GLOWA-DANUBE: INTEGRATIVE TECHNIQUES, SCENARIOS AND STRATEGIES REGARDING THE GLOBAL CHANGE OF THE WATER CYCLE

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Abstract: The GLOWA-Danube project has the objective to develop, to apply and to exploit integrative techniques for the modelling of the water cycle in the Upper Danube catchment (gauge Achleiten/Passau). Scientists from the disciplines meteorology, hydrology, hydrogeology, glaciology, plant ecology and remote sensing as well as environmental and agricultural economy, environmental psychology, tourism and water supply represent the natural and socio-economic aspects of the water cycle. The numerous processes and interactions in the models of all disciplines are structured by common use of the Unified Modelling Language (UML). Besides water, fluxes of energy and matter are modelled. The implementation results in a modelling system called DANUBIA which integrates the core competences and models of the disciplines. It will finally serve as decision support system for water resource management and water-related institutions and interest groups. The first preliminary results of the prototype of DANUBIA show a reasonable spatio-temporal pattern of modelled variables within the catchment area. In the future, the DANUBIA system will be used to run scenarios of a changing environment, which result from a change in climate, land use or in actors' behaviour in the region, in order to give scientifically based decision support to all stakeholders as an aid to sustainable water resource management.
Keywords: Integration, Decision Support, Danube, GLOWA, UML, Modelling, Water Resource Management, Stakeholders

GLOWA-DANUBE: INTEGRATIVE TECHNIKEN, SZENARIEN UND STRATEGIEN FÜR DEN GLOBALEN WANDEL DES WASSERKREISLAUFS

Zusammenfassung: Ziel des GLOWA-Danube Projektes ist die Entwicklung und Anwendung von integrativen Techniken und Methoden zur modellhaften Abbildung des Wasserkreislaufs im Einzugsgebiet der Oberen Donau (Pegel Achleiten). Dabei werden die wesentlichen Disziplinen, die am Wasserkreislauf und der Nutzung der Wasserressourcen beteiligt sind, miteinbezogen: Meteorologie, Hydrologie, Hydrogeologie, Glaziologie, Pflanzenökologie und Fernerkundung auf der naturwissenschaftlichen, und Wasserwirtschaft, Umweltökonomie, Agrarökonomie, Umweltpsychologie und Tourismusforschung auf der sozio-ökonomischen Seite. Die Integration der Kernkompetenzen dieser Disziplinen und ihrer Modelle resultiert in der Entwicklung des Entscheidungsunterstützungssystems DANUBIA. Anwendung findet dieses Modell in der Unterstützung von Entscheidungen der Wasserwirtschaft und anderer wasserrelevanter Institutionen und Interessensverbaenden. Ein erster, bereits entwickelter und implementierter Prototyp von DANUBIA weist bereits alle wesentlichen Züge der Integration, wie direkte Modellkopplung und objektorientierter Aufbau, auf. Die ersten vorläufigen Modellergebnisse zeigen Parameter mit einem in ihrer Größenordnung realistischen räumlichen und zeitlichen Verhalten. Zukünftig sollen mit DANUBIA Szenarien einer sich ändernden Umwelt erstellt werden, die sich als Konsequenzen von Änderungen im Klima, der Landnutzung oder des Verhaltens der Akteure in der Region ergeben und kann so Entscheidungsträgern verschiedener Disziplinen als ein wirkungsvolles Werkzeug zur Seite gestellt werden.
Schlüsselworte: Integration, Entscheidungsunterstützung, Donau, GLOWA, UML, Modellierung, Wasserwirtschaft, Interessensverbände

1. Introduction

1.1. The GLOWA-programme

In 1999, the German Federal Ministry of Education and Research (Bundesministerium fuer Bildung und Forschung, BMBF) started a programme on the Research of Global Change of the Water Cycle (Globaler Wandel des Wasserkreislaufs, GLOWA). The overall objective of the programme is to investigate the effects of global change on regional water resources and to develop strategies for a sustainable management of water within a catchment area. Central to this objective is the integration of all water-related disciplines in order to find integrated solutions to water resource competition and water use conflicts, in contrast to the disciplinary approaches of the past. To achieve this ambitious objective, atmospheric processes, ecosystem functions and their natural variability as well as the strong influence of human activities have to be accounted for in a scientifically based way.

Currently, the GLOWA programme supports five projects in Europe, Africa and the Middle East. In addition to the Upper Danube catchment area of the GLOWA-Danube project, the ongoing investigations concentrate on the River Elbe in north-eastern Germany and the Czech Republic (GLOWA-Elbe), the River Volta in West Africa (GLOWA-Volta), the catchment areas of the Wadi Draa in Morocco and the River Oueme in West Africa (IMPETUS), and the River Jordan in the Middle East (GLOWA-Jordan River).

1.2 GLOWA-Danube

The GLOWA-Danube project has been chosen to investigate and to explore new integrative techniques and methods, leading to a decision support system for water resource management in the Upper Danube catchment area. The project partners of GLOWA-Danube form a broad scientific basis: The disciplines of meteorology, hydrology, hydrogeology, plant ecology, glaciology and remote sensing represent the natural sciences, while the socio-economic perspective is accounted for by the disciplines of agricultural and environmental economy, environmental psychology and tourism research. Together with the computer science group and a human capacity unit, 13 different partners from Germany and Austria are currently involved in the project.

