Presentation

Use of Geographic Information Systems (GIS) in Crop Protection Warning Service

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SUMMARY

One of the important aims of the Governmental Crop Protection Services (GCPS) in Germany is to reduce spraying intensity and to guarantee an environmentally friendly and economical crop protection strategy. ZEPP is the central institution in Germany responsible for the development of methods in order to give an optimal control of plant diseases and pests. So far more than 40 met. data-based models were developed, most of which are introduced into practice. This study shows how to obtain results with higher accuracy for disease and pest simulation models by using Geographic Information Systems (GIS). The influence of elevation, slope and aspect on met. data were interpolated with GIS methods and the results were used as input for simulation models. The output of these models will be presented as spatial risk maps in which areas of maximum risk of the disease are displayed. The modern presentation methods of GIS will furthermore promote the use of the system by farmers.

KEYWORDS

Interpolation, GIS, temperature, relative humidity, risk maps, plant disease model

INTRODUCTION

During the last 40 years a number of weather based forecasting models have been developed for the control of plant diseases and pest attacks (KLEINHENZ AND JÖRG 2000). Several forecasting models have been established and introduced into practice to support the decisions in the control of diseases in Germany (KLUGE and GUTSCHE 1984; GUTSCHE 1999; GUTSCHE *et al.* 1999; KLEINHENZ and JÖRG 1999, KLEINHENZ and JÖRG 2000; ROSSBERG *et al.* 2001; HANSEN *et al.* 2002). In some agricultural areas, however, the distance between met. stations is more than 60 km. Thus forecasting models did not give satisfying results for plots located at such large distances to met. stations (ZEUNER 2007).

With the help of Geographic Information Systems (GIS) a plot specific classification of met. data will be calculated. To reach this aim, complex statistical interpolation methods are used (ZEUNER 2007). These calculated spatial input parameters for the current disease forecasting models should help to get satisfying forecasting results for areas between two or more distant met. stations. With the use of GIS, daily spatial risk maps will be created in which the spatial and the temporal process of first appearance

and regional development are documented. These risk maps may lead to a reduction of fungicide intensity and give best control.

In this study the new method to calculate the input parameters for forecasting models with GIS is validated on the first appearance of potato Late Blight. The models SIMBLIGHT1 and SIMPHYT1 predict the first appearance for Late Blight and are in practical use (KLEINHENZ *et al.* 2007). While SIMPHYT1 depends on a statistical approach forecast, the result of SIMBLIGHT1 basis on the current infection pressure and could be displayed in three classes (Figure 1). The results will be presented as spatial maps and graphs showing the Late Blight risk. Figure 1 and 2 show the difference between the current and the new risk maps in Germany as simulated by the model SIMBLIGHT1. SIMBLIGHT1 calculates infection risk of Late Blight is shown in three infection classes symbolized by different colours. Risk maps will be implemented into an internet application to provide a comfortable access to the system for farmers and advisers.

Figure 1: *Current SIMBLIGHT1 presentation. The prognosis results are shown at the met. station's location with coloured cloud symbols.*

Figure 2: *The new presentation of a spatial risk map for Late Blight as simulated by SIMBLIGHT1.*

MATERIAL AND METHODS

Workflow

The following steps have to be taken to reach the aim of building spatial risk maps:

 Step 1: data management
 Step 2: interpolation of met. data
 Step 3: calculation of the forecasting model using the results of the interpolation
 Step 4: display of the results as a risk map

Step 1 deals with data management. First hourly met. data are imported from a weather database which are necessary for the forecasting models SIMPHYT1, SIMPHYT3 and SIMBLIGHT1. Then a

