PUBLIZIERBARER Endbericht Studien
(gilt nicht für andere Projekttypen)

A) Projektdaten

Titel:	GIS data base and methodology for estimating impacts of climate change on soil temperatures and related risks for Austrian agriculture (CLIMSOIL)
Programm:	ACRP - 1st Call for Proposals
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Projektwebsite:	http://www.boku.ac.at/CLIMSOIL/
Schlagwörter:	Bodentemperatur, Geographisches Informationssystem, Monitoring, Schädlingsmodelle, Maiswurzelbohrer, Engerlinge
Projektgesamtkosten:	290.600 Euros
Fördersumme:	236.600 Euros
Klimafonds-Nr:	A963763
Projektstart & Ende	Start: 01.01.2010 Ende: 31.12.2012

B) Projektübersicht

1 Executive Summary

(German)
Das Hauptziel des Projektes war die Entwicklung eines GIS-Modells zur hochauflösenden und genauen Bodentemperatursimulation und die Erstellung einer dafür notwendigen Datenbasis. Dieses GIS soll für das kurz- und langfristige Monitoring von klimatischen Bedingungen und Klimawandeleinflüssen auf die landwirtschaftliche Produktion einsetzbar sein, um daraus Risiken bzw. Anpassungsmaßnahmen ableiten zu können. In Österreich existiert bislang keine gesammelte Datenbank über Bodentemperaturmessreihen unter unterschiedlichen Landnutzungen, was ein erstes Ergebnis des Projektes ist. Wegen der fehlenden (parametrisierten und kalibrierten) Modelle gab es bisher keine hochauflösenden Bodentemperaturmappen und –zeitreihen unter Berücksichtigung der Landnutzung auf räumlicher Basis. Diese wird nun im vorliegenden Projekt als Teilergebnis dargestellt. Die standortspezifische Kalibrierung des entwickelten Bodentemperaturmodells zeigt einen mittleren Fehler von unter 0.5 °C in allen Tiefen für tägliche Mittel-, Maximum- und Minimumtemperaturen.
Das GIS-Modell und die Datenbasis basiert auf die existierende österreichische digitale Bodenkarte (http://gis.lebensministerium.at/ebod) und anderen GIS-Daten (Landnutzung, Topografie), wobei bisher neuentwickelte GIS-Modelle wie GRAM (Trnka et al., 2006; Schaumberger, 2007) oder ein Schneedeckenmodell (Schaumberger, 2009) genutzt wurden. Das adaptierte GIS-Modell (nach Implementierung des Bodentemperaturmodells) erlaubt die Simulation der Bodentemperatur auf Feldgrößeneinheiten in Österreich auf täglicher Basis und für beliebige Zeitperioden und Szenarien. Weiter kann damit ein zeitnahes Monitoring von Bodentemperaturen unter landwirtschaftlich genutzten Flächen durchgeführt werden. Dies kann einerseits dazu genutzt werden um Abschätzungen zu langfristigen Trends bei Bodenprozessen zu verbessern (z.B. Bodenhumusgehalte, Stickstoffauswaschung, Treibhausgasemissionen aus Böden) und andererseits, um Risikoabschätzungen oder Warnhinweise treffsicherer zu machen (z.B. Monitoring, Vorhersage und Warnhinweise für bodenbürtige Schädlinge). Beides, Monitoring und Vorhersage von Schädlingen benötigen normalerweise arbeitsintensive Methoden wie die Installierung und Kontrolle von Fangfallen. Außerdem werden bisher Temperatursummenmodelle der Lufttemperatur auch für bodenbürtige Schädlinge verwendet. Viele wichtige Schädlingsstadien sind in diesem Fall aber nicht oder nur ungenau bestimmbar, wie das Erscheinen der Larve beim Maiswurzelbohrer (*Diabrotica*), der jedes Jahr beträchtliche ökonomische Schäden verursacht. Ein diesbezüglicher Algorithmus unter Nutzung der Bodentemperatur wurde im Projekt CLIMSOIL mit Hilfe vergangener und projekteigener Erhebungen in Feldexperimenten entwickelt und kalibriert. Der verbesserte Schädlingsalgorithmus erlaubt eine genauere und repräsentative Bestimmung und Vorhersage der Entwicklungsstadien des Schädlings, basierend auf der genauen Kenntnis der Basistemperatur (von 11.7 °C) und der jeweiligen Temperatursummen in einer bestimmten Bodentiefe sowie der Einbeziehung einer größeren Anzahl von Einflussfaktoren für eine Vorhersage. Insgesamt wird dadurch eine zielgerichtete und effizientere Bekämpfung des Schädlings ermöglicht also auch eine verbesserte Abschätzung des Schadpotentials.
Eine verbesserte Datenbasis wurde in CLIMSOIL auch für eine zweite wichtige Schädlingsgruppe, der Engerlinge im Grünland, erstellt. Dies erfolgte durch Erhebungen (Zählungen der Befallsdichte und Artenbestimmung) auf Grünlandflächen mehrerer Betriebe in unterschiedlichen Regionen. Die erhobene Datenbasis erlaubte jedoch keine Ableitung eines bodentemperaturabhängigen Schädlingsmodells, wahrscheinlich wegen einer zu geringen Variation der Standortbedingungen oder zu ungenauen Bodentemperaturdaten um einen signifikanten Bezug zur Bodentemperatur herzustellen. Dennoch konnten neue Erkenntnisse hinsichtlich der beeinflussenden Standortbedingungen gewonnen werden (wie der große Einfluss des Humusgehaltes) was ebenfalls im GIS-Modell darstellbar wäre.

Eine weitere Anwendung des Bodentemperaturmodells wurde durch einen Algorithmus für das Kohlenstoff-Stickstoff (C/N) Verhältnis im Boden (unter Winterweizen und Mais) demonstriert, wobei der Algorithmus mithilfe der Simulationen eines komplexen Pflanzenwachstumsmodells erstellt wurde. Die entwickelten bodentemperaturabhängigen Algorithmen wurden schließlich für Klimaszenarien gerechnet um den Einfluss des Klimawandels auf die Bodentemperaturen, den Maiswurzelbohrer und das C/N Verhältnis im Boden exemplarisch für den Nordosten Österreichs (Marchfeld) zu zeigen. Anhand dieser Ergebnisse nehmen die mittleren Bodentemperaturen in 10 cm Bodentiefe bis zu den 2050er-Jahren im Vergleich zur Periode 1980-2009 je nach Szenario um 1.7-2.3 °C (Groß-Enzerdorf) zu.
Das C/N im Boden Verhältnis zeigt dabei einen leichten (nicht signifikanten) abnehmenden Trend, was durch höhere Humusabbauraten erklärt werden könnte. Einen signifikanten Trend hin zu einer schnelleren Entwicklung zeigt unter denselben Szenarien hingegen der Maiswurzelbohrer, wobei in den 2050er-Jahren das Eintrittsdatum des Erscheinens der ersten Larve um 10-19 Tage und das Erscheinen der ersten Käfer um 16-24 Tage früher stattfindet.
Das im CLIMSOIL Projekt entwickelte GIS-System erlaubt eine räumlich hoch auflösende (Feldgröße) und repräsentative (in Abhängigkeit der Güte der Eingangsdaten: Wetterparameter, Bodeneigenschaften, Bodenbedeckung und Management) sowie genaue Bodentemperatursimulation auf Tagesbasis für unterschiedliche landwirtschaftliche Nutzung und Bodenbedeckung. Das GIS-System kann für vergangene, gegenwärtige und künftige (z.B. Wettervorhersage, Klimaszenarien) Zeitperioden eingesetzt werden, wie zum Beispiel auch für operationelles Monitoring oder Vorhersagen. Das eröffnet ein weites Anwendungsfeld, was für bodentemperaturabhängige Prozesse wie bodenbürtige Schädlinge oder das C/N Verhältnis im Boden vorgestellt wurde. Für ein zeitnahes Monitoring als auch für Anwendungen unter Klimaszenarien ist allerdings eine weitere Verbesserung hinsichtlich der erforderlichen Rechenzeit (auf Österreich bezogen) erforderlich. In diesem Zusammenhang wird das im CLIMSOIL erstellte GIS-System in einem neuen ACRP Projekt (AgroDroughtAustria) genutzt, das die Weiterentwicklung zu einem operationellen, über Internet zugänglichem, Monitoringssystem zu Auswirkungen klimatischer Extreme (Trockenheit, Hitze) auf die Pflanzenproduktion zum Ziel hat.

(English)
The main motivation for the project was to develop a data base and a spatial (GIS) model for an accurate and high resolution soil temperature model applicable for monitoring and warning issues on climate and climate change impacts in agricultural production, and related assessments of adaptation and mitigation options. For Austria till now there existed no data base on soil temperature records under various land use which was the first outcome of the project. Due to the missing appropriate models, there existed also no accurate soil temperature maps and data bases for climatic periods (past or scenarios) related to land use types at high spatial resolution, which will was developed and demonstrated for agricultural land use as a result of the project. Site based calibration results of the developed soil temperature model show a mean error of the simulated soil temperatures at any depth below 0.5 °C in daily mean, maximum and minimum temperatures.
The GIS-model and data base was built on the existing digital soil map of Austria (http://gis.lebensministerium.at/ebod) and other up to date data bases (land use, topography) using new developed and tested GIS-tools such as GRAM (Trnka et al., 2006; Schaumberger, 2007) or snow cover models (e.g. Schaumberger, 2009). The adapted GIS model (after GIS implementation of the soil temperature model) allows for simulation of soil temperatures at field scale in Austria for different climatic periods and scenarios on a daily basis. Moreover, it can also facilitate a close to real time monitoring of soil temperatures in Austrian agricultural soils. This can, on the one hand, significantly improve the assessments of long term trends (such as soil organic matter changes, nitrate leaching of soils, greenhouse gas emissions of soils) and, on the other hand, make methods for the estimation of agricultural risks more reliable, like monitoring and forecasts of soil born pest development and risk. Both, monitoring and forecasts of pests commonly depend on labour-intensive methods like the installation and inspection of yellow traps catching flying stages of pests. Moreover, commonly used

degree-day-models predicting the appearance of certain pests are based on air-temperatures only. Many important phenological events aren't even predictable at all with these methods, e.g. the hatching of first instar larvae of soil dwelling pests like *Diabrotica* (Western corn root borer), which causes every year significant economic damages. A related impact model using soil temperatures for *Diabrotica was* developed and calibrated in CLIMSOIL using past and own field experimental data. It allows for more accurate predictions, based on the finding of the real base temperature of 11.7 °C and the relevant temperature sums at a certain soil depth. A broader variety of key parameters of the pest is further used for the forecasts. This can facilitate precise application of plant protection methods and help to estimate the risk of yield loss caused by the pest.

