Use of geographic information systems in warning services for late blight*

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One of the important aims of the German Crop Protection Services (GCPS) is to reduce spraying intensity as part of an environmentally friendly crop protection strategy. ZEPP is the central institution in Germany responsible for the development of methods with the goal of improving the control of plant diseases and, to this end, more than 20 meteorological data-based models have been developed and introduced into practice. This study shows that it is possible to improve the accuracy of the results given by the models by using Geographic Information Systems (GIS). The influence of elevation, slope and aspect on meteorological data was interpolated with GIS and the results were used as input for forecasting models. The results will be presented as spatial risk maps on which areas of maximum disease risk are displayed. The modern presentation methods of GIS enable the results to be displayed in a more user-friendly way.

Introduction

In the last 40 years many weather-based forecasting models have been developed for the control of potato late blight (Kleinhenz & Jörg, 2000). SIMPHYT1 and SIMPHYT3 have been established to provide the best control of late blight in Germany (Gutsche, 1999; Gutsche *et al*., 1999; Hansen *et al*., 2002; Kleinhenz & Jörg, 2000; Roßberg *et al*., 2001). SIMPHYT1 predicts the first appearance of late blight and SIMPHYT3 calculates infection pressure. A new model class for late blight, the SIMBLIGHT1 model class, is in practical use (Kleinhenz *et al*., 2006).

In the future a combination of the current forecasting models: SIMPHYT1, SIMPHYT3 and SIMBLIGHT1 with Geographic Information Systems (GIS) should help to improve forecasting results for local areas between two or more meteorological stations. With the use of GIS, daily spatial risk maps will be created in which the spatial and the temporal processes of first appearance and regional development of late blight are documented. Basing crop protection measures on risk maps may lead to a reduction in the frequency of fungicide applications and give better control of late blight. To reach this aim it is necessary to prepare the parameters (meteorological, geomorphologic and plot-specific parameters) of the forecasting models with a spatial index (Zeuner, 2003). Complex statistical interpolation methods are needed. The results of these interpolations are used as input to run the current forecasting models SIMPHYT1, SIMPHYT3 and SIMBLIGHT. The results will be represented as spatial maps showing late blight risk. Figs 1 and 2 show the difference between the current and the new risk maps in Germany. Risk maps will be imported into an Internet application to provide farmers and advisers with convenient access to the system.

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Materials and methods

The following steps have to be taken to build spatial risk maps:

(1) import of hourly meteorological data from the weather database
(2) combination of meteorological data with the geographic information of the meteorological station
(3) preparation of geographical basic data
(4) interpolation of meteorological data
(5) calculation of the forecasting model using the results of the interpolation
(6) display of the results as a risk map.

The first three steps deal with data management. In step one, hourly meteorological data are imported from our weather database as required by all three forecasting models: SIMPHYT1, SIMPHYT3 and SIMBLIGHT1. Step two gives a geographic reference to the meteorological data in order to spatialize it. In step three, the database needed to characterize the meteorological data for the interpolation is required. To store the data a spatial database will be implemented. In step four, different kinds of interpolation methods are investigated to identify and modify the method which gives the best results in interpolating meteorological data. Step five uses the interpolated meteorological data as input parameters to calculate the forecasting models. 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 in the year, the daily infection risk of late blight in Germany.

Fig. 1 The old SIMPHYT3 presentation indicates the prognosis results at the meteorological stations with coloured clouds.

Database

In this project much data was needed. In forecasting models, the main imported meteorological parameters which have to be interpolated are temperature and relative humidity. These parameters are collected by 570 meteorological stations across Germany as shown in Fig. 3. These meteorological stations are operated by the German Meteorological Service and by GCPS. Data is stored in a database called AGMEDAWIN (Keil & Kleinhenz, 2006). Interpolation methods try to calculate parameter values for each cell of a grid throughout the landscape (Blüthgen & Weischet, 1982). Elevation, aspect, slope and geographic position of the meteorological station are the main information used in this interpolation. A digital elevation model published by Behrens & Scholten (2002) was used to obtain all information about the landscape. Forecasting models need more input parameters than just interpolated meteorological data, such as prevalence of potato crop, cultivar or soil moisture. These parameters are collected in an additional database.

