17th European Symposium on Computer Aided Process Engineering – ESCAPE17
V. Plesu and P.S. Agachi (Editors)

Global modelling with LIS for water pollution

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Abstract

In this paper it is presented an application from the category of land surface models (LSM) that analyzes the impact of water pollution. The application is land information system (LIS). There are used models for energy balance and models for different fluxes involved in this process.

Keywords

Land surface models, land information system, aquatic medium, vegetation, simulation

1. Introduction

A great challenge in the process of predicting natural phenomena was the huge volume of data to be considered. But, with the undergoing technological process this inconvenient has been overcome and software for simulating environmental processes have gained an increased importance. For this reason numerous systems have been developed in the last years, but the main problems that occur are:

- If the system is too complex it takes too much to be loaded or it requires considerable amount of data.
- If the system is too simple then its features may be too restrictive and may not take into consideration every possible situation.

In this paper we shall present a simulation realized with LIS describing the dynamic of air – soil – water evolves in the process of water pollution.

2. Problem Statement, background

LSM represents systems for prediction of land dynamics of water, energy, air, soil and of various biochemical reactions. These systems are based on equations of soil, vegetation, water (in all aggregation forms).
The pioneers of the weather prediction systems were Vilhelm Bjerkness and Lewis Fry Richardson (in the early twenty century). From that moment since today a lot of systems have been developed. Among the most recent LSMs are for example, the systems developed by Foley et al.1996 [1], Dai and Zeng 1997 [2], Walko et al. 2000 [3], Oleson et al. 2004 [4], Land Information System [5].
LIS wines NASA's 2005 Software of the Year Award. This software was developed also in the spirit of "open source". The LIS software system consists of the following components:

- LIS driver: the core software that integrates the use of LSMs, data management techniques, and high performance computing.
- Community land surface models such as CLM2, Noah, and VIC
- Visualization and data management tools such as GrADS -DODS server

Water pollution has direct fatal effects on the aquatic ecosystems, but in the same time, indirect noxious effects on all the other ecosystems. The dependence between all the ecosystems can be very well modelled with LSM.
The parameters used in the equations of the model can be estimated by the specific measurement. The pollution of the diverse ecosystems depends also of the pollutant. For example in the Cadmium case, the Cadmium concentration does not have to be taken into account due to diffusion exchange between atmosphere and leaves , since cadmium is not present in the steam. One of the most known examples of the noxious effect of water pollution is acid rains, where evaporation of the water from the lakes is one of the ways of participation of SO_2 in the acid rains formation. [6]

3. Paper approach

3.1. Methodology

The model used for simulation is LIS. The structure of LIS is presented in the figure 1.

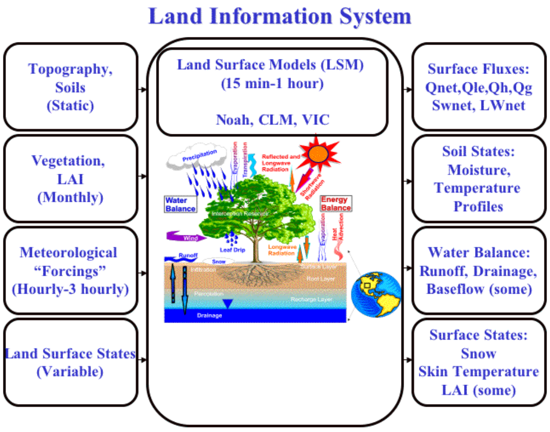

Fig. 1. – The structure of LIS

The initial model CLM has one vegetation layer, 10 unevenly spaced vertical soil layers, and up to 5 snow layers, depending of the snow depth.
The two balances used in the model are water balance and energy balance. For modelling a certain system, both of them are used. In our simulation, the main process taken into account is the vaporization in the lakes that depends of the energetic flux at the surface of the lake.
The energy balance model accounts all energy coming in and all energy going out of a certain system. No energy is accumulated: the system is in equilibrium. In our simulation, the system is the Earth. The energy balance equation is:

$$Q^* = K^* + L^* = Q_H + Q_E + Q_G \qquad (1)$$

where
- K^* is the net shortwave radiation
- L^* is the long wave radiation
- Q^* is the net all-wave radiation, which is the balance between K^* and L^*
- Q_H is the sensible heat flux
- Q_E is the latent heat flux
- Q_H is the subsurface heat flux

3.2. Experimental arrangement

The process simulated is the vaporization in the lakes. The amount of energy per unit mass necessary for vaporization is called the heat of vaporization or latent heat of vaporization given by:

$$L = (2500 - 2.29 * T) * 10^3 \qquad (2)$$

where T is the lake water temperature.
The equation for lake temperatures is adopted from the one-dimensional six-layer thermal stratification model in Bonan LSM model [7].

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left[(k_m + k_e)\frac{\partial T}{\partial z}\right] + \frac{1}{c_w}\frac{d\Phi}{dz} \qquad (3)$$

where

- T – Lake temperature (K)
- k_m – Molecular diffusion coefficient ($m^2 s^{-1}$) and $k_m = k_w/c_w$
- k_e – Eddy diffusion coefficient ($m^2 s^{-1}$)
- k_w – Thermal conductivity of water ($W m^{-1} K^{-1}$)
- c_w – Heat capacity of water ($J m^{-3} K^{-1}$)
- Φ – Solar radiation heat source term ($W m^{-2}$)

