GIS-based analysis of spatio-temporal variation of climatological growing season for Austria

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Abstract

The temperature-driven length of growing season significantly influences management and productivity of grassland. In the past decades a trend of an earlier start of growing has been observed in many European regions, especially in the temperate zones. Climate experts expect an increase of this trend in the future due to global warming. A GIS model has been developed to determine start and end of growing season by using daily temperature surfaces in high spatial resolution. The data set for generating the temperature maps can be both observations in the past and climate scenarios. Several temperature threshold variations, according to state-of-the-art definitions of the climatological growing season, are processed and result in maps of information about start, end and length of the growing season. With long-term analysis of yearly results, spatial and temporal shifts can be identified and spatially visualized. It provides a data base to support an understanding of climate impact on local scaled changes of environmental conditions. Therefore, adaptation strategies do not have to be based purely on changing signals of temperature but also on grassland-relevant interpretation of climate data in growing season parameters.

Keywords: GIS, grassland productivity, spatial interpolation, temperature

Introduction

The growing season can be defined as a period of time when basic environmental factors are suitable for growth. Plants in temperate zones are generally adapted to the seasonal cycle and are sensitive to temperature changes and to the length of photo period (Menzel, 2002). Analysis of spatio-temporal changes of the growing season needs long-term series of observations and their processing by a simple GIS model. The concept of climatological growing season based on temperature meets these requirements. Compared with grassland-specific phenological observations, temperature measurements at weather stations are available at a relatively high spatial density for most regions and over many years. Phenological events such as leaf unfolding in spring or leaf colouring in autumn are widely used as indicators to identify start and end of growing season (Linderholm, 2006). Timing of most phenological phases can be directly observed but also predicted by using temperature. The strong correlation between temperature and plant phenology, particularly in spring, allows a simplified definition of the climatological growing season based on temperature (Menzel, 2003). The proposed temperature-driven approach approximates grassland-specific phenological indicators of the growing season with a strong focus on their spatial implementation.

Materials and methods

Continuous temperature surfaces on a daily basis provide the background for the analysis of growing season by using temperature thresholds. The strong elevation dependency of temperature is the key factor for interpolation, especially for all applications on complex terrain. The implemented geostatistical algorithm refers to the state–of-the-art method *Residual Kriging*, which combines two different approaches (Goovaerts, 1997). Firstly, the monthly lapse rates are calculated by regression analysis of monthly mean temperature at each station and its elevation. To consider different lapse rates for lowland and highland mainly caused by inversions, the study region is separated according to both categories. Regressions are set up for each area and the resulting linear functions are applied on a Digital Elevation Model (DEM) with a spatial resolution of 250 meters. The elevation-dependent part of temperature is spatially interpolated by this altitudinal gradient-based first step. Secondly, the residuals of daily mean temperature are interpolated by Ordinary Kriging and added to the monthly surface of elevation-dependent mean temperature (Tveito, 2007). The different lapse rates of lowland and highland are smoothed at a small transition zone between the two areas which approximately reflects the elevation range of inversion height.

The start of growing season is assumed when daily mean temperature in spring exceeds a certain threshold for some consecutive days. A simple and widely used criterion found in literature is a threshold of 5°C and a period of five days (Frich *et al*., 2002; Sparks *et al*., 2005). We implemented this criterion as a raster algebra algorithm within ESRI ArcGIS programming environment. Five consecutive daily temperature surfaces are loaded and verified according to the proposed criterion. The results of this *Simple Thermal Definition* (*STD*) are stored in a raster dataset where each cell contains the date of start of growing season of the analysed year. The end of growing season is calculated by the inverted criterion: daily mean temperature drops below 5°C for at least five consecutive days.

STD with one single temperature-threshold is mainly used for station-based analysis but causes problems if spatial data with continuous temperature fields are taken into account. In some parts of the processed surfaces of growing season, unrealistic and misleading results have been found, particularly for extreme weather situations. Therefore, we extended the STD approach to a *Multiple Thermal Definition* (*MTD*) following the work of Brinkmann (1979) and Menzel *et al*. (2003). Different thresholds of daily mean and minimum temperature are combined to balance the sensibility of determination of start and end of growing season. The implemented raster algebra algorithm sets the start if mean temperature of a 10-day period exceeds 6°C and the criterion of STD is fulfilled on any five consecutive days within the 10 days. Additionally, a frost event within this period must not occur. This example of temperature-threshold combination defines a warm period in spring without harmful frosts. The end of growing season is processed in a similar way but with a focus on cold periods when growth slows down (Schaumberger, 2011). The temperature interpolation as the critical input for calculation of growing season was validated by leave-one-out cross validation.

Results and discussion

The estimated temperature at all Austrian weather station sites (total number of 270) was extracted from selected raster datasets and compared to the observations. A very strong correlation of 15,303 values of mean temperature was found with an R^2 of 0.98, a slope of 1.002, and a RMSE of 1.25°C. The statistics for minimum temperature are similar: an R^2 of 0.95, a slope of 1.000, and a RMSE of 1.72°C.

Raster surfaces of start, end and length of growing season according to STD and MTD have been calculated for the years 1971 to 2010 for the entire area of Austria at 250 meter resolution. Figure 1 shows the STD results as averages at all Austrian weather station sites. Trends of start and end are comparable to the findings of Menzel und Fabian (1999) who analysed long-term observations of phenological phases. The growing season starts earlier and ends later compared with the beginning of our study period, and results in an increase of duration with 3.2 days decade^{-1}. MTD results on stations sites are very similar to STD results

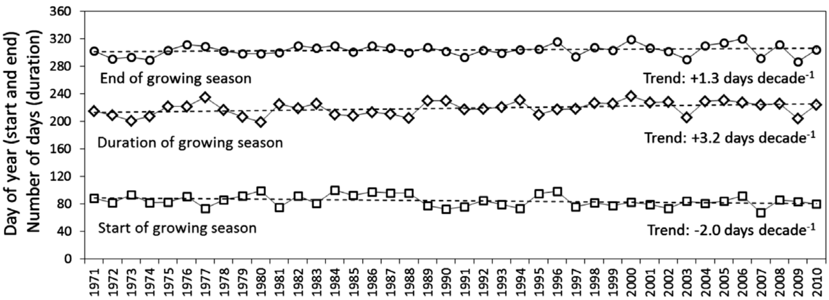

Figure 1. Growing season (STD) trends for Austria over 40 years (average at all weather station sites)

but differ at the interpolated area between, especially in complex terrain. Realistic assignments of interpolated temperature to start or end of growing season require more than one single temperature-threshold.

Conclusions

The climatological growing season does not consider the growth requirements of individual plant species, but gives a temperature-driven average with focus on climate. Long-term time series of start and end of growing season show changes along the timeline. To observe, visualize and evaluate changes also in their spatial dimension, a GIS-based analysis of growing season is needed and proposed by this work. In contrast to phenological observations, temperature values can also be derived from climate change models and processed in the same way as historical data to analyse future trends of growing season. Climate impact on grassland management can be estimated better – a pre-condition to work on efficient adaptation strategies.

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