The data base for the second pest (white grub), built during the project was based on farm inspections for collecting data on grub densities and species distribution. The field investigations for developing a related model to estimate grub damage risk, however, did not (yet) result in a soil temperature related model, probably due to a still too weak data base on pest sensitivity to soil temperature. However, the experiments resulted in new findings of conditions for the pest occurrence (e.g. the significant correlation of the pest occurrence with humus content of the soil), which also could be monitored by the applied GIS.

Another application of the soil temperature model is demonstrated by an algorithm for the soil C/N-balance of winter wheat and maize crop which was developed by using simulation results of a complex crop model. The developed soil temperature dependant algorithms were finally applied under climate change scenarios to demonstrate the potential climate change impacts on soil temperatures, the Wester Corn Root Worm and the soil C/N ratio. This was demonstrated at a site representing north-eastern part of Austria (Marchfeld). According to the results, for the 2050 period the annual mean soil temperatures increases at 10 cm depth depending on the scenario by 1.7-2.3 °C (Groß-Enzersdorf). The soil C/N ratio shows a slightly (not significant) decreasing trend which can be the result of higher decomposition rates. Significant changes, however, are shown for pest phenology of *Diabrotica,* where a shift to earlier pest occurrence by 10-19 days (first larvae) and 16-24 days (first beetle) can be expected compared to the current conditions.

In conclusion, the developed GIS-system allows a high spatial resolution (field scale) and representative (defined by the input data: weather data, spatial soil input data, crop cover and management information) accurate soil temperature simulation at daily basis und for various agricultural land use and crop cover. The GIS system can be applied for past, current and future (i.e. weather forecasts, climate scenarios) time periods, for example also for operational monitoring and forecasts. This opens a wide field for potential applications, which was demonstrated for soil born pest and soil C/N-balance. For close to real time monitoring as well as for simulation of climate scenarios in reasonable time, however, further GIS optimization regarding the run time of the simulation has to be carried out. In this context, the developed GIS-system was included in a follow up ACRP project (AgroDroughtAustria), which is focused on the development of an operational real time monitoring system for impacts of climatic extremes on crop risks (drought, heat, etc.) for public use.

2 Hintergrund und Zielsetzung

Accurate soil temperature estimation is important for the soil temperature related processes simulated at a daily time step. For example, denitrification during the freezing/thawing periods can result in substantial trace gas fluxes during the winter period. In a daily time step model, the strongly diurnal variability of the energy balance makes it difficult to simulate soil temperatures accurately, especially near the soil surface. On the other hand the input parameters should be kept as simple as possible to allow an easy parameterization and a wide applicability of the model.

Soil temperature 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. Gupta, 1984; Sepaskhah and Boersma, 1979). Especially, for spatial applications there was no available methodology on which algorithms would perform best regarding availability on relevant input data. Moreover, there are no spatial soil temperature scenarios (maps) available for various agricultural land uses in Europe. According to this fact the proposed project is aimed to develop an improved data base for spatial soil temperature simulation to provide a tested and calibrated soil temperature model for GIS-implementation. A set of model algorithms were compared and tested for the development of the model.

A regionalized potential estimation basically needs a spatio-temporal application based on 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 soil temperature 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.

Soil temperature simulation can provide the data basis for the spatial representation of high risk areas, endangered by soil-dwelling pests. Simulated soil temperatures regarding climate change scenarios can be used to assess the future development of these risk areas, because many important pest species have soil-living developmental stages and/or run through their diapause hidden in the soil. It is therefore clear that their phenology strongly depends on soil temperatures. Among others, the first occurrence of pest species in spring, their speed of development or the number of generations produced within one season are key data for any plant protection measures. While some of these data are determinable with common monitoring methods (e.g. yellow traps for the trapping of a wide range of flying insects), others remain concealed below ground, which impairs appropriate timing of plant protection measures.

In this project, two important soil born pests in Austria were investigated, to demonstrate the additional value of the developed spatial (GIS-based) soil temperature model and data base. In specific, related algorithms were developed and calibrated to predict important phenological steps or occurrence of pests. The pests considered in this project included the most destructive maize pests in the world, the western corn rootworm *(Diabrotica virgifera virgifera)* and as most important pest for grasslands, the soil-dwelling grubs of the cockchafer (*Melolontha melolontha*) and the garden chafer (*Phyllopertha horticola; Scarabeidae, Coleoptera*).

3 Projektinhalt und Ergebnis

The objectives of CLIMSOIL were:

Objective 1: To improve and extend the Austrian soil data base regarding measured soil temperature series. To test and compare different model algorithms for soil temperature simulations, according to the available spatial soil data base.

Objective 2: To parameterize, calibrate and validate impact models for simulating temperature dependent processes in agroecosystems. This includes the development and calibration of phenology models for the western corn rootworm (*Diabrotica virgifera virgifera)* and white grub densities in grassland, with regard to soil temperatures. For soil processes and functions models will be validated to simulate accordingly crop phenology, nitrogen balance and soil organic matter dynamics in the three selected target regions.

Objective 3: To develop and calibrate an algorithm suitable for GIS implementation and to create spatial soil temperature maps for various scenarios and land uses at high spatial and time resolution (e.g. monthly means) for Austria.

Objective 4: To demonstrate applications of soil temperature maps and scenarios for assessing climate change impacts and adaptation options for selected target regions in Austria (monitoring/prediction of below ground pest phenology; applying two pest models for pest risk assessment; application of soil-crop models to demonstrate impacts and trends on crop phenology and growth and nitrogen balance and organic balance in soils).

The main results of CLIMSOIL are as follows:

Results 1

- Improved soil data base on measured soil temperature series
- Test and evaluation of soil temperature algorithms regarding their performance for spatial soil temperature simulation

Establishing an Austrian soil temperature data base on daily basis:

Data of past and ongoing soil temperature measurements were collected in continuation of the first project year. The data were quality checked and gathered in a data base. Beside soil temperature the data set includes also other daily meteorological parameters, vegetation and soil cover status and soil physical properties of the measurement sites. For the validations of soil temperature models are now available more than 20 locations where the soil temperature is measured in 39 places.

The altitudes of the selected locations vary from 140 m until 1912 m above sea level and they are situated almost all over Austria. Each station has its own EXCEL file, where the following information is provided:

- meta information about the station, soil temperature station and weather stations.
- crop type, crop rotation, begin and end of the crop growth.
- soil profile, soil horizon and laboratory analysis of soil parameters.
- measured soil temperatures in different depths.
- measured weather data: daily average air temperature, daily maximum and minimum air temperature, relative humidity, global radiation, wind velocity, precipitation.

Testing and evaluating different soil temperature simulation methods:

The models SoilTempSimV2 and STOTRASIM were compared for simulated soil temperatures in different soil depths at four different test sites with accurate measurements. SoilTempSimV2 is the test version of the soil temperature model developed in WP 3 and STOTRASIM is a statistical based model which was calibrated on these sites before.

The 4 locations are Petzenkirchen "Viehlos", Pettenbach "Lysimeter2", Purbach „Measuring station3" and Obersiebenbrunn „Agricultural school". They are representative for dry, semi-dry and humid regions. At each location, data concerning physical soil properties are available, and also soil temperature measurements.

Some input parameters for SoilTempSimV2, such as soil moisture and actual evapotranspiration, were determined from the soil water balance computed by STOTRASIM model.

Model validation:

Soil temperatures were simulated for the entire period with soil temperatures' observations by using SoilTempSimV2 and STOTRASIM in the four selected stations.

In order to quantify the models' accuracy and efficiency, the simulated values were compared with the measured values, and the statistical analysis was a helpful tool to analyse the models' goodness of fit. The results are presented in the Annex of the project report.

Based on the evaluation results SoilTempSimV2 was further improved and finally implemented in GIS in the version SoilTempSimV3 (see WP3).

Results 2:

- Data on *Diabrotica* larval hatch and adult emergence
- *Diabrotica* phenological development linked to soil temperatures and integrated into model; model tested at same field site
- Evaluation of whit grub occurrence and density in grassland sites and impacting factors
- GIS Algorithms for crop phenology and growth (over ground biomass) of maize as input for the soil temperature model
- Algorithm for nitrogen balance and organic balance in soils (C/N ratio) based on process simulations

Influence of soil temperature to larval and adult hatch of the Western Corn Rootworm – WCR (*Diabrotica virgifera virgifera*) in Austria and related interactions to maize development and yield risk:

Based on the GIS implemented soil temperature model an algorithm was developed and tested in order to allow the prediction of larval and adult hatch of WCR in different climates in Austria.

The procedure contained the following steps: (I) definition of the lower temperature threshold for larval development of WCR in the laboratory, (II) Collection of phenological data of WCR in certain locations where soil temperature data were available, (III) Correlation of critical phenological events (larval and adult WCR hatch) with the necessary amounts of heat units [degreedays], (IV) Validation of the algorithm by comparison of observation data of beetles hatch with prediction of the model for locations in different Austrian regions. Another goal was to find future trends for WCR beetles feeding on the maize silk and thereby affecting pollination of the cobs. For that reason it was important to find a temporal correlation of hatch of WCR adults and the flowering stage of maize, as the silken threads of the cobs are preferred for feeding. Alternatively WCR development was compared with the phenology of neighbouring common plants e.g. flowering or fruit formation. Like in insects also plant development is correlated highly to temperature sums. So it might be possible that different organisms are dependent on temperature in different ways but nevertheless distinct growth stages would coincide. However, a possible coincidence of developmental stages of plants and insects has to be validated for several years. Such indicator plants are free available and might be of interest for farmers.

In the laboratory experiments the lower temperature threshold for WCR was determined as 13.0°C. It seemed to the authors that temperature thresholds determined in the laboratory were not fully reliable under field conditions. Therefore another way of its assessment was chosen: calendar dates of hatching WCR larvae in Deutsch Jahrndorf between 2009 and 2011 were compared with corresponding accumulation of heat units by the help of a calculation program. By varying the basic temperature stepwise between 10.0° and 13.0°C a good accordance of the corresponding heat units during all years was found at 11.7°C at a soil depth of 6 cm.

The main result of the project team AGES was the identification of the lower temperature threshold (11.7°C), the amount of heat units for first WCR larval hatch (279 degree days) and for first WCR adult hatch (648 degree days). These values were used for calibrating the pest algorithm, which was implemented in the GIS-system together with the soil temperature model. Demonstration result of the GIS-simulation is illustrated in GIS maps (see below). With the help of this GIS maps a prediction of first larval or first adult hatch of WCR in different Austrian regions is now possible in near real time. During three years of observation a trend was seen that in cold years maize flowers one week after first WCR beetles hatch whereas in warm years flowering starts 3 weeks after that. The silk of young maize cobs are exposed accordingly to a more intensive feeding of WCR beetles in warm years and there might be a higher risk of poor pollination. Correlation of WCR stages with phenological stages of the indicator plants *Tilia cordata*, *Ligustrum vulgare* and *Rosa canina* were found indeed during 3 years of the project work – nevertheless they have to be assured by further observations.

