Spatial simulation of crop conditions - application for crop risk monitoring, crop management and water footprint estimation

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Abstract. Spatial mapping and monitoring of crop conditions (crop stress and risks, growing conditions, water use etc.) becomes more and more important for practical applications in crop management at the stakeholder level as well as for more reliable regional assessments. This study demonstrates a GIS based model system for agricultural land in Austria, designed for high spatial resolution, and focused on the estimation of spatial crop growing conditions for monitoring and mapping. It is demonstrated for soil born pest, driven by soil temperatures, and crop water balance parameter actual transpiration for water footprint estimation.

Key words

Crop risk monitoring, GIS, soil temperature, crop water use, water footprint

Introduction

The estimation of crop stand or crop growing conditions, crop water use or crop stress indicators in a high spatial resolution (i.e. field level) basically needs a spatio-temporal application of site-calibrated models. Finding a balance between model complexity and simplification required for spatial implementation is challenging both for the selection and the development of appropriate models. The implementation of a Geographic Information System (GIS) as a precondition for a spatial application includes the design of a structured data management component as well as the development of algorithms for high-performance procedures to handle data in a high spatio-temporal resolution. Spatial simulation can provide the data basis for the spatial representation of high risk areas of crop stresses, crop water use and others. Climate change scenarios can be used to assess the future conditions or trends in the crop growing environment.

Soil temperature simulation is a good example to demonstrate the challenges of spatio-temporal applications of i.e. phenology and risk of soil-dwelling pests. This is because simulation of actual soil temperature is the result of many site conditions, and requires a complete consideration of the conditions and dynamic processes within the soil-crop-atmosphere system. However, the models of different complexity strongly depend on available input data regarding the many fold factors influencing soil heat balance and heat transfer within soils (e.g. Eitzinger et al., 2000; Gupta, 1984; Sepaskhah and Boersma, 1979). Especially, for spatial applications algorithms would perform best, which consider the availability on relevant spatial input data.

Material and methods

A soil temperature model needs to be based on other dynamic inputs within the GIS-environment (simulated by further sub-models or measured data) such as soil cover (biomass development or mulch and snow cover) and soil water content. Required inputs for the presented model are, on the one hand, time-dependent data such as daily mean, maximum and minimum air temperatures, global solar radiation, soil surface albedo, total aboveground biomass, snow (as snow water equivalent), actual daily evapotranspiration and daily values of the pore volume of the soil (which can vary due to soil cultivation) and volumetric soil water content at all relevant depths. On the other hand, configuration and parameterisation data which are regarded as time-independent, such as soil composition (sand, clay and organic fraction), annual mean air temperature, and some empirical parameters are also necessary. As output the soil temperature model will deliver daily mean, maximum and minimum soil temperatures and volumetric ice content (during freezing periods) for all the desired depths. Further outputs are related to other sub-models such as soil water balance parameters of different crop stands. In combination with calculated above ground biomass, water use (water footprint) of crop stands can be estimated at a spatial scale.

Figure 1 gives an overview of all data needed for the implemented raster-algebra algorithms of the GIS-based simulations of the above discussed parameters. Most of the proposed geodata are results of more or less complex sub-models. Different kinds of air temperature (Schaumberger *et al.*, 2011), global radiation, reference evapotranspiration (Schaumberger *et al.*, 2008a), snow cover (Schaumberger *et al.*, 2008b), the above ground biomass and precipitation are mainly based on weather data only available at Austrian weather stations. These station data are transformed by GIS based methods like geostatistical interpolation approaches into surfaces as a precondition for the implemented spatial soil temperature model (Dobesch *et al.*, 2007). Actual evapotranspiration and soil water content respectively are the outcome of a soil water balance model according to Allen *et al.* (1998) and proposed by the Food and Agriculture Organisation of the United Nations (FAO). All sub-models are further described in detail (methodology, results and their evaluation) in Schaumberger (2011).

