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Towards a modelling framework for integrated assessment in arid and semi-arid regions

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Abstract: Climate variability in combination with socio-economic processes acting on the land may induce a reduction of resource potential and hence cause land degradation. Any forecasting attempt to increase societal early warning capacity has to take the interaction between climate and socio-economics on the land into account. The DeSurvey Integrated Assessment Model (DeSurvey IAM) is a framework to develop policy support systems with the aim to support planners and policy makers that deal with regional development and desertification. Using the DeSurvey IAM, policy makers can carry out an integrated assessment of the impact of different external factors and policy options on a number of relevant indicators.

The DeSurvey IAM has been developed with the objective to address a number of policy themes concerning regional development and desertification in arid and semi-arid regions: sustainable agriculture, water resource management and land degradation. By using these themes as a starting point for model integration and by linking the model to policy relevant drivers and indicators we intend to support policy makers at national and regional level by providing assistance in:

1. Understanding the important processes in a region or river basin as well as their mutual interaction;
2. Identification of current or future problems in the region or river basin;
3. Impact assessment of possible policy measures to mitigate identified problems;
4. Evaluation of different alternatives;
5. Improving communication between actors from different sectors and disciplines.

The core of the DeSurvey IAM is an integrated modelling framework based on scientific knowledge from previous EU-projects and builds on the MODULUS and MedAction Policy Support Systems. At present, the framework contains some 20 models (e.g. climate, hydrology, water management, erosion, salinisation, vegetation growth, land use, macro-economics, crop choice, irrigation) operating at different spatial and temporal resolutions. Depending on the problem at hand and the data available, a region-specific application can be set up that contains a specific combination of models incorporated. This flexible combination of models allows application for Spain (i.e. an entire country) at national, regional and local (1 km) levels with a temporal resolution varying between monthly (bio-physical components) and yearly (socio-economic components), as well as application for the Guadalentín river basin in Spain at regional to local (1 ha) levels and with a temporal resolution varying between minutes (bio-physical components) and years (socio-economic components).

In the development of the system, focus has been on the scientific and software integration of models with different spatial and temporal scales and resolutions and the applicability of such a system for the envisaged end-users, the policy makers and planners in the region or river basin. The paper provides an overview of the DeSurvey IAM and illustrates how it can help to assess the impact of alternative policies.

Keywords: *Policy Support System (PSS), Spatial Decision Support System (SDSS), Integrated Assessment (IA), desertification, modelling framework*

1. INTRODUCTION

Over the past decades a wealth of models related to desertification has been developed. Many of them were developed for specific issues and applied to specific locations. Over time some of these models evolved into more generic models that could be applied to a wide range of locations. Nonetheless, the models remained often uni-sectoral while the problem context is interdisciplinary. Realising the need for more integrated approaches and the inclusion of feedback loops between different disciplinary models, the MODULUS and MedAction projects aimed at developing an integrated model in which linkages between individual models were created.

The DeSurvey Integrated Assessment Model (IAM) builds on the concepts of the MODULUS and MedAction Policy Support Systems (PSS) and aims to take them to the next level. Where the earlier systems and research had a strong focus on finding scientifically corrects methods for integrating models with different temporal resolutions and modelling paradigms, in DeSurvey the focus has been on comparing and evaluating model complexity and spatial resolution. Furthermore, the DeSurvey IAM has evolved into a modelling framework, which allows the users to create a Policy Support System for a specific location and a specific resolution by using the components that are included in the framework, as well as by adding new components to the model library of the framework. Previous research in MODULUS and MedAction had a main focus on European regions; DeSurvey includes case studies in the Sahel, the Magreb, Chile and China. This requires a thorough investigation of the applicability of previously developed components and might lead to the development of new components that better resemble the processes in those regions.

