et al., 2013 and Wu et al., 2014), and lowers production rate by varying the planting date, particularly for subsistent farmers (Ndomba, 2010).

Climate models for a warming world, according to Linderholm (2006), predict that rising CO2 levels in the atmosphere will modify a range of climates, weather patterns, and biological phenomena, such as the length of the growing season (LGS). As a result of an earlier start and later conclusion of the growing season (GS), global air temperature rises may cause changes in growth seasons in different parts of the world (Liu et al., 2016). In addition to spatiotemporal fluctuation of air temperature, climatic conditions such as photoperiod, precipitation, continuous very low air temperature, and wind may influence the timing of the GS's start (SGS) and end (EGS) (Nagai et al., 2015). Furthermore, the data of the growing season can be influenced by the amount of urban heat island (US Environmental Protection Agency, 2016).

In contrast, the variability of GS has an impact on climate change. Variations in the thermal growth season, as well as variations in albedo, according to Liu et al. (2016), can manage climate change by exchanging carbon and water with the atmosphere. Spatio-temporal variability at the beginning (SGS) and end (EGS) of the growing season can influence meteorological processes and seasonal climate by influencing evapotranspiration and physical properties of the land surface such as latent and sensible heat, albedo, and aerodynamic roughness (Polgar & Primack, 2011; Schwartz et al., 2013).

The GS has a high degree of inter-annual fluctuation, with its parameters (start, end, and length) exhibiting the most significant shifts. The fluctuations are a valuable climatic indicator with a wide range of important climatological uses. Changes in agricultural history, for example, can result in reduced yields of conventional crops that aren't fully developed due to reducing the LGS. Depending on water availability, increases in LGS may allow for earlier planting, insuring maturity, and the chance of many harvests (Linderholm, 2006). GS variations are extremely sensitive to regional temperature anomalies, which can be attributed to atmospheric teleconnection patterns (ATPs) (Irannezhad & Klve, 2015). Knowing how long the GS will last and when it will end aids in selecting the appropriate cultivar in specific areas (Moeletsi& Walker, 2012), resulting in increased interest in many parts of the world (e.g., Cook & Vizy, 2012; Cui et al., 2017; Ronchail et al., 2002; Sabziparvar & Jahromi, 2018; Segele & Lamb, 2005). It is an important factor in regulating the maturity of cultivars grown under different rainfall regimes (Akinseye et al., 2015; Stewart, 1988). Changes in the length of the growing season can have an impact on agricultural yield and pricing in both positive and negative ways. Warming is expected to reduce main agricultural yields in general, but crops in particular locations may benefit (IPCC, 2014).If the growing season is extended, farmers may be able to vary their crops or harvest many times from the same plot. It may, however, limit the types of crops grown, encourage the growth of foreign species or weeds, and increase the requirement for irrigation. A prolonged growing season, for example, could alter the functioning and structure of a region's ecosystems, affecting the range and types of animal species in the area (US Environmental Protection Agency, 2016).

Globally, the methodologies and definitions used to establish the start and end of GS vary depending on the climate variable(s) that determine the GS. Temperature-based GS definitions may be suitable in regions where the growing season is primarily temperature limited, as mentioned by Linderholm (2006), but at lower latitudes, other variables such as precipitation and evapotranspiration must be addressed. Threshold based definitions using temperature (Cui & Shi, 2021; Linderholm, 2006; Liu et al., 2016; Sabziparvar & Jahromi, 2018; Song et al., 2010), rainfall and evapotranspiration (Akinseye et al., 2015; Jimmy Byakatonda et al., 2018; FAO, 1978; Segele & Lamb, 2005) and model based definitions (Byun & Lee, 2002; Dunning et al., 2016; Liebmann et al., 2012; Ndomba, 2010; Odekunle, 2004) have been used to determine the indices of GS.

Assessing the impact of climate variability on GS is a critical step towards understanding their relationship and future readiness to establish planting dates. Furthermore, evaluating the methodology and definition of the GS parameters/indices (start, end, and length) is critical in order to find and employ applicable globally acceptable method and definition. As a result, the definitions of GS established by many scholars based on a variety of climatological factors, as well as the relationship between LGS and climatic variability, and their patterns around the world, have received adequate consideration in this review. Growing season and growing period have similar definitions, for example, "length of growing period is defined as the period during the year when average temperatures are greater than or equal to 5 ^{0}C (Tmean>= 5 ^{0}C) and precipitation plus moisture store in the soil exceed half the potential evapotranspiration (P > 0.5 PET)" (Fischer, 2009); 'the length of the growing season in any given region refers to the number of days when plant development takes place' (EPA, 2016). As a result, the term "growing season" appears frequently in this assessment.