Scarabaeidae larvae in Austrian mountainous grassland and the associated damage risk considering management regime, soil characteristics and soil temperature:

Recently the soil-dwelling grubs of Scarabaeidae beetles (Coleoptera), mainly the cockchafer (*Melolontha melolontha*) and the garden chafer (*Phyllopertha horticola*), caused severe damages to Austrian cultivated grassland. Heavy grub feeding to the grass roots reduces the grass yield and can even endanger farmers by causing their farm machines to slip down slopes on the detached sward.

The available literature on the biology of the problematic Scarabaeidae species describes climatic and soil conditions as main factors responsible for high densities of the larvae (white grubs). In combination, these factors cause high soil temperatures, which might enhance the development of high grub densities. The objectives of Bio Forschung Austria were to survey grub densities in damaged and undamaged grassland sites and find associated environmental variables. Focus was laid on investigating if the developed soil temperature model can contribute to defining white grub damage risk areas. For that, 10 farm inspections for collecting data on grub densities were performed in the Eastern Alps (Styria) from September 1st until October 4th 2011. At each farm, 2 sampling sites with differing damage histories were defined, resulting in a total of 20 sites covering a wide range of grub damage levels. At each sampling site (500 m^2) 24 subsamples (20x20 cm) of the topsoil (A-horizon, 10 cm) were dug out and searched for white grubs. All grubs were counted and determined to species level. In addition to estimating the grub densities, the management regime (number of cuts, manuring intensity) of a site was recorded and soil samples were taken to analyze soil chemical (humus, DOC, N_{min}, NH_4, pH in H_2O and KCl) and physical (sand, silt, clay content) characteristics. Further soil characteristics (depth of A-horizon, water supply) as well as topographical data (inclination, aspect) were obtained from internet databases. The collected grubs (altogether 1,422 individuals) were largely determined as *P. horticola*, which indicated that grub damages in Styrian mountainous grassland are mainly caused by this species. The sampled grub densities ranged from 1 to 303 individuals/m^2. Sites which had recently been affected by grub damages constantly tended to higher grub densities than the respective sites which had not shown grub damages in previous years. This result confirmed the farmers' observations on high risk and low risk sites. Multiple linear regression analyses showed that nearly 40% of the *P. horticola* grub density distribution could be explained by a combination of the humus content and the depth of the A-horizon. Both parameters were positively related to the number of *P. horticola* larvae per site. According to logistic regression analyses, the probability of grub damage was negatively related to the cutting frequency and positively correlated to the humus content of a site. These results indicate an important role of humus for the development of high grub densities and an effect of management intensity on the resulting grub damage. Direct relationships between soil temperature, derived from the CLIMSOIL soil temperature model, and the measured grub densities and damage rates could not be found, probably due to confounding site and management factors. Further investigations on this important topic, including on-site measurements of soil temperature, are strongly recommended.

Development of algorithm for soil C/N-balance for GIS implementation based on crop model application:

CERES crop model for maize and winter wheat (DSSAT 4.0.2.0) were applied after calibration and validation. CERES-Maize and CERES-Wheat are process-based, management-oriented models, which simulate the daily time-step effects of the cultivar, crop management, weather, soil, water and N on crop growth, phenology and yield. The input requirements for CERES include weather and soil conditions, plant characteristics, and crop management._The crop model validation results showed good results (see Annex of the project report for more details).

Based on the detailed crop model outputs an algorithm for soil C/N-balance was developed with satisfying results for maize for GIS implementation as follows:

<u>C/N balance equations:</u>

Soil Layer 0-20 cm:

C/N (0-20cm) = 11.68266867764 + (0.006450141264595*soil temperature) + (-0.03212430094582*soil water)

$r^2 = 0.461$

RMSE = 0.063

Soil Layer 20-40 cm:

C/N (20-40cm) = 11.94541247865 + (0.001836885528526*soil temperature) + (-0.04966091097416*soil water)

$r^2 = 0.477$

RMSE = 0.017

Simulation based on: medium soil, weather data Groß-Enzersdorf 1981-2010

Results 3:

- Development and test of the soil temperature model for GIS implementation

Development and test of a GIS-based soil temperature model:

During the project the SoilTempSimV3 model for soil temperature simulation was developed (tested and improved in 3 versions). The final version was calibrated and tested at a site in Groß-Enzersdorf (Austria) on its accuracy to simulate soil temperatures for uncovered soil and soil covered with a mulch layer of different density (2500, 4000 and 5000 kg ha^{-1}) during the time period from 1st April to 24th May 2012. Further test site was Wagna (Styria) with validation on different crop cover types.

SoilTempSimV3 is a one-dimensional simulation model for calculating soil temperatures on a daily time step basis. It has been written in Java and was tested on Java version 1.6.0_31. The model allows inclusion of ground coverage by biomass or a snow layer and accounts for the freezing/thawing effect of soil water in its calculations. Required inputs for the 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, and on the other hand, configuration and parameterisation data that is regarded as time-independent, such as soil composition (sand, clay and organic fraction), annual mean air temperature, and some empirical parameters. As output the model will deliver daily mean, maximum and minimum soil temperatures and volumetric ice content (during freezing periods) at any depth.

As compared to the previous version SoilTempSimV2, mainly the following improvements have been made in SoilTempSimV3:

- During snow-free periods, the soil surface temperature is now calculated more accurately by solving the surface energy balance, instead of just prescribing the soil surface temperature by empirical relationships. The influence of the ground heat flow is now treated correctly, and variation of long-wave atmospheric counter-radiation due to changing cloud cover is now also accounted for. The diurnal range of soil surface temperature is now calculated by sophisticated formulas derived by Fourier analysis of the diurnal variation of the components of the heat balance equation and the solution of the partial differential equation for heat conduction in the soil.
- For thin snow layers, the effect of partial snow cover is now included in the simulation by applying an interpolation of the top boundary condition between the case of snow-free soil surface and dense snow cover.
- For the bottom boundary condition, a new mode is now available, that allows the model to assume sinusoidal variation of soil temperature with the period of a year. That allows a significant reduction of the number of soil layers that have to be simulated, because this new boundary condition can be applied in depths of just about 2 m, whereas the other two boundary conditions (zero heat flow or temperature fixed to annual mean air temperature), which where the only options available in SoilTempSimV2, can only be applied to soil layers in depths of about 10 m or greater.

The test of the SoilTempSimV3 model at the site in Groß-Enzersdorf was simultaneously used to calibrate the model for treating the effect of soil coverage by a mulch layer. A comparison of the simulation results of SoilTempSimV3 with that of the SoilTempSimV2 model (that was also calibrated again with the input data, to make the results comparable) showed a clear improvement of accuracy and explanatory power of the model. For daily mean soil temperature in 10 cm depth, the root-mean-square (RMS) error has been reduced from about 2.4 °C in SoilTempSimV2 to 0.8 °C in SoilTempSimV3, whereas the coefficient of determination (R^2) has been increased from 0.9 to 0.97. For daily maximum and minimum soil temperatures in the same depth, the RMS error remained higher, but still could be reduced from 2.2 °C on an average to 1.1 °C, whereas the R^2 value increased from 0.86 to 0.96.

Results 4:

- GIS based soil temperature maps and trend in soil temperatures under different climate scenarios for the 2050s at two different sites in Austria
- Results of trends for the selected pest risks (Western Corn Rootworm) under different climate scenarios for the 2050s at two different sites in Austria
- Spatial characteristics of pest risks in the target regions (map)
- Results and trends of soil temperature sensitive processes (C/N ratio) under different climate scenarios for the 2050s at two different sites in Austria
- Spatial characteristics of these processes in the target regions (map)

GIS implementation and demonstration of spatial modelling of soil temperatures and soil temperature related processes for Austria:

Soil temperatures influence many ecological processes. Modelling of soil heat balance is complicated because of its dependency from many factors of the atmosphere-plant-soil system. Solar net radiation, for example, is responsible for soil warming. Daily and seasonal deviations are mainly explained by variations in balance of short-wave solar and long-wave terrestrial radiation. Especially in complex terrain, surface temperature derived from global radiation is an important background of soil temperature modelling. Another important factor is soil moisture. Interactions between both, soil heat and water balance, control the cultivation suitability of many agricultural fields. Growth and yield of crops are strongly correlated with soil temperatures (DeLucia *et al.*, 1992, Keller *et al.*, 1997). Many phenological stages of crops are determined by temperatures and most models use air temperature for growing degree day calculations. McMaster und Wilhelm (1998) found that soil instead of air temperature could improve the prediction of phenological stages significantly.

Soil temperature affects not only crops but also the existence and geographical extension of diseases and pests. Regional based analysis of these effects need tools like Geographic Information Systems (GIS). In scientific literature many soil temperature models with very different requirements on data and process complexity can be found. There are simple approaches (Krumbiegel, 1973) and more complicated ones like that of Suckow (1985). The complexity depends on the application area which differs in spatial and time scale. Applications for large study regions (Zheng *et al.*, 1993) show simple structures whereas demands on small scale GIS applications are considerably high (Pape und Loffler, 2004).

It is difficult to find a balance between dynamic, process-oriented and site-based models with a huge number of variables and necessary simplifications for GIS applications due to limited availability of spatial data. Besides radiation, heat balance, soil moisture and evapotranspiration (see Boulet *et al.*, 2007), land use is also an important parameter for soil temperature modelling (Paul *et al.*, 2004, Plauborg, 2002). Hence, adjustments to agricultural crops are reasonable and necessary for specific applications of soil temperatures (Stone *et al.*, 1999). In this project we developed a GIS application which is adjusted to two different cultures, grassland and maize. It can be easily extended for other crops, by adding estimated parameters for crop growth and development.

GIS-implementation:

The stand alone version of the developed soil temperature model (see above), adjusted to numerical parameters, was modified and integrated into a Geographical Information System (GIS). Therefore, numerical input parameters were substituted to their raster data equivalents, e.g. instead of a single air temperature value a continuous surface of air temperatures for the entire area of Austria is the input of the GIS soil temperature model. The basis for some geostatistical interpolation approaches is a Digital Elevation Model (DEM). We used this model in 250 meter resolution were the structures of complex Austrian terrain can be sufficiently considered. The GIS soil temperature model require another constant information about the soil: available field capacity and fraction of sand. Both data are available for two soil horizons, for topsoil (0 to 20 cm) and subsoil (20 to 40 cm). According to Baeumer (1978, 44f), the main root biomass of most cultures can be found in the first 40 cm of soil. The available field capacity is derived from the Digital Soil Map of Austria (eBOD) by using pedo transfer functions (Murer, 2009, Murer *et al.*, 2004). The sand fraction is also a dataset provided by eBOD and as well as the field capacity prepared by the Bundesamt für Wasserwirtschaft, Institut für Kulturtechnik und Bodenwasserhaushalt, Petzenkirchen (IKT).

