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Integrated modelling software platform development for effective use of ecosystem models

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ABSTRACT

Ecological modelling is increasing in importance to facilitate the development of sustainable management planning of terrestrial ecosystems and integrate social and economic objectives. As models have become more complex and include many state variables, modelling software platforms have been developed to support development projects. However, few modelling software platforms integrate software components or applications to facilitate the interpretation of simulation results. Recent advances in computing technology and the increasing availability of free or open-source software allow the efficient integration of different software applications to support modelling development efforts and analysis of simulation results. The application AMSIMOD ("Application for the Management of SImulation MODels"), which was developed to manage the ZELIG-CFS gap model, is introduced as an example of an integrated modelling software platform to facilitate and analyze simulation results with the stand visualization system and the Quantum GIS geographic information system. Future advancements in the development of this type of modelling platform are discussed. Typical frameworks for model management and analytical applications should have the capacity to manage several models and simulation results at different spatial scales and the ability to generate management scenarios. Also, end users should have access to various types of reporting tools and analytical and numerical processing utilities.

1. Introduction

The development of ecosystem simulation models to predict the dynamics of terrestrial ecosystems is at the heart of ecological modelling. Ecosystem simulation models, through the application of the basic principles of systems analysis, have contributed to improving the understanding of the processes that govern ecosystem dynamics (see Doren et al., 2009; Sierra et al., 2009). They have also been used to predict the impacts of different types of disturbances (Klenner et al., 2000). Due to environmental concerns expressed by the public, ecosystem models are increasingly being used to ensure the sustainable management of terrestrial ecosystems and the integration of social and economic objectives (Kelly et al., 2013). Indeed, it is increasingly recognized that management planning requires predictions of ecosystem dynamics and simulation models are among the most robust tools to achieve this goal (Seidl et al., 2012).

As knowledge on ecosystem processes and dynamics has improved, many ecosystem models have become inherently more complex in the representation of nonlinearity in the processes and feedback mechanisms and heterogeneous spatio-temporal variability. However, the causal relationship between model complexity and predictive capacity still remains controversial (Larocque, 2012). Even if model complexity in terms of representation of processes and feedback mechanisms might not generally increase as much as might be anticipated in the forthcoming decades, it is likely that ecosystem models will simulate more processes with different degrees of complexity in the algorithms, contain more state variables representing ecosystem components or processes and will be increasingly integrated. Jakeman and Letcher (2003) identified five types of integration: (1) combined treatments of widely different subjects, such as environmental, economic and social issues; (2) involvement of stakeholders in the modelling process; (3) use of a complex systems perspective merging knowledge from different disciplines; (4) combination of biological, chemical or physical processes and models in a unified

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system; and (5) linkages of different temporal and spatial scales. In particular, one of the reasons that will justify the intensification of model integration is that decision-makers on ecosystem management issues will require knowledge information from different disciplines (Kelly et al., 2013). For effective implementation and use of more complex or large integrated models, there is a need for efficient integrated modelling software platforms.

Advances in computer technology in recent decades, including the exponential increase in the performance of computers and progress in software engineering such as modularity or object-oriented designs (e.g., Voinov and Shugart, 2013; David et al., 2013), have led to the development of large simulation systems with efficient execution times and of modelling software platforms to create and manage ecological models (Voinov and Fishwick, 2008; Scheller et al., 2010; Yang et al., 2011; Kelly et al., 2013). Many modelling software platforms have been developed. They were classified in three groups by Lorek and Sonnenschein (1999): software frameworks, modelling tools and simulators. Software frameworks are applications with utilities that facilitate the programming of simulation models using languages, such as C++ or logo, within an integrated development environment. Good examples are ECOSIM (Steenbeek et al., 2013), NetLogo (Wilensky, 1999) and Source Integrated Modelling System (Welsh et al., 2013). Modelling tools consist of applications with user-friendly graphical interfaces to develop models, automate their execution and display results. Good examples include Stella (Richmond, 2004) and ProbMoT (Čerepnalkoski et al., 2012). Thus, modellers focus more on modelling concepts than programming. Simulators include applications that are based on the use of a specific model. They do not allow users to modify the code, but the values of parameters can be modified for adaptation to specific ecosystem types or conditions. Simulators are best suited to meet the needs of ecologists who do not develop models, but conduct experiments using existing models. A good example is the Universal Simulator (Holst, 2013). In addition to the examples mentioned above, many other efforts resulted in the development of rich and useful modelling platforms that have facilitated modeller's work by significantly reducing the time required for programming and by facilitating the visualization of simulation results. In particular, the advent of graphical user interfaces has greatly improved the examination of simulation results on high-quality line or scatter graphs or histograms. These user-friendly graphical interfaces are essential for visualizing the patterns of change in the variables of interest. Examining only the simulation results at the end of the simulation period is not sufficient. For instance, examining how predicted species abundance in grassland or forest ecosystems change over time may allow users to draw inferences on potential successional pathways. The abundance of some species may grow and decline, oscillate or simply decline. The examination of ecosystem dynamics over time may allow model users to modify simulation conditions or parameters based on previous results.