2 Methodology:

This is a systematic review attempted to look at various literatures from around the world addressing the reversible bearing between parameters (start, end and length) of the growing season and climate variability.It is organized in a manner that the topics addressed by the literatures best fits the problem. The preliminary selection of the literatures has been made by their title and abstract. Then further selection has been made by their internal core message. References cited on the selected literatures were also assessedfor additional information. The selection process only considered papers that dealt directly with the subject and those that concentrated on the techniques for determining growing season and its interconnection with climate variables. The systematic review also captures the current research for future interdisciplinary scientific research.

3 Definition of the growing season:

Because of regional differences in growing season conditions, there is currently no universal definition of growing season criteria (Walther & Linderholm, 2006). The definition of the growth season (start, end, and length) varies depending on where the various climatological characteristics are limited. Definitions using temperatures may be considered valid in areas where the growing season is largely temperature limited (Jones et al., 2002; Liu et al., 2016; Sabziparvar & Jahromi, 2018), but at lower latitudes other factors such as precipitation and evapotranspiration must be taken into consideration (Akinseye et al., 2015; Linderholm, 2006; Lupi Edao et al., 2018; Segele& Lamb, 2005). If temperature is not a constraint, the ratio of precipitation to potential evapotranspiration (P/PET) determines the beginning, end, and type of growing period (FAO, 1978).

3.1 Temperature based definitions:

Various studies used two widely used definitions of the start of the growing season (thermal) in areas where temperature is a determining factor (northern hemisphere mid- and high-latitude areas) (Linderholm et al., 2008; Liu et al., 2016; Sabziparvar & Jahromi, 2018; Walther & Linderholm, 2006). It is defined as the first day when the daily mean air temperature exceeds a threshold (Liu et al., 2016) and the final (or first) day in a predetermined number of days when the daily mean air temperature first exceeds a threshold (Linderholm et al., 2008). There are three temperature thresholds used in determining the thermal growth season: 0 °C, 5 °C, and 10 °C, with the 5 °C threshold receiving the most attention (Cui et al., 2017). According to Jones et al., (2002); Linderholm et al., (2008); Liu et al., (2016); Sabziparvar & Jahromi, (2018); Walther & Linderholm, (2006) the end of the thermal growth season is defined as the last day in a set number of days where the minimum daily mean temperature is below the threshold..

In terms of frost, the start is defined as the last day of a predetermined number of days with an average daily temperature above the threshold occurring after the last frost of the winter season (Jones et al., 2002; Linderholm et al., 2008; Liu et al., 2016; Sabziparvar & Jahromi, 2018; Walther &Linderholm, 2006).The length of thermal growing season is defined as the number of days between the start and end of the growing season (Jones et al., 2002; Linderholm et al., 2008; Liu et al., 2016; Sabziparvar & Jahromi, 2018; Walther & Linderholm, 2006).

In general, in most of the studies the definitions are made based on the indices of the start (five indices), end (six indices) and length of the growing season (seven indices) as summarized in Table 1.

Table 1:Summary of thermal growing season indices

Parameters	Indices	Definition	References
Start of growing season	<5 d > 5 ^{0}C (SI 1)	4-day spell with *T*mean remaining above 5 ^{0}C	(Jones & Briffa, 1995)
	=5 d > 5^{0}C (SI 2)	5-day spellwith *T*mean remaining above 5^{0}C	(Carter, 1998)
	>5 d > 5^{0}C (SI 3)	6-day spellwith *T*mean remaining above 5^{0}C	(Sabziparvar & Jahromi, 2018)
	=5 d > 5^{0}C Fr (SI 4)	5-day spell after the last *T*mean spring frost with *T*mean remaining above 5^{0}C	(Jones et al., 2002)
	>5 d > 5^{0}C Fr (SI 5)	6-day spell after the last *T*mean spring frost with *T*mean remaining above 5^{0}C	(Liu et al., 2016; Walther & Linderholm, 2006)

