Experience with the use of different model types within an interactive decision support system to climate change adaptation of agriculture

K.-O. Wenkel¹, M. Berg¹, W. Mirschel¹, R. Wieland¹, B. Köstner²

¹ Institute of Landscape Systems Analysis of the Leibniz Centre for Agricultural Landscape Research, Muencheberg (Germany)
² Technical University Dresden, Institute of Hydrology and Meteorology
The use of land resources is changing in time
The use of land resources is changing in time

Most important driving forces:

- Increasing demand and rising prices for energy, fuel, food and feed
- Climate changes
What we can observe in the last years?

• Trend to closer crop rotations  
  (concentration on a few cash and energy crops)

• Large scale forest conversion  
  (from pure to mixed forest stands)

• Change of the tillage system in agriculture  
  (from conventional to no-tillage system)

• Increasing interest to irrigation

Land Cover changes are rather seldom!
The central questions for the future:

How we can manage our regional land and water resources in a sustainable way?

What are the best management practices to converge to this ambitious objective?
Prerequisites for a sustainable resources management:

- Better knowledge on landscape functions

- Better skills and tools for the integrated impact assessment of land use and climate changes

- New generations of interactive usable decision support systems to support sustainable resources management
In general we can distinguish two types of DSS:

• DSS which are based on models, which describe the impacts of changes qualitative (mostly expert or rule based models).

• DSS which are based on process oriented or statistical mathematical models (quantitative models).
LandCaRe-DSS
An interactive usable GIS and model-based knowledge and decision support system for climate change impact assessment and adaptation of agriculture to climate change.
The Project LandCaRe 2020

LandCaRe 2020: Land, Climate and Resources – Foresight and Potentials in Rural Areas under Regional Climate Change
(managed by Barbara Koestner, TU Dresden)

Interdisciplinary project conducted by 5 German institutions
including the research fields of meteorology, ecology, agronomy, socio-economy, modelling and computer science

Duration of Project:
Nov 2006 – March 2010
Some remarks to the concept of the LandCaRe-DSS in general
The LandCaRe-DSS is a GIS and model based information and decision support system for strategic planning to support farmers and regional stakeholders to find cost effective solutions to adapt the agriculture on climate change in rural areas.

It provides:

- improved knowledge on the past and future climate change in the respective region
- assessment of the potential ecological and economical impacts of climate change on farm and regional scale
- knowledge on potential agricultural climate adaptation strategies
- suitable tools for interactive simulations to compare alternative climate change adaptation strategies for agriculture
LandCaRe-DSS – overview (oversimplified)
Model - GIS - Coupling

GIS maps
- Soil quality index
- DGM
- Hydromorphy
- Soil type
- Slope

Weather/Climate, Parameter, Management

Simulation results
- Yield of winter wheat
- Irrigation water demand

GIS-Interface

LandCaRe-DSS models

MONICA

GIS-Interface

YIELDSTAT

Data base
- Model
- Maps

Soil parameters
- Organic matter
- Clay content
- Permeability
- Water content
- pH value
- Salinity
- Micronutrients
- Biological properties

Monsoon
- Temperature
- Precipitation
- Solar radiation

Simulation results
- Yield
- Irrigation

GIS Interface
LandCaRe-DSS - main characteristics

- **Interactive** (the user decides which simulations and calculations to execute and runs almost all models by himself)

- **Dynamic** (a large variety of simulations can be run, analysed and compared by the user. The chosen preconditions will affect the simulation result)

- **Spatial-oriented** (the user chooses the desired level of detail by zooming between regional or farm level. Based on this choice different models will be activated for execution)

- **Web-based** (central support, control and update of the entire DSS software and all supporting data)

- **Extendable** (open for further add-ons; frequent update of information, knowledge and data)

LandCare-DSS works with different climate scenarios and different regionalization methods (WETTREG; STAR; CLM)
One of the most important problems in terms of climate impact assessment and decision support:

