IDŐJÁRÁS
Quarterly Journal of the Hungarian Meteorological Service
Vol. 113, No. 1–2, January–June 2009, pp. 13–22

Coupled land-air parameterization scheme (LAPS) and non-hydrostatic mesoscale model (NMM) for use in agricultural planning

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(Manuscript received in final form December 5, 2008)

Abstract—Characterization of climatic hazards for agriculture can be done using global circulation models (GCMs) and/or regional circulation models (RegGCMs). The GCMs provide credible information of climate, at least for subcontinental scales, while the RegCMs are used to determine specific characteristics of the weather in mesoscale. Regardless of whether these models provide meteorological data through either long-term or short-term runs, the land surface models are strong links between the underlying surface and the atmosphere. Recently they have been remarkably improved in the segment of the parameterization of turbulent fluxes inside and above the tall grass canopies, making them more relevant, in assessing how regional climate may affect agriculture. Except these schemes many other environmental/agricultural models (UV radiation, plant diseases, crop, irrigation models, etc.), linked with the new generation of non-hydrostatic mesoscale models, can provide highly sophisticated information for farmers and agricultural planners. In this paper we shortly describe environmental models, mostly designed in the Centre for Meteorology and Environmental Predictions, University of Novi Sad (Serbia). All of them are linked with the NMM non-hydrostatic mesoscale model for the purpose of an intensive use in agricultural planning. The description and comments are supported by the corresponding numerical simulations.

Key-words: GCMs model, RegCMs models, environmental/agricultural models, agricultural planning

1. Introduction

Agricultural planning – strategic (long-term) and tactical (short-term) – needs to appreciate climate-related and other risks to attain the producer's goals and spell out the sort of information that farmers need to aid their planning – e.g., climate, technical/management information, market. A key aspect needed in linking climate and weather risk to agricultural planners is to appreciate the overall management system in question from the viewpoint of decision makers. Managers need information for both tactical and strategic decision-making. Climate disasters can be divided into extreme events (e.g., tornadoes, hail, flash floods and severe thunderstorms, effect of prolonged drought and floods) and regional climate anomalies (mesoscale storms, small-scale severe weather phenomena). Global climate change may produce a large number of climatic disaster occurrences. This is based on the fact that a linear increase in the average of a climatic variable implicates a non-linear increase in the occurrence probability of extreme values of the variable. Assessing and forecasting the impacts of short-term climate variability and weather risk, as well as their relationship to extreme events could help mitigate the effects of climate variability and scheduling agricultural activities (*Everingham et al.*, 2002; *Meinke* and *Stone*, 2005).

Characterization of the climatic hazards for agriculture can be done using global circulation models (GCMs) and/or regional circulation models (RegCMs). The GCMs provide credible information of climate, at least for sub-continental scales, while the RCMs are used to determine specific characteristics of the weather in mesoscale. Regardless of whether these models provide meteorological data through either long-term or short-term runs, the land surface scheme is a remarkable link between the underlying surface and atmosphere. This link together with the mesoscale non-hydrostatic model is a base for use a number of environmental models (UV radiation, plant diseases, crop, irrigation, water, and chemical transfer in soil models, etc.) in agricultural science and practice for different purposes, particularly for planning.

The focus of this paper is directed to short description of environmental models, which are available in the Centre for Meteorology and Environmental Predictions (CMEP, in further text), Department of Physics, Faculty of Sciences, University of Novi Sad (Serbia). Most of them are designed in this institution and linked with the NMM non-hydrostatic mesoscale model for the purpose of an intensive use in agricultural tactic and strategic planning (*Mihailovic*, 2005; *Mihailovic* and *Lalic*, 2006). Descriptions are pursued by examples of corresponding numerical simulations.