In the first project phase, research is focussed on the development of a prototype of a web-based Global Change Decision Support System called DANUBIA. This tool for integrative environmental monitoring is based on existing data of the study region and on existing disciplinary models for the description of the various water-related processes. The DANUBIA system will be able to produce scenarios of the consequences of future global change and to give support to decision makers by clarifying the impacts of different potential water resource management strategies. With the help of such a system, it will be possible to develop and to analyse scenarios from natural and social science perspectives.

Potential stakeholders of the GLOWA-Danube project are, among others, the administrative authorities on the regional level of the countries involved, water supply companies, farmers and the farming industry, the hydro-power industry, tourism organisations on the regional and local level, insurance companies as well as NGOs like ICPDR (International Commission for the Protection of the Danube River) national park authorities, WWF (World Wildlife Fund) or BUND (German Environmental Protection Organisation).

<u>The study area</u>

The Upper Danube catchment is situated in Southern Germany, the west of Austria, the east of Switzerland, and with smaller parts in the Czech Republic and Italy (*Figure 1*). It comprises about 77,000 km², 8.2 Mio. inhabitants and an altitude difference of more than 3,500 m from the summits of the Alps to the Danube lowlands. Whilst in the southern parts it is a true Alpine catchment, the central region consists of flat to undulating mountain foreland terrain. The northern boundaries are characterised by typical low mountain ranges. Human activities range from extensive agriculture in the Alps to agro-industry in the forelands, from scattered dwellings in remote valleys to large cities like Munich, from small family-run businesses to high-tech industry. Due to these strong gradients in almost all natural and socio-economic factors the chosen study region is highly sensitive to the consequences of a future global climate change. Already existing water use conflicts resource between agriculture, industry, tourism and a changing population structure may increase severely in the future.

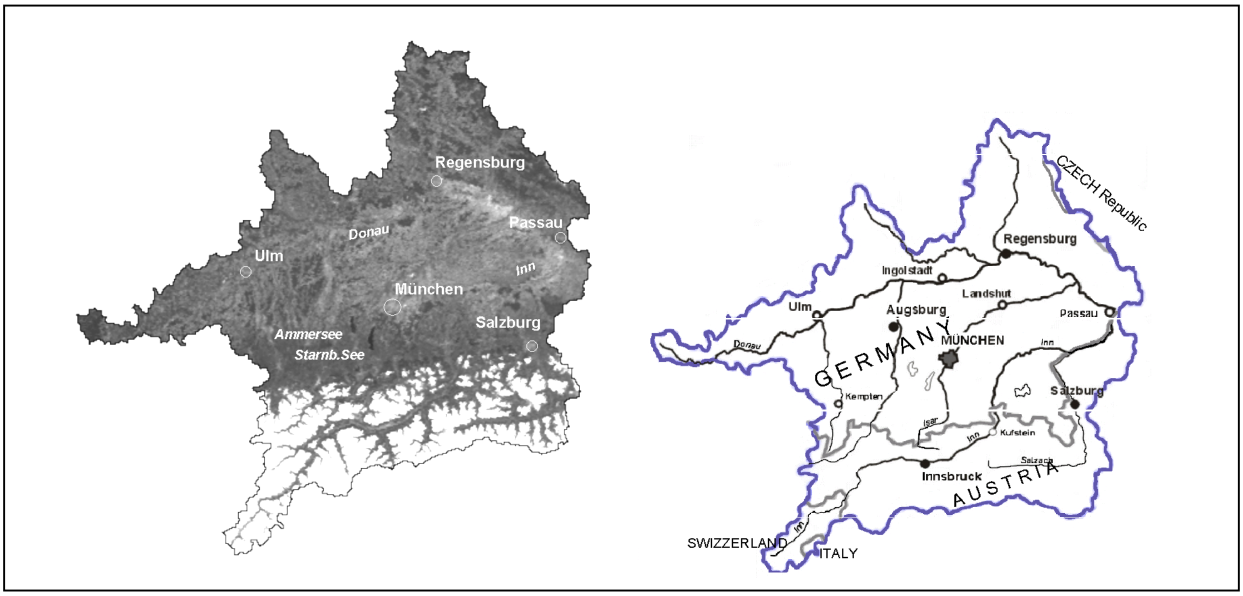


Figure 1. The Upper Danube catchment. The NOAA-AVHRR satellite image of the Upper Danube catchment (left side) taken in April 1995 highlights the topography of the study area: In the south the Alps are still covered in snow, whereas the alpine valleys are already snow free.

2. Integration techniques

The true integration of all disciplines involved in GLOWA-Danube is crucial for the creation of successful decision support system DANUBIA. Each single discipline within the project is based on a long experience and well-established models in their own domain. These disciplinary models are generally highly sophisticated and specialised in the model core, in order to account for the needs of disciplinary research. Competences away from the model core, however, are usually less developed, and often boundary conditions are kept constant or are described in a simplified way. Such models are not prepared for coupling with other disciplines and hence only have a limited capability in dealing with complex questions and integrated scenarios. Within GLOWA-Danube integrative techniques have been developed and applied in order to overcome the mentioned deficiencies and to exploit the existing disciplinary expertise for an integrative research of the water cycle.