In the development of the DeSurvey IAM we have aimed to develop a generic model, but with the understanding that there is no one model that fits all regions prone to desertification. Different regions face different problems and have different socio-economic cultures and structures. Moreover, data availability varies to a large extent in various regions around the world. On the other hand, there are also a number of universal drivers and processes related to desertification. Instead of striving for one model that has to fit to every region, we have decided to develop a modelling framework that allows selecting different model components according to the actual situation. The current version of the system provides flexibility with respect to temporal and spatial resolutions, as well as the complexity of the simulated processes. Depending on the extent of the area, the data availability and the need for accuracy, selections for appropriate model components can be made.

This paper provides an overview of the integrated modelling framework (section 2) and the components that are included in this framework (section 3). It describes the different configurations that can be made with the model components that are included in the current framework and provides an example of such an application in section 4. In the last section we then draw some conclusions and provide recommendations for further research, development and application.

2. THE INTEGRATED MODELLING FRAMEWORK

Recently developed integrated models can largely be distinguished in two groups: the first group links models through a so-called waterfall approach; calculations are carried out in a model chain where model A gives input for model B and model B for model C. In the second group, to which the DeSurvey IAM belongs, model components are linked dynamically and include feedback loops; model A provides input to model B, but model B in-turn also provides input to model A. The latter approach best represents the interconnectivity of real-world processes and allows for non-linear behaviour and the appearance of emerging developments in the integrated model.

In the DeSurvey IAM the level of complexity of the models is limited by the emerging understanding that complex process models are not necessarily better than simple process models. Moreover we argue that it is better to have a simple model that can be parameterised and validated rather than a more complex model that is over-parameterised and for which the dynamic interconnections between sub-models are imperfectly understood. Finally there is the reality that data for parameterisation, calibration, and validation is time consuming and expensive to obtain and is lacking throughout much of the countries prone to desertification.

The DeSurvey IAM integrates models with different paradigms and temporal and spatial resolutions. The theory behind the integration is system dynamics. Within this framework there are models that are more suitable at the coarser 1 km resolution and others that are more suitable at the detailed 1 ha resolution. Some of the models can be applied at both resolutions. An overview of the current structure of the DeSurvey IAM is provided in figure 1, an overview of the individual components in section 3.

