Improvement of air temperature interpolation in mountainous regions for grassland-specific spatial analysis of growth dynamics

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Abstract

A simple temperature sum model (TSM) has been adapted for the purpose of estimating the growth dynamics of grassland in a complex terrain. It requires time series of daily mean temperatures and model parameters calibrated and optimized on phenological observations. By means of geostatistical methods time series of daily mean temperature are interpolated to a high resolution Digital Elevation Model (DEM). In order to include the effect of slope, aspect and the sky view factors on temperature, modelled daily global radiation sums on the grid are assimilated into the interpolation procedure of temperature. Feeding the data sets into the phenological model, the entry dates of the desired grassland phases can now be calculated at each grid element of the DEM.

Keywords: phenology, complex terrain, spatial interpolation, climate change

Introduction

Spatial models for analysing grassland growth, the dominant crop in mountainous regions, need continuous surfaces of model parameters to cope with the topography. The most important of these is temperature as it is the driving force for growth. This study presents methods for improving standard spatial interpolation of temperature and their application on grassland growth phases, adjusted to the conditions of a complex terrain. As an example the phase of flowering of *Dactylis glomerata* is estimated for Austria by using TSM as a basis of interpolated daily temperature grids.

Materials and methods

The daily temperature grids are the critical input to the proposed TSM. Following the approach ‘first interpolate, then calculate’ the performance of daily temperature surfaces affects the quality of the TSM results enormously and is a key requirement especially for the application in complex terrain. The interpolation has to consider the lapse rates, their ambiguous behaviour in the context of temperature inversions and the apparent difference between south- and north-facing areas (Lhotellier, 2007). The monthly lapse rates differ in lowland/valleys and in mountains because of inversions in autumn, winter and spring. Therefore, the study region is split into two altitudinal ranges with a transition zone between them, where adjusted geo-regressions with height reduced kriging (Goovaerts, 2000) are applied separately. The regression is built on monthly averages of temperature at weather stations and applied on a DEM with a resolution of 250 meters. The residuals of daily mean temperature are interpolated with ordinary kriging and then combined with the monthly grid of the height reduced fraction of temperature. The three-layer method considers the slightly different elevation regressions of temperature in both altitudinal ranges and thus approximates the effect of inversions. The transition layer reflects the elevation range in which the real inversion height varies.

The temperature difference of south- and north-facing slopes are derived from the correlation between monthly long-term average of diurnal temperature range and radiation. By using the Solar Analyst tool in ArcGIS only the geometrical aspect of radiation was considered to cover the topographic impact on temperature (Fu and Rich, 2002). The algorithms are applied on a DEM. Before combining the diurnal temperature range with radiation data, they had to be spatially interpolated by using the three-layer method as proposed for the daily mean temperature values above (cross validation shows an R^2 of 0.82, slope of 0.99, and intercept of 0.05). The shift of mean daily temperature values due to topographical effects on daily global radiation sums is expressed by daily grids of temperature-correction values.These values are combined with the geostatistically interpolated surface of daily mean temperatures. Finally, a 'focal statistics' tool smooths the grids (3×3 cells). The developed algorithms are implemented in Visual C# and include several tools of ArcGIS software library.

To show the effect of the temperature interpolation improvements of the above proposed interpolation method on growth we selected the phenological phase '*Dactylis glomerata*: Flowering'. The spatial algorithms of temperature summation are built on three optimized parameters, which are the commencement date of temperature summation, the temperature threshold and the temperature sum at the entry date of the phenological phase as it was introduced by Réaumur (1735). In order to find out the optimum set of parameters we iterate over a wide range of each parameter and compare the estimated entry dates with 632 spatio-temporally smoothed phenological observations for the years 1990 to 2008 from 45 meteorological stations. The optimum parameter set is identified by the least Root Mean Squared Error (RMSE) of this comparison over all stations and years with 5.07 days and is used for spatial processing.