2.1. The proxel concept

A *proxel* is the basic spatial unit for all processes described in the DANUBIA system. “Proxel” stands for process pixel. It enables the natural sciences to couple their models on a common spatial platform and to exchange variables with a well-defined spatial representation. The agreement of the socio-economic disciplines to such a raster-based modelling approach allows a direct coupling of natural to socio-economic models on the same spatial basis for the first time. A key to the approval of the proxel concept in the socio-economic sciences is the commitment to agent-based modelling. In this approach, human activities are spatially resolved and represented by describing multiple actors with varying preferences and a distinct behaviour and decision-making.

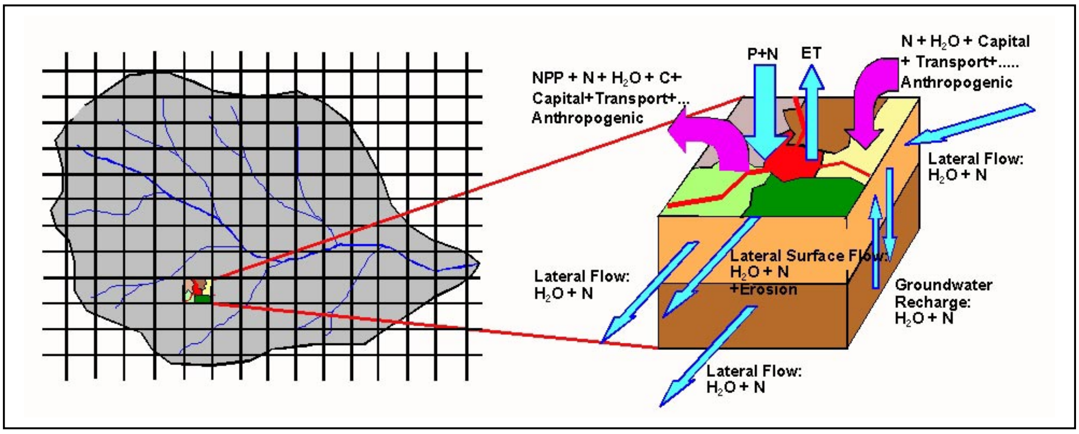


Figure 2. The proxel concept is used for the spatial representation of all disciplinary processes

2.2. Object-orientation

A second key element of the DANUBIA concept is the object-orientation of the model. Each sub-model is regarded as an independent object with certain, well-defined public functionalities and a private modelling core. All other partners can profit from this expertise by using the offered public methods and parameters. Additionally, the well-established advantages of object-oriented modelling like inheritance and simple re-use of once implemented functionalities contribute to a successful application within DANUBIA. Finally, the object-orientation enables the model to be run over the world wide web in several locations at the same time(see section 2.4).

