Design of the DANUBIA DSS

- with a special focus on the coupling of groundwater models (MODFLOW) with hydrological models

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Outline

• General Coupling and Integration Concept of the GLOWA-Danube Project : The DANUBIA DSS

• Coupling MODFLOW to
  – Hydraulic and SVAT Models
  – to Socio-Economic Models

• Selected Results

• Conclusions
GLOWA-Danube (www.glowa-danube.de): Summary

- Consequences of Global (Climate) Change in the Upper Danube Catchment (Water Supply, Land Use, Agriculture, Economy, Tourism ..)

- Decision Support System ‘DANUBIA’

<table>
<thead>
<tr>
<th>What is DANUBIA ? (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DANUBIA is</td>
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<tr>
<td>- a coupled simulation system, comprised of <strong>16 individual sub-models</strong></td>
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<td>- <strong>models run on different computers</strong> and exchange data via internet protocols</td>
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<td>- theoretically completely distributed</td>
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<tr>
<td>- actually: Cluster with 26 nodes</td>
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<tr>
<td>- <strong>6 socio-economic models, 10 natural science models</strong></td>
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<tr>
<td>- mainly well-established, widely used <strong>standard models</strong> (e.g. MODFLOW, DAFLOW, MM5) in the natural science sector,</td>
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<tr>
<td>- mainly <strong>newly developed, context specific models</strong> in the socio-economic sector (e.g. ‘WaterSupply’)</td>
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</table>
What is DANUBIA? (2)

• DANUBIA is (continued)
  – all models coupled via a JAVA based framework architecture (link to
data base, control of spatial and temporal aspects of data exchange,
control of data types, visualization ….)
  – models, interfaces, framework conceptualized using UML
  – able to provide a large number of output variables in tabular form,
    maps, movies etc.
    • currently restricted to about 75
  – a user friendly web interface is under development
    • currently results and use are restricted to model developers
  – Upon completion of the third project phase DANUBIA will be available
to the public under a public license agreement (2010)

The Central Głowá-Danube Infrastructure

Parallel cluster computer to run DANUBIA:
• 26 nodes
• 52 CPUs
• 30 GB RAM
• 1 TB Storage

To simulate a 30 Year scenario ~ 10 days
The DANUBIA Architecture

The DANUBIA Architecture
Controller

Data exchange = simple and transparent

Model

Internally complex

Idea: Reduce complexity and redundancy
Coupling: Analysis of dependencies (static view)

Model Coupling: 1) “strong” coupling (GLOWA-Danube)

Problems: delay, (unwanted) feedback, validity of exchange data …

Model: timestep

Models
1: LandSurface
2: GroundWater
3: RiverNetwork

Variables
a: groundwater recharge
b: groundwater level
c: infiltration
d: river level
Observation: The scheme is valid only if all the Actors compute at the same time step. The non-Actors group (Groundwater, Rivernetwork, Landsurface) compute at much smaller time steps (one hour, one day), but I did not know how to represent it.

Coordinated Behaviour of DANUBIA Models

- A model is blocked \( \text{waitForGetData} \) if the coordination condition for \( \text{getData} \) is not satisfied (similarly, \( \text{waitForCommit} \)).
- The correctness of the coordination can be formally verified with model checking techniques.
The challenges of coupling 16 models

- All models use the same spatial discretisation of 1 km by 1 km:
  - Simplifies data exchange.
  - Poses severe problems namely to socio economic models, hydraulic models, meteorological models (usually not raster based or much finer or coarser rasters)

- Models have different temporal discretisation ranging from 15 min (plant growth) to one year (agro-economic model)
  - (Irresolvable) feedbacks and delays of data exchange
  - Tracing errors and uncertainty is almost impossible

Integration of MODFLOW into the DANUBIA DSS

The MODFLOW (Finite Difference) Numerical Concept

For each cell, for each timestep:
- Changing fluxes – from cell to cell, from cell to sinks, from sources to cells
  - Water balance
  - Head changes
  - Storage changes

\[
\frac{\partial h}{\partial t} + \frac{\partial}{\partial x}\left(hK_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(hK_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(hK_z \frac{\partial h}{\partial z}\right) + \frac{\partial S}{\partial t} = 0
\]
### Coupling of hydrological models in GLOWA-Danube

**Important DANUBIA philosophy:** Make interfaces as simple as possible! ⇒ minimize number of exchange parameters

- **Physically based** Models
  - Unsaturated Zone – Richards’ Equation: SWAT-PROMET
  - Groundwater – Boussinesq- Equation: FD - MODFLOW

- Surface Waters – Saint-Venant- Equations: DAFLOW

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**The two sides of dynamic model coupling**

1. **‘Technically’**:  
   - How to control and link two different codes? (software engineering or programming problem)

2. **‘Conceptually’**:  
   - How to guaranty that the linkage makes sense, i.e. is a meaningful representation of natural processes

3. Do the individual models to be coupled make sense at all?
**Coupling MODFLOW - Technically: Interfaces**

- **MODFLOW advantage:**
  - **Modular design:** boundary conditions (i.e. interfaces in a wider sense) can be used and parameterized individually (→ packages)
  - boundary condition files (packages) are read at each stress period