Results and discussion

The temperature interpolation was validated by using independent observations from 652 stations of the National Hydrological Service on a daily base for 2003. We found a very strong correlation of interpolated and observed data with an R^2 of 0.97, a slope of 0.97, an intercept of 0.71, and a Mean Absolute Error of 1.21°C. The optimal parameter triple for the TSM was found with the 92nd day of the year as the commencement date of summation, 3°C as the temperature threshold and 449°C as the temperature sum at the entry date. The regression analysis of estimated entry dates of flowering of *Dactylis glomerata* from gridded results and the spatio-temporal smoothed phenological observations shows an R^2 of 0.71, a slope of 0.89, an intercept of 16.24, and a Mean Absolute Error of 4.28 days.

The spatial result presented in Figure 1 shows a detail of the flowering dates of *Dactylis glomerata* in the alpine valley 'Ennstal' for the year 1999. Additionally, the exact values on the defined transect through the valley are displayed in Figure 2. This curve shows the effect of north and south exposed areas very clearly, especially at the small hill in the centre of the valley. The entry dates on south-facing areas are slightly earlier than at the valley floor or at the north-facing slopes. Therefore, the implementation of the effects of slope and aspect into temperature interpolation procedures could be helpful for studies based on high resolution DEMs and could serve as a starting point for more sophisticated spatial models.

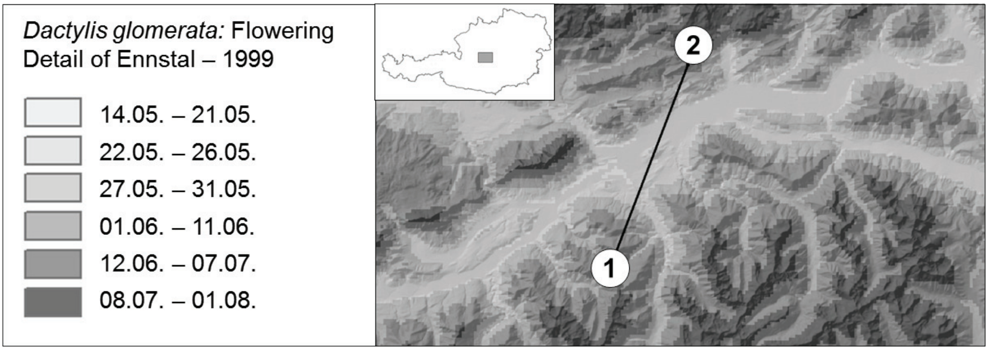

Figure 1. Continuous surface of entry dates of flowering of Dactylis glomerata on the base of TSM in detail for Ennstal (Styria) in 1999 (transect from South ① to North ② in Figure 2)

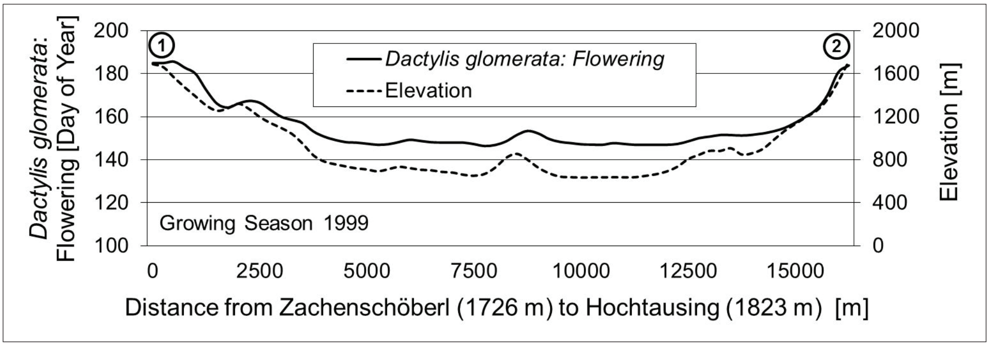

Figure 2. Raster values of entry dates of flowering of Dactylis glomerata along an example transect (defined in Figure 1) through the Ennstal from South ① to North ② in 1999

Conclusion

The spatial analysis of grassland growth dynamics based on temperature interpolation excluding the effect of slope and aspect represents a very strong simplification. This approach cannot describe the growth in spatial detail but can only provide a first guess of the spatial distribution of phenological entry dates in a complex terrain. Our approach is particularly adjusted for the requirements of a complex terrain. Alternatively, temperature time series (e.g. possible future climate scenarios) can be fed into the modelling system in order to assess the effect of climate variability and change on grassland growth and yield.

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