2.3 The Unified Modelling Language

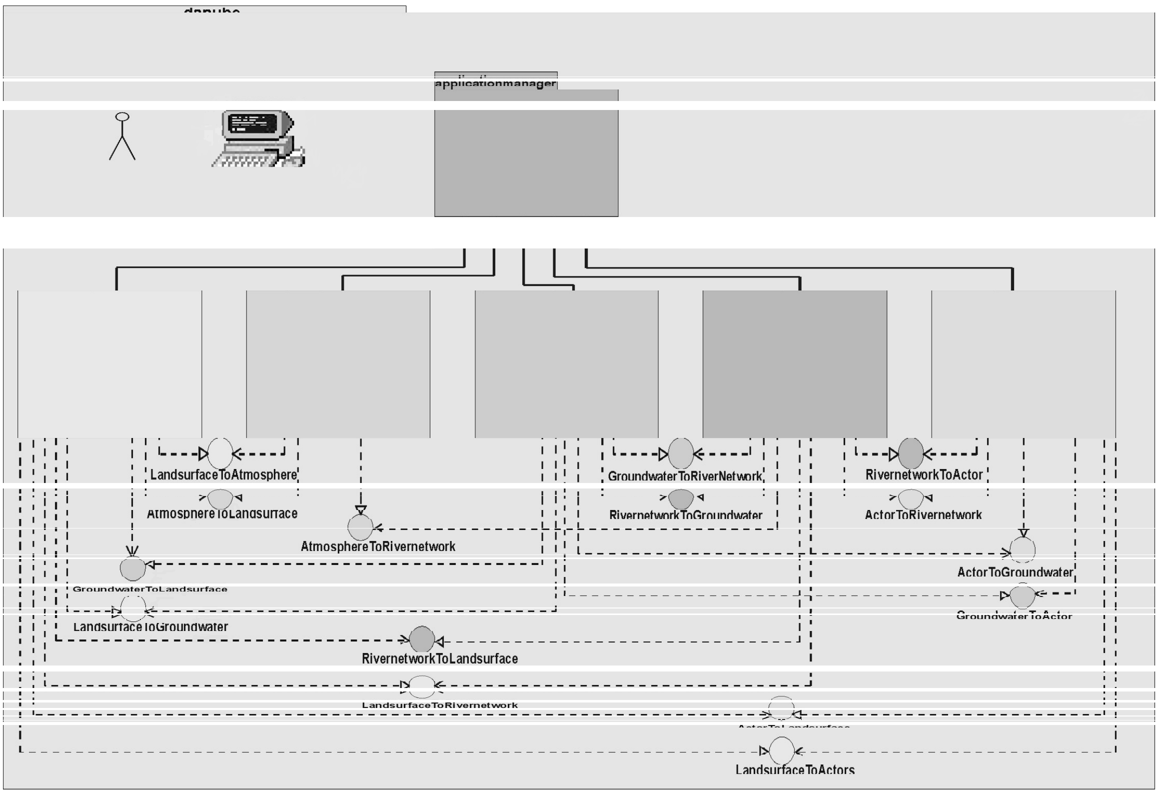


Figure 3. A simplified UML-diagramme of the DANUBIA system

In modern computer science and software engineering, the Unified Modelling Language UML has been established as a quasi standard for large projects with heterogeneous partners (Booch, Rumbaugh, Jacobson, 1999). In the GLOWA-Danube project, UML has been used for the design of the model framework of the DANUBIA system as well as for the definition of all interfaces between the model components (*Figure 3*). The UML served as a common language between the disciplines, and helped in explaining the disciplinary models as well as in defining unique core objects and interfaces between those objects. With the common commitment to designed interfaces, a clear and unambiguous basis for the exchange of parameters and variables between the core models could be established.

2.4 A web-based system

The DANUBIA decision support system has been designed from the beginning as a web-based model. Due to its object-orientation, each single component can be run in a different location (*Figure 4*). Hence all project partners can maintain their model or various derivates of their component locally, but contribute at the same time to the global model. Communication between the model components is realized by making use of Remote Model Invocation techniques (RMI). A central database stores all data relevant to more than one component, thus avoiding redundancies and inconsistencies, e.g. the simultaneous use of two different digital elevation models. Data relevant to one component only is kept locally with the component, avoiding unnecessary network traffic. The user can start the simulation from a web user interface from anywhere in the www.

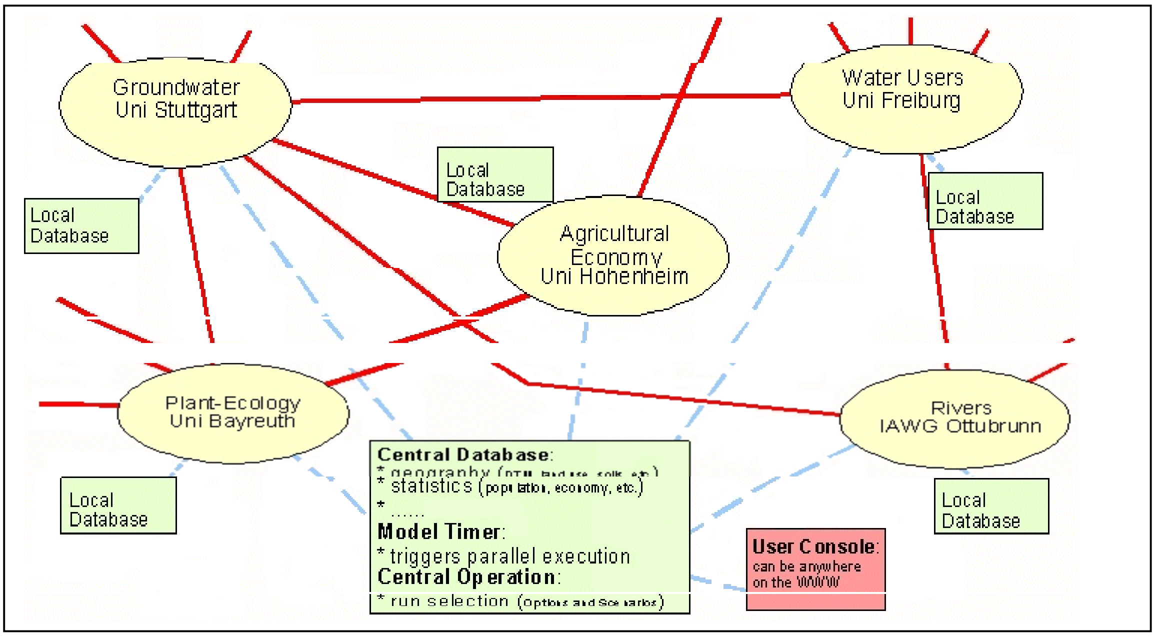


Figure 4. The Communication of disciplinary models and execution of local computations by the application of of web-based techniques and services over the ***www*** *(Remote Method Invocation RMI). The solid lines symbolize the connections between the different computers via www. The dashed lines are the connection of the models to a local and a central database*

2.5 Scientific integration

Besides these aspects of technical integration, the scientifically sound coupling of the former disciplinary models required bilateral or even multilateral discussions and negotiations of the contributing disciplines. The delineation of core competences allows a consistent description of all physical and socio-economic processes that have to be modelled exactly once within the DANUBIA system. The land surface serves as an example with its different physical processes taking place simultaneously (*Figure 5*).