The Eq. (3). is solved numerically and calculates temperature for six-layer deep or shallow lakes. The boundary conditions are zero heat flux at the bottom and the net flux of energy at surface F_0 ($W m^{-2}$):

$$F_0 = \beta S_{n,g} - \left(L_{n,g} + H_g + LE_g + M\right) \qquad (4)$$

where

- $S_{n,g}$ – Solar radiation absorbed by the lake ($W m^{-2}$)
- $L_{n,g}$ – Net long-wave radiation ($W m^{-2}$)
- H_g – Sensible heat flux ($W m^{-2}$)
- LE_g – Latent heat flux ($W m^{-2}$)
- M – Snow melt ($W m^{-2}$)
- β – Fraction of solar absorbed in the surface layer

3.3. Case study

The simulation is useful for analyzing the boundary condition for the net flux of energy at surface, described in the Eq. (4). The variable $S_{n,g}$ is specific for each type of lake and depends of the chemical structure of the water compounds.
The factors $L_{n,g}$, H_g, LE_g, M are simulated in the LIS, in connection with the CLM between 30^0 N – 50^0 N latitude and 20^0 E – 30^0 E longitude. In the next section are presented the results of the simulations. Better results will be obtained with the Noah and VIC models, which are also embedded in LIS.

3.4. Results and discussions

With the next forth simulations can be calculated the flux of energy at surface of the lake. We have to consider that accordingly with the chosen period (11 June 2001), the snow melt is constant and equal with 0 for all the country

3.4.1. Net long-wave radiation

The net long-wave radiation is determined by the absorbed incoming long wave radiation and outgoing long wave radiation. The irradiance and frequency of the emitted radiation increase with temperature.

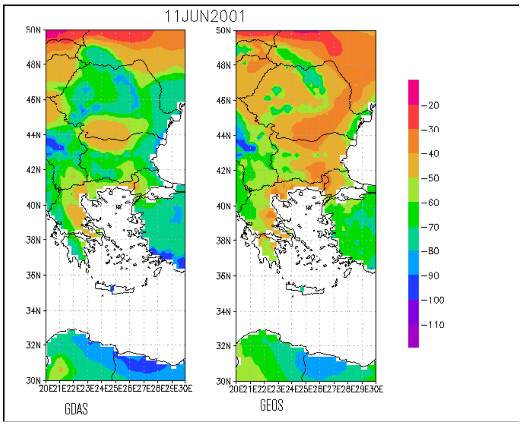

Fig. 2. – The simulation for Ln,g

3.4.2. Sensible heat flux

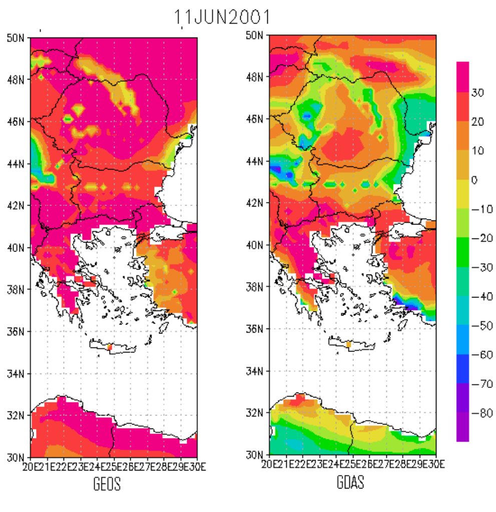

Fig. 3. – The simulation for H_g

Heat is transferred by molecular and turbulent sensible heat transfer. The boundary layer structure and heights would be different in function of the input conditions. For realizing the simulation, like for net long-wave radiation, two different models of datasets were used: GEOS (Goddard Earth Observing System) and GDAS (Global Data Assimilation System). The update frequency for GDAS is every 6 hours and the update frequency for GEOS is every 3 hours.

3.4.3. Latent heat flux

The latent heat flux is directly proportional with the evaporation. Naturally, the evaporation in the mountains is lower than in the rest of the country.
We used LIS for ¼ degree. For a greater precision it is indicated to use LIS for *5 km* or *1 km* areas that involve more important hardware resources.

4. Conclusions/Remarks/future work

Predicting the evolution of natural phenomena as well the impact of human action on natural environment may be the first necessary step in developing a strategy for maintaining Earth's natural balance.
For the future work we plan to make measurements of different pollutions in the Romanian's lakes and to continue the simulations for observing the impact of the pollutions on the surroundings. This work wants to be one of the first projects developed in Romania for demonstrating the influence of the water pollution by simulation that takes into account all the environmental parameters.

References

1. J.A. Foley. I.C. Prentice, N. Ramankutty, S. Levis, D. Pollard, S. Sitch, A Haxeltine. An integrated biosphere model of land surface processes, terrestrial carbon balance, and vegetation dynamics. 1996, Global Biogeochemical. Cycles, 10(4), 603-628
2. Y. Dai. Q. C. Zeng. A land surface model (IAP94) for climate studies. 1998, Advances in Atmospheric Sciences, 14, 433-460
3. R. L. Walko, L.E. Band, J. Baron, T.G.F. Kittel, R. Lammers, T.J. Lee, D. Ojima, R.A. Pielke, C. Taylor, C. Tague, C.J. Tremback, P.L. Vidale, Coupled atmosphere-biophysics-hydrology model for environmental modeling, 2000, Journal of Applied Meteorology 39: 931-944
4. K. W. Oleson, Y. Dai and Coauthors. Technical description of the Community Land Model (CLM). NCAR Tech. Note TN-461+STR, 2004
5. NASA Goddard Space Flight Center - Land Information System. http://lis.gsfc.nasa.gov
6. V.F. Krapivin, C. Nitu, V. Yu. Soldatov. Computer simulation of acid rains, Suceava, Romania, 2006
7. G. B. Bonan. A land surface model (LSM version 1.0) for ecological, hydrological, and atmospheric studies: technical description and user's guide. NCAR Technical Note. National Center for Atmospheric Research, Boulder, Colorado, 1996