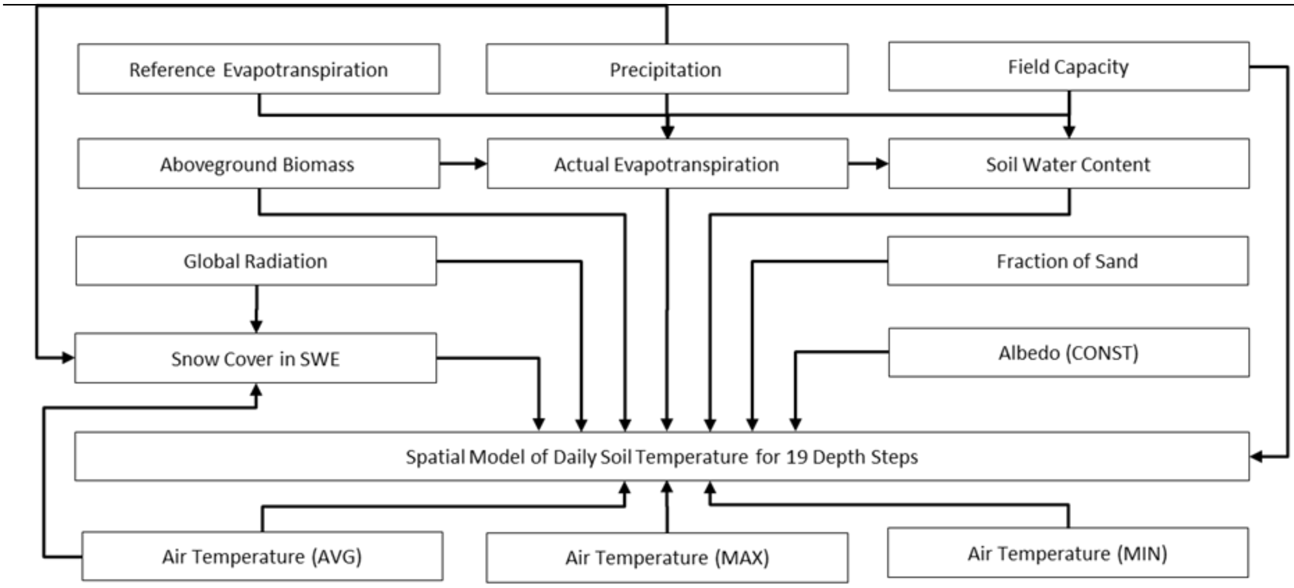


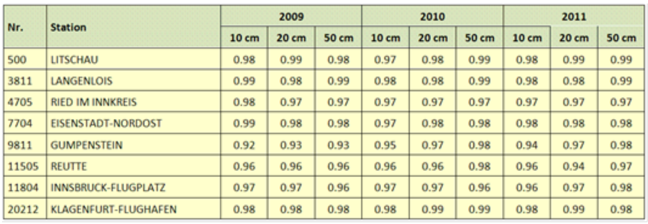
***Figure 1.** Base data and data flows of the GIS model system for agricultural risks based on soil temperature (Schaumberger, 2011)*

To demonstrate crop risk conditions, soil born pests in Austria were investigated, to demonstrate the additional value of the developed spatial (GIS-based) soil temperature model. In specific, related algorithms were developed and calibrated to predict important phenological steps or occurrence of the western corn rootworm *Diabrotica virgifera virgifer.*

Results and discussion

For calibration of the model parameters a field experiment with accurate soil temperature measurements and accurate soil and ground cover data (straw mulch) was carried out in 2011. Based on the calibrated model parameters the model performed very well in estimation of daily maximum, minimum and mean temperatures at different soil depths. Table 1 demonstrate the statistical performance of the validation of the soil temperature model. As soil temperature simulation is based on processes simulated by the other sub-models this confirms the good performance of the whole simulation system.

***Table 1.** Validation of Soil Temperature Model (V3) for three soil horizons at ZAMG weather stations (Coefficients of Determination)*



Nr.	Station	2009			2010			2011		
		10 cm	20 cm	50 cm	10 cm	20 cm	50 cm	10 cm	20 cm	50 cm
500	LITSCHAU	0.98	0.99	0.98	0.97	0.98	0.99	0.98	0.99	0.99
3811	LANGENLOIS	0.99	0.98	0.99	0.98	0.98	0.99	0.98	0.98	0.99
4705	RIED IM INNKREIS	0.98	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
7704	EISENSTADT-NORDOST	0.99	0.98	0.98	0.97	0.98	0.98	0.98	0.98	0.98
9811	GUMPENSTEIN	0.92	0.93	0.93	0.95	0.97	0.98	0.94	0.97	0.98
11505	REUTTE	0.96	0.96	0.96	0.96	0.96	0.98	0.96	0.94	0.97
11804	INNSBRUCK-FLUGPLATZ	0.97	0.97	0.96	0.97	0.97	0.96	0.96	0.97	0.98
20212	KLAGENFURT-FLUGHAFEN	0.98	0.98	0.98	0.98	0.99	0.99	0.98	0.99	0.98

Figure 2 shows results of simulated phenology for *Diabrotica virgifera virgifera* based on the simulated soil temperature sum in 6 cm soil depth. The main result was the identification of the lower temperature threshold (11.7°C), the amount of heat units for first WCR larval hatch (279 degreedays) and for first WCR adult hatch (648 degree days). The start day for temperature accumulation is defined with 1st of March. Each map of soil temperature (6 cm layer) is processed by map algebra algorithm where the values of each cell are summed up until the day of the proposed temperature threshold is reached.