End of growing season	<5 d < 5 ^{0}C (EI 1)	4- day spell with *T*mean remaining below 5 ^{0}C	(Jones & Briffa, 1995)
	=5 d < 5^{0}C (EI 2)	5- day spell with *T*mean remaining below 5^{0}C	(Carter, 1998)
	>5 d < 5^{0}C (EI 3)	6- day spell with *T*mean remaining below 5^{0}C	(Sabziparvar & Jahromi, 2018)
	10 d < 5^{0}C (EI 4)	10-day running mean of *T*mean falling below 5^{0}C	(Linderholm et al., 2008; Liu et al., 2016)
	Fr OR = 5 d <5^{0}C (EI 5)	First autumn/winter *T*mean frost OR 5-day spell with *T*mean remaining below 5^{0}C	(Jones et al., 2002)
	Fr OR > 5 d < 5^{0}C (EI 6)	First autumn/winter *T*mean frost OR 6-day spell with *T*mean remaining below 5^{0}C	(Walther & Linderholm, 2006)
Length of growing season	<5 d > 5 ^{0}C |<5 d < 5 ^{0}C (LI 1)	Start (SI 1), end (EI 1)	(Jones & Briffa, 1995)
	=5 d > 5^{0}C | =5 d < 5^{0}C (LI 1)	Start (SI 2), end (EI 2)	(Jones et al., 2002)
	>5 d > 5^{0}C | >5 d < 5^{0}C (LI 2)	Start (SI 3), end (EI 3)	(Sabziparvar & Jahromi, 2018)
	=5 d > 5^{0}C Fr | 10 d < 5^{0}C (LI 3)	Start (SI 4), end (EI 4)	(Walther & Linderholm, 2006)
	>5 d > 5^{0}C Fr | 10 d < 5^{0}C (LI 4)	Start (SI 5), end (EI 4)	(Linderholm et al., 2008; Liu et al., 2016)
	=5 d > 5^{0}C Fr | Fr OR = 5 d < 5^{0}C (LI 5)	Start (SI 4), end (EI 5)	(Jones et al., 2002)
	>5 d > 5^{0}C Fr | Fr OR > 5 d < 5^{0}C (LI 6)	Start (SI 5), end (EI 6)	(Walther & Linderholm, 2006)

3.2 Precipitation based definitions:

On areas where temperature is not the limiting factor for growing season, the definitions related to precipitation and potential evapotranspiration take part(Linderholm, 2006). The definitions most likely related to the end, cessation and length of the rainy season(s). Based on station data, threshold-based measures have been used by different researcher's in order to define the onset and end of growing season in relation to onset and cessation of rainy season in specific areas. As an example, the start of growing seasonis the date when rainfall accumulated over three consecutive days should at least 20 mm (25 mm within 10 days, Byakatonda et al., 2018) and when no dry spell within the next 30 days exceeded 7 days (8 days, Segele & Lamb (2005); 10 days, Byakatonda et al. (2018); 21 days exceeded 9 days, Edao et al. (2018)) (Akinseye et al., 2015). According to them if consecutive dry spell has happened within the predefined number of days, then the start is considered as a false start. In addition, the rainfall must deliver at least 50% of the local crop water requirement (Omotosho et al., 2000) or exceeds half the evaporation assuming a daily evaporation of 5 mm (Akinseye et al., 2015 and FAO, 1978). According to Segele & Lamb (2005), the onset is defined when daily rainfall exceeds 10 mm in the arid, northern Rift Valley and the eastern lowland, areas of Ethiopia.

Likewise, the cessation date over wet (dry) regions is taken as the first day of a dry period that lasts for at least 20 (15) days(Segele & Lamb, 2005).Cessation is defined when precipitation remains below 1/2PET for a specified time (Benoit, 1977; Cook & Vizy, 2012; FAO, 1978).It is after the traditional rain cessation day when the soil water content down to 60-cm depth is evaporated, with a daily PET of 5mm, assuming a soil water retention capacity of 100 mm (Akinseye et al., 2015 andEdao et al., 2018).Based on Araya and Stroosnijder (2011); J. Byakatonda et al. (2016); Byakatonda et al. (2018),it is believed to occurafter 50% of pentad total potential evapotranspiration surpasses pentad rainfall on the seventh day. For this to happen, the shortfall period must be followed by a 10-day dry stretch. Furthermore, according to Moeletsi and Walker (2012)**,** the final day on which rainfall of 25 mm or more was deposited over the preceding 10 days and at least 20 mm was accumulated in the following 20 days is considered the commencement of rains in dry and semiarid regions. In these places, the end of the rainy season is determined by looking for the final day on which the cumulative rainfall of 25 mm over 10 days occurs. As a result, the length is calculated by subtracting the start and finish dates.

Mugalavai et al. (2008) and Raes et al. (2004) used '*depth*' method to determine the start and cessation dates. The approach takes into account a cumulative rainfall depth that will bring the top 0.25m of the soil profile to field capacity in four days or less. The amount of rainfall necessary to elevate the soil water content from wilting point to field capacity was calculated using the total accessible soil water (TAW) for the primary soils during the first stage for annual crops. The adequate threshold value for the rainfall will be determined according to the area's soil profile and field capacity. The date on which the water stress in the root zone of a crop surpasses a threshold value is used to determine cessation.

The LGS is defined as the period between the beginning of the rainy season and the end of the growing season, and it is calculated by subtracting the beginning of the rainy season from the end of the growing season (Linderholm et al., 2008).

3.3 Model definitions:

Byun and Lee (2002) employed 'Available Water Resources Index (AWRI)' estimates in mountainous Asian nations to establish the commencement and cessation dates. The AWRI is calculated by taking qualitative account of the values of cumulative precipitation, daily decrease (by runoff, evapotranspiration, infiltration, etc.) of water, and accumulation duration. They have exploited the following relationships in doing so.

$$\boldsymbol{E = \sum_{N=1}^{D} \left(\sum_{m=1}^{N} P_m/N\right)}$$

where P_m is the m-day prior daily precipitation, N is a dummy variable, and E is the representative value of water resources acquired throughout D days.