geographic reference is providing to the met. data because the weather database is not a georeferenced. Thereafter that it is necessary to prepare the data base which is needed to characterise the met. data for interpolation. Step 2 is the main and the most difficult step. Different kinds of interpolation methods are compared to identify a method which gives the best results in interpolating met. data. Step 3 uses the interpolated met. data as input parameters to calculate the forecasting models (Figure 3). The last step is to connect the results to an internet application in which spatial information is displayed as a risk map of the first appearance and later on the daily infection risk of Late Blight for Germany.
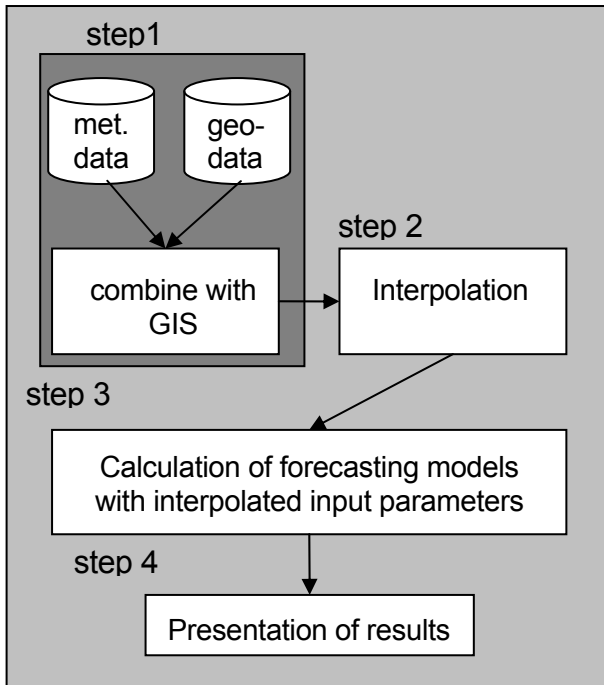
Figure 3: *Infrastructure to calculate risk maps.*

Data base

Met. data

The met. data are collected by 570 automatic met. stations all over Germany (Figure 1), operated by the German Meteorological Service (DWD) and by the GCPS. The stations are at least equipped with sensors for measuring temperature, relative humidity, precipitation and global radiation. All data are tested of plausibility and stored in a database called AGMEDAWIN (KEIL and KLEINHENZ 2007).

Geodata

A digital elevation model (dem) published by BEHRENS AND SCHOLTEN (2002) was used to obtain all necessary information about the relief. The dem describes the landscape as a three-dimensional grid. It represents the earth's surface through digitally stored x, y, z values, where the x and y values specify the horizontal position and z-value of the vertical height of the grid cell (BILL 1999). With the help of mathematical, statistical methods, it is possible to calculate follow products from the dem. These derivatives are, for example, slope, slope direction, slope, or slope edges. The dem and various derivations from the dem provide as basis for the characterization of the meteorological parameters.

Spatial join

In order to store the results of interpolation, a grid was laid out over Germany. At present, the GCPS uses about 570 met. stations to represent agriculturally used area of Germany (some 200.000 km²), that is on average one met. station per 350 km². With the new GIS method, a grid cell has a size of one km² and after interpolation is represented by a virtual met. station (Liebig and Mummenthey 2002).

Interpolation method

Two groups of methods have been tested to find the best interpolation method for met. data. First, there are the *deterministic interpolation methods,* e.g. Inverse Distance Weighted (IDW, "nearest neighbour method") and Spline Interpolation (SI) which are based on distance analyses. These methods were compared to *geostatistical interpolation methods* like Kriging and Multiple Regression (MR) which use mathematical and statistical procedures.

MR is an interpolation method that allows simultaneous testing and modelling of multiple independent variables. MR is a highly general and therefore very flexible data analysis system. It is used whenever a quantitative variable, the dependent variable, is to be studied as a function of, or in relation to, any factors of interest, i.e. the independent variables (Javis *et al.* 2002, Cohen *et al.* 2003). So parameters that have an influence on temperature and relative humidity, e.g. elevation, slope, aspect, can be tested simultaneously. MR uses matrix multiplication and only variables with a defined minimum influence will be included into the model. The result of MR is a formula (x = const + A_1*$const_1$ + A_2*$const_2$+ A_3*$const_3$+…+ A_x*const) which allows to calculate a parameter set for each grid cell from which independent variables are known (Javis 2002; Zeuner 2007, Mense-Stefan 2005).

RESULTS AND DISCUSSION

Interpolation of temperature and relative humidity

The first calculations with the four interpolation methods showed that deterministic interpolation methods were not suitable. IDW and SI have been rejected due to the fact that differences in elevation are not accounted for, because the elevation has been identified as a major factor for interpolation of considered meteorological parameters. Although producing similarly good results, the method Kriging was not able to produce as fast calculation times as compared to MR. So it was also rejected because the performance is also very important to produce daily risk maps in the internet. So method MR was chosen and the results are shown in the following.