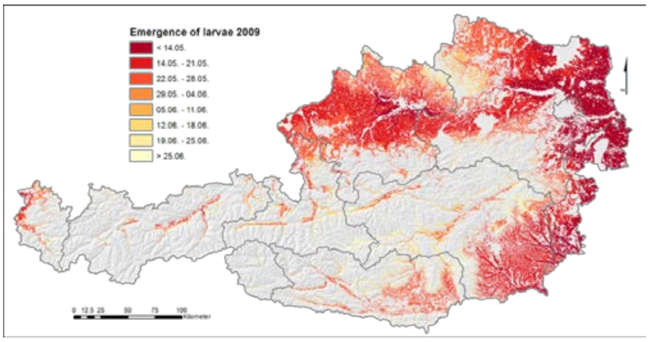


***Figure 2.** Soil temperature sum model to estimate the entry dates of the phenological stage „Emergence of larvae of Diabrotica virgifera virgifera“ in 2009 (1x1 km resolution, for arable land (Maize)).*

For regional water footprint estimation of different crops, beside above ground biomass, water balance parameters of crop stands, need to be simulated in the spatial context and in a high spatial resolution (Fig. 1). Based on the above presented algorithms a result for actual evapotranspiration is shown in Figure 3.

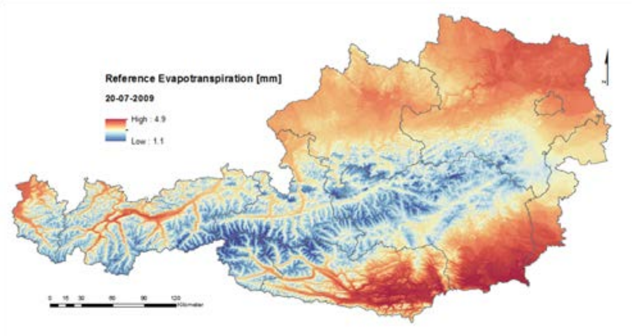


Figure 3. *Simulated actual evapotranspiration of grassland on July 20th 2009 in 1x1 km spatial resolution.*

Water use efficiency of crop stands strongly is determined by actual evapotranspiration. Actual evapotranspiration, however, is again strongly determined by water availability and soil water resources available for the crop. Moreover it is varying with weather conditions, crop type, crop status and crop management. These factors determine evapotranspiration demand and resistance of evapotranspiration with large variation in spatial and time scales. Therefore soil-crop water balance models need to be calibrated well within the environmental conditions of a domain to be reliable mapped or monitored by i.e. using GIS. Water use efficiency and related water footprint of crops or crop products are further related to the biomass produced per unit of area. So it is crucial to consider representative yield or biomass estimates, which could be provided by calibrated crop models (i.e. Thaler et al., 2012) or statistical yield data at appropriate scales. Both approaches still can have significant uncertainties, for example application of crop models (Eitzinger et al., 2012) or common uncertainties in statistical yield data. However, due to consideration of spatial variations of actual evaptranspiration within a domain a significant better estimate can be expected than by extrapolation of site based simulation or local experimental results.

Conclusions

Agricultural production conditions are determined to a great extent by local climatic conditions, which can vary significantly in various spatial and time scales depending on the orography, landscape structures, canopy and surface conditions. For practical applications such as spatial monitoring and mapping of growing conditions, the knowledge on spatial gradients in climatic parameters related to a defined time scale are further necessary for spatial agrometeorological modelling. In combination with Geographic Information Systems areas regarding local croppings risks, cropping conditions and crop water use can be quantified and regionalized. So GIS is a helpful tool to regionalize and compare water footprint calculations of different crops and regions with the crop water balance. The factors influencing water use efficiency in crop production are manyfold and varying with crops, crop management, environmental conditions and scales. So still there is a big research gap on developing regional adapted methods.

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