And the AWRI is calculated from the accumulated precipitation determined by the preceding equation:

$$\boldsymbol{W = E/\sum_{N=1}^{D}(1/N)}$$

where W is the AWRI, a broad term that indicates the amount of existing water resources.

As a result, the onset is the date of the lowest AWRI value, and the cessation is the date of the highest AWRI value.

Ndomba (2010) and Odekunle (2006) employed the 'percentage cumulative mean rainfall values' approach in dekadal and pentad diurnal scales, respectively. The procedure for the method is as follows: 1) calculate the percentage of the mean annual rainfall that occurs at each 10- (5-) day interval throughout the year based on the mean annual rainfall that occurs at each 10- (5-) day interval throughout the year. 2) adding up the percentages of the 10- (5-) day periods. 3) Finally, plot the cumulative percentage versus time throughout the year. The time of rainfall onset corresponds to the first point on the graph with the largest positive curvature, while the time of rainfall retreat corresponds to the last point with the greatest negative curvature. These points of greatest curvature, which correspond to the start and end of rain, account for 7-8% and more than 90% of yearly rainfall, respectively.

(Dunning et al., 2016, 2018; Liebmann et al., 2012; Liebmann& Marengo, 2001) have used a 'anomalous accumulation' strategy. It entails subtracting the long-term annual-mean daily average from the sum of daily precipitation (annual rainfall / number of days). This total is known as the "anomalous accumulation." Because cumulative precipitation (relative to onset) exceeds what would be projected from climatology from that day forward for this specific year, the day after the anomalous accumulation number reaches its absolute minimum is deemed the start of the rainy season. The day with the greatest anomalous accumulation, on the other hand, marks the end of the rainy season because relative accumulation after that day is less than expected by climatology. The start and end dates of each year are used to calculate the total, length, and rate of the wet season.

To account for seasons that span calendar years, the period of the year when the wet season occurs, known as the climatological water season, must first be identified. First, the climatological mean rainfall for each day of the calendar year, Qi, is computed, where i ranges from 1 January to 31 December, and the climatological daily mean rainfall Q is obtained. The climatological cumulative daily rainfall anomaly on day d, C(d), is calculated as follows:

$$\boldsymbol{C(d) = \sum_{i=1Jan}^{d} (Q_i - \bar{Q}}$$

Where *i* is a number ranging from January 1 to the day (d) to which the calculation applies. The minimum and maximum values of the plot of C(d) versus days of the year represent the climatological water season's start (d_s) and end (d_e), respectively.

Each year, the beginning and cessation dates are estimated independently by calculating the daily cumulative rainfall anomaly on day D, A(D):

$$\boldsymbol{A(D) = \sum_{j=d_s-50}^{D} (R_j - Q}$$

Where R_j is the amount of rain on day j and j varies from ds 50 to the day under consideration (D). For each year, A(D) is calculated for each day from d_s- 50 to d_e + 50. Because rainfall remains persistent in occurrence, duration, and intensity after the minimum, the start date in A(D) is the day after the minimum, and the end date is the day after the maximum.

Dunning et al. (2016) extended this strategy to areas with bimodal rainfall patterns by employing the following formula:

$$\boldsymbol{A(D) = \sum_{j=d_{s1}-20}^{D} (R_j - \bar{Q}}$$

Where R_j is the rainfall on day j and j ranges from d_{s1}− 20 to the day being considered (D). A(D) is calculated for each day from d_{s1}− 20 to d_{e1}+ 20, and for each day from d_{s2}− 20 and d_{e2}+ 20, for each year.

Because the dry periods between successive wet seasons may be shorter than 100 days, duration of 20 days (rather than the 50 mentioned above) was employed to ensure the proper season was caught. For example, the small dry season occurs just in July and August along West Africa's southern coast. The minima and maximum of A(D) were used to calculate onset and cessation dates once more.

This method can also be used to determine the planting dates of individual crops. In Brazin, for example, the start and conclusion of the growth season for soybean is established using

$$\boldsymbol{A(t) = \sum_{n=1}^{t}(R(n) - R_{ref})}$$

where R(n) is rainfall for day n and R_{ref} is a reference rainfall value, both in mmday^{-1}. The value of R_{ref} used was 2.5mm day^{-1}, representative of a soybean seedling's needs(Abrahão & Costa, 2018).