Besides constant information (topography and soil), the GIS soil temperature model is mainly based on weather data. All of them are needed in daily time steps and in raster data format as continuous surfaces for the entire area of Austria. The need of such a large study area is based on methodological reasons, because geostatistical interpolations require a minimum set of data from as many weather stations as possible. Additionally, the continuous fields of parameters over the unlimited area of Austria allow a maximum of spatial flexibility in calculation of soil temperatures and in defining study regions by project partners and stakeholders.

Figure 1 provides an overview of all data needed for the implemented soil temperature raster-algebra algorithms. 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.*, 2008b), snow cover (Schaumberger *et al.*, 2008a), the aboveground biomass and precipitation are mainly based on weather data only available at Austrian weather stations. These station data were 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 described in detail (methodology, results and their evaluation) in Schaumberger (2011). This publication contains also a detailed discussion of existing literature regarding the implemented spatial models. Therefore, a substantial part of Schaumberger (2011) is an inseparable part of this report and has been developed in the course of the CLIMSOIL project.

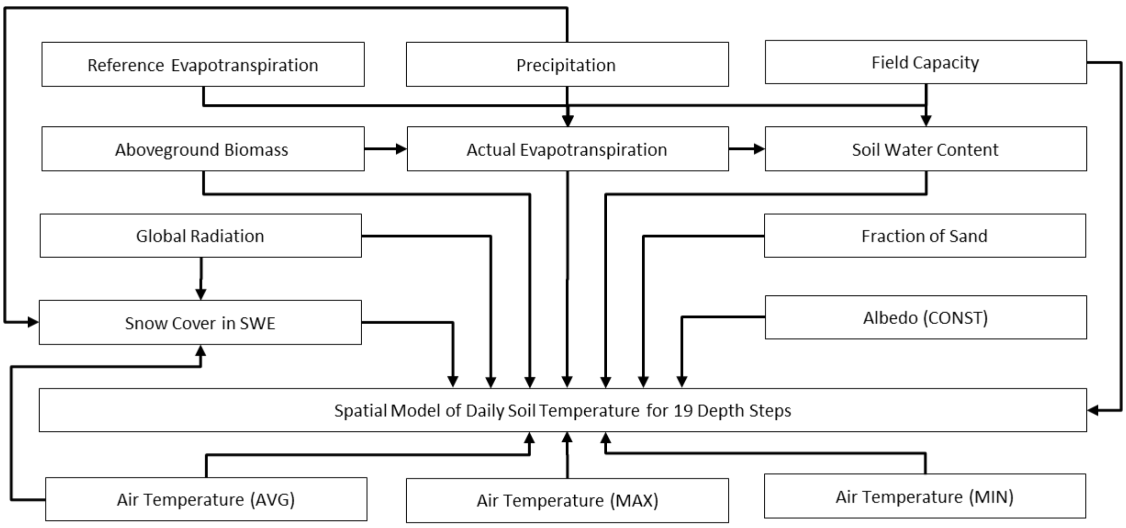
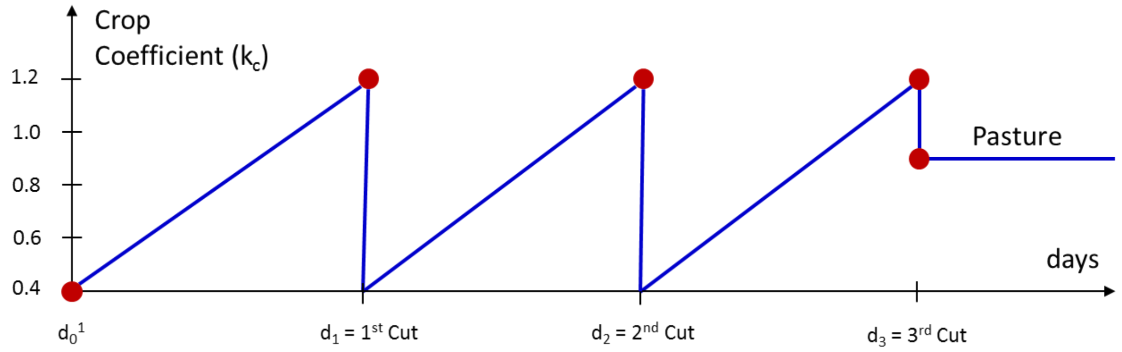


Figure 1: **Basis data and data flows of the GIS soil temperature model**

The GIS soil temperature model has to be able to consider different agricultural crops. Development of several cultures are mostly correlated with increase of aboveground biomass. This growth-related value changes day by day and is used as a direct soil temperature model parameter and also as an input for soil water balance (see Figure 1). To demonstrate the adaptability of the developed model to different cultures we selected grassland and maize.

The crop-dependent biomass development is determined by several phenological stages. For simplification of the complex growing process we used a “crop coefficient” driven approach introduced by Allen *et al.* (1998). Figure 2 shows the trend of grassland biomass with three cuts. From the start of growing season, indicated by a combination of different temperature criteria (Schaumberger, 2011, 87ff, Schaumberger *et al.*, 2012) the biomass increases linearly up to the first cut and in the same way up to the following cuts. The slope of increase is determined by cutting dates which are modelled on the base of temperature sums and their statistical analysis proposed by Schaumberger (2011, 100ff). The aboveground biomass [kg per hectare] is a modification of the crop coefficient based on complex crop growth model outputs, which is simply a multiplication of crop coefficient with 5000 in case of grassland.

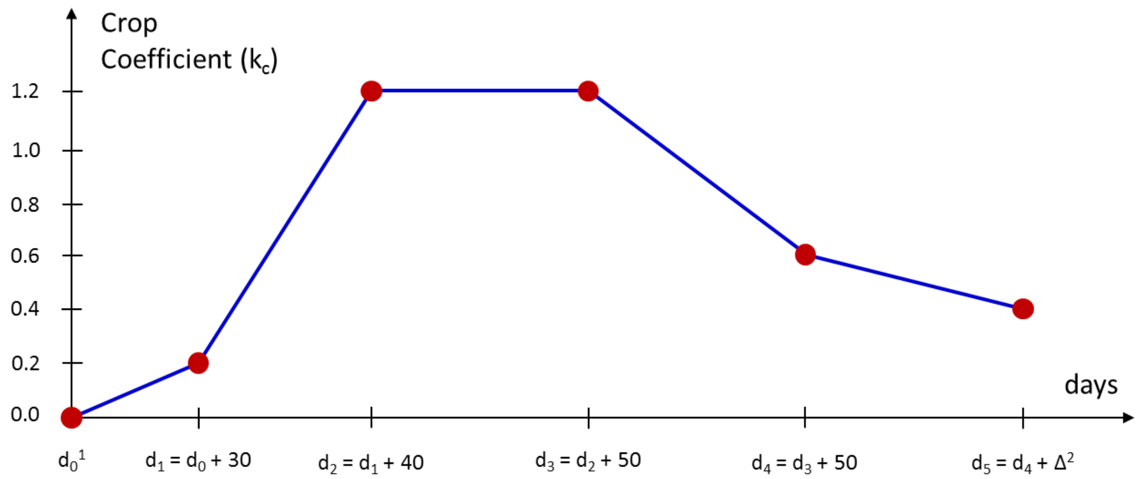
The trend of the crop coefficient for maize is displayed in Figure 3. The start of growing seasons is also a combination of temperature criteria but differs a little bit from the start time for grassland which is defined in Schaumberger (2011, 87ff). For a time window of 10 days the average air temperature has to reach at least 12 °C. For five consecutive days the temperature has to be more than 10 °C per day. Additionally, the temperature must not fall under 3 °C. These values were tested in GIS by using temperature surfaces. Some variations of these criteria are applied and each result map was then discussed with experts. The mentioned set of criteria was finally used for calculation of crop coefficient and the derived aboveground biomass which is based on a multiplication factor of 8000.



[1] Start of growing season (grassland) defined by a criteria combination based on daily mean air temperature

Figure 2: **Trend of crop coefficient adjusted to a three-cut-system of grassland**

On the contrary to grassland, maize starts with a crop coefficient of 0 and phenological stages are constant periods (values derived from crop model outputs). Actual evapotranspiration, the key factor of soil water balance, is the result of the multiplication of reference evapotranspiration and crop coefficient. For all days before the maize biomass starts to grow the actual evapotranspiration is set to 0 and this would not represent the real situation. Therefore, we implemented a correction. For all crop coefficients at the beginning of a season below 0.2 the soil moisture will be taken into account. If the soil water content is above 90 % of field capacity, the soil is wet and evaporation occurs, the crop coefficient is set to 1. For all situations where the soil water content is below 90 % we assume that the soil is dry and the crop coefficient is set to 0.2. After crop coefficient reaches 0.2, no corrections are necessary anymore and the crop adjusted evapotranspiration is calculated as Allen *et al.* (1998) proposed. We start our analysis from March, 1st up to November, 15th. Outside of this period we simplified the actual evapotranspiration for maize as well as for grassland and substitute it with a constant value of 0.1.



[1] Start of growing season (maize) defined by a criteria combination based on daily mean air temperature
[2] Δ = November, 15th – d_4

Figure 3: **Trend of crop coefficient adjusted to maize**

Test of the implemented soil temperature GIS-model:

Although the stand alone (numerical) version of the soil temperature model was validated successfully (see above), we tested again the GIS-implemented version of the model. The site-based soil temperature model algorithm was re-implemented in GIS by using Visual C# and the COM class library ArcObjects from ESRI.

Therefore, the original numerical input data has to be substituted by spatial data in raster format which are then processed in the implemented map algebra algorithms. The calculations, based on weather and soil parameters, were executed for the entire area of Austria in 250 meters resolution for the years 2009 to 2011 on daily time steps. All input and output data are integrated into a raster GIS (Bartelme, 2000, 116) and structured in ArcGIS FileGeodatabases (Childs, 2009). The soil temperature results of 19 different soil depths are prepared as continuous surfaces for use in any other agrometeorological and phenological GIS model.

Soil temperatures were calculated for 19 soil depths (2, 4, 6, 8, 10, 15, 20, 25, 30, 40, 50, 60, 70, 90, 120, 180, 300, 540 and 1000 cm) and each day of the study period from 2009 to 2011. The results are almost 21,000 maps of Austria in 250 meter resolution. In order to analyse the huge amount of results, single sites need to be selected. Soil temperatures at these sites are used to build time series and a dataset for validation. To get single values from maps the GIS function "Extract" was implemented. This algorithm accesses the daily soil temperature maps automatically, reads the values of each map at defined geographical positions and stores the extracted values in a list. This list is the base for analysis like the examples given in Figure 4 and Figure 5.