2. Short overview of the land-air parameterization scheme (LAPS)

We will shortly summarize the main features of the LAPS by setting a focus on the parameterization of processes relevant in agricultural science and practice. The LAPS, developed at the Faculty of Agriculture and CMEP, University of Novi Sad (Serbia), describes mass, energy, and momentum transfer between the land surface and the atmosphere. This scheme is designed as a software package that can be run as part of an environmental model or as a stand-alone one. The LAPS includes modeling the interaction of the land surface and the atmosphere, under processes divided into three sections: subsurface thermal and hydraulic processes, bare soil transfer processes, and canopy transfer processes. They are: interaction of vegetation with radiation, evaporation from bare soil, evapotranspiration including transpiration and evaporation of intercepted water and dew, conduction of soil water through the vegetation layer, vertical water movement in the soil, surface and subsurface runoff, heat conduction in the soil, and momentum transport within and above the vegetation. A single layer “sandwich” approach for canopy is chosen for the physical and biophysical parameterization. The scheme has seven prognostic variables: three temperature variables (foliage, soil surface, and deep soil), one interception storage variable, and three soil moisture storage variables. For the upper boundary conditions the following forcing variables are used: air temperature, water vapor pressure, wind speed, short wave and long wave radiation, and precipitation at a reference level within the atmospheric boundary layer. The surface fluxes are calculated using resistance representation. The soil module is designed as a three-layer model, which is used to describe the vertical transfer of water in the soil. The LAPS uses the morphological and physiological characteristics of the vegetation community for deriving the coefficients and resistances that govern all the fluxes between the surface and atmosphere. The details about this scheme are available in many papers appeared in the last decade. However, the main features and recent redesign of the LAPS scheme can be found in *Mihailovic et al.* (2004) and *Mihailovic et al.* (2008).

3. *The main features of the NMM non-hydrostatic regional model*

In agricultural planning the non-hydrostatic mesoscale model (NMM), designed in the National Centre for Environmental Prediction (*Janjic*, 1994; *Janjic et al*., 2001), with LAPS implemented in it (*Mihailovic*, 2003), is used in providing outputs for other models. The key features of the model are as follows: a fully compressible, non-hydrostatic or hydrostatic model; mass-based sigma-pressure hybrid terrain following system but with constant pressure surface above 400 hPa and Arakawa E-staggering; Adams-Bashforth and Crank-Nicholson time integration schemes; high-order advection scheme; scalar and energy conserving feature; Coriolis, curvature and mapping terms; one-way nesting; lateral boundary conditions suitable for real-data; and one-way nesting and full physics option to represent atmospheric radiation, surface and boundary layer, as well as cloud and precipitation processes. In the running procedure usually for the initial and boundary meteorological conditions, we use the NCEP objective global analysis gridded data with a 1° horizontal increment, for 23 pressure levels (up to 50 hPa). The lateral boundaries of the model domain are available every six hours from the NCEP data. In runs we work with a horizontal increment of $0.222° \times 0.205°$ and a time step of 100 s. In the preparation phase, surface parameters, either observed or predefined (topography, sea surface temperature, soil and vegetation types, soil temperatures and wetness, slopes and azimuths of the sloping surfaces), were interpolated to the model grid. The topographic data set used is the one provided by the U.S. Navy with 10 × 10 arc min resolution. The vegetation data set is available from USGS with 30 arc s × 30 arc s resolution, following the classification by *Dickinson et al*. (1986). For soil textural classes, the UNEP/FAO data set was used, after converting from soil type to soil textural ZOBLER classes (*Zobler*, 1986). Albedo and surface roughness variations were computed in the preprocessing stage according to the vegetation type.

4. BAHUS model for providing the messages of occurrence of plant diseases: A short description

BAHUS is a biometeorological model fully developed in the CMEP. It is designed for providing the messages of occurrence of plant diseases and the proper time for pesticide application (*Mihailovic et al*., 2001; *Mihailovic et al*., 2002). Components of this model are: (1) input module – providing meteorological and biological data that are representative for a selected area; (2) modeling module – consisting of empirical relations and conditions related to the diseases occurrence and the intensity of infection, and (3) output module – giving following messages: risk of infection, duration of incubation period, time of the first symptoms, etc. Depending on the method selected in the modeling module, following meteorological data should be provided by input module: maximum air temperature, minimum air temperature, mean daily temperature, actual values of temperature, relative humidity, precipitation, and the duration of leaf wetness.

In the modeling module, BAHUS uses a method defined by *Mills* (1944), later modified by *Jones et al.* (1980), based on air temperature, relative humidity, and duration of leaf wetness in order to describe the intensity of apple scab infection. Requirements for fire blight blossom infection defined by *Steiner* (1990) are incorporated in degree-days (DD) by Mills (1955) and MARYBLIGHT methods (*Steiner* and *Lightner*, 1992). These methods are based on accumulation of DD and degree-hours (DH), which are defined as a number of degrees over the base temperature during one day and one hour, respectively (*Zoller* and *Sisevich*, 1979; *Mills*, 1955).

