CLIME DSS: Developing an environmental information system for knowledge transfer.

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Introduction

The CLIME project (http:/clime.tkk.fi, accessed 31.5.2006) investigated the possible effects of climate change on selected European lakes, with the hope of more general applicability of the results. The project combined physical and ecological limnologists, watershed modelers, climatologists, systems analysts, sociologists, and other researchers; and linked them with end-users representing water utility managers, watershed managers, and other decision makers. The project involved, e.g., research on the links between climate and weather on lake dynamics, modeling of watershed processes, and use of models. An important part of the project was development of an information system (IS) for internal use within the project, and, especially, for general use after the end of the project. The main problem to be solved by the IS was thus the transfer of knowledge from the research domain, through the modeling and engineering domain, into the management and decision making domain.

The climate change projections that have been made by climatologists (PRUDENCE project, http://prudence.dmi.dk/, accessed 31.5.2006) imply a major effect on the dynamics of lakes throughout Europe. The projections and the possible implications in different cases contain large uncertainties. The subject, i.e., climate, its change, hydrological processes and material transport in the catchments, characteristics and behavior of lakes is large and extends to economics and social subjects. Climate change is a process which happens over a long time period.

Description, monitoring and management of lakes is an important task and objective of the European Water Framework Directive (WFD) (http://ec.europa.eu/environment/water/water-framework/index_en.html, accessed 31.5.2006). The directive's overall environmental objective is the achievement of 'good status' for all of Europe's surface- and ground-waters by year 2015. The 'status' is defined in WFD as a deviation from 'original, natural condition'. In the current phase (year 2006) the main emphasis of the implementation of WFD is on making the monitoring programs operational and on preparing the River Basin Management Plans (RBMP) for River Basin Districts (RBD) and organizing the associated public consultations. RBMP have an associated Programme of Measures.

Climate change is an issue that has to be addressed beyond RBD and thus it has to be studied and communicated accordingly. RBMP and Programme of Measures have to take into account uncertainties associated with climate change (Environment Agency, UK, 2006).

The problem of knowledge transfer from research to management and decision making is hard. Climate change and other such issues are studied in the academia from the scientific point of view. An interesting problem for a scientist is one that has not been studied before and is intellectually interesting. For the analysis the problem is abstracted, which process is driven by the properties of the natural system and by

the foreseen solution method. None of these issues are often the most relevant to the manager or decision maker. IS development and related research tends to focus on completeness and expressiveness of the solutions. Neither of these do not have much apparent value to the managers of natural systems. The modelers of natural systems typically apply simulation models, which force the focus on, e.g., daily average temperatures and runoffs, and their time series, while the manager may be more interested in, e.g., probabilities of critical situations and required mitigation measures. A scientist aims at understanding a system or an object, while a manager or decision maker is mostly interested in things like schedules, economic risks, and maintenance.

Scientific and technological objectives

The CLIME DSS development project set out to develop a software system, which can be used to inform managers and policy makers of climate change and its potential effects on lakes in Europe. It was essential to incorporate uncertainties into the information presented to the users.

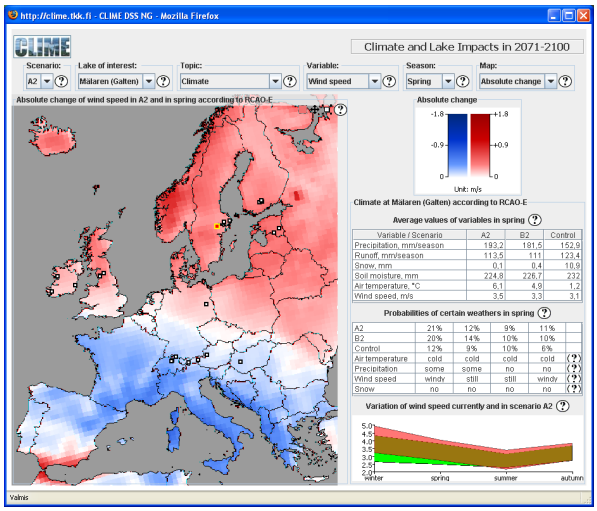
Bayesian networks (BN) (see for example Neapolitan, 2003) was selected in the very beginning as the main methodology to incorporate and transfer the scientific knowledge that CLIME would produce. BN are, in general, tools for probabilistic reasoning. They have become or are becoming an object of much interest in various application areas because of this property and also because of effective solution algorithms that have been developed since late 1980's. The main scientific objective in the development of the several BN that were built in the CLIME project and were later added to the CLIME DSS was elicitation and analysis of expert knowledge and analysis of simulation models and their results.