Interpolation methods

Two groups of methods have been tested to find the best interpolation method for meteorological data. On one hand, there are *deterministic interpolation methods* such as the Inverse Distance Weighted (IDW, 'nearest neighbour method') and spline (SI) interpolations which are based on distance analyses. On the other hand, *geostatistical interpolation methods* like Kriging and Multiple Regression which use mathematical and statistical procedures to interpolate meteorological data are also available.

IDW interpolation determines grid cell values using a linearly weighted combination of data from several adjacent meteorological stations. The weight is attributed as a function of inverse distance. The surface being interpolated depends on

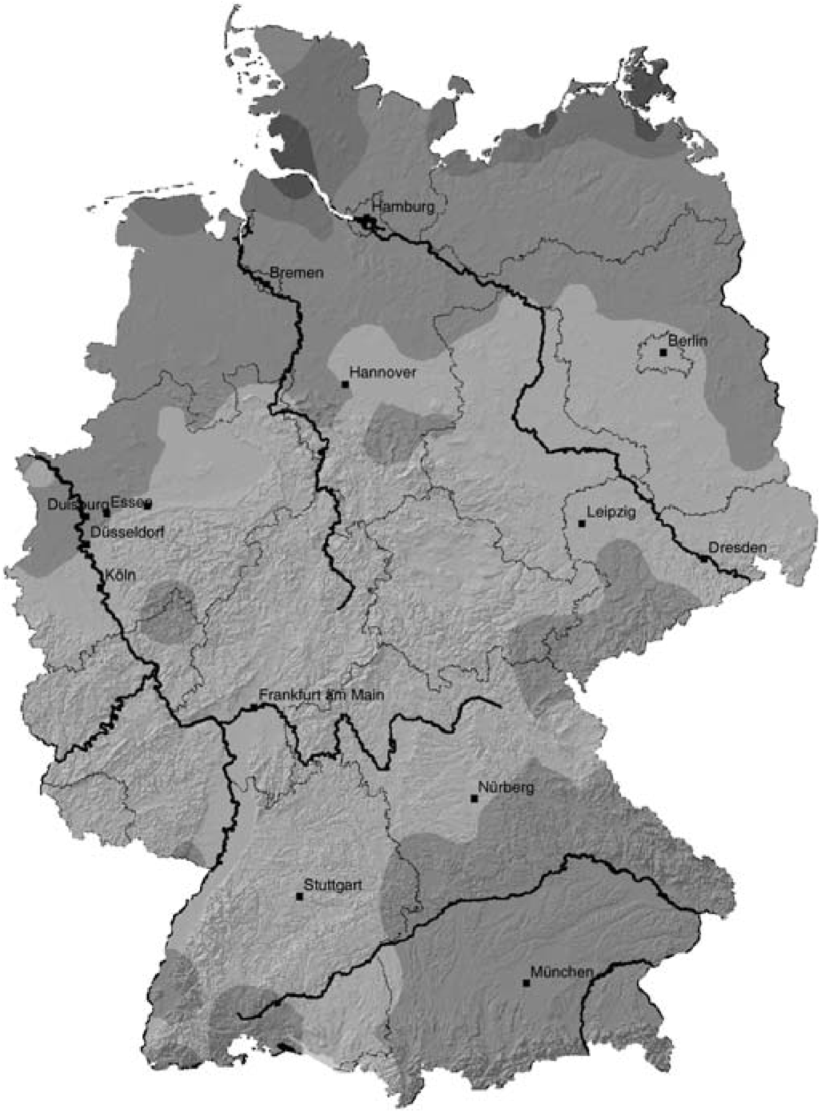

Fig. 2 The new presentation of a spatial risk map for potato late blight.

one single parameter only, the distance to the meteorological stations used for interpolations (ESRI, 2003).

SI uses a basic minimum curvature technique. It ensures a smooth (continuous and differentiable) interpolation, in conjunction with continuous first-derivative surfaces. Because rapid changes in values may occur in the vicinity of the data points, this model is not suitable for the estimation of the second derivative (ESRI, 2003).

The Kriging method is based on a regionalized variable which assumes that spatial variation in the phenomenon represented by z-values is statistically homogeneous throughout the surface. This hypothesis of spatial homogeneity is fundamental to the regionalized variable theory. Spatial variation is quantified by a semivariogram (ESRI, 2003).