3.4 Land surface phenology method:

An alternative approach to the estimation of LGP is the direct utilisation of multispectral remote sensing data. This involves the investigation of spatial patterns in vegetation on the land surface as observed by satellite sensors. Vegetation indices collected from optical sensors on board satellites provide information on the greening of vegetation throughout the year and its senescence. The beginning, end, and duration of growing seasons can be derived from the time series using various methods (e.g., de Beurs & Henbry (2010), White et al. (2009)).Different researchers employed sensors and data sources such as the Advanced Very High-Resolution Radiometer (AVHRR), SPOT VEGETATION, Moderate Resolution Imaging Spectroradiometer (MODIS), and Normalized Difference Vegetation Index (NDVI) (example, Boschetti et al., 2009; Reed et al., 2009; Vrieling et al., 2013).

The most widely used way to determine the SGS and EGS is the variable threshold method provided by White et al. (1997).It calculates the annual maximum and minimum NDVI per year and per pixel. The average value of both is used to determine the threshold. The SGS and EGS points are when the NDVI profile surpasses the threshold value in either an upward or downward direction.

4 The relationship between climate variables and LGS and their trends

According to the Intergovernmental Panel on Climate Change, (IPCC (2007)), climate change is "clear and unambiguous" where the global temperature increase is most pronounced at higher latitudes. A broad range of measurements (e.g., lower arctic Sea ice extent and rising ocean heat content) combined with natural world indicators (e.g. poleward migration of temperature sensitive fish, mammals and insects, etc.) provide unambiguous evidence for global warming. The facts on the climate system tell us that the observed warming rate varies year on year, decade on decade, and place on place. Since 1900, the mean surface air temperature has increased by about 1 0C (0.80 0F) per decade (EPA, 2016). More than half of this increase has occurred since the mid-70s (Figure1, Wolff et al. 2020).

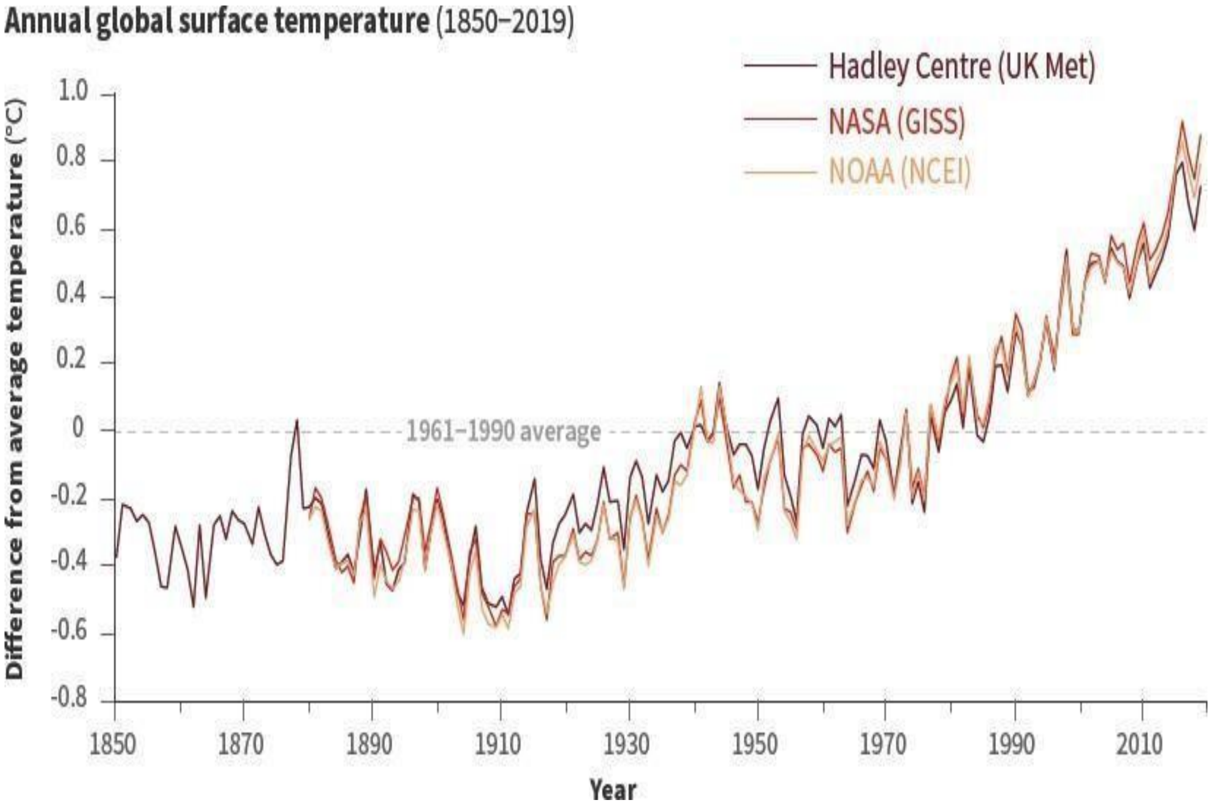

Figure 1: Annual global surface temperature (1850-2019) from UK Met Office Hadley Centre (maroon), US National Aeronautics and Space Administration Goddard Institute for Space Studies (red), and US National Oceanic and Atmospheric Administration National Centers (orange)*(adapted from Wolff et al., 2020).*