To validate the results of the interpolation, 13 met. stations were not used in the interpolation process. After that the deviation between calculated values and measured data of these stations was compared. The period of time of this study was from January to August in the years 2003 to 2006. For all stations, MR was able to calculate results with highest accuracy (table 1). In all cases considered, the coefficient of determination (CoD) ranged between 96 and 99% for temperature and 92 and 96% for relative humidity. For all 13 met. stations, the mean deviation for temperature was less than 0.1°C and for relative humidity less than 0.6 % as calculated with MR. The absolute maximum and minimum for the temperature was less than 4.7°C and for the relative humidity less than 32.6 %. In addition, the data have been tested on significance between calculated and measured data using a t-test. The test indicated that for all stations the differences between the calculated and measured values were at random. The method MR gave plausible results, so this method was chosen to interpolate met. data to be used as input for the forecasting models.

Table 1: *Deviation between calculated values and measured data with MR*

year	2003	2004	2005	2006	2003	2004	2005	2006
parameter	temperature [°C]				relative humidity [%]			
CoD	96%	96%	99%	98%	94%	96%	95%	92%
mean deviation	0.0	0.0	0.0	0.1	0.3	0.1	0.1	-0.6
maximum	4.4	4.1	4.3	4.7	19.6	32.6	21.6	21.2
minimum	-3.8	-4.5	-4.5	-4.1	-18.9	-21.9	-22.8	-22.8
t-test	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

n.s. = not significant   n = 92.160 hours/year

Forecasting models

Results of the forecasting models SIMBLIGHT1 and SIMPHYT1 running on calculated met. data were validated against a set of field data collected between 2000 and 2007 in Germany. A model result was defined as correct when the date of the first appearance given by one of the models was earlier than the date of the first outbreak observed in field. In figures 4 to 8 the results of this study is displayed in box-whisker-plots. The results of the model with interpolated input are denoted with "a –v" and those with measured input with "a –m".

More than 90 % of all calculations have been classified as correct whereas in 2002 less than 60 % correct calculations were made. This is due to a high amount of precipitation during the spring and summer months in 2002. The various data sets yielded a similar percentage of correct results.

In all years, the mean deviation of the model results with –v were gave better results with respect to the first appearance of Late Blight found in field compared to results with –m. For example in the year 2001 the mean results of SIMBLIGHT1 -v showed a five to eight days higher accuracy than the calculations based on data measured by a distant met. station. In all other years the results for mean deviation were similar.

The largest differences between the minimum and maximum deviation (range) were shown by SIMBLIGHT1 in 2002. The range of SIMBLIGHT1-m exceeded that of SIMBLIGHT1-v by more than 30 days. In all other years and also with the model SIMPHYT1, the range of results with –v was 5 to 20 days less compared to –m. The results show that calculations based on interpolated data have a higher accuracy in comparison to field data for Late Blight because of their spatial index. Through this a detailed definition of the first treatment is possible, this effects in high efficiency.