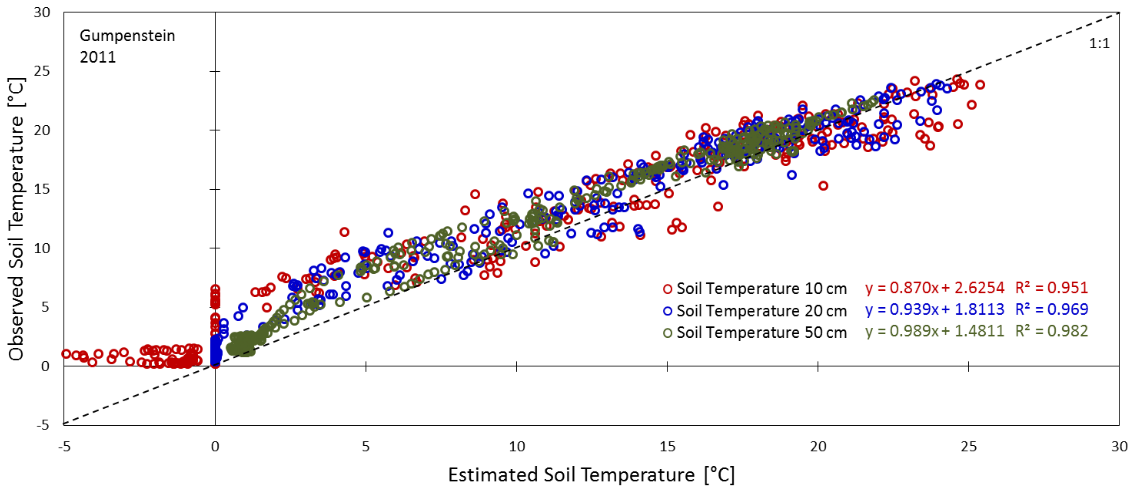


Figure 4: **Comparison of modelled and observed soil temperatures at Gumpenstein in 2011 for 10, 20 and 50 cm soil depth (grassland)**

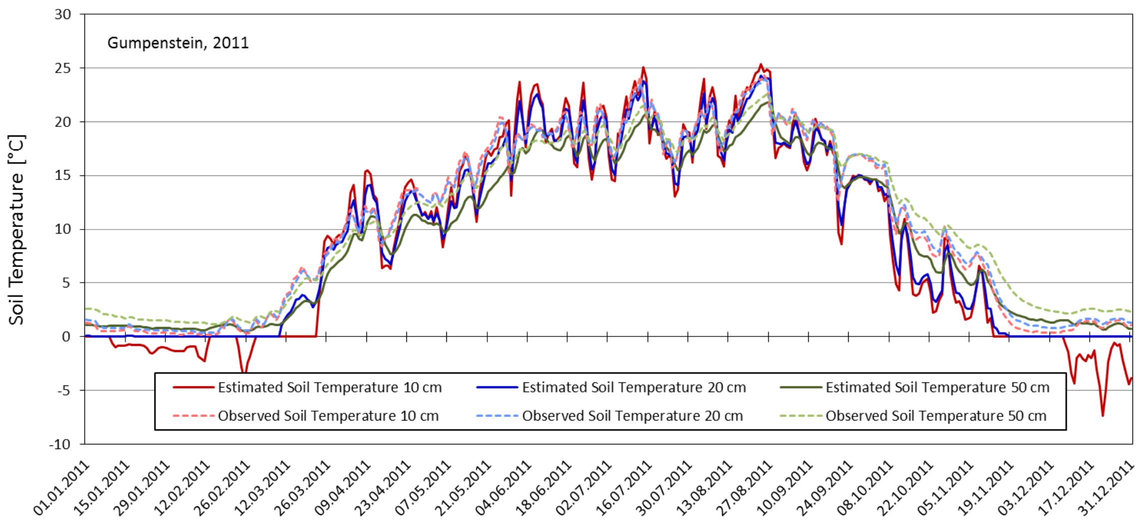


Figure 5: **Trend of modelled and observed soil temperatures at Gumpenstein in 2011 for 10, 20 and 50 cm soil depth (grassland)**

Both figures show grassland model results in comparison to observed soil temperature of selected depths at Gumpenstein for 2011. It should be kept in mind that the vegetation surface at this site is not a three-cut grassland which is assumed by the model but a weather station typical lawn. Figure 4 shows the correlation between model results and observed temperatures which is very strong in any soil depth. There are no systemic errors except the negative temperature estimations for the first layer (10 cm soil depth).

Figure 5 explains this behaviour. The reason for considerable deviations between topsoil model results and observations during the winter months is the use of a very simple snow cover model. It cannot provide exact and full information about the real snow cover. The evaluation und a detailed model description can be found in Schaumberger (2011). Uncertainties in snow cover influence the temperatures of the first few centimetres of soil significantly as it is displayed in *Figure 5*. The figure also shows another effect. Generally, the model underestimates in spring and overestimates in autumn. Whilst the underestimation is quite moderate the deviations in autumn are higher. At the end of growing season the vegetation surface could be very different to that one which is considered in the soil temperature model. Compared to temperature and biomass increase in spring the reduced temperatures and the uncertainties of vegetation cover at the end of growing season the estimates become more and more imprecise. The model is not able to react absolutely correct under these changes in late season. However, the correlation over the whole growing period is very strong and provides excellent results. The regression analysis of all study years (R^2 in 2009 is 0.92, in 2010 0.95) indicates a very high quality of the processed temperature maps and ensures a reliable base for any models that need soil temperature as input.

Trend series show model estimates of one single site over a defined period but not the spatial dimension of the results. Figure 6, Figure 7 and Figure 8 show the spatial aspect in results for one example day in 2009 and selected depths. The raster data are restricted to the area where soil information is available, these are agricultural lands with mineral soil.

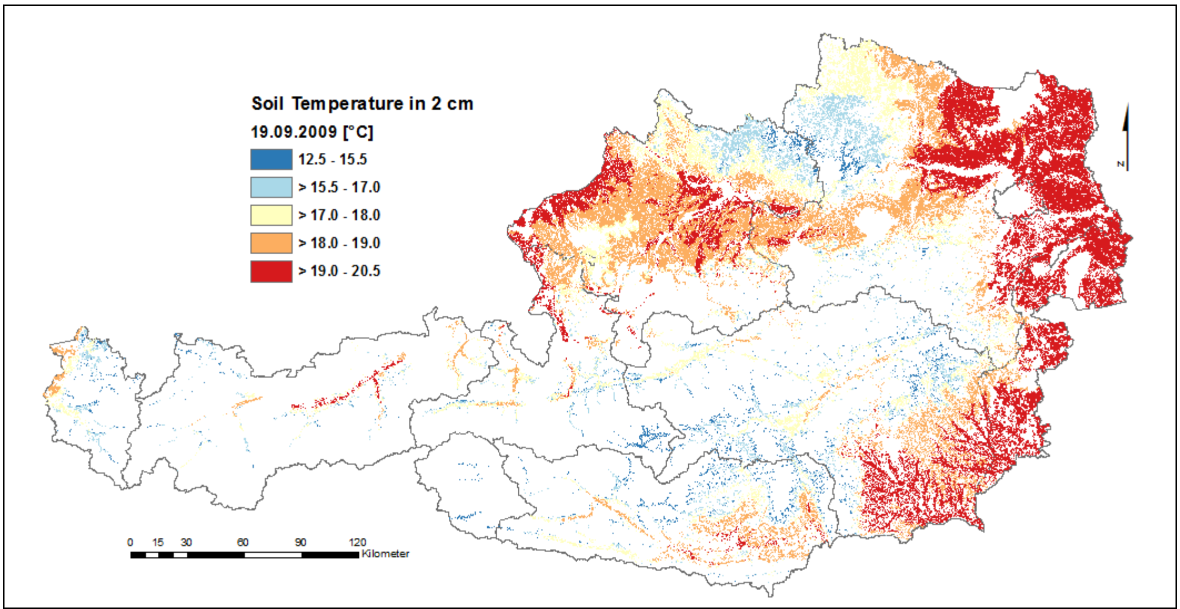


Figure 6: **Surface of soil temperatures in 2 cm soil depth on September 19th, 2009**

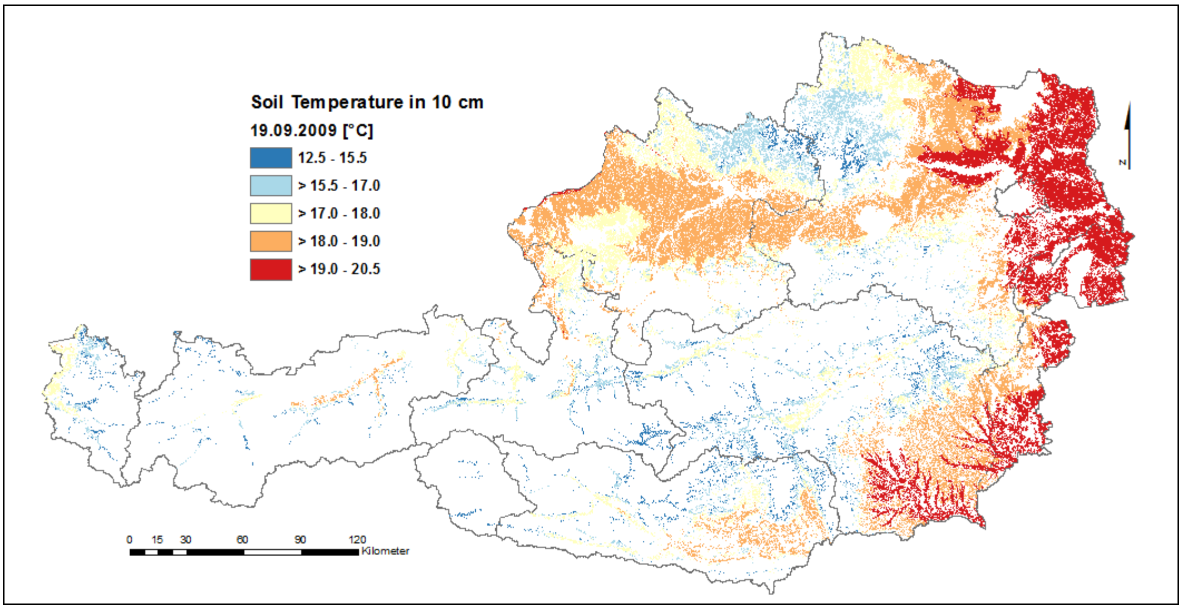


Figure 7: **Surface of soil temperatures in 10 cm soil depth on September 19th, 2009**