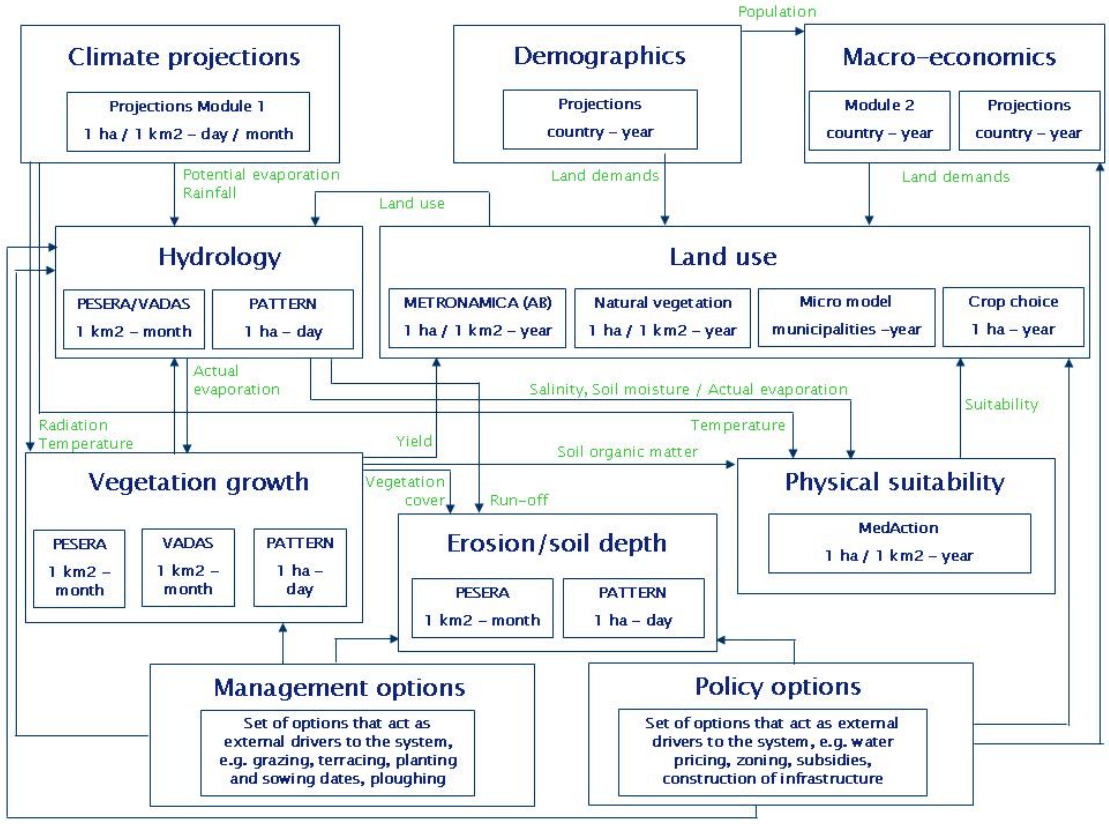

Figure 1: System diagram showing the structure of the DeSurvey IAM

2.1. Software environment

The DeSurvey IAM is developed and run under GEONAMICA, a software environment designed to build decision support systems based on spatial modelling and (geo)simulation. It has been developed over the past 15 years and has been used to generate a number of integrated spatial decision support systems (Hurkens et al, 2008).

GEONAMICA offers a set of components for the storage of map data, time series and cross-sectional data. It provides generic model components, a model coupling mechanism and a simulation engine based on the Discrete Event System Specification (DEVS) formalism (Zeigler, et al. 2000). A model controller manages the integrated model. It makes sure the individual models interact properly with each other and with the user interface components by telling each model when to perform certain, predefined actions (inversion of control principle). To create a user interface, GEONAMICA includes a configurable skeleton application and a rich class library of user interface components, such as map display and editing tools, list and table views and two-dimensional graph editing components.

The strength of GEONAMICA lies in the fact that it provides a generic structure for the models that allows them to be integrated more easily, while enabling complex dynamic models to be executed efficiently. The environment is set up in such a way as to enable users to run simulations interactively, by allowing them to intervene in the system and observe the results of their actions directly in a comprehensive manner or store the results for more detailed subsequent analysis and/or presentation. The GEONAMICA system also enables the inclusion of additional or improved models, providing a pathway for continuous improvement in the future.

3. INDIVIDUAL MODEL COMPONENTS

Most of the modules currently included in the DeSurvey IAM are (parts of) existing models that have been adapted for this purpose:

Climate projections (1 ha / 1 km^2, year): The climate projections provide information about the expected precipitation and temperature for 2050 at the 1000 x 1000 m resolution. Furthermore use is made of historic data to provide monthly, daily or rainfall storm values as required by the other modules. At the 1 ha resolution use is made of a weather generator to generate sub-models rainfall storms.

Demographics (country/region, year): In the current version of the DeSurvey IAM it is foreseen to provide the user with the possibility to enter population scenarios. In later versions this component can be replaced by an age-cohort model to simulate population dynamics.

Macro-economics (Macro-economic model (Ortega et al., 2007) – country, year; Projections – country/region, year): The objective of the macro-economic model is to model the impact of the macro-economic behaviour on the land use demands. In case no data is available to apply the macro-economic model, this model can be replaced by (user-defined) projections for jobs or land use demands.