However, the majority of modelling platforms either facilitated the model development process or provided user-friendly visualization graphic interfaces. As far as can be evaluated from the literature in ecological modelling, there are relatively few integrated modelling software platforms, with different applications integrated within the same application framework to efficiently display simulation results in different scales or formats or conduct complex numerical analysis. For instance, the dynamics of forest ecosystems can be simulated at the individual-tree, sample plot, landscape or regional levels. The possibility of displaying and analyzing these different types of simulation results at different scales using graphics, Geographic Information Systems (GIS) or numerical analysis tools within an integrated environment can greatly simplify the work of modellers and end users (Steenbeek et al., 2013). There are many GIS or numerical analytical applications that can be used independently of each other, but considerable time can be wasted in transferring simulation results between applications. First, there are compatibility issues between applications, such as data format. Second, the management of different types of simulation results in different output files can quickly become cumbersome, particularly when they are exported to other applications. Third, license issues may prevent software integration, especially for commercial software. However, the increasing availability of sophisticated free or open-source software allows the development of integrated tools. The integrated approach used by Steenbeek et al. (2013), one of the few examples developed specifically for the modelling of terrestrial ecosystems, combines modelling tools and GIS.

Due to the variety of ecosystem models available and requirements of model developers and end users, it is unlikely that a single software platform can meet all the needs with respect to model development facilities, visualization of simulation results and numerical analysis. For this reason, there must be a compromise between the level of complexity in the modelling platforms and analytical tools that can be used to manage as many models as possible. In this paper, we introduce an example of an integrated modelling software platform used to facilitate the management of the simulations of a forest succession model and display simulation results. Future directions in the development of integrated modelling software platforms are discussed.

2. Example of an integrated modelling software platform: AMSIMOD

AMSIMOD ("Application for the Management of SImulation MODels") is an integrated modelling software platform that was developed to manage the simulations of the ZELIG-CFS gap model (Larocque et al., 2011a,b). Even though the software platform was originally designed for the management of ZELIG-CFS, the following functional requirements were considered important to facilitate the use of AMSIMOD for other models in the future:

- The platform must be user-friendly, with meaningful menus and submenus strategically located in the main window of the integrated modelling software platform. Therefore, users should not have to read an extensive user's manual to understand the basic functionalities.
- The executable version of the model must be independent of AMSIMOD. Thus, a particular model can be compiled independently using programming languages such as Fortran, C/C++ or C# and be made available to AMSIMOD upon request.
- Three groups of users were identified: (i) researchers developing ecosystem models, (ii) decision-makers who are responsible for the management of terrestrial ecosystems and (iii) undergraduate and graduate students who use ecological models to learn about ecosystem functioning or are being educated in modelling. It is assumed that these users need a software platform that will enable them to conduct simulations with ease and visualize results in different formats.
- Functional linkages with other applications must be automated as much as possible.

2.1. The ZELIG-CFS model

ZELIG-CFS originates from ZELIG, a gap model with the basic structure of JABOWA and FORET, that was originally developed by Urban (1990, 2000) and Urban et al. (1991). It simulates competition between individual trees, the occurrence of single-tree mortality and regeneration. Tree growth and seedling establishment depend on the intensity of light interception, a site fertility