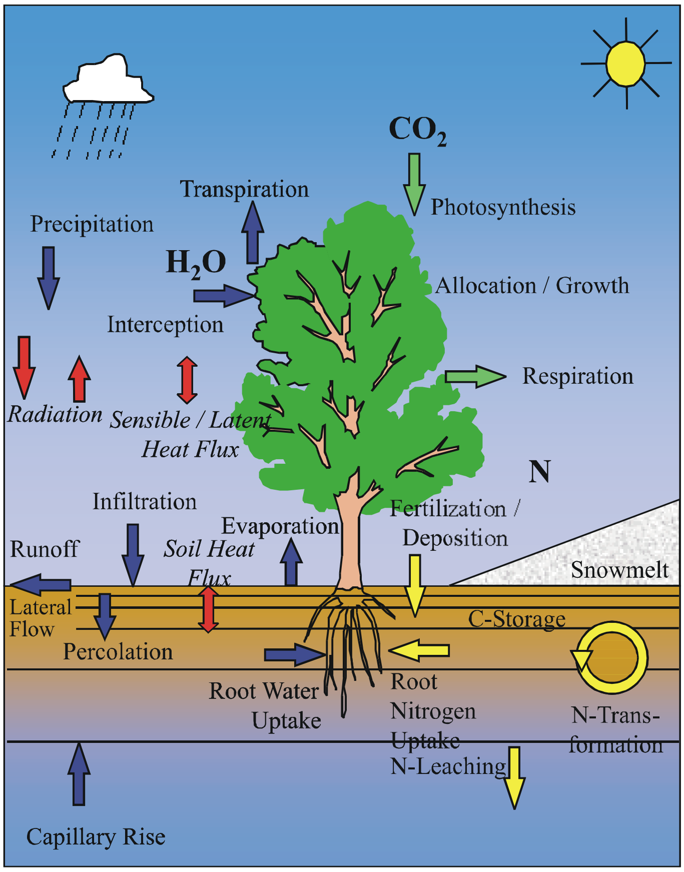


Figure 5. Coupled processes of the land surface

These processes were previously modelled in different depth, complexity and redundancy by various models of the project groups involved, i.e. hydrology and remote sensing (Schneider, Mauser 2000), glaciology (Kuhn 2002) and plant ecology (Thornton 1998). After recognising and delineating each group's core competences in mutual agreement, six objects representing process-groups could be defined: *surface, soil, snow, biological processes, radiation-balance and scaling*. Three of these (*snow, biological processes and radiation- balance*) remain the domain of a single project group, while the three other objects are implemented by joint efforts of two or all three groups. Thus the most sophisticated algorithms of each modelled process could be implemented in the respective component by the most competent group. At the same time, each group could rely on the expertise of the other groups in areas where it did not feel competent. Consequently, the entire *landsurface* object is profiting most from each single discipline's expertise, while avoiding unnecessary simplifications or even redundant modelling of the same processes.
Similar measures of a sound scientific integration are taken between other project partners of neighbouring disciplines, always being guided by the concept of relying on the core competences of each discipline.

3. Decision Making and Support

When running scenarios with the DANUBIA system, different processes may produce a certain pressure on the current use of water and land, resulting finally in a change in the allocation of these resources. Within the system, the various demands for change have to be evaluated and ranked within a hierarchy, before a decision, e.g. a modified land use, is established. For example, a sudden clearing of a whole forest by a winter storm will change the land use for certain and without any objection, while the wish for a new skiing area expressed by a tourist actor might be opposed by another actor representing nature conservation. This process of decision finding is referred to as decision making *within* DANUBIA.

On the other hand, stakeholders and decision makers of water resource management regularly face decision-making and the allocation of water resources. Here, DANUBIA can help to clarify the consequences of certain decisions with scenarios, before the decision is actually taken. The analysis when and where to use DANUBIA in such a decision making process can be referred to as decision making *with* DANUBIA or decision support.

3.1 Decision-making within DANUBIA

Within the DANUBIA system, a decision-making component has to be established that decides a change in land use and land cover, and decides a change in water use. *Figure 6* illustrates various pressures that could be produced by the model's components. They are collected in so-called containers where the actual decision-making process takes place. The exact definition of this process is still under discussion; in a first version, it will comprise a hierarchical decision-making according to pre-defined rules by the project partners. These rules rank the occurring pressures according to given weights. Later on, more intelligent and flexible rules will be adopted, in close collaboration with the real decision making process to be learned from the project's stakeholders. Cost-benefit analysis can provide decision rules where rational decisions are to be taken with an objective of utility maximisation. Fuzzy logic techniques might prove to be more suitable, if no precise weighting is possible. Multi-criteria analysis and decision aid could be a solution for complex scenarios with various decisions to be taken at the same time and only partially known consequences.