Hydrology (*PESERA* (Kirkby et al., 2008)/*VADAS* (Ortega et al., 2004) – 1 km^2, month; *PATTERN (Mulligan, 2004)* – 1 ha, day): The hydrology modules simulate a number of different hydrological processes such as precipitation and irrigation, interception, runoff, evapotranspiration, infiltration, changes in soil moisture, salinisation, and aquifer recharge and extraction. For hydrology a detailed and a coarse component are available. Since the available hydrology model components from *PESERA* and *VADAS* were very similar we have decided to merge them into one hydrology component for the 1 km^2 resolution. In principle this component can also be used in data poor areas at the 1 ha resolution, but this application is not foreseen as part of this project. The *PATTERN* hydrology component operates at the 1 ha resolution and incorporates more detailed process knowledge than the *PESERA*/*VADAS* component. The *PATTERN* component includes a run-off component to neighbouring cells and is therefore only suitable at the detailed 1 ha resolution.

Vegetation (*PESERA* – 1 km^2, month; *VADAS* – 1 km^2, month; *PATTERN* – 1 ha, day): The plant growth module simulates the biomass growth and the vegetation cover of crops and natural vegetation. For vegetation dynamics one detailed and two coarse components are available. At the 1 ha resolution we apply the *PATTERN* vegetation growth module for both natural vegetation and crop types. At the 1 km^2 two components are available, one from *VADAS* and one from *PESERA*. Since the plant growth model in *VADAS* provides more detail on crop dynamics, this component is used whenever sufficient data is available. In those cases the *PESERA* vegetation growth module is used to simulate the growth of the natural vegetation. When data availability is limited, the *PESERA* vegetation growth module is used to simulate the growth of the natural vegetation as well as crops.

Erosion/soil depth (*PESERA* – 1 km^2, month; *PATTERN* – 1 ha, day): The erosion component calculates the long term average loss of (fertile) soil from hill slopes. For erosion a detailed (*PATTERN*) and a coarse (*PESERA*) component are available. The *PATTERN* component calculates soil depth as well as erosion. *PESERA* only calculates erosion. *PATTERN* is only applicable at the 1 ha resolution. *PESERA* is applicable at both spatial resolutions.

Physical suitability (*MedAction* (van Delden et al., 2007) – 1 ha / 1 km^2, year): The suitability module combines factors such as soil moisture, soil salinity, temperature and slope to calculate the suitability of a location for the growth of plants. The same suitability module is used at both resolutions, although the elements that are taken into account to compute the suitability differ slightly based on result from other components on the basis of which the suitability is calculated.

Land use (*METRONAMICA* (White and Engelen, 1997) and *METRONAMICA AB* (van Vliet and van Delden, 2008)– 1 ha / 1 km^2, year; Natural vegetation – 1 ha / 1 km^2, year; Micro-economics – municipality, year; Crop choice – 1 ha, year): The objective of the land use module is to allocate the (changes in) demand for land use on the land use map. In its simplest form only the *METRONAMICA* land use component is used. If there is a need to not only provide information on the land use class, but also the activity (e.g. number of people or jobs on a cell) and data is available to model this, then the *METRONAMCA AB* (Activity Based) component is used. The other three components provide the opportunity to model specific vegetation types in more detail. In this case *METRONAMICA* or *AB* provides the general land use classes (residential, industry, commerce, agriculture, natural vegetation) and dedicated components simulate what natural vegetation type or crop type will be allocated on natural vegetation or agricultural cells. The natural vegetation component is suitable at 1 ha and 1 km^2 resolution. The micro economic model is used to calculate crop choice at a resolution of 1 km^2 level of the municipalities; the crop choice model to calculate crop choice at the 1 ha resolution.

3.1. Different configurations

As stated before, the DeSurvey IAM can be set up in different configurations depending on the number of models incorporated (in data rich areas a larger number of models can be incorporated), the spatial and temporal resolution (in small areas more detail can be captured), the type of models incorporated (the macro-economic model that models economic development in the country and between regions is more relevant for country-wide applications than for test areas), and the way the process is modelled (similar processes need different equations when modelling them at different resolutions).

To illustrate this concept we provide two examples:

a) For applications that cover a large area (for example country-wide applications) and where data availability is high (e.g. Spain) we select a configuration with a large number of components with a resolution at local level of 1 km^2 and a temporal resolution varying between months (bio-physical components) and years (socio-economic components).