Multiple Regression (MR) allows simultaneous testing and modelling of multiple independent variables. Parameters having an influence on temperature, e.g. elevation, slope and aspect, can be tested simultaneously. Multiple Regression uses matrix multiplication and only variables with a minimum influence will be included into the model. The result of MR is a formula ($x = \text{const} + \text{A1*Const}_1 + \text{A2*Const}_2 + \text{A}_3\text{*Const}_3 + ... + \text{A}_x\text{*Const}$) that allows a parameter to be calculated for each grid cell from which independent variables are known (Javis *et al.*, 2003; Zeuner, 2003; Mense-Stefan, 2005).

Interpolation process (data management)

In order to save the results of interpolation, a grid is built over Germany. At the moment the area of Germany (357 050 km^2) is represented by *c.* 570 meteorological stations, which corresponds to one meteorological station for each 626 km^2. A grid cell is 1 km wide which means that after interpolation each square kilometre of Germany is represented by a virtual meteorological station (= grid cell) (Miller, 2000; Liebig & Mummenthey, 2002).

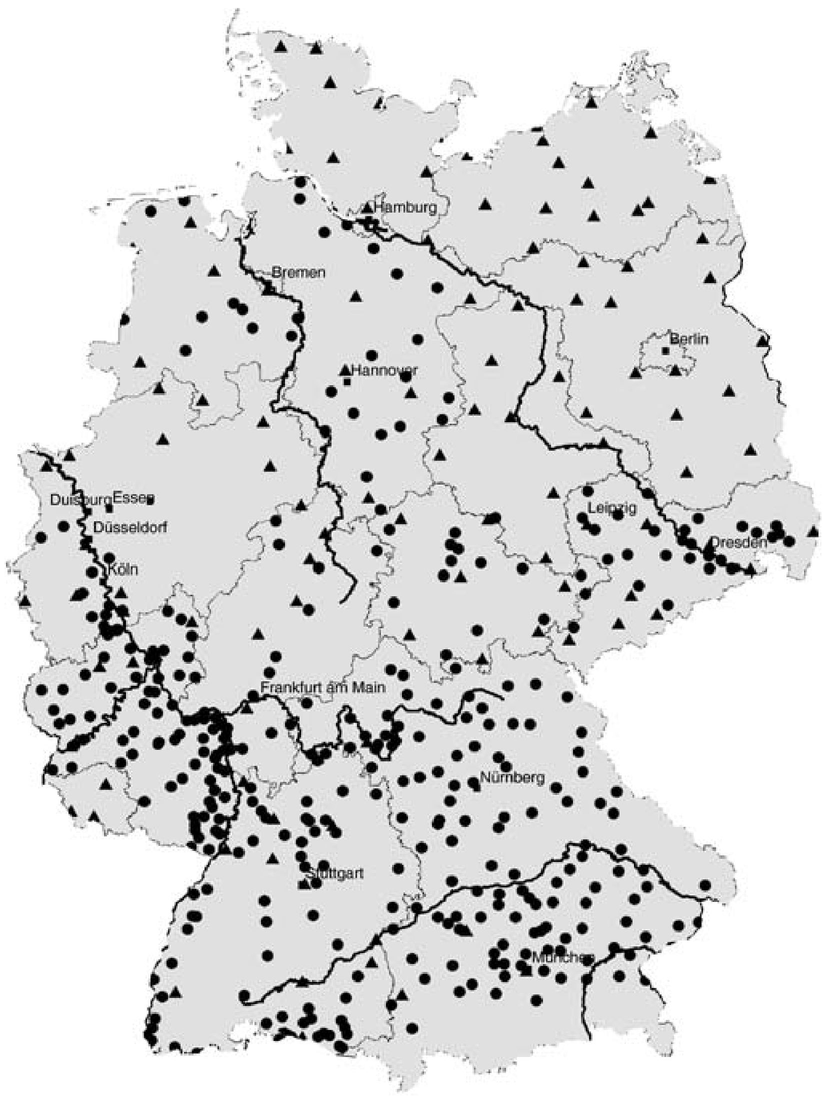

Fig. 3 Network of German meteorological stations. Triangles are stations from the German meteorological service and circles are stations from the GCPS.