Exposure and dissemination of uncertainties

Solution for this problem:

Multi-Ensemble and Multi-Model Simulations
Projection of the development of climatic water balance by use of different climate regionalization methods and different climate scenarios

Example: Meteorol. Station Dresden -Klotzsche
Overview of the impact assessment models used in the LandCaRe-DSS

<table>
<thead>
<tr>
<th>Model</th>
<th>Model type</th>
<th>Spatial resolution</th>
<th>Spatial application level</th>
<th>Country</th>
<th>Region</th>
<th>Farm</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAUMIS (yield)</td>
<td>empiric-statistical</td>
<td>municipal</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>RAUMIS (irrigation water demand)</td>
<td>dynamic</td>
<td>municipal</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>BAGLUVA (evapotranspiration, recharge)</td>
<td>dynamic-statistical</td>
<td>100x100 m</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>EROSION (erosion risk)</td>
<td>empiric-statistical</td>
<td>100x100 m</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>ZUWABE (irrigation water demand)</td>
<td>dynamic-statistical</td>
<td>100x100 m</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>LANUVER (land use distribution)</td>
<td>stochastic-statistical</td>
<td>100x100 m</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>ONTO (ontogenesis for arable crops)</td>
<td>statistical</td>
<td>climate</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>PHAENO (phenology for wild plants)</td>
<td>statistical</td>
<td>climate</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>VEGPER (duration of vegetation period)</td>
<td>dynamic</td>
<td>climate</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>GL-PROD (grassland yield, quality)</td>
<td>empiric-statistical</td>
<td>100x100 m</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>YIELDSTAT (crop yield)</td>
<td>dynamic-statistical</td>
<td>100x100 m</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>MONICA (agro-ecosystem as a complexe)</td>
<td>dynamic</td>
<td>100x100 m</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>EÖM (farm economy calculator)</td>
<td>economic calculator</td>
<td>100x100 m</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

11 models are integrated up to now
Software solution

• The DSS is programmed as Open Source in C++ and use Open Source Software (QT, GSL, HDF, ...) so much as possible.

• Besides the traditionally “Windows Icon Menu Pointing Interface” (WIMP) we use a further User Interface, the “Zooming User Interface (ZUI)“.

• The LandCaRe-DSS prototype was developed by the ZALF-research group. The transfer into a Web-based DSS system was realized by the Living-Logic company (Bayreuth).
Some short virtual impressions of the LandCare-DSS
Real-time analysis of climate data (climate projections) and simulated impacts on plant phenology
Analysis of regional climate, climate change and impacts on plant phenology (more in detail)

Change in temperature, precipitation and other climatic parameters during the whole year

Changes in ontogenesis of winter wheat caused by climate change
LandCaRe-DSS - usage at regional level

Ecological impact assessment of climate and land use changes on a high spatial resolution (max.250x250m)

• changes of crop yield on arable land
• changes of yields on grassland
• changes of potential erosion risk, regional evapotranspiration and ground water recharge
• irrigation water demand

Winter wheat yield calculated for the Prenzlau region, Germany
Regionalisation: WETTREG
Climate scenario: A1B
Climate period: 1991-2020
Crop rotation: winter wheat-winter oilseed rape
Simulation of the probably spatial crop distribution based on a given crop ratio for a selected area.
# Erosion risk in comparison between conventional and no tillage (WETTREG, scenario A1B)

<table>
<thead>
<tr>
<th>Year</th>
<th>Uckermark</th>
<th></th>
<th>Weisseritz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional tillage</td>
<td>no tillage</td>
<td>conventional tillage</td>
</tr>
<tr>
<td></td>
<td>[t/ha]</td>
<td>[t/ha]</td>
<td>[t/ha]</td>
</tr>
<tr>
<td>2005</td>
<td>0.55</td>
<td>0.33</td>
<td>2.42</td>
</tr>
<tr>
<td>2025</td>
<td>0.50</td>
<td>0.32</td>
<td>2.57</td>
</tr>
<tr>
<td>2045</td>
<td>0.45</td>
<td>0.28</td>
<td>2.54</td>
</tr>
<tr>
<td>2075</td>
<td>0.58</td>
<td>0.28</td>
<td>2.91</td>
</tr>
</tbody>
</table>
Total yield for non-irrigated scenario and irrigated scenario (100% sugar beet and potatoes, 30% winter wheat and silage maize) and total irrigation water demand for the Weisseritz region taking into account the current cropping ratio