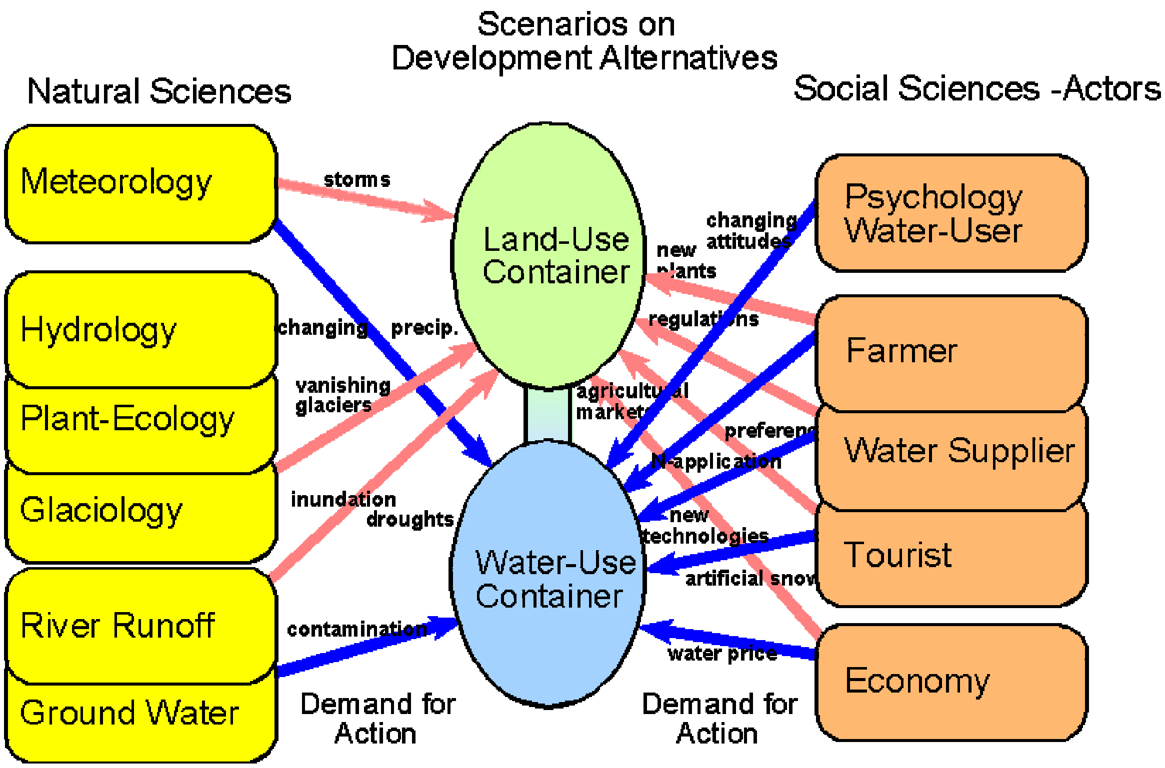


Figure 6. From the natural science side as well as from the actors side there are various demands for changes in land and water use. In a first version the decision-making will take place using pre-defined hierarchical rules

In any case, the decision once taken by the containers will lead to a modified input to the DANUBIA system which, in the continuing simulation, will react correspondingly and give an immediate feedback to the decision made.

3.2 Decision-making with DANUBIA

In the process of decision-making *with* the DANUBIA system stakeholders' participation is most obvious. Here, the stepwise approach will confront stakeholders in a first step with simple scenarios of a changed climate, water use, water resource management, demography, or actors' preferences. It can reveal certain sensitivities of single parameters and quantify feedback mechanisms. In a second phase, scenarios are developed in direct co-operation with single stakeholders, thus shaping model runs closely to the needs of the decision maker. Here, specific questions of single stakeholders can be answered and scenarios in the perspective of a single stakeholder can be run.

A third type of scenarios is the simultaneous involvement of several stakeholders. Such integrated scenarios might include interactions of different players during the scenario run. These complex scenarios will mirror the reality of a strongly interacting society best, but care has to be taken in the choice of the scenario as well as in the analysis of the decision making process of each single stakeholder involved. Only a clear idea of the basis on which decisions are taken within a certain authority will allow for a decision support with DANUBIA close to reality. Obviously, this can only be achieved in close collaboration with the stakeholders.

4. First Results

A first system prototype called DANUBIA 0.9 was generated to show the feasibility of the approach. The version's name "0.9" should indicate that this prototype only shows DANUBIA's framework with the management of space (proxel) and time. It shows that the system itself is already running, the interfaces and the data exchange between the components are correctly performed and the resulting spatial and temporal pattern of the different calculated parameter are consistent. There is no claim of correctly calculated numbers. This is one of the aims of the next steps.

DANUBIA 0.9 is performed on a LINUX-Cluster using 9 nodes for the different processes. In the current model set-up the spatial resolution is set to 1 km² and the temporal resolution of the single models (TimeController), as well as network communication (Wrapper) has already been implemented. The time-steps within the different components vary from 15 minutes (Landsurface) to once per year (HouseholdActor).

In DANUBIA 0.9 the course of the water from a cloud to the gauge at Passau is modelled for the year 1999 and the entire catchment area of the Upper Danube. This is done by including 8 components from different spatial models (*Figure 7*) and a central database.