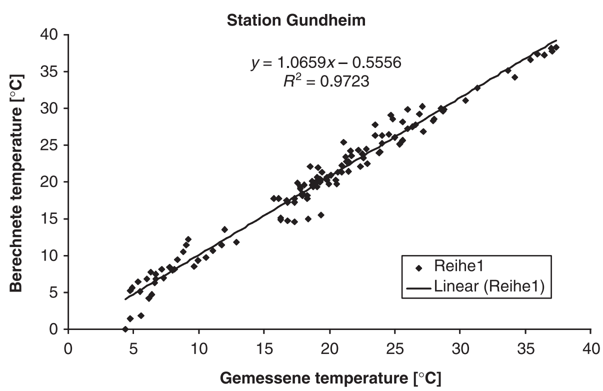

Fig. 4 Comparison of measured and interpolated temperature by the MR method, at the station Gundheim.

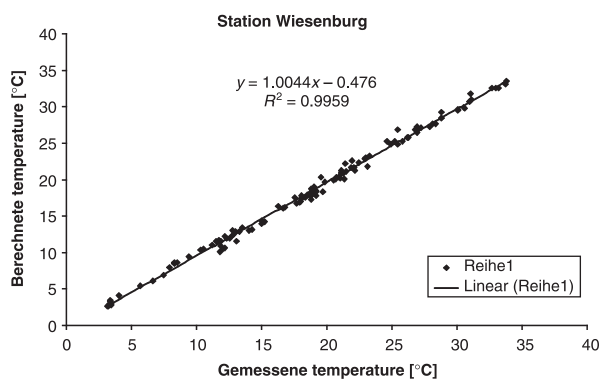

Fig. 5 Comparison of measured and interpolated temperature by the MR method, at the station Wesenburg.

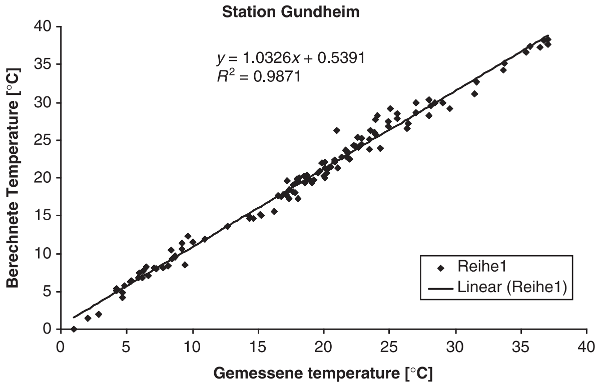

Fig. 6 Comparison of measured and interpolated temperature by the Kriging method, at the station Gundheim.

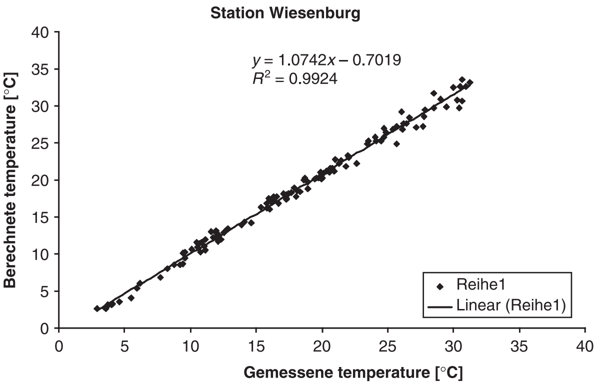

Fig. 7 Comparison of measured and interpolated temperature by the Kriging method, at the station Wesenburg.

Results

Interpolation

The first calculations with these four interpolation methods showed that deterministic interpolation methods were not suitable. IDW and SI methods were rejected due to the fact that differences in elevation could not be accounted for in the interpolation of meteorological parameters. Therefore, we concentrated on geostatistical interpolation methods. The following results show a comparison between the Kriging and MR methods. Temperature and relative humidity were calculated for the period from 2000 to 2005 for two German federal states (Brandenburg and Rheinland-Pfalz). To compare the measured data with interpolated data, some meteorological stations were left out of the interpolation process. After calculation, the interpolated values were compared to the measured values of the meteorological stations. Graphs in Figs 4, 5, 6, 7 and 8 show the results for two meteorological stations which have been left out.