As temperatures rise, so do other climate variables, such as precipitation. In a paper published in 2006 (Chaponniere et al., 2006), the authors argued that, due to an increase in global temperature, there will be an increase in average water vapour (WV), evaporation (EV), and precipitation (WV). This increases the rate of hydrological cycling, and different regions will experience an increase or decrease in precipitation simultaneously. An increased number of hot day and heat wave events across all land regions in the century, particularly in areas with declining soil moisture levels. A rise in precipitation in the high latitudes of the Northern Hemisphere, a decrease in rainfall in China and Australia, and an increase in precipitation in the Pacific small island states and equatorial areas in the century, the patterns of which were largely driven by major ocean current changes (Dore et al., 2005).The brief rains in East Africa (Greater Horn of Africa) are exacerbated as the Indian Ocean warms due to a weak east/west dipole pattern (Cook &Vizy, 2012). Rainfall is projected to be distributed differently, with greater rainfall in the tropics and higher latitudes, but decreasing rainfall in the existing dry semiarid to arid mid-latitudes and interiors of large continents, according to Chakraborty et al. (2014). Changes in the air's surface temperature and near-surface absolute humidity are expected to raise the heat index (a measure of the combined effects of temperature and moisture) (Chaponniere&Smakhtin, 2006). The hydrological cycle is inextricably linked to changes in air temperature and global radiation balance (IPCC, 2007). Total yearly precipitation has increased on average across land regions around the world at an average rate of 0.08 inches each decade since 1901(US Environmental Protection Agency, 2016).

Cropping is inextricably tied to precipitation and temperature (especially the length of the growing season) (see part 4 above). Changes in temperature and precipitation, in addition to other determining factors, are the key climate variables that affect agricultural productivity (World Bank, 2007), and evidently change the distribution of agroecological zones (Kurukulasuriya & Rosenthal, 2003). Water availability is an important variable for agriculture, particularly in arid regions such as Africa, which is directly dependent on rainfall distribution (Kurukulasuriya & Rosenthal, 2003), and temperature is critical in temperature-sensitive areas (Linderholm, 2006).

Depending on the region and environment, air temperatures, frost days, rainfall, and daylight hours determine the growing season. Because air temperatures, frost days, and rainfall are all linked to climate, these growth season factors may fluctuate as a result of climate change. The increase in frost-free season length of almost two weeks from the beginning to the end of the twentieth century is a notable development that is consistent with changes in mean temperature (Kunkel et al., 2004). According to studies, there is a significant change in temperature (increase) in the temperate zone, but no significant change in precipitation. (Tomczyk & Szyga-Pluta, 2019) discovered that there were more significant changes in heat conditions than in precipitation conditions in Poland from 1966 to 2015. The growth season is distinguished by an increase in average air temperature as well as an increase in total air temperature.

Many studies have examined changes or trends in the thermal growing season on a regional or global scale; for example, Frich et al. (2002) discovered that the thermal growing season was significantly extended throughout the major mid-latitude regions of the Northern Hemisphere during the second half of the twentieth century. Walther and Linderholm (2006) discovered that the thermal growing season was extended by roughly 20 days in the twentieth century in the Greater Baltic Area (an earlier start of 12 days and a later end of 8 days). From 1951 to 2007, the thermal growing season was extended by 2.3 days per decade in northern China and 1.3 days per decade in southern China, according to Song et al. (2010). According to Tomczyk and Szyga-Pluta (2019), during the study period, 1966-2015, the growing season began earlier, while the growing season ended later and later in Poland. Furthermore, Aalto et al. (2021) found that after controlling for the effects of other predictors, the used northness predictor (a proxy for incoming direct solar radiation) in Europe showed reasonable but relatively weak effects for mean GS conditions, with growing seasons beginning earlier (ca. 1.5 days) and GS lasting approximately three days longer over southern versus northern aspects. According to Cornes et al. (2019), the thermal GS in Europe has increased at a pace of about 5 days every decade since 1965. Sabziparvar and Jahromi (2018) discovered the most significant changes in tGSS and tGSE of 9.6 (earlier start) and 10.8 (delay) days per decade for northwest Iran between 1986 and 2005. Since 1895, the average length of the growing season in the contiguous 48 states has increased by around two weeks. LGS has increased at a rate of around 2.2 days per decade in the West, compared to nearly one day per decade in the East (EPA, 2016). Mueller et al. (2015) depicted global LGS trends from 1956 to 2005 (Figure 2). They concluded that the majority of the world's land mass has a longer growing seasonOver the last 50 years, the size of regions with growing seasons longer than 250 or 300 days increased from 35 to 38 percent and 27 to 28 percent of extratropical land-area, respectively. The data glitch in South America caused a significant drop in LGS (Figure 2A).