   Components that will be included in the applications to Spain and Italy are: climate projections, population projections, macro-economic module, hydrology *PESERA*/*VADAS*, natural vegetation growth *PESERA*, crop growth *VADAS*, erosion *PESERA*, physical suitability *MedAction*, land use *METRONAMICA-AB* and the micro model for crop choice.

b) For applications that cover a relatively small area (for example regional applications) and where data availability is high (e.g. Jeffara, Guadalentin) we propose a configuration with a large number of components with a resolution at local level of 1 ha and a temporal resolution varying between days (bio-physical components) and years (socio-economic components).

   Components that will be included in the application to Jeffara are: climate projections and weather generator *PATTERN*, projections for land use demands based on population and job projections, hydrology *PATTERN*, vegetation growth *PATTERN*, erosion and soil depth *PATTERN*, physical suitability *MedAction*, land use *METRONAMICA*, natural vegetation and crop choice.

4. POLICY IMPACT ASSESSMENT

External drivers, policy options, management options and indicators have been developed in close collaboration with potential users to ensure the policy relevance of the system. We have aimed to incorporate those policy and management options that are available at the moment or seem possible to enforce in the coming ten years. Many users stressed the importance of including indicators that are included in their National Action Programmes (National Action Programmes (NAP) are one of the key instruments in the implementation of the United Nations Convention to Combat Desertification (UNCCD)). Furthermore, we have sought to identify a few high level indicators that would give a first impression of developments in the entire region.

External drivers that are incorporated in the system are climate projections, population scenarios, scenarios for macro-economic variables and market prices for crops. Policy options that can be assessed are water pricing, zoning, subsidies, construction of infrastructure, water use restrictions, water extraction restrictions and reforestation. Moreover, the management options that are included are grazing, terracing, planning of ploughing, planting and sowing dates, irrigation quantity and irrigation techniques.

The DeSurvey IAM calculates as part of its dynamic (sub-)model outputs a large series of spatial indicators in the fields of desertification and land degradation, water management and agricultural practice, such as environmentally sensitive areas, water shortage and agricultural profits. This is possible because the DeSurvey IAM includes the dynamic models required to update the spatial data layers that form the basis of such indicators. Based on its dynamic indicators (all available simultaneously and per simulation time step), the system allows the user to explore and assess the effects of mitigation measures on the desertification status of either an entire watershed or of a precise location in the watershed (spatial entities of 1 ha or 1 km^2). Indicators are grouped into social, environmental and economic indicators.

4.1. System operation

Figure 2 shows an overview of the user interface of the DeSurvey IAM and its application for the Jeffara region in Tunisia. This user interface contains a dedicated section for policy makers as well as a dedicated section for modellers. Figure 2 shows the access point for the policy maker and the detailed land use map of the Jeffara region. The policy interface facilitates a policy analyst in carrying out an impact assessment study with the DeSurvey IAM. In the first step the drivers are set-up in the *input* section. These drivers are grouped into external factors policy options and management options. A next step is to set-up integrated *scenarios* based on a combination of driving forces. Next the model is run and afterwards the results can be viewed and analysed in the *indicator* section.

For modellers access is provided through the parameter section in the main window. Clicking on this part of the system shows the system diagram (similar to figure 1) and by clicking on each of the model components the underlying sub-model is opened and all data and parameters can be viewed and adapted.

By providing this dual interface we aim to cater for the needs of both modellers and policy analysts, in displaying the information most relevant to their respective interests.

The generic DeSurvey IAM modelling framework has been tuned to the Tunisian context in close collaboration with local scientists and (potential) users. Based on their input, processes have been adapted and relevant policy options and indicators included.