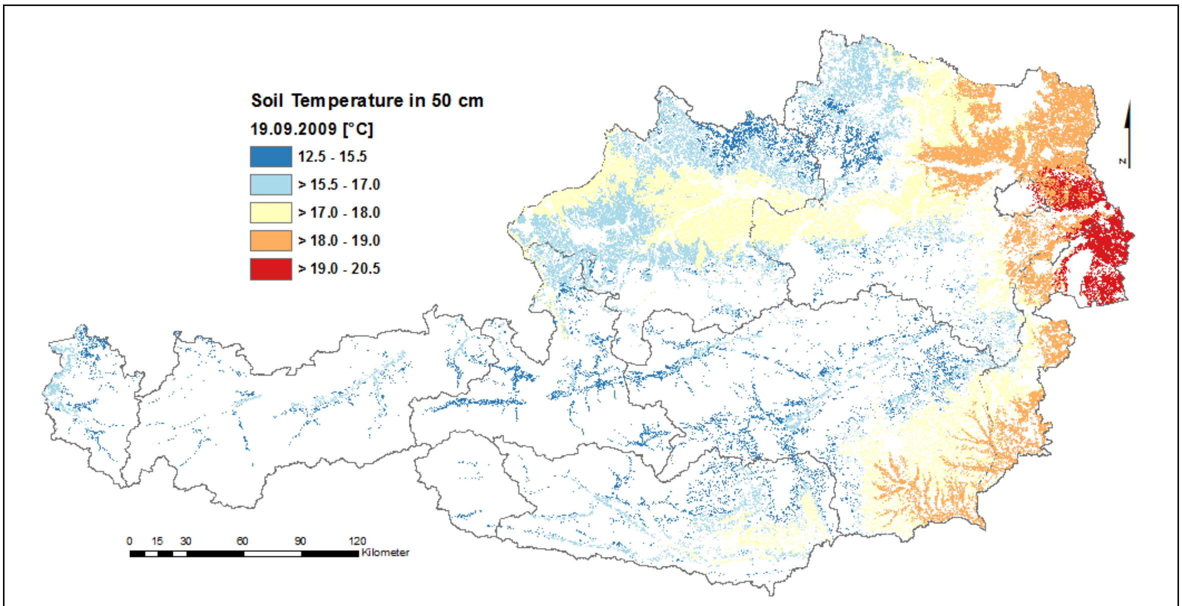


Figure 8: **Surface of soil temperatures in 50 cm soil depth on September 19th, 2009**

The soil temperature in top layer (Figure 6) is very sensitive to air temperature, but temperatures get more and more damped in deeper layers (*Figure 7* and *Figure 8*). The displayed example shows that the atmosphere affects the soil temperatures with increasing time shift and lower variations in deeper soil layers. For each day of the study period 19 maps according to the 19 analysed soil depths like that showed in Figure 6 to Figure 8 are available for further studies.

Demonstration of GIS-implemented soil temperature based algorithms:

One of these studies could be the implementation of temperature sum models based on soil temperatures. The following example shows an application for estimation of entry dates of phenological phases. Phenology has a long tradition to link management activities of farmers with weather and climate conditions. Phenological analysis has been proved as an effective instrument to observe climate change (Chmielewski, 2003). The yearly variations of the same phenological phases show the impact of climate on biosphere directly. Time series of these phenological observations indicate changes in life cycles of fauna and flora due to climate (Chmielewski, 2007).

Figure 9 and Figure 10 show the results of phenological analysis for WCR (*Diabrotica virgifera virgifera)* based on the implemented algorithm of soil temperature sum in 6 cm soil depth, developed within CLIMSOIL (see above).

The start day for temperature accumulation is defined with 1st of March and the base temperature is 11.7 °C. The estimated entry date for emergence of larvae is the day where the temperature sum (above the base temperature of 11.7 °C) reaches 279 degree days. The date of adult emergence enters with a temperature sum of 648 °C. 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. Then, this day of year is stored in a new raster surface which gives a spatial information of entry dates for the whole study region as it is shown in *Figure 9* and *Figure 10*.

The estimates depend on the quality of temperature sum model (evaluation features are given by AGES), but also on the performance of soil temperature model and its spatial input data (see *Figure 4* and *Figure 5*).

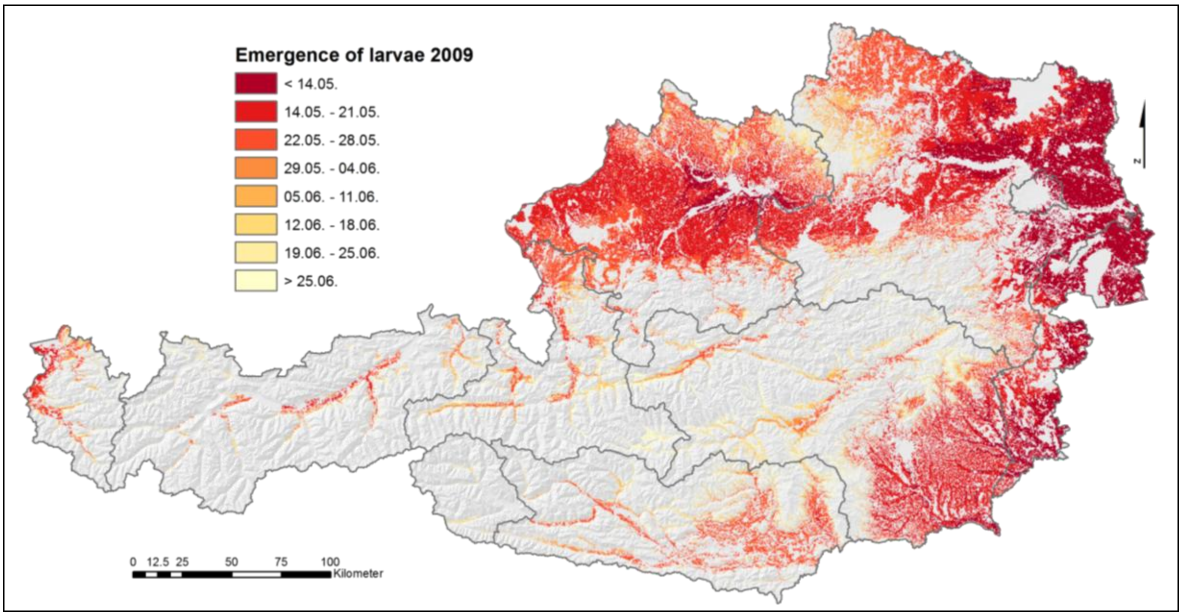


Figure 9: **Soil temperature sum model to estimate the entry dates of the phenological stage „Emergence of larvae of *Diabrotica virgifera virgifera*“ in 2009**

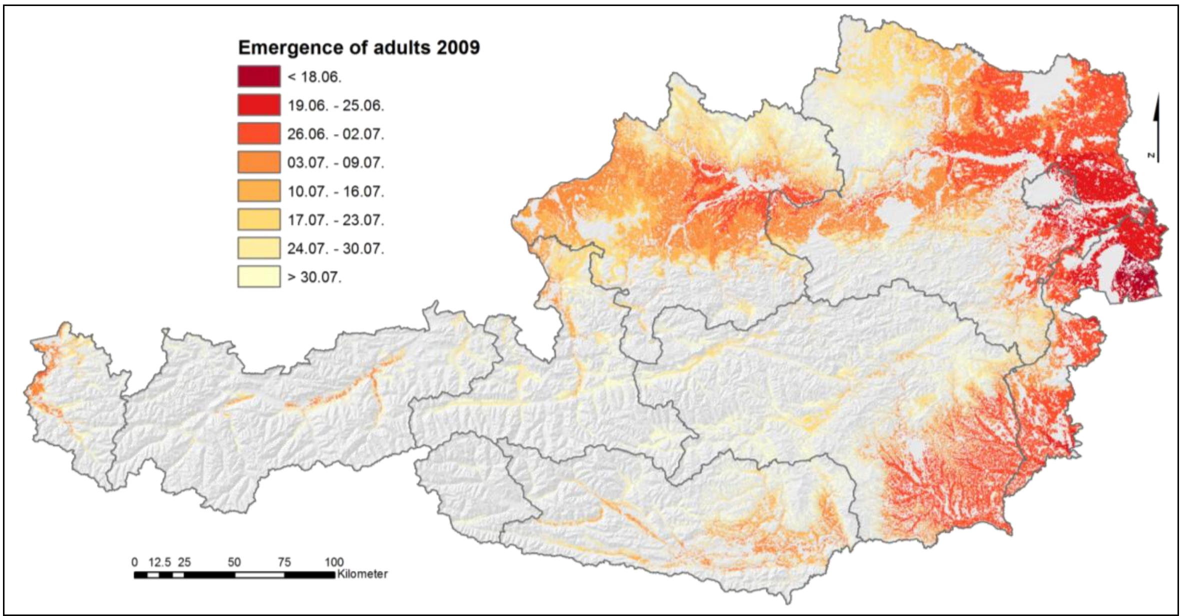


Figure 10: **Soil temperature sum model to estimate the entry dates of the phenological stage „Emergence of adults of *Diabrotica virgifera virgifera*" in 2009**

A further algorithm which was developed within CLIMSOIL is the soil C/N ratio for winter wheat and maize crop:

The soil temperature results can be processed by map algebra algorithms in a comparable way as numerical variables. For example, we calculate the C/N-Ratio based on a linear regression with two independent variables: soil temperature and soil water content. For example, the equation for winter wheat is defined as

*C/N (0-20cm) = 11.6826 + (0.0064*soil temperature) + (-0.0321*soil water content)*

The algorithm was developed and validated by crop model application on the base of soil temperatures in 10 cm soil depth. The model was implemented in map algebra where both variables were processed as daily raster surfaces. The results are daily maps that are analysed by extracting all values of a single cell representing the site Gumpenstein (Figure 11).

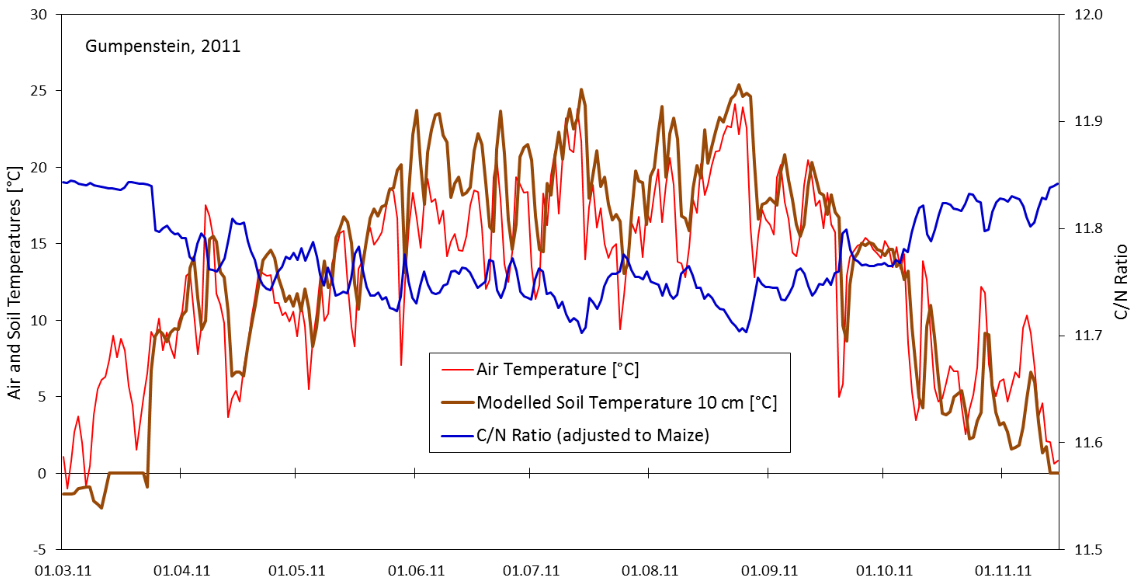


Figure 11: **C/N ratio based on daily soil temperature and soil moisture under winter wheat compared to air temperature and 10 cm soil temperatures at Gumpenstein in 2011.**

Demonstration of the developed algorithms under climate change scenarios:

Impact of climate change on soil temperatures and wester corn rootborer development under different climate scenarios for the 2050s at a representative site for north-eastern Austria (Groß-Enzersdorf, Marchfeld region):

Figure 12 shows, as an example, the change of the mean annual soil temperatures at 10 cm depth for three selected soil types under maize (representing the Marchfeld region) under three different climate scenarios for the 2050s. The increase of soil temperatures range between 1.7-2.3 °C, which reflect to a great extent the temperature signal from the climate scenarios (not shown). However, in shorter time scales (i.e. considering the change of seasonal development of the specific crop cover) the deviations can be significant, and especially when different soil cover types and crop management options are compared.