Cook and Vizy (2012) discovered that growing season days (GSDs) had dropped by up to 20% along the western Guinean coast, whereas GSDs have increased by 5-10% in certain eastern locales in their extensive study of Africa. Because of a thermal low in the Sahel, there will be more summer rain and a 30% longer growth season in the central and eastern Sahel, with shorter seasons in areas of the western Sahel. Increased mid-tropospheric moisture divergence in the boreal spring greatly shortens the rainy season in Tanzania and southern Kenya, whereas boreal spring GSDs in Somalia and southern Ethiopia are eliminated by a northward shift of rainfall in the eastern Sahel. Due to increased southwesterly moisture transfer from the tropical Atlantic, increased rainfall in January and February extends the growing season by 5–15 percent across central Africa (Congo basin).

Severe (40-80%) reductions in austral spring growing season days are associated with reduced precipitation and higher evapotranspiration in subtropical southwest Africa, particularly Angola and the southern Democratic Republic of the Congo (Cook &Vizy, 2012). According to Tongwane and Moeletsi (2015), the start of the rainy season differs by four-seven weeks and the end of the rainy season differs by one week, and the average coefficient of variation of seasonal rainfall is 39% between 1950 and 1999 at Butha-Buthe in Lesotho. The frequency and duration of dry periods within a season, according to Segele and Lamb (2005), have a substantial impact on the length and quality of the Kiremt growing season in Ethiopia. Several dry-spell researchrevealed that 3-5 days without rain are very common across most of the Kiremt region, with extended intervals of more than 10 days only occurring in the lowlands of extreme western and northeastern Ethiopia, where rainfall variability is high. Akinseye et al. (2015) hypothesised that there is a temporal lag of at least seven days in Mali between the mean onset date and traditional farmer sowing dates for crops. These variances in growing season have an impact on farmers' production as well as their energy and resources, particularly subsistence farmers.

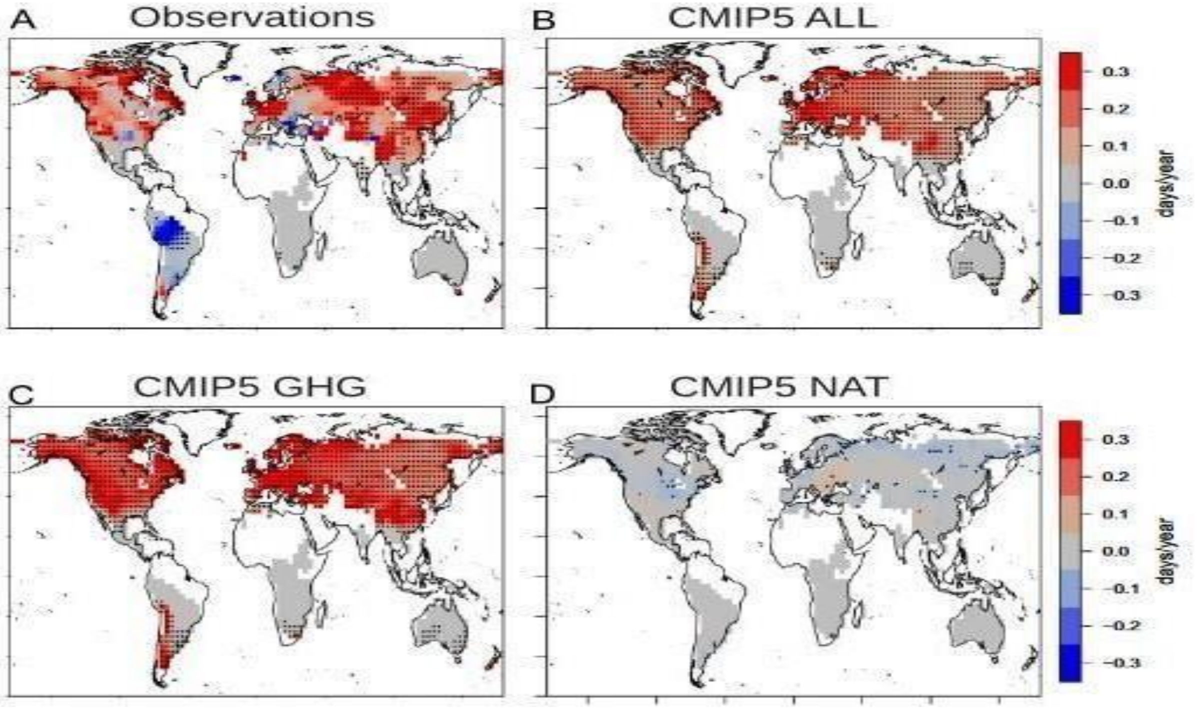

Figure 2: Global trend (significant at the 5%-level)ofLGS 1956–2005 in observations (A) and CMIP5(Coupled Model Intercomparison Project Model 5)-simulations under ALL forcing (B), GHG (greenhouse gas) forcing (C) and NAT (changes in natural) forcing (D)*(Adapted from Mueller et al., 2015).*