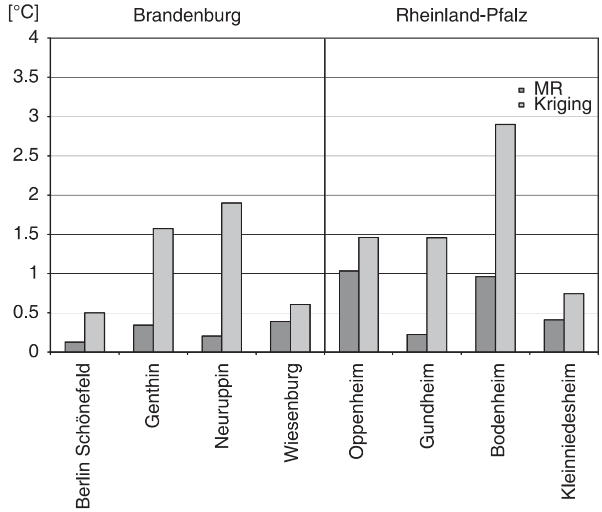

Fig. 8 Mean difference temperature values recorded and calculated by the Kriging and MR methods in Brandenburg and Rheinland-Pfalz.

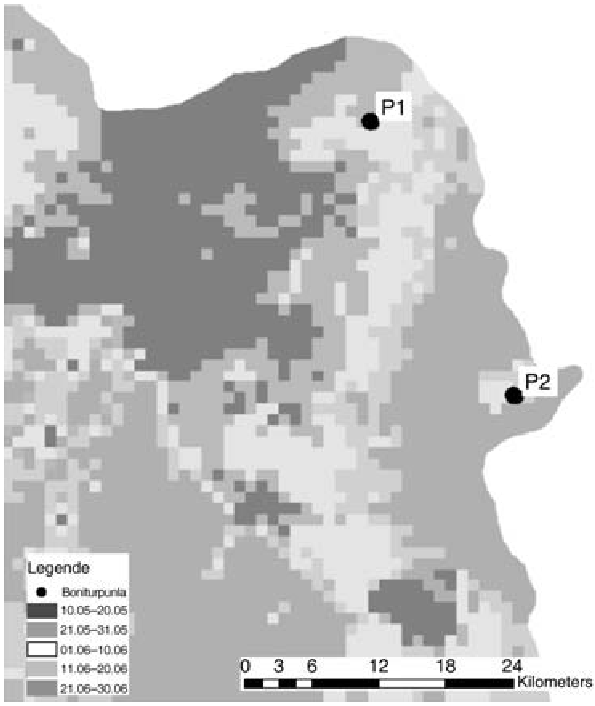

Fig. 9 Spatial risk map calculated by the forecasting model SIMBLIGHT1 with interpolated meteorological data in 2005 for a small region in Rheinland-Pfalz.

In Figs 4, 5, 6 and 7 a comparison between real temperatures and interpolated temperatures at the location of the meteorological stations Gundheim and Westerburg in Brandenburg and in Rheinland-Pfalz is shown. Both interpolation methods in the two federal states were able to calculate results with high accuracy. The coefficient of determination in all cases ranged between 96 and 99%. The results showed no significant differences