The development of the CLIME DSS was both a scientific and a technological problem. The objective was to develop a graphical and attractive tool for the user. The main objective of the tool should be to provide information and knowledge, but it should also allow the user to model and analyze his/her case in some rudimentary level. The nature of the DSS as a knowledge transfer tool set the following technological objectives for the software system:

- the information that is provided has to be palatable to a range of users,
- the DSS should support the users in learning and gaining of insight,
- it should be possible to easily update and add to the information the DSS provides,
- the capability to update and add information to the system should be as comprehensive as possible,
- the data model of the DSS should be compatible and linked to the CLIME database

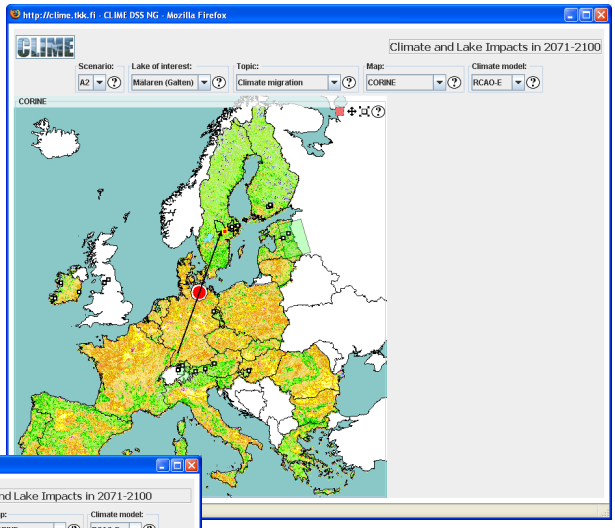
The CLIME database stores information from which the pages of the CLIME website are generated. It also stores information about the research lakes; core meteorological, hydrological, and limnological datasets; and data that is used in the modeling projects. The CLIME database is partly a relational database, whose relational model was designed based on standard or shared data models from other projects, and partly a

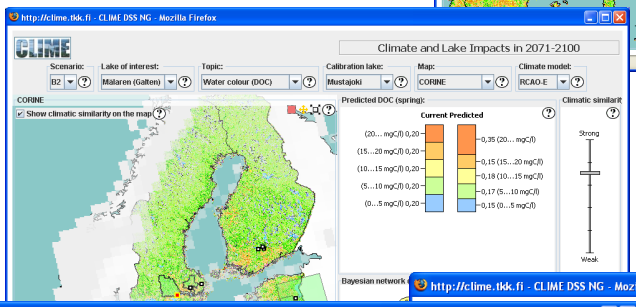
collection of files in a file system. Figure 1. depicts a usage scenario of the CLIME DSS.