<table>
<thead>
<tr>
<th>Year</th>
<th>Total yield (non-irrigated) [Mio GEU]</th>
<th>Total yield (irrigated) [Mio GEU]</th>
<th>Yield increase due to irrigation [%]</th>
<th>Mean irrigation water amount on irrigated area [mm/ha]</th>
<th>Total irrigation water demand [Mio m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>4,67</td>
<td>4,94</td>
<td>5,7</td>
<td>74</td>
<td>13,77</td>
</tr>
<tr>
<td>2025</td>
<td>4,76</td>
<td>5,00</td>
<td>5,1</td>
<td>67</td>
<td>12,44</td>
</tr>
<tr>
<td>2045</td>
<td>4,85</td>
<td>5,18</td>
<td>6,9</td>
<td>93</td>
<td>17,17</td>
</tr>
<tr>
<td>2075</td>
<td>5,06</td>
<td>5,48</td>
<td>8,4</td>
<td>116</td>
<td>21,53</td>
</tr>
</tbody>
</table>

¹GEU – grain equal unit
Use of LandCare-DSS on the local or farm scale

- Simulation of the impacts of climate changes
- Interactive simulations to compare alternative climate change adaptation strategies for agriculture under consideration of different price-costs relations for agricultural products and operation funds
Selection of agricultural fields and the model for scenario simulation
MONICA - a new developed process based Agroecosystem model
Results of farm specific scenario simulations for different climate adaptation strategies
Experience with the use of different model types
Approaches for climate impact assessment on agriculture

- In the majority of the climate change impact assessment studies, crop growth models were employed.

- The used models differ in scope, temporal and spatial scale, complexity or model approach.

- Differences among tested models are often larger than those between single models and observations.
Uncertainties

Observed versus simulated regional wheat grain yield for three studies

Olesen & Bindi, 2002
### Agro-ecosystem Modelling - the parametrization problem

**Example:**

Crop Simulation Model GEGROS, Wageningen
(X.Yin, H.H. van Laar, 2005)