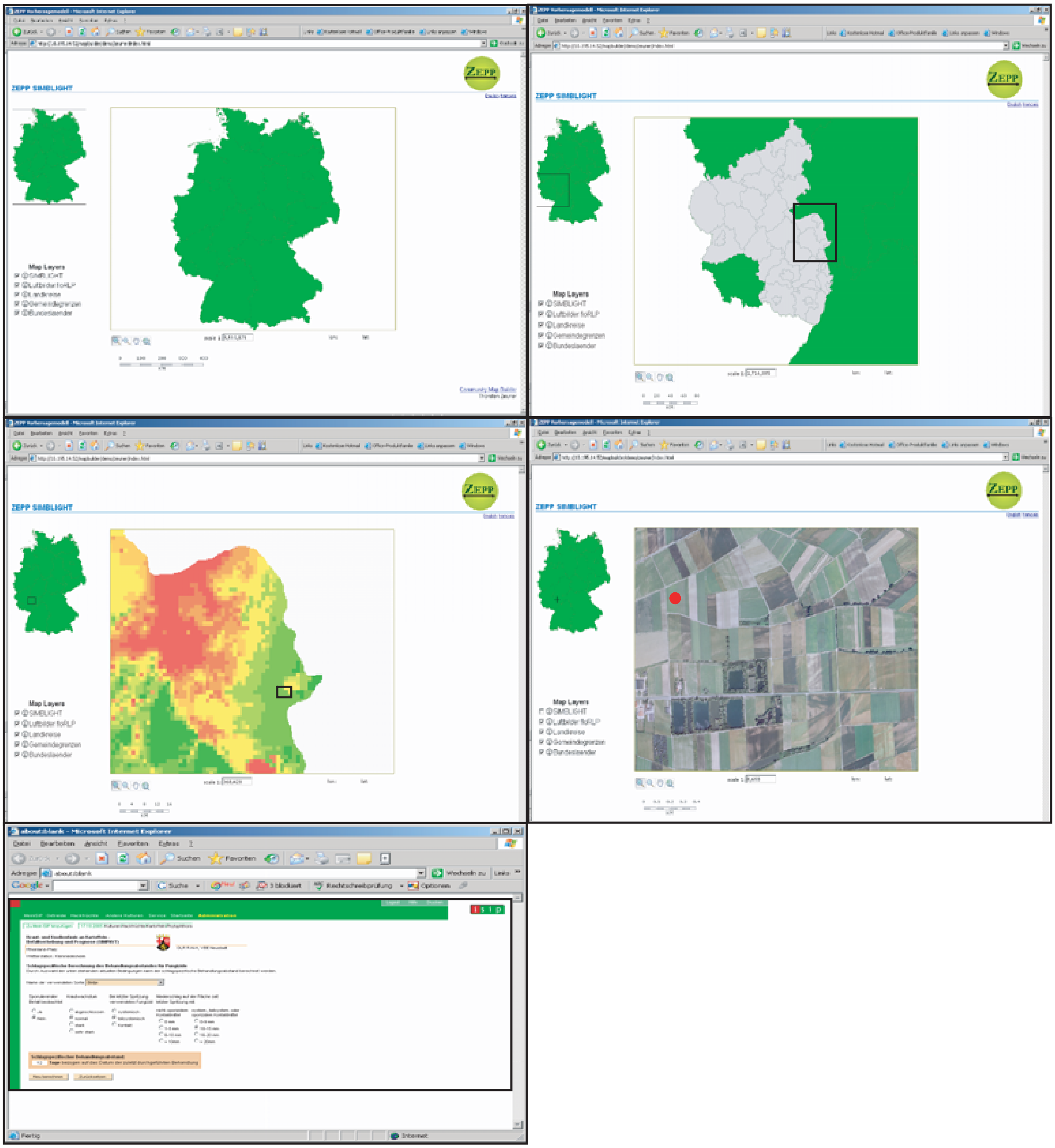

Fig. 10 Example screenshots showing how a farmer can use the DSS in an Internet application.

between the two interpolation methods in both federal states. The differences between the Kriging and MR methods become visible in Fig. 8. The differences between the Kriging values and measured values in both federal states ranged between 0.5 and 2°C. Differences were smaller for MR, ranging between 0.3–1°C. The semivariogramm of the Kriging method did not use the digital elevation model to correct the calculated *z*-value. Therefore, the lack of elevation information could be a reason for the inferior results given by the Kriging method. As a consequence of these analyses, MR was chosen for the interpolation of temperature values.

The interpolation of relative humidity showed similar results compared to temperature interpolation, although calculated values for relative humidity were generally less accurate. The coefficient of determination varied between 92 and 96% and mean differences of the relative humidity were 5–10%

compared to recorded values. Comparison of the two methods revealed differences between the two federal states. In Brandenburg, differences between recorded values and values given by the Kriging method were double than when MR was used. In Rheinland-Pfalz, it was the opposite. Considering the fact that a parallel development with two different interpolation methods was not practical and that MR had provided good results for temperature calculations, it was concluded that MR should also be used for the interpolation of relative humidity.