To use other forecasting models, more meteorological input data play an important role. So it is necessary to analyse if MR is also able to calculate parameters such as soil temperature, leaf wetness or precipitation with high accuracy. With soil temperature this method seems to be successful. But for leaf wetness and precipitation it is not useful because of regional variations of precipitation especially in the summer months. For these parameters, other sources have to be found, so e.g. radar measurement of the DWD could be used to classify precipitation.
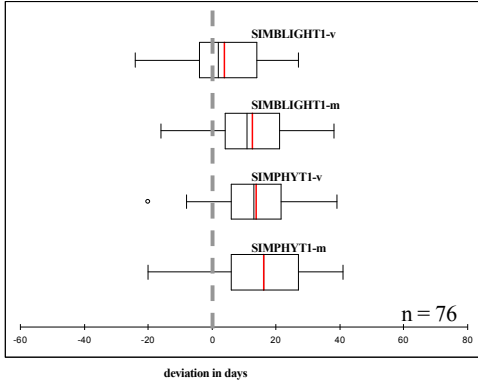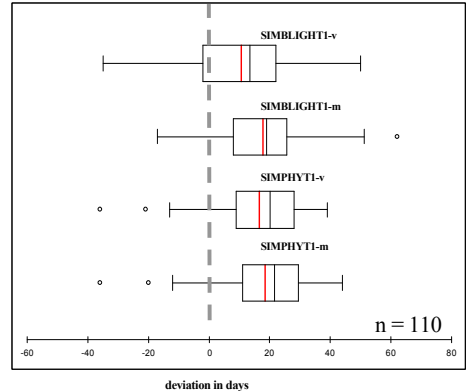
Figure 4: Box-Whisker-Plots of differences between the first appearances of late blight in the field and the model result of SIMBLIGHT1-v-m and SIMPHYT1-v-m in Germany in 2001.
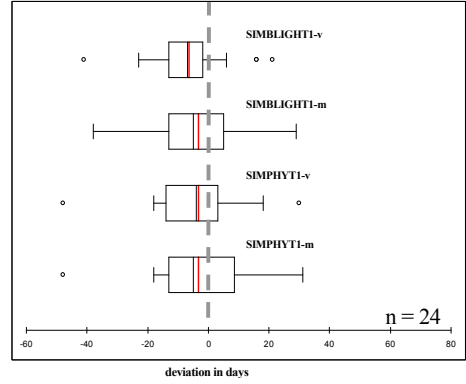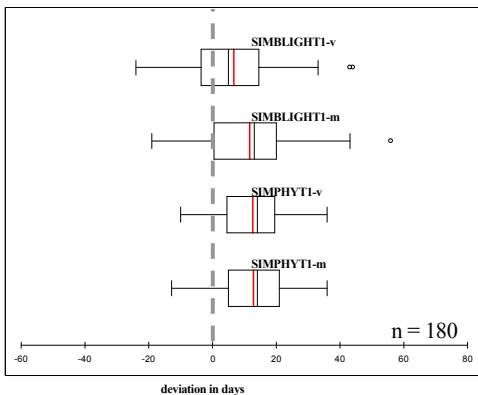

Figure 5: Box-Whisker-Plots of differences between the first appearances of late blight in the field and the model result of SIMBLIGHT1-v-m and SIMPHYT1-v-m in Germany in 2002.
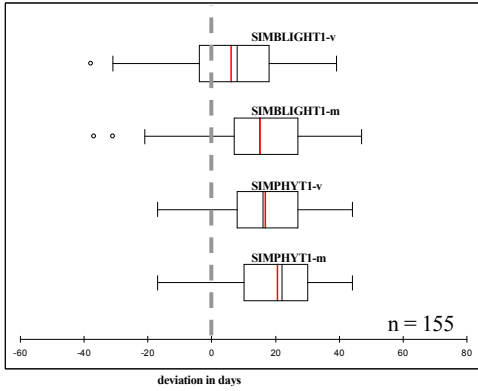
Figure 6: Box-Whisker-Plots of differences between the first appearances of late blight in the field and the model result of SIMBLIGHT1-v-m and SIMPHYT1-v-m in Germany in 2004.

Figure 7: Box-Whisker-Plots of differences between the first appearances of late blight in the field and the model result of SIMBLIGHT1-v-m and SIMPHYT1-v-m in Germany in 2005.

Figure 8: Box-Whisker-Plots of differences between the first appearances of late blight in the field and the model result of SIMBLIGHT1-v-m and SIMPHYT1-v-m in Germany in 2006.

CONCLUSIONS

By the combination of forecasting models for plant diseases and the analyses and interpolation methods based on GIS, a significant advance in advice to farmers can be realized. GIS methods will help to obtain more detailed calculations and results with higher accuracy and validity than before. Spatial maps will show hot spots of maximum risk which will make the results of forecasting models easier to understand and to interpret. This gets the decision support a step closer to the aim of a reduced pesticide use and an economical and environmental friendly crop protection strategy.

The results and methods of this study will initiate the introduction of risk maps in crop protection warning service. The internet platform www.isip.de is currently implementing a web GIS application to make use of the new methods. The new components will comply with all relevant standards (OGC, INSPIRE) to ensure interoperability with other geoservices. 'Improving decision support in plant production with GIS', this conference). GIS presentation methods will make DSS results easier to understand and will lead to a higher acceptance of warning systems by farmers.

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