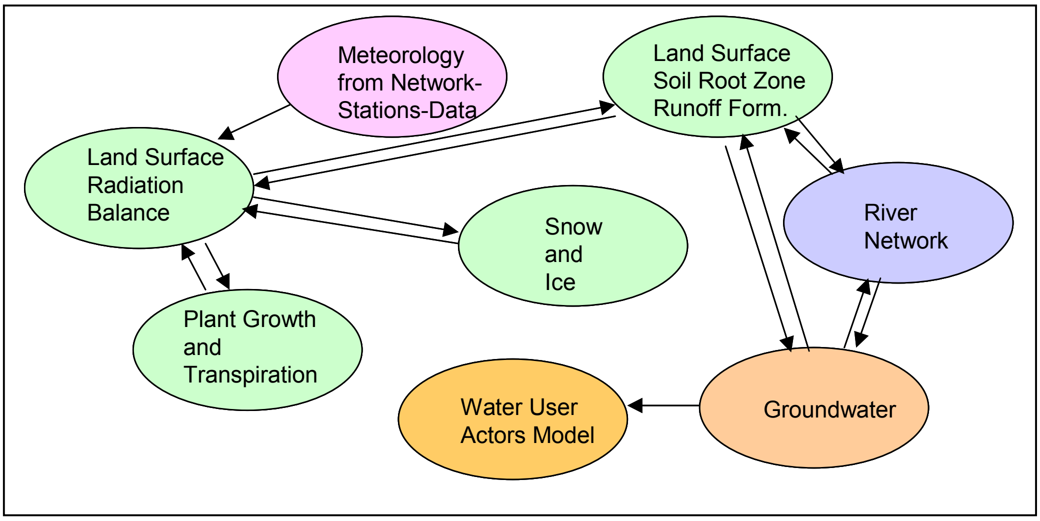


Figure 7. The model components of DANUBIA 0.9

As first results it reproduces a general spatial and temporal pattern of various parameters, like snow cover and snow melt, radiation balance, surface evaporation, air temperature, soil moisture, ground water recharge and precipitation and a lot more. The parameters are calculated within the different disciplinary models using not only the central database, but also local databases which provide data only used by one model. Within these models a variety of parameters are calculated. But only parameters which are needed by another model are exchanged through the interfaces. The calculation process and the algorithms are private to the specific model. These techniques enable the quick data exchange using the web. Some quick shots of parameters modelled with the DANUBIA prototype are displayed in *Figure. 8a-c*

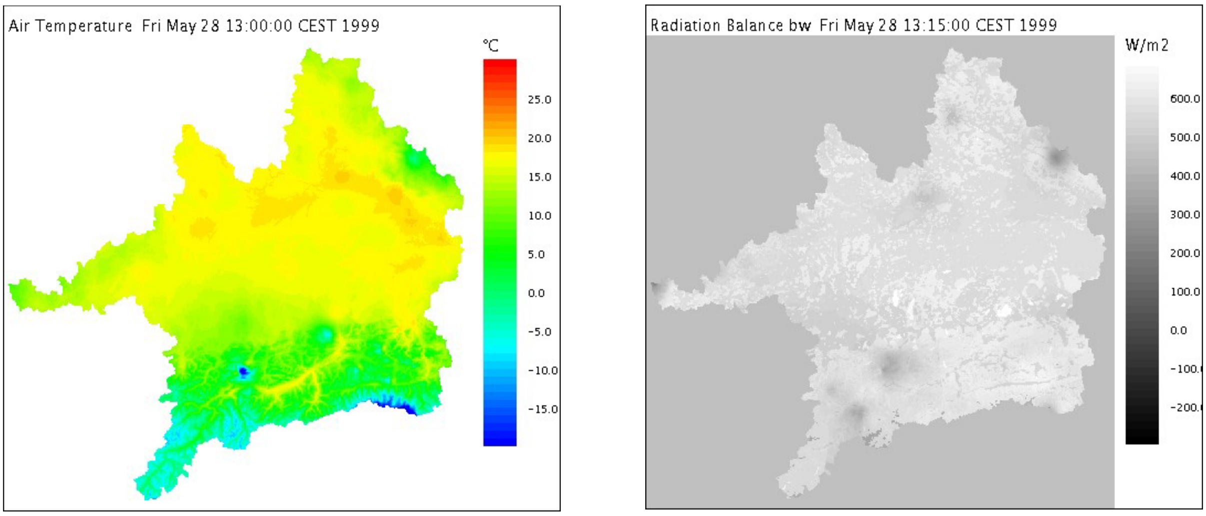


Figure 8a. On the left the air temperature for May 28, 13:00 is displayed, on the right the radiation balance for the next time step 13:15. To calculate the radiation balance the air temperature of 13:00 is used among other variables.