5. NEOPLANTA: A short description of the first Serbian UV index model

The numerical model NEOPLANTA is developed by *Malinovic et al.* (2006) in the CMEP. It computes the solar direct and diffuse UV irradiances under cloud-free conditions for the wavelength range 280–400 nm (with 1 nm resolution) as well as the UV index. Effects of O_3, SO_2, NO_2, aerosols, and nine different ground surface types on UV radiation are included. The model calculates instantaneous spectral irradiance for a given solar zenith angle, but there is also a possibility for calculation of the UV index for the whole day at half-hour intervals from sunrise to sunset. Also, there is a possibility of taking into account daylight saving time. Atmosphere in the model is divided into several parallel layers (maximum 40). It is assumed that the layers are homogeneous with constant values of meteorological parameters. The vertical resolution of the model is one kilometer for altitudes below 25 km, and 5 km above this height. The upper boundary of the highest layer in the model is 100 km. The model uses standard atmosphere meteorological profiles. However, there is also an option of including the real time meteorological data profiles from the high-level resolution mesoscale models. The required input parameters are the local geographic coordinates and time, or solar zenith angle, altitude, spectral albedo, and the total amount of gases. The model includes its own vertical gas profiles and extinction cross-sections, extraterrestrial solar irradiance shifted to terrestrial wavelength, aerosol optical properties for ten different aerosol types (*Hess et al.*, 1998), and spectral albedo for nine different ground surface types. Output data are spectral direct, diffuse, and global irradiance divided into the UV-A (320–400 nm) and UV-B (280–320 nm) part of the spectrum, biologically active UV irradiance calculated using the erythermal action spectrum by *McKinley* and *Diffey* (1987), UV index, spectral optical depth, and spectral transmittance for each atmospheric component. All outputs are computed at the lower boundary of each layer.

6. Numerical simulations with coupled NMM – other environmental models

To demonstrate how coupled NMM and different environmental models can provide sophisticated information for tactical and also strategic planning in this field, we designed three illustrative numerical simulations, which are widely recognizable in agricultural practice.

6.1. Use of NMM model with the LAPS scheme for forecasting of extreme temperatures

The air temperature at 2 m is a reliable indicator of the underlying surface's thermal state (i.e., the quality of the surface parameterization), because the surface temperature strongly affects the air temperature at 2 m. This temperature is determined diagnostically. From the diurnal course of 2-meter temperature are derived extreme temperatures, which are variables on the list of key parameters in the agricultural practice. In this case study, we performed a numerical simulation using the above mentioned NMM model coupled with the LAPS surface scheme (*Mihailovic*, 2003; *Mihailovic et al*., 2008). The starting time of the simulation was 00:00 UTC, June 5, 2002, and the simulation period was 24 hours. The domain (*Mihailovic et al.*, 2008) was centred in 45.0°N, 19.0°E with (101, 99) cells distributed longitudinally and latitudinally. The domain had 651 grid cells. The cover types include water (22.7%), crops (i.e., short grass canopies) (39.9%), tall grass (4.3%), short grass patches (3.2%), evergreen needle leaf (2.6%), deciduous broadleaf (4.3%), and mixed woodland (23.0%), while the soil textural classes were water (22.7%), loamy sand (4.5%), sandy loam (11.5%), silt clay loam (36.6%), clay loam (19.7%), sandy clay (2.5%), and silt clay (2.5%). *Fig. 1* shows air temperature values obtained from the NMM plotted against observed values taken from the SYNOP data set of June 5, 2002. It compares the temperature extremes. For the temperature extremes, the simulated maxima are in better agreement with the observations than the simulated minima.

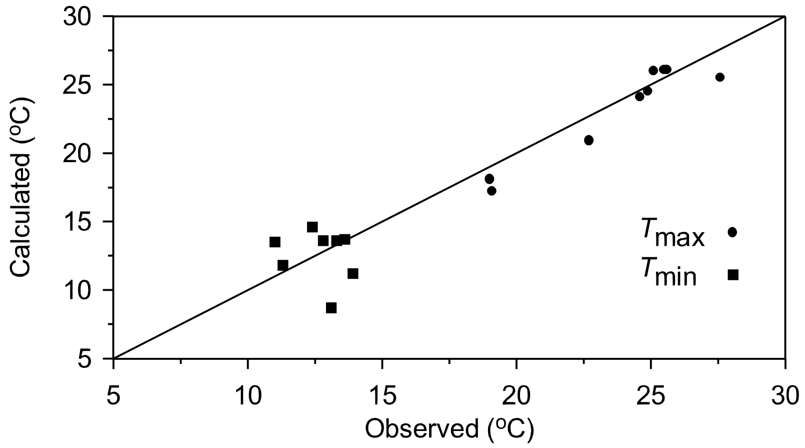

Fig. 1. Air temperatures at 2m obtained by the NMM (including LAPS) plotted against the observed values taken from the SYNOP data of June 5, 2002). Comparison for the temperatures extremes.