Forecasting models

Meteological data was interpolated by MR and results were then made available to the forecasting models. Fig. 9 shows the results given by the model SIMBLIGHT1 for 2005 in a small region in Rheinland-Pfalz. SIMBLIGHT1 could forecast the date of first treatment against potato late blight. Calculations differentiate 13 classes of emergence dates. The model is based on the parameters of temperature and relative humidity. Fig. 9 shows areas of high, medium and low risk for the first appearance of late blight in 2005. The model predicted that infection of late blight would start early in the north-western part of the area and spread to the south-east. Two monitoring points (P1 and P2) are displayed in the map. Field records from these monitoring points were used to verify the calculation results. Infections at P1 (in the maximum risk area) were recorded earlier than at P2 (in the low risk area). A time difference of 14 days between the first appearance of late blight at P1 and P2 was recorded, which coincided well with our calculations. The absolute differences between forecasted and recorded dates for first occurrence of late blight were only three days, which must be regarded as a highly accurate result. The slight difference was probably due to an underestimation of relative humidity by the MR method. However, further tests are needed to verify this hypothesis.

Use of the system by the farmers

Results provided by the forecasting models will be made available to farmers via an Internet application. Fig. 10(a) displays the first page of this website. A map of Germany with the 16 German federal states is shown and allows farmers to zoom to one of the federal states in order to get more detailed information. Fig. 10(b) shows the administrative borders of the counties within the federal states of ‘Rheinland-Pfalz’. Farmers then have to choose areas which are of interest to them to zoom the map to display more details, as shown in Fig. 10(c). A new layer is displayed on the map, showing the spatial behaviour of late blight. At a scale of 1: 10 000, the background of the map will change and digital pictures of the area will be presented so that the farmers can find their own fields (Fig. 10d). A mouse click on the field will open a popup window, where the farmer can make a plot-specific calculation for his own field (Fig. 10e). Additional information about his field will have to be inserted, e.g. cultivar or soil tillage, and a plot-specific forecast will be calculated for his field.

Conclusion

The combination of forecasting models with analyses and methods from GIS is a milestone in advising farmers. GIS methods and analyses provide more detailed and more accurate calculations than ever before. In particular, GIS and forecasting models can facilitate the control of potato late blight. A reduction in the number of applications can be achieved, guaranteeing an economical and environmentally friendly crop protection strategy. Results of forecasting models are easier to understand and interpret because, for example, spatial maps can show hot spots of maximum risk. The clear and vivid presentation methods of GIS make the decision support system results easier to understand and lead to a higher acceptance of warning systems by the farmers.

Utilisation de Systèmes d’Information Géographique pour les avertissements agricoles relatifs au mildiou de la pomme de terre

Un des objectifs importants des Services de la protection des végétaux allemands (GCPS) est de réduire l’intensité des pulvérisations de produits phytosanitaires dans le cadre d’une stratégie de protection des cultures plus environnementale. La ZEPP est l’institution centrale en Allemagne responsable du développement des méthodes dont le but est d’améliorer la lutte contre les maladies des plantes. Pour cela, plus de 20 modèles basés sur des données météorologiques ont été développés et appliqués. Cette étude montre qu’il est possible d’améliorer la précision des sorties des modèles en utilisant des Systèmes d’Information Géographique (SIG). L’influence de l’altitude, de la pente et de l’orientation sur les données météorologiques a été interpolée à l’aide de SIG et les résultats ont été utilisés comme entrées dans les modèles de prévision. Les résultats sont présentés sous forme de carte des risques spatialisés sur lesquelles apparaissent les zones les plus à risque pour la maladie. Les méthodes modernes de présentation des SIG permettent à l’utilisateur de visualiser les résultats de façon plus agréable.

Использование Географической информационной системы службами предупреждения в отношении фитофтороза картофеля

В рамках щадящей для экологии стратегии защиты сельскохозяйственных культур одной из важнейших целей Службы защиты растений Германии (GCPS) является сокращение интенсивности опрыскивания. ZEPP представляет собой центральное учреждение в Германии, несущее ответственность за разработку методик и преследующее своей целью совершенствование борьбы с заболеваниями растений; для этого им было разработано и введено в сельскохозяйственную практику более 20 метрологических моделей, основанных на базах данных. Настоящее исследование показывает, что представляется возможным соверш-

енствовать точность результатов применения моделей с помощью Географической информационной системы (ГИС). Влияние высоты над уровнем моря, уклона и общих метеорологических данных интерполировалось с ГИС, а результаты использовались для ввода в модели прогнозирования. Конкретные результаты будут представлены в виде пространственных карт риска, с указанием зон максимального риска заболеваний. Современные методы презентации ГИС позволяют выводить результаты в более удобной для пользователя форме.

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