#### Table 1. Constants used in GEGROS, Descriptions of symbols are given in Appendix L.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Equation</th>
<th>Value</th>
<th>Unit</th>
<th>Program code</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_x$</td>
<td>$2.4 \times 10^8$</td>
<td>J kg$^{-1}$</td>
<td></td>
<td>IMAVAP</td>
</tr>
<tr>
<td>$a_{X}$</td>
<td>$1200$</td>
<td>J m$^{-1}$ s$^{-1}$ K$^{-1}$</td>
<td></td>
<td>VAICA</td>
</tr>
<tr>
<td>$\rho$</td>
<td>$0.067$</td>
<td>kPa °C$^{-1}$</td>
<td></td>
<td>PSYCH</td>
</tr>
<tr>
<td>$D_{max}$</td>
<td>$210$</td>
<td>mmol mol$^{-1}$</td>
<td></td>
<td>O2</td>
</tr>
<tr>
<td>$D_{max}$</td>
<td>$8.314$</td>
<td>J K$^{-1}$ mol$^{-1}$</td>
<td></td>
<td>TIO23</td>
</tr>
<tr>
<td>$E_{max}$</td>
<td>$404.9$ for $C_3$</td>
<td>μmol mol$^{-1}$</td>
<td></td>
<td>TIO23</td>
</tr>
<tr>
<td>$a$</td>
<td>$3$</td>
<td>mol mol$^{-1}$</td>
<td></td>
<td>HH</td>
</tr>
<tr>
<td>$f_{mol}$</td>
<td>$0$</td>
<td>-</td>
<td></td>
<td>FPGFED</td>
</tr>
<tr>
<td>$f_{mol}$</td>
<td>$0$ for $C_3$</td>
<td>-</td>
<td></td>
<td>PG</td>
</tr>
<tr>
<td>$f_{mol}$</td>
<td>$0$ for $C_3$</td>
<td>-</td>
<td></td>
<td>PG</td>
</tr>
<tr>
<td>$\phi$</td>
<td>$0.2$ (relevant for $C_3$)</td>
<td>-</td>
<td></td>
<td>22</td>
</tr>
<tr>
<td>$\theta^*$</td>
<td>$0.7$</td>
<td>-</td>
<td></td>
<td>THETA</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>$0.2$ for PAR</td>
<td>-</td>
<td></td>
<td>SCP</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>$0.8$ for NIR</td>
<td>-</td>
<td></td>
<td>PCD</td>
</tr>
<tr>
<td>$M_{eq}$</td>
<td>$11$ for short-day crop</td>
<td>hour</td>
<td></td>
<td>MSP</td>
</tr>
<tr>
<td>$M_{eq}$</td>
<td>$18$ for long-day crop</td>
<td>-</td>
<td></td>
<td>MSP</td>
</tr>
<tr>
<td>$\delta^*$</td>
<td>$-2$</td>
<td>degrees</td>
<td></td>
<td>INSP</td>
</tr>
<tr>
<td>$V_{FW}$</td>
<td>$0.50$</td>
<td>g C g$^{-1}$</td>
<td></td>
<td>PCRSH</td>
</tr>
<tr>
<td>$V_{FW}$</td>
<td>$0$</td>
<td>g N g$^{-1}$</td>
<td></td>
<td>PCRSH</td>
</tr>
<tr>
<td>$W_{FW}$</td>
<td>$0.25$</td>
<td>g m$^{-2}$ cm$^{-1}$</td>
<td></td>
<td>WEB</td>
</tr>
<tr>
<td>$T_{C}$</td>
<td>$1$</td>
<td>d</td>
<td></td>
<td>TCP</td>
</tr>
<tr>
<td>$C_{C}$</td>
<td>$6$</td>
<td>g C g$^{-1}$</td>
<td></td>
<td>CCR84</td>
</tr>
</tbody>
</table>

*Values of the marked symbols may slightly vary, depending on crop and experimental conditions.*
Climate or land use change impact assessment on the regional scale

In the most cases we are confronted with restricted information.
Experience from case studies

In general, statistical as well as mechanistic process oriented models adequately predict agronomic yield and other ecological values at a given scale.

Different model types need different quantities of input data and parameters.

Because at the regional scale we often do not have all the necessary and valid data for the use of complex mechanistic models, the so called REMICs (models of intermediate complexity) have an advantage for regional resources management simulation.
Results of predicted climate impacts on yields of winter wheat using different model types: YIELDSTAT (statistic-dynamic) and MONICA (mechanistic).

- Farm within the district: Weisseritzkreis
  - Soil: Lö 4c
  - Meteorological station: Dresden-Klotzsche

- Farm within the district: Uckermark
  - Soil: D4a03
  - Meteorological station: Angermünde
Conclusions

The development of an interactively useable decision support system for climate change adaptation makes high demands on the implementation concept as well as the modules included into the system.

A further important experience is, that the models which are to be included into decision support systems have to be robust, well documented and above all have to be separately verified in space and time before their inclusion into the DSS framework.

DSS supports the possibility of multi-model simulations. This is a prerequisite to assess the uncertainties resulting from different model types, yielding different simulation results with the same inputs.

The first results from the test phase show, that a reasonable use of complex model-based decision support system at the farm as well as the landscape planning level is only possible either involving the model's creators or specially trained people.
Thank You for Your attention !!