6.2. An example of use the BAHUS model linked with the NMM model for plant diseases prediction

In this numerical simulation we demonstrate an example of the assessment of meteorological conditions suitable for appearance of: (i) apple fire blight (infection intensity ranged as none, low, moderate, and high), (ii) grape downy mildew (duration of incubation period), and (iii) potato late blight (duration of incubation period) for Novi Sad area during spring period in year 2008. In the forecasting procedure we supposed, based on our experience, that biological conditions were satisfied: (i) for apple (flowering) after March 15 and (ii) grape and potato (certain stadium of growth) after April 20. Weather data file of the BAHUS input module included the following elements: (i) data from SYNOP data set describing previous weather conditions and (ii) the NMM model outputs including predicted state of weather (*Fig. 2*). Using these data the BAHUS model has been continuously run after March 15, in order to assess disease appearance risk on daily bases. Obtained results are presented in *Table 1*.

According to BAHUS model, until May 5, thermal and humidity conditions for fire blight, downy mildew and late blight appearance were not auspicious. Although on April 11 air temperature exceeds lower threshold for fire blight DH accumulation (*Fig. 2*), it was obvious that following temperature decrease will cause termination of the disease development process. On May 12, according to air temperature forecast (*Fig. 2*), at the end of the incubation period, downy mildew has been expected in next two days, while, in case of fire blight, epiphytic infection potential (EIP) should pass 100% on the same time. On May 26 and June 18, suitable conditions were also recorded for downy mildew appearance. However, for incubation period starting on June 12, a little bit longer duration has been expected due to forecasted temperature decrease (*Fig. 2*).

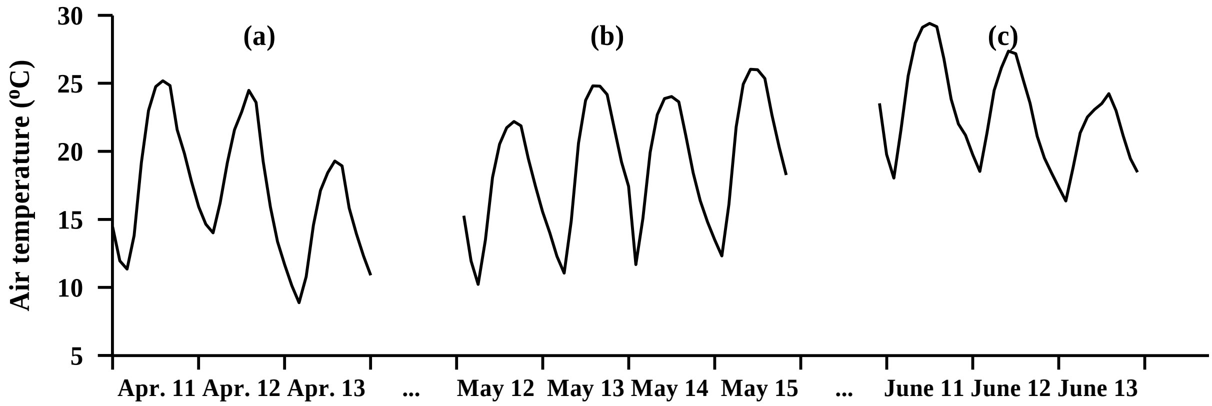

Fig. 2. NMM model forecast of 2m air temperature for periods: (a) April 11–13, (b) May 12–15, and (c) June 11–13 for year 2008.

Table 1. Simulated assessment of disease appearance (i.p. = incubation period) based on meteorological conditions

Date/Disease	Fire blight	Downy mildew	Late blight
Before April 11	no risk	no risk	no risk
April 11	hi risk – no infection	no risk	no risk
April 12	medium risk – no infection	no risk	no risk
April 13	medium risk – no infection	no risk	no risk
April 14	no risk	no risk	no risk
Before May 12	EIP = 15.7 – no infection	less than 2 days till the end of i.p.	no risk
May 13	EIP = 64.1 – no infection	end of i.p.	no risk
May 14	EIP = 123 – infection		no risk
Before May 26		last day of i.p.	no risk
Before June 11		i.p. in progress	end of i.p. in next 7 days
Before June 18		last day of i.p.	