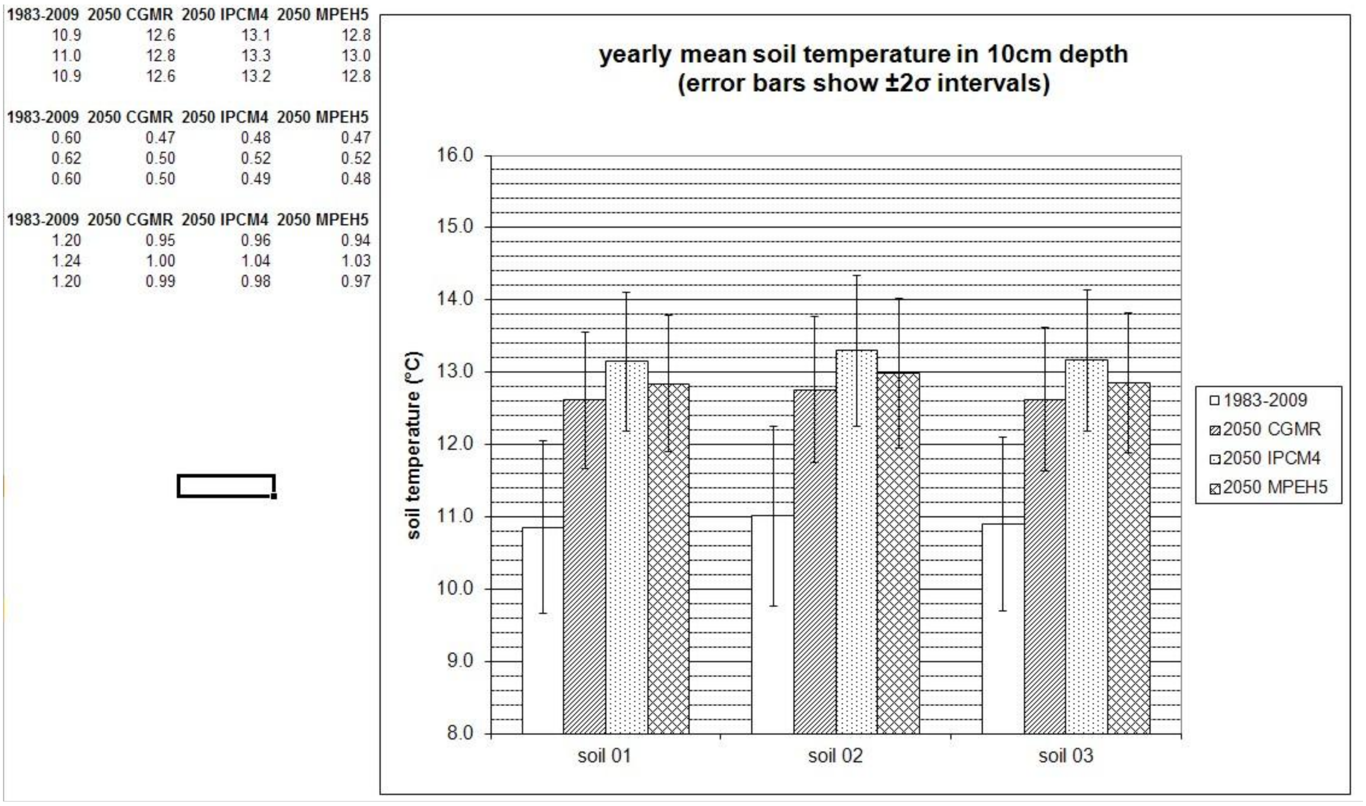


Figure 12: **Change of mean annual soil temperatures at different soils in 10 cm depth at the site in Groß-Enzersdorf under three different climate scenarios and soil conditions for maize (Soil classes with mean available water capacity: Soil 01= 118 mm; Soil 02= 190 mm; Soil 03= 233 mm).**

Based on the soil temperature changes the developed pest algorithm for western corn rootworm was applied under the same scenarios as shown in Figure 12. Significant changes are shown for pest phenology of *Diabrotica,* where a shift to earlier pest occurrence by 10-19 days (first larvae) and 16-24 days (first beetle) can be expected compared to the current conditions, for the conditions in eastern Austria (i.e. Marchfeld region).

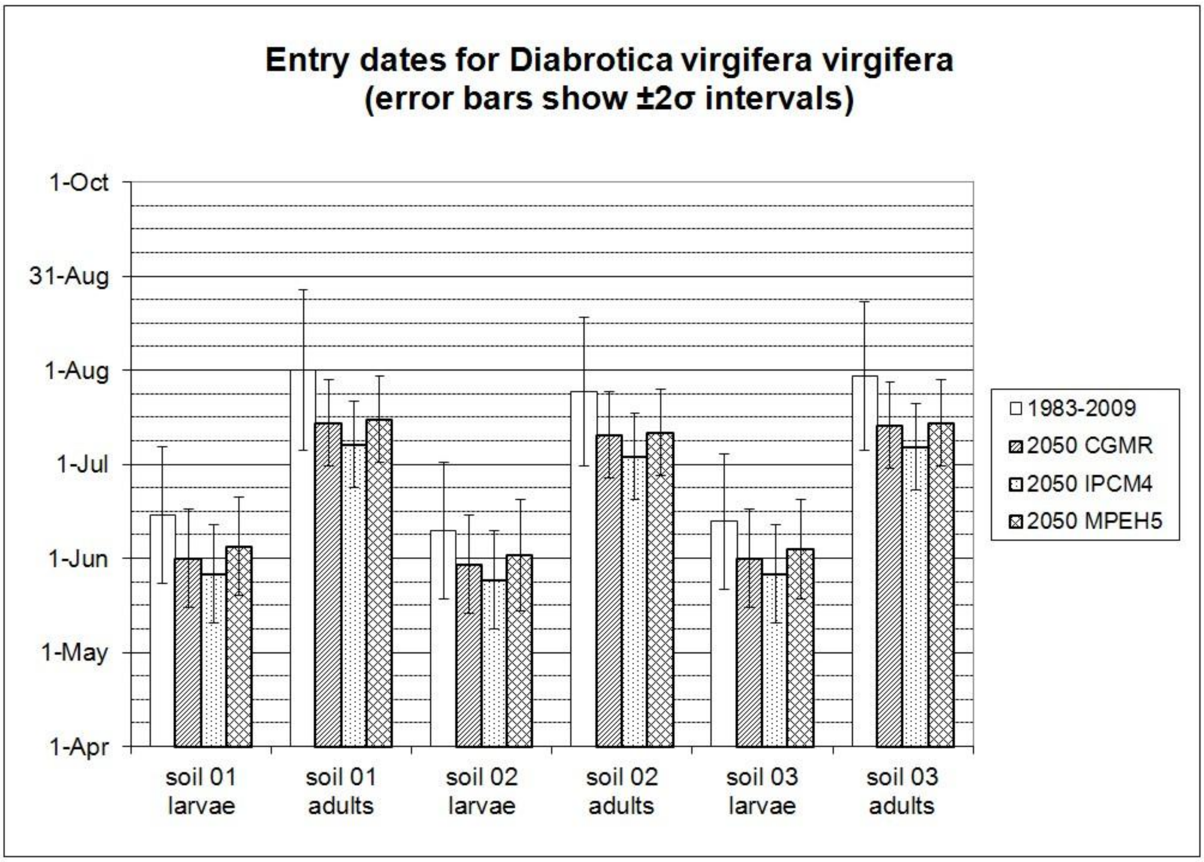


Figure 13: **Change of the pest phenology of western corn rootworm under various climate change scenarios and at three different soils based on soil temperatures at 6cm depth under maize.**

4 Schlussfolgerungen und Empfehlungen

Main results of the project:

• A soil temperature data base on measured soil temperature series under various conditions and from several sites in Austria was established and available for research in Austria (i.e. for model calibrations).

• A sophisticated and flexible soil temperature model with limited input parameters for agricultural land use applications was developed and tested for Austrian conditions.

• The soil temperature model is available as stand-alone as well as GIS-implemented version, with a high application potential for practical as well as scientific applications (i.e. climate change impact studies).

• New results on the phenology of two important pests in Austria were obtained, which allow a better monitoring of pest risk. This includes especially a better estimation of the influence of soil temperature.

• A high spatial resolution GIS system for monitoring of crop growing conditions was extended for soil temperature and soil temperature related processes (pest model, soil C/N-balance model).

• The relevant application potential of the GIS-system for monitoring, risk assessments and warning system was increased significantly and will now further improved for estimating extreme weather impacts on crops (follow up project on agricultural heat and drought monitoring).

Conclusions:

Beside specific findings of the investigated pests, the main innovation was the development of GIS-implemented soil temperature model with applications for pest algorithms and other soil born processes.

The work on a Geographic Information System to provide soil temperature information for the entire area of Austria in high resolution was conditioned by an extremely high processing effort. The site-based soil temperature model, developed by BOKU, uses numerical values from excel sheets but the GIS implementation needs memory intensive raster surfaces for each single variable. One raster surface that covers Austria in 250 meter resolution consists of more than 3 million of single values structured in a matrix. Optimized read and write access as well as efficient management of data are the challenges of this software development. The ability to run the model with huge amount of data is in focus of each implemented algorithm, but for all that the system reached the edge of its capability. Extensive debugging and software tests had to be executed with generated test data in raster (matrix) format. The same data had to be also prepared as single (vector) values for the site-based model in order to compare and validate the correctness of GIS implementation.