- **DANUBIA approach:**
  - Output from DANUBIA partner models (e.g. groundwater recharge) is read and aggregated at each time step (e.g. 1h) within the JAVA environment and converted to the required package files
Coupling MODFLOW: Time Control

• **Problem:**
  – In a coupled system like DANUBIA the system must control the individual models (read – run – write)

• **MODFLOW advantage:**
  – Each stress period represents a fully completed OS command
  – Therefore the whole process can be controlled using OS command sequences (batch files, shell scripts)

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Coupling MODFLOW

convert DANUBIA DataTables to ASCII Grid
Files

PREPROCESSING

Postprocessing

DANUBIA
Java

Files

Files

MODFLOW

Fortran

Prepares new input files

run Modflow

modify and write output to ASCII Grid files

convert ASCII Grid files to DANUBIA tables

Process mainly based on OS commands and Fortran code executed from JAVA code
Selected Conceptual Aspects of integrating MODFLOW

Example A) Groundwater Recharge to link unsaturated zone and groundwater

Example B) Groundwater and River Levels to link groundwater and rivers

1) Groundwater Recharge to connect unsaturated zone and groundwater

- Soil or root zone
- Unsaturated zone
- Saturated zone - groundwater zone

Precipitation
Infiltration
Percolation

Groundwater Recharge: Definition used in many physically based unsaturated zone models (also: lysimeters)

Groundwater Recharge: Standard definition used in groundwater modelling

but actual recharge depends on:
- depth to the groundwater
- relief
- heterogeneities in the unsaturated zone
- lateral flow
2) Groundwater - River Interactions: Using the MODFLOW River or Drain Package

RIVER PACKAGE

\[ Q_{RV} = \frac{K_h \cdot L \cdot W}{M} (H_{RV} - h) = C_{RV} (H_{RV} - h) \]

DRAIN PACKAGE

\[ Q_{D} = K \cdot L (h - d) = C_{D} (h - d) \]

where:
- \( K \): hydraulic conductivity of the river/drain bottom
- \( L \): Length of the river in a cell
- \( W \): width
- \( M \): thickness
- \( h \): hydraulic head

Problems:
- Numerical Stability (River Package)
- How to define Groundwater and River Levels using a common datum?
- Definition of a hydrologically consistent DEM on a coarse raster
- …
Coupling MODFLOW to socio-economic models

- Interface Socio Economic Model to MODFLOW:
  - Water Demand – Extraction from Wells
  - Can be easily realized using the well package

- Interface MODFLOW to Socio Economic Model:
  - groundwater level is not a sufficient input parameter for a socio economic model
Natural science values to interpreted “signals” (flags)

everything is fine → critical situation → catastrophic situation

1 2 3 4 5

The integrated assessment concept in GLOWA-Danube

From each model cell → For each zone → To each model cell

- Soil
- Groundwater
- Rivernetwork

read from partner model → aggregate values calculate flags → send flags

 calculates:
- GroundwaterQuantityFlag
- WSCFlag
- DrinkingWaterQuantityFlag

exports
- DrinkingWaterQuantityFlag
uses:
- GroundwaterQuantityFlag to decide

Household
Farming
Tourism
Economy
Water Balance of the Upper Danube, Period 1971-2000

Precipitation: 1078 mm/a
Evapotranspiration: 481 mm/a
Runoff: 597 mm/a

Mean Discharge at Gauge Achleiten (76653 km², 1971-2000): 587 mm/a
+ 1.7 %

But: the long term average of the discharge at one gauge is not a means to validate a DSS!
Results: Scenario Simulations

IPCC-Szenario B2 (delta T = 2.7K/100a) Trend in Seasonal Precipitation Pattern 2005 -> 2104

Winterly Precipitation

Summerly Precipitation

Results:
Scenario Simulations

Dry Scenario

Wet Scenario

<table>
<thead>
<tr>
<th>GroundwaterRecharge Deviation from Reference</th>
<th>GroundwaterQuantityFlag</th>
<th>DrinkingwaterQuantityFlag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater Recharge Flag: 01.12.2000 00:00</td>
<td>drinkingwater/quantity 01.12.2000 00:00</td>
<td>drinkingwater/quantity 01.12.2000 00:00</td>
</tr>
<tr>
<td>sensitive</td>
<td>normal</td>
<td>normal</td>
</tr>
</tbody>
</table>
GLOWA Status

- GLOWA-Danube Summary:
  - an extremely sophisticated modeling framework has been built
  - the system is working, yet it is not applicable in practice yet
  - three more years to go will hopefully be enough to make the necessary improvements

Conclusions

- Include stakeholders early to define the management problems and objectives of modeling clear enough

- Analysis your management tasks, data availability and other resources very carefully in order to find out which models to use, how complex the system must be and how simple it can be
Specific recommendations

- Do not attempt to couple everything
  - If dependencies are small, ignore them

- Do not always attempt model the entire area as a whole
  - If natural divisions exist - use them

- Each interruption of the process chain (spatial or dependencies) gives you the possibility to limit uncertainty and error propagation and therefore better control

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Thank your for your attention!
Integrated participative communication process

Stakeholders - Deciders

- definition of aims
- definition of indicators
- definition of scenarios
- decisions/programmes
- ok? NO

Scientists - Modellers

- simulations
- reflection
- adaptation
- negotiation
- YES

RIVERTWIN 2007

GLOWA-Danube 2007