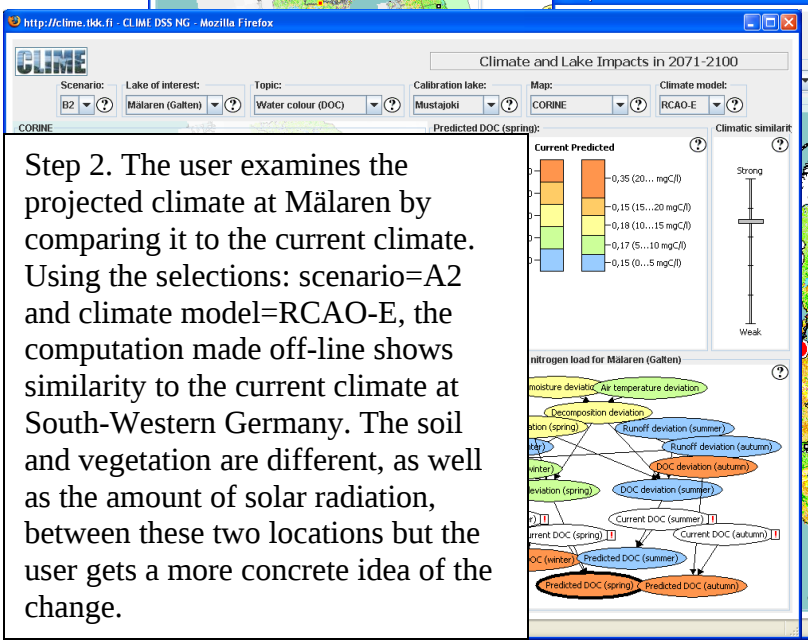
Step 1. The user examines the climate change in Europe and in the selected location. In this case, the user has selected Lake Mälaren (Galten, shown with yellow/red rectangle). On the right side are average values of climate variables in the selected season in current climate and as projections in climate scenarios A2 and B2. Also shown are probabilities of typical daily weather and change in the variation of the selected climate variable (wind speed in this case).

Step 2. The user examines the projected climate at Mälaren by comparing it to the current climate. Using the selections: scenario=A2 and climate model=RCAO-E, the computation made off-line shows similarity to the current climate at South-Western Germany. The soil and vegetation are different, as well as the amount of solar radiation, between these two locations but the user gets a more concrete idea of the change.





Step 3. The user has zoomed into the Nordic countries and is using the results of DOC modeling done at Mustajoki (South Finland) for Lake Mälaren. The climatic similarity is shown on the map and it indicates



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Methodology, scientific achievements, and main results

A methodology for eliciting and using expert knowledge, and using the results of the environmental simulation models in the construction and parameterization of the BN was developed within the project (Koivusalo et al. 2005). Within this domain the problem of filling the conditional probability tables (CPT) of a BN in certain cases was solved (Kokkonen et al. 2005). A method was developed for deriving the CPT associated with a child node and its parent nodes using link strength parameters that are assigned to each link from a parent node to a child node.

The problem of developing an effective DSS was analyzed and an observation was made that the process of using an information providing software system such as the CLIME DSS can be compared to learning. One of the existing paradigms of learning, i.e., Bloom's Taxonomy (Bloom, 1956), proved to be a useful guide in the IS development. Bloom's taxonomy and the reasoning behind it state for example that people advance into the level where they can solve problems using some applications or tools, only after they have acquired the required knowledge and built comprehension skills on top of that.

Web was adopted as the main platform for implementing the CLIME IS, which includes the CLIME DSS. The standard web server was enhanced with

- document server, which builds web pages from a database and text templates,
- RDBMS front end, which serves interactive web pages for managing the CLIME database, and
- DSS server, which provide data and information for the DSS application.

The DSS was implemented as a Java applet, i.e., a software program, which is downloaded from a website and executed instantly. A design goal was to distribute the computational task among the client, the server, and the off-line applications optimally. This helped to maintain the internal logic of both the DSS applet and that of the server relatively simple. The BN and most climate change visualizations were computed off-line (Jolma et al 2005b). Geospatial data is processed and served on-line. The maps are served using the standard WMS protocol. Other geospatial data, most importantly the location specific distributions needed by the BN, are computed by the server on-demand and served as XML messages. The client application contains an implementation of an algorithm, which solves the selected BN with data from a selected location. This architecture (Figure 2.) allows focusing on the usability and easy extending of the system, which further enhances possibilities for using the system in a cooperative manner (Jolma et al. 2005a).