6.3. The NEOPLANTA model for UV radiation prediction and its use in assessment of climate change impact on development of plant diseases

Based on an assessment of important diseases of wheat and other cereals, sugarcane, deciduous fruits, grapevine, vegetables, and forestry species, climate change may reduce, increase, or have no effect on some diseases (*Chakraborty et al.*, 1998). Changes will occur in the type, amount, and relative importance of pathogens and diseases. Host resistance may be overcome more rapidly due to accelerated pathogen evolution from increased fecundity at high CO_2 and/or enhanced UV-B radiation. However, uncertainties about climate change predictions and the paucity of knowledge limit our ability to predict potential impacts on plant diseases. Both experimental and modeling approaches are available for impact assessment research.

For the purpose of this paper we demonstrated the performance of this model by comparing UV index values, obtained by the coupled NMM and NEOPLANTA, with measurements recorded with a Yankee UVB-1 biometer (see *Yankee Environmental Systems Inc*., 2000). For the test, we have selected data for ten days, measured in the years 2003, 2004, and 2005, with cloudiness less than 0.2. The device used is located at the Novi Sad University campus (45.33^{o}N, 19.85^{o}E, 84 m a.s.l.). All other details about model run can be found in *Malinovic et al.* (2006). *Fig. 3* depicts comparisons between the calculated diurnal variations of UV index for cloudless days in 2003, 2004, and 2005. From this figure, it is seen that the NEOPLANTA model gives values that are very close to the observations.

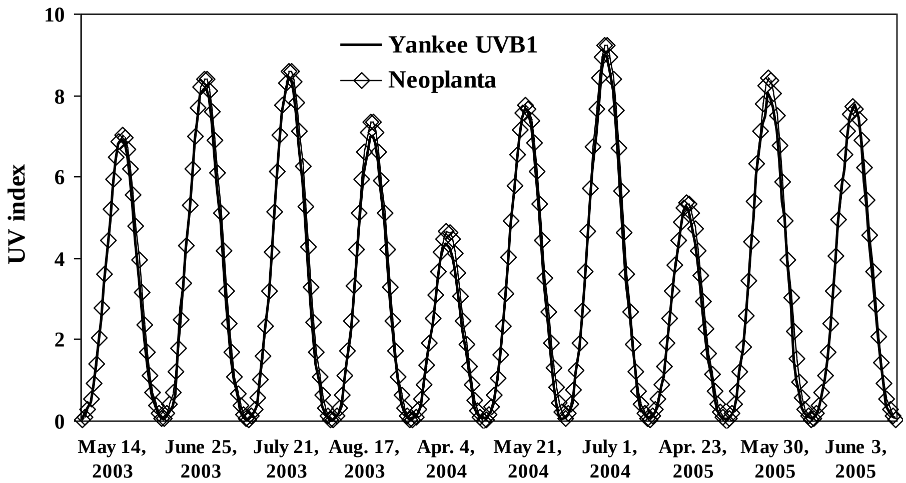

Fig. 3. Variation of UV index obtained by the NEOPLANTA model compared with the observations in Novi Sad for cloudless days.

As the development and implementation of mitigation strategies take long time, more research is urgently needed and we hope this paper will stimulate interest. For example, it is planned to carry out further research on the risk of the damages and yield losses in orchards and crop fields by plant diseases, increased UV radiation, and heat waves as a consequence of climate change. It will be done on the basis of analysis of outputs obtained by running (i) climate ECHAM model, (ii) regional NMM model with the LAPS scheme, (iii) NEOPLANTA UV radiation model, (iv) BAHUS model for forecasting the occurrence of plant diseases, and (v) a selected crop model. This assessment is particularly important for the central and southern parts of Europe which are potentially the most vulnerable regions in Europe regarding the climate change. It was one of the main reasons why the NEOPLANTA model has been developed, tested and prepared as a user friendly software that can be easily linked with the NMM model.

7. Conclusions

We considered a wide range of possibilities for use of coupled mesoscale non-hydrostatic model and land surface scheme for application in agriculture planning on both tactical and strategic levels. Specifically, in this paper we shortly described the NMM non-hydrostatic model and the LAPS scheme. Additionally, we briefly elaborated two environmental models (BAHUS – for prediction of plant diseases and NEOPLANTA – for prediction of UV radiation) which are fully developed in the Centre for Meteorology and Environmental Predictions, University of Novi Sad (Serbia). Finally, we performed numerical simulations with the coupled NMM-LAPS model and the aforementioned environmental models, giving three examples of forecasting the quantities which are on the list of key parameters that are important in agricultural practice and its planning activities.

Acknowledgement—The research work described in this paper has been funded by the Serbian Ministry of Science under the project "Modeling and Numerical Simulations of Complex Physical Systems", No. OI141035 for 2006-2010.

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