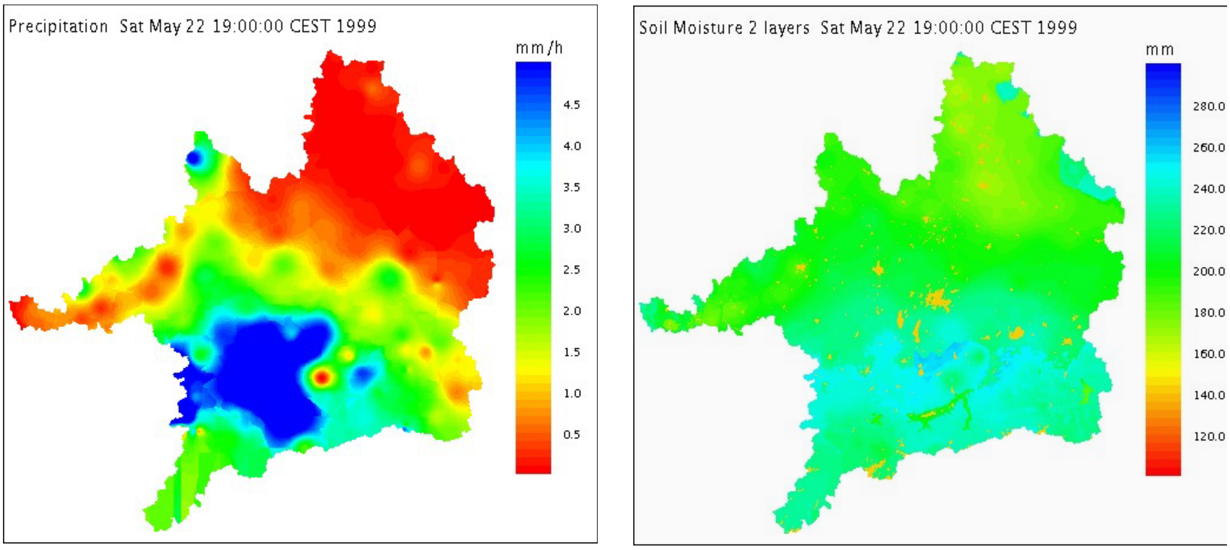
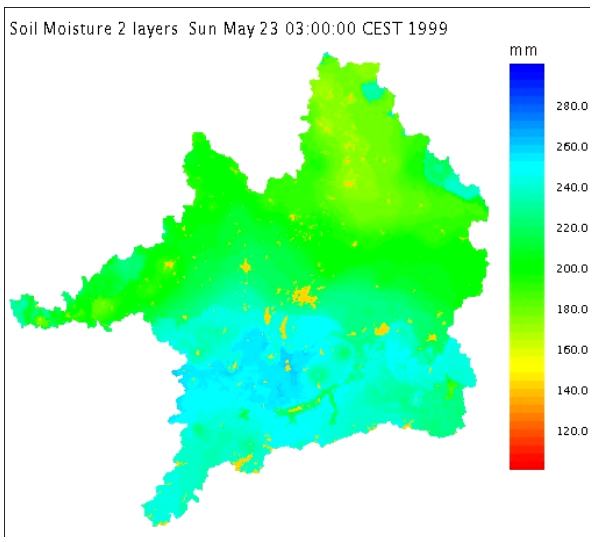
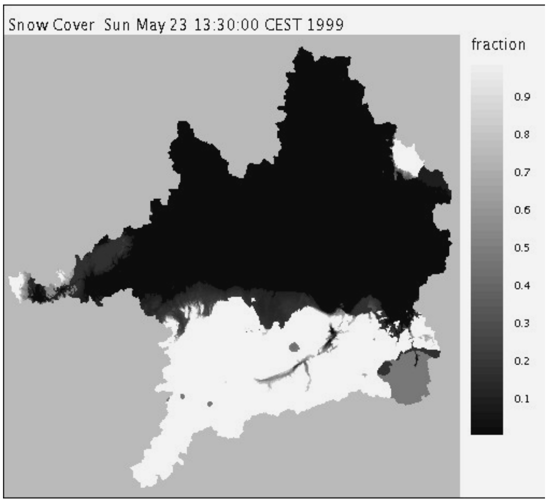


Figure 8b. Precipitation on May 22,19:00 (left) and soil moisture on May 22 19:00 and May 23 03:00. It can be seen that the soil moisture development is delayed by several hours relative to the precipitation event.





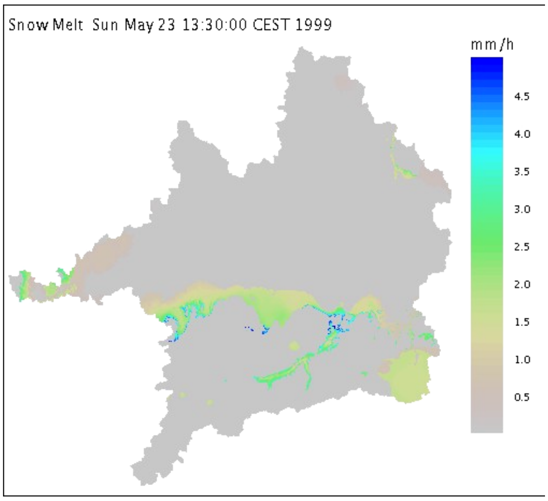


Figure 8c. Comparison of snow cover and snow melt. Snow cover is displayed as fraction of a proxel. The spatially interpolated air temperature and precipitation from station data is used among other data to calculate these variables.

However, DANUBIA is not limited to the constellation shown above. The framework design allows fast and simple changes to e.g. a sub-catchment, another period or another spatial resolution, provided that the data are available and algorithms are suitable for another spatial scale. Studies on scaling are currently under way.

5. Conclusions and Outlook

The project GLOWA-Danube is a highly integrative scientific project. Within the first working period it has been shown that a web-based model integrating natural as well as socio-economic sciences can be performed using an object-oriented approach.

The next steps during the first research phase are focusing on:

- the implementation of additional models: a farming actor, a tourism actor, drinking water supply and an economy actor
- the direct coupling of the MM5 mesoscale meteorological model instead of the current atmosphere model that depends on data from meteorological stations, in order to be able to model the future
- improving the current simplified model-prototype
- validating the model results
- testing to what extent the current process description are suitable for other spatial scales
- running first scenarios

One of the major topics in the next research phase will be testing the possibilities of transferring DANUBIA to other regions, especially moving downstream the Danube catchment.

6. Acknowledgements

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