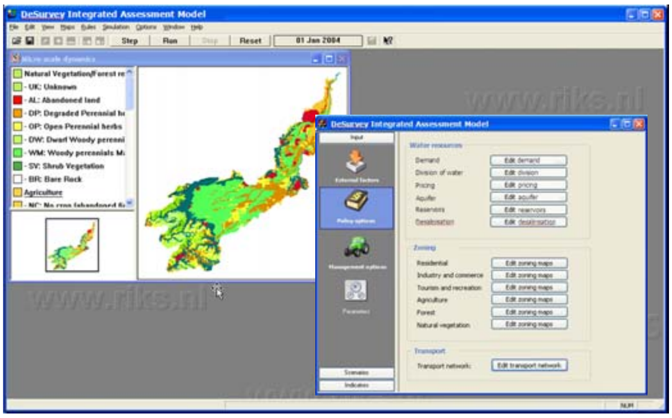

Figure 2: Overview of the user interface of the DeSurvey IAM

5. DISCUSSION AND CONCLUSIONS

The DeSurvey IAM is a flexible modelling framework that allows incorporation of a wide range of pre-existing model components when setting-up an application for a new region, building on a number of previous (European research) projects. The main improvements that have been realised through the DeSurvey project are an increased flexibility for configuring the integrated model, a better understanding of applying models at different spatial resolutions, and an improved user interaction. Below we provide some findings and points of discussion for the different elements of the DeSurvey IAM.

Model integration

As opposed to the waterfall approach for model integration, the dynamic approach that is the basis of the DeSurvey IAM represents real world interlinkages in their true complexity. In a policy context, this approach helps to identify the unintended side-effects of policies implemented in one branch of government on other branches, as well as win-win situations that can be created, and allows discussion of the trade-offs that may need to be made between policy areas.

Although initial research on the integration of models with different temporal and spatial resolutions and developed on different modelling paradigms has taken place, this is still a field that needs further attention. In particular we would emphasise that calibration, validation and sensitivity analysis of integrated models is still in its early stages, and that there is a need to identify the level of uncertainty associated with forecasts. These developments have been restricted in current projects by data and time limitations. We are currently in the process of calibrating and validating different applications of the DeSurvey IAM and hope to report on this in the coming months.

Reusability, modularity and flexibility

Nowadays there is much of discussion about the modularity and flexibility of (integrated) models. Mainly driven by the high costs of developing new models reusability of existing components is seen as a promising way forward. Given the advanced software technology and the need for an appropriate architecture to enable this modularity and flexibility, IT obtains a prominent place in the development of modelling frameworks. The DeSurvey IAM is a framework that includes a range of models for different levels of complexity and data availability and thus facilitates the reusability of components. Although this greatly decreases the time to set-up an application to a new region, it still remains a time-consuming task for a trained academic.

The application of the DeSurvey IAM to non-European countries has just started. Components with an origin in European countries, especially those related to socio-economic processes, need to be well-tested and to some extent adapted before they can be seen as ‘generic’ socio-economic components for the Maghreb, the Sahel, Latin America and China.

User interaction

The development of the DeSurvey IAM has taken place in close interaction with different user organisations in- and outside Europe. This has helped to frame the system and make it relevant to policy. Since the DeSurvey IAM is developed as part of a research project, there is only limited time for actual training and implementation during the project. However, to ensure that the system will be used after the project more time for these aspects is required.

The DeSurvey IAM is developed as a tool for strategic planning and support in the development of long-term integrated visions for the region or watershed. Through what-if analysis it shows the impact of (a combination of) policy options and external factors on a range of policy-relevant indicators. It thus enables learning and facilitates communication between actors from different disciplines. The system is not suited for operational management and detailed planning. When training users it is important to clarify the added value of the system as well as its limitations.

As discussed before, the DeSurvey IAM is a rather complex system, but still has the aim of supporting policy analysis. We have developed a dual user interface that provides easy access to policy makers and detailed access to modellers. The policy interface follows the steps of a policy impact assessment study, while the modellers interface allows the user to show and adapt all data and parameters included. For both types of users we have developed some practical examples to show the added value of using the system.

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