High elevations, near water bodies, and areas with substantial forest cover have less year-to-year variance in GS factors, but this variability is predicted to increase as urban land use grows. GS features (start, finish, length, and rising degree days sum (GDDs)) vary significantly across Northern Europe. Local topography, proximity to bodies of water, forest cover, and urban land use were all influenced by such variation, which was primarily dominated by latitudinal and elevational gradients (Aalto et al., 2021). Temporal fluctuations in GS variables have remained smaller near lakes and the sea, as well as in areas with extensive forest cover, indicating mechanisms associated with latent and sensible heat transfer, as well as radiation interception, which can have implications for local temperature buffering (Aalto et al., 2021 and De Frenne et al., 2021).

The variability of GS, on the other hand, has an impact on climate change. According to Polgar and Primack (2011) and Schwartz et al. (2013), spatio-temporal variability at the beginning (SGS) and end (EGS) of the growing season can affect meteorological processes and seasonal climate by influencing evapotranspiration and physical properties of the land surface such as latent and sensible heat, albedo, and aerodynamic roughness. According to Polgar and Primack (2011), spatiotemporal differences in the leafy phase may alter biogeochemical activities such as CO2 uptake by photosynthesis and the emission of biogenic volatile organic compounds. It may also cause phenological mismatch between plants and their animal pollinators and eaters, which increases the risk of biodiversity loss (Amano et al., 2010; Polgar&Primack, 2011). Variations in the thermal growth season, according to Liu et al. (2016), can regulate climate change by exchanging carbon and water with the atmosphere and modifying albedo.

5 Conclusion:

Climate change is undeniable. It caused changes in the intensity, amount, and patterns of meteorological and climate variables like as temperature and rainfall. It is projected to result in long-term shortages of water and other resources, deteriorating soil conditions, drought and desertification, and production reduction (by shortening the growing season). Climate change, on the other hand, may benefit temperate regions greatly. Because crops require enough warmth and precipitation to flourish, changes in the amount and pattern of these parameters affect production. Climate change has distinct effects in different parts of the world. Increased temperatures in the middle and upper latitudes will lengthen growing seasons and expand crop-producing areas poleward, benefiting countries in these regions. Higher temperatures, on the other hand, are expected to have a detrimental impact on growth conditions in lower latitudes, particularly in areas where temperatures are already close to or at the optimal range for crop development. A surge in potential evapotranspiration would exacerbate drought stress, particularly in the semiarid tropics and subtropics.

Because air temperatures, frost days, and rainfall are all affected by climate, climate change may cause these growth season variables to fluctuate. Global air temperature rises may induce adjustments in the growing season by changing the start and end dates. Aside from spatiotemporal fluctuations in air temperature, environmental variables such as photoperiod, precipitation, persistently very low air temperature, and wind may impact the start (SGS) and end (EGS) times of the GS. Climate change, on the other hand, is influenced by GS variability. By exchanging carbon and water with the environment, changes in the thermal growth season and albedo can assist to moderate climate change. Spatio-temporal variability at the start (SGS) and end (EGS) of the growing season can change evapotranspiration and land surface physical attributes such as latent and sensible heat, albedo, and aerodynamic roughness, hence altering meteorological processes and seasonal climate.

Determining the beginning and end of the growth season can be challenging since there are different definitions of the beginning and end of the growing season based on the climatic variable that the area is limited of. Temperature-based definitions of growing season are primarily used in places with limited temperature, such as mid- and high-latitude zones. Tropical, semi-arid, and arid areas utilised a rainfall- and evapotranspiration-based definition for growing season, whereas locations where rainfall is the determining factor used a rainfall- and evapotranspiration-based definition. However, when it comes to predicting the start and end dates of rainfall in specific years, the method based on rainy days outperforms the method based on rainfall volume, as the former provided more realistic dates than the latter.

Because they are designed to account for soil moisture availability, threshold-based methods are appropriate for local agronomic investigations based on station data. Thresholds, on the other hand, cannot be determined in a consistent manner. They are very susceptible to bias and resolution, which is a big issue for climate models, which contain biases not just in overall totals but also in daily rainfall distributions, making it impossible to define a dry day in a model. The Anomalous Accumulation technique, for example, has the advantage of defining the rainy season as a period of consistent precipitation above a reference value that can be set to an agronomically relevant number.

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