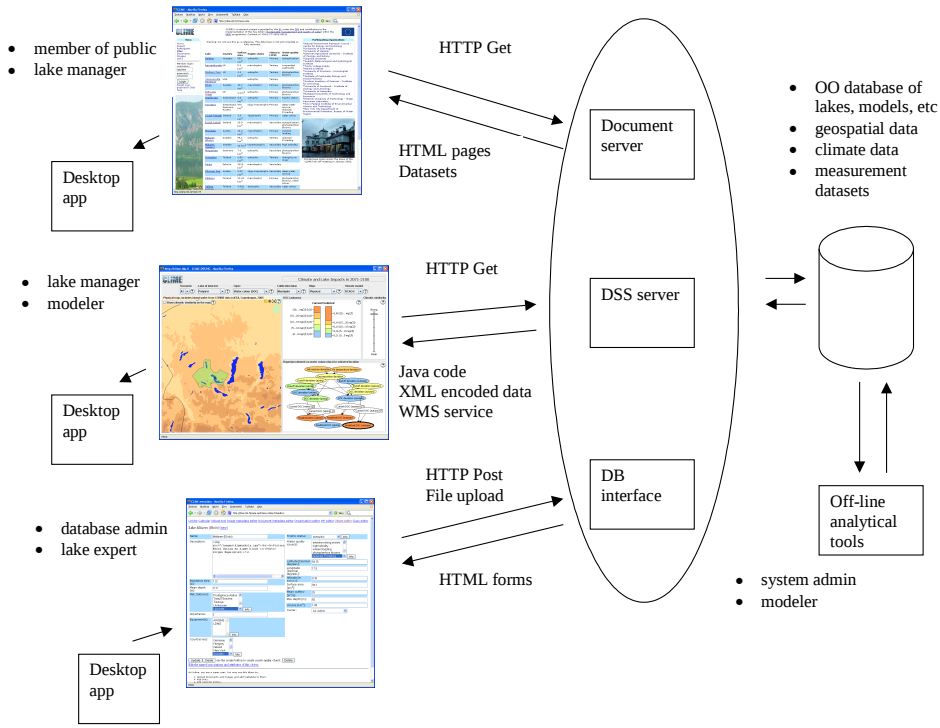

Figure 2. The architecture of the CLIME information system.

Conclusions

The main conclusion from the initial analysis was that the main functionality, which the CLIME DSS has to deliver, is to be an information provider and knowledge transfer tool. Another initial result was the observation that climate change has to be taken into account in the application of WFD, but it is not very clear how.. It was also observed that the CLIME research lakes are very different from each other and pose very different problems for the managers. The time frame of WFD is from few years to ten years, while the time frame in which climate change was studied in CLIME was from 70 to 100 years. CLIME did not study all things related to lakes and lake management and it did not study the inevitable change in land cover on catchments.

The main task of the DSS is to be a part in transferring the knowledge gained in CLIME into more general knowledge. The DSS development project was useful also in a more general sense. It studied the general problems of knowledge processing and transfer and cooperative modeling.

The development of BN showed that it is possible to summarize the results of simulation modeling as BN. Interactive BN are useful in informing about the causal links in the systems and about the associated uncertainties. Experiments with the DSS in applying single BN at different locations with different climatic forcing indicate that limited regionalization of the results is possible. The developed IS provides a functional platform for such a regionalization analysis.

The DSS system as a whole seems to be rather robust and it delivers rather well the required functionalities. It is possible to easily update and add data to the DSS data

storage. The functionality is divided into several logical places making the maintenance rather easy.

The graphical user interface of the DSS applet is very usable in the scope of its design goals. It makes some key characteristics of climate change easy to understand and it introduces the user with the BN approach. The interface allows the user to interact with several BN, which have been prepared for the issues studied in CLIME. It is easy to imagine how the CLIME DSS methodology could be applied to other similar geospatial problems.

Dissemination and exploitation of results

The CLIME DSS will be maintained and, within limits, enhanced by researchers of the Helsinki University of Technology for an unspecified time. Currently some issues regarding dissemination and exploitation of the CLIME DSS are still open. The issues include:

- Will the CLIME DSS be open to public?
- Will the CLIME DSS be hosted at some other organization?
- Should the CLIME DSS be exploited as such or would it be more useful to derive more specific (geographically or problem-wise) system from it?

There are currently open and forthcoming discussions regarding the application of the CLIME DSS somehow in the context of Nordic countries, in European wide research and policy support, and in North American policy support (through the CLIME partner NYC-DEP).

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