During the project, experiments for collecting data on pests were carried out in 2 target regions (Lower Austria and Styria) with the original plan to provide finally GIS-maps of the implemented algorithm calculations for only these selected regions. If the region of soil temperature calculation would be restricted to smaller area, the processing time could have been reduced significantly. However, we decided to keep the entire area of Austria as CLIMSOIL study region because all model input data were already calculated for whole Austria due to methodological requirements. The main reason for that is to maintain a maximum of flexibility in defining new study regions for any purpose. Soil temperatures for analysis are available for all regions and can be accessed by project partners or other stakeholders. If the study regions would be restricted in advance there are no chances to generate soil temperature results outside of these regions without a complete repetition of the whole process. To avoid this substantial disadvantage we produced results for all agricultural fields of Austria and for both cultures, grassland and maize.

The runtime for processing soil temperatures for one day (19 soil layers) is approximately one hour. Therefore, the calculation for the study period (2009 to 2011 with about 1100 days) and for two cultures (grassland and maize) takes about 50 days. Under these conditions the system is ready and can be used as a monitoring tool for the implemented applications (soil temperature estimation, pest algorithms, soil N-balance).

Applications with the use of climate scenarios usually need to consider at least 30 year time periods. Additionally, more than one scenario should be calculated to cover a certain range of uncertainty related to climate model outputs. All input data (temperature, global radiation, evapotranspiration, snow cover, albedo, aboveground biomass, soil water balance, precipitation) have to be prepared in this case for at least 30 years. If these parameters are available as continuous surfaces in high resolution the chance to realise soil temperature calculation for 30 years would be only theoretically possible.

However, the resolution of climate scenario data are generally rough, even dynamical and/or statistical downscaled data exist in a spatial resolution of some kilometres in the best case. If the study region for application of soil temperature model would be restricted to an area of few kilometres, the climate model data, also in kilometres resolution, would hardly show any spatial variation within such small study regions. Therefore, the application of the site-based (standalone version) soil temperature model, was chosen as alternative for the demonstration of the soil temperature model and related algorithms under climate change scenarios. The site-based approach calculates the temperature for a single position which is representative for the region around. Due to the rough resolution of climate data, the GIS model could not analyse soil temperature in more spatial detail, but would need a huge overhead of processing time and memory space.

If the study region would be extended to the entire area of Austria in order to get a spatial variation of climate change signal, the processing time would increase enormously. A 30-year-calculation needs 10 times more processing effort than the calculation that we have done for our study period (2009 to 2011). This means an extension from 50 days to approximately 500 days, 24 hours each day, just for running the GIS soil temperature algorithms for one single climate scenario. The effort for preparing of all the input data cannot be estimated and depends on the available resolution of climate data. These are the reasons why GIS model was not used for analysing climate scenarios and their impact on soil temperature changes within CLIMSOIL due to limited resources. Hence, all scenarios were calculated by using the site-based model.

Recommendations:

Although high resolved GIS models with a high number of independent parameters are not able to calculate climate scenarios with day by day calculations for at least 30 years without a significant amount of processing time and memory space over large regions, it could make sense and would be possible with an acceptable computing time in smaller regions with significant topographic variations and climate gradients. This option could be recommended for future applications, indeed with the existing design of the GIS-system.

Further it is recommended to continue and strengthen research on the investigated (and other important) pests and soil related processes in order to develop and calibrate algorithms for warning systems under Austrian conditions. Such results could be used and implemented in the GIS-system for operational use (i.e. warning and forecasting).

Outlook:

During 2012 part of the project team successfully applied for a follow up project regarding crop drought and heat risk monitoring. CLIMSOIL was an ideal base for such an application and the further research will go on under the new project, where the aim is to extend the GIS-based monitoring and forecasting system for further crop risks, ready for operational use (to be used via an already existing web site of the Austrian Ministry of Agriculture).

All research groups dealing with high resolution mapping of climate and climate change impacts can use the methods and findings of our project for their own research. The findings are extremely important for the development of tailored services (i.e. monitoring, risk warning systems) for stakeholders (i.e. farmers), which have to be site specific and reliable.

C) Projektdetails

5 Methodik

The work of the project was carried out in 4 Work Packages (WP), which contained as methods the establishment of data bases, model comparison and development (soil temperature, pest models, soil processes) and GIS-implementation and demonstration (incl. application of the models under climate change scenarios):

WP 1:
In a first step a data base on measured soil temperature data under various soil cover (e.g. crop types) was established from available past data sets and from ongoing field experiments in Austria (Goettlesbrunn, Kirchberg, Gross-Enzersdorf, Salzburg, Gumpenstein). The data set was used for comparison of soil temperature models/algorithms and developing and testing of algorithms suitable for GIS implementation (see WP 3). The data base was structured with uniform format and meta information, which is available for other scientific projects in Austria. Further climate scenarios were developed for the model demonstration under WP4.

WP 2:
Two pests which are sensitive to soil temperatures were investigated in this Work Package in field experiments from 2010-2011 in order to develop and calibrate relevant pest models for GIS implementation. The first one, the western corn rootworm, is one of the most important pests of maize worldwide. The aim of the analysis was to link important below-ground developmental stages of the rootworms with the accumulation of certain temperature sums. An existing model developed in the USA was examined for their relevance in eastern Austria by comparison with our own results. It was adapted to regional climatic conditions and to soil-temperatures. The resulting soil-temperature dependent model was implemented in the GIS model and demonstrated for climate change scenarios.
The other pest investigated was “white grub” in permanent grassland. Farm inspections for collecting data on grub densities and species distribution were carried out in 2011-2012 including regression analyses with grub densities and simulated soil temperatures regarding soil conditions and management history.
Further a process oriented crop growth model (DSSAT) was applied to establish an algorithm for soil N-balance under a defined maize management scenario for the region of eastern Austria, where soil wetness and soil temperature plays a crucial role.

WP 3:
WP3 started in 2011. In 2011 the evaluated soil temperature algorithms were combined in a stand-alone soil temperature model (software programming) considering limitations of available inputs from an existing GIS-system for monitoring crop growth conditions. The developed model SoilTempSimV3 was tested and parameterized on the soil data sets available from WP 1. A sensitivity analysis of the model against important model input parameters completed the study. For GIS-implementation the program code of the model was based on Visual C# with integration of standardized GIS methods provided by the ESRI ArcObjects class library.

WP 4:
WP4 started in 2011. The soil temperature model (WP3), soil C/N-balance and a pest algorithm (WP2) were implemented in the GIS. Further, the GIS-implemented algorithms for soil temperature, C/N-balance and pest development and risk were validated for selected sites in Austria. After successful evaluation, the algorithms for soil temperature calculation, pest phenology and soil C/N-balance (for maize) were applied and demonstrated for current climate (providing GIS Maps) und for climate scenarios (selected site).

6 Arbeits und Zeitplan

<u>Time schedule of the Work packages and the foreseen meetings (in bold letters).</u>

WP	**Month (0= first month, 36= last month)**																	
	0	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**	**32**	**34**	**36**
1	**a**						**b**						**c**						**d**
2																			
3																			
4																			

Management meetings among the partners:

a. Kick-Off meeting among the partners.

b. Second general meeting.

c. Third general meeting.

d. Final meeting, including internat. symposium to be held in Austria (BOKU)

7 Publikationen und Disseminierungsaktivitäten

<u>Following publications of CLIMSOIL were made or are under preparation:</u>

- Schaumberger, A., Schaumberger, J., Eitzinger, J., Grabenweger, P., 2013. Räumliche Modellierung von Bodentemperaturdaten für Österreich. 14. Klimatag, April 4-5 2013, BOKU Vienna (CCCA, klima+energiefonds, BOKU), Poster **(second price for scientific quality and innovation).**
- Eitzinger, J., Thaler, S., Grabenweger, P., Schaumberger, A., Schaumberger, J., Murer, E., Krammer, C., Grabenweger, G., Pilz, C., Kahrer, A., Trska, C., Kromp, B., Hann, P. 2012. Raumbezogene Simulation der Bodentemperatur auf landwirtschaftlichen Flächen in Österreich und potenzielle Anwendungen zur Klimafolgenabschätzung. 13. Klimatag, 2012, BOKU Vienna (CCCA, klima+energiefonds, BOKU), Abstract (Vortrag).
- Eitzinger, J., Murer, E., Schaumberger, A., Garbenweger, G., Kromp, B., 2010. GIS data base and methodology for estimating impacts of climate change on soil temperatures and related risks for Austrian agriculture (CLIMSOIL). 12. Klimatag, BOKU 2010 (CCCA, klima+energiefonds, BOKU), Poster.
- Murer E., C. Krammer , J. Eitzinger and P. Grabenweger, 2011: GIS data base and methodology for estimating impacts of climate change on soil temperatures and related risks for Austrian agriculture (CLIMSOIL). IUGG Congress Melbourne, Australia. Earth on the Edge: Science for a Sustainable Planet. Poster.

- Murer E., C. Krammer and J. Eitzinger, A. Kahrer und C. Pilz, A. Schaumberger and B. Kromp, 2012: GIS data base and methodology for estimating impacts of climate change on soil temperatures and related risks for Austrian agriculture (CLIMSOIL). 4th International Congress EUROSOIL 2012, Bari, Italy. Soil Science for the Benefit for the Mankind and Environment. Poster.
- Manuscript to be submitted till June 2013 to "Ecological Modelling":
  Grabenweger, P., Eitzinger, J., Lalic, B. Hann, P., Trska, C., Wechselberger, K., Kromp, B.: A Model to Calculate SoilTemperatures Accounting for Frozen Soil Conditions
- Manuscript to be submitted till June 2013 to "Journal of Pest Science":
  Hann, P., Trska, C., Wechselberger, K., Kromp, B.: Scarabaeidae larvae in Austrian mountainous grassland and the associated damage risk considering management regime, soil characteristics and soil temperature.

- **Compiled CLIMSOIL final report to be published till June 2013 in BOKU-Met report (http://www.boku.ac.at/met/report/) (available online):**
  Eitzinger, J., Thaler, S., Grabenweger, P., Schaumberger, A., Schaumberger, J., Murer, E., Krammer, C., Grabenweger, G., Pilz, C., Kahrer, A., Trska, C., Kromp, B., Hann, P. 2012. Spatial monitoring of soil temperature under agricultural land use and potential applications for monitoring of soil processes and pests and assessments of climate change impacts.

Other dissemination activities:

- Project web-site at http://www.boku.ac.at/climsoil/index.html. The web site will be maintained also after the end of the project in the context of the follow-up project AgroDroughtAustria.
- Results of CLIMSOIL were reported to the Commission of Agrometeorlogy (Region Europe) of the World Meteorological Organization and will be partly published in a relevant WMO report in 2013. The project leader is involved in a WMO Expert team and in COST actions dealing with related problems of agrometeorology. In that sense the published results of the project will help also significantly to build international cooperation activities. A related bilateral project proposal for agricultural risk monitoring in cooperation with Czech Republic (Mendel Univ. Brno) is planned for 2014.