FAO-MOSAICC

Modelling system for Agricultural impacts of climate change

EU/FAO Programme on Improved Global Governance for Hunger Reduction (GCP/INT/130/EU)

Technical report: Development of the forestry component of MOSAICC

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Last edited 20141007

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1. Introduction

1.1. Presentation of MOSAICC

Information on potential impacts of climate change is key in the elaboration of national adaptation plans and policies. Given the large uncertainties about the future of the climate and the response of human systems, model simulations offer interesting possibilities to test scenarios, explore potential impacts and understand how different processes interact with each other.

In the framework of the joint EU-FAO programme on improving global governance for hunger reduction, FAO has developed an integrated system to carry out climate change impact assessments at national level. This server-based system called MOSAICC (Modelling System for Agricultural Impacts of Climate Change) has been built in association with various scientific institutions in Europe (universities, research centers) and combines climate data downscaling, hydrological, crop yield and economic models.

1.2. Background: Forest and climate change

Climate change poses a great challenge to agricultural but also to forest production systems, potentially threatening those who particularly depend on local food and wood production for their livelihood.

Forests are particularly sensitive to climate change, because the long life-span of trees does not allow for rapid adaptation to environmental changes. Unlike in agriculture, adaptation measures for forestry need to be planned well in advance of expected changes in growing conditions because the forests regenerated today will have to cope with the future climate conditions of at least several decades, often even more than 100 years.

Forests act both as sources and sinks of greenhouse gases (GHGs), through which they exert significant influence on the earth's climate. While most GHGs come from fossil fuel combustion, about one third comes from other activities like agriculture (mainly CH4 and N2O), deforestation (mainly CO2), fossil fuel production (mainly CH4) industrial processes (mainly CO2, N2O and F-gases) and municipal waste and wastewater (mainly CH4) (Victor and Zhou, 2014). Forests can contribute to the mitigation of climate change.

1.3. The new Forestry component

The development of the forestry component of MOSAICC was initiated with the recruitment of Mr. Renaud Colmant, forestry engineer. The objective was to integrate in MOSAICC a model able to simulate the impacts of climate change on forests' dynamics under different scenarios. The following activities included a review of models and studies at FAO and in the literature related to climate change impact assessments in forestry, the elaboration of a proposal for the module including the description of the objectives, the data flow, the input data and their format, the set of indicators, the methodology and if applicable the model(s) to be integrated and the development of the module and the interface in collaboration with the IT consultant of the project (Mr. Mauro Evangelisti).

1.4. Support from Wallonie-Bruxelles International (WBI)

The recruitment of Mr. Renaud Colmant benefited from financial support from the Wallonie-Bruxelles International, a public international relations body of Belgium. The assignment spanned from February till July 2014 (6 months).

2. Description of the work completed

2.1. First approach of MOSAICC

Throughout the first couple of weeks of the assignment were devoted to the familiarization of the forestry engineer with the platform MOSAICC, to understand how the models where working separately and then comprehend the links between one another. François Delobel, Climate Impact Officer and Technical Coordinator of MOSAICC, presented the two crops models (WABAL and AQUACROP), the hydrological model (STREAM) and the economic model (CGE). Hideki Kanamaru, Climate Impact Officer, explained to the forestry engineer how the statistical downscaling portal for climate data was working and answered to the questions on the subject.

2.2. Review of the literature

The impacts of climate change on forest's dynamics are a quite new field of study. Different kinds of models exist to assess those impacts but are not often applicable for broad areas. The first challenge was to understand the existing types of forest models and the difference between them. The main types of forest models are:

- Empirical forest growth and yield models
- Process-based models
- Ecological/Landscape models

2.2.1. Empirical forest growth and yield models

Empirical forest growth and yield models were developed aiming to predict growth and yield using statistical techniques and calibrated for comprehensive data-sets as yield tables. Empirical forest growth models can be used directly for decision-makings at stand ıevel (Vanclay 1994).

They are adequate for describing growth for a range of silvicultural practices and site conditions. Their relatively simple data input requirements and accuracy in predicting growth have made them the principal yield models of forest management. Growth and yield models exist for practically all of the most important forest types throughout the world. Some models predict wood quality properties and most have been extensively validated.

However, this approach ignores potential changes in environment, genetics, site and silviculture that might occur from rotation to rotation since there is no link to underlying causes of productivity. Moreover, productivity is based on dominant height (Site Index) rather than the capacity of the site to fix carbon and produce biomass (Net Primary Productivity - NPP; Mg/ha/yr) (Coulombe *et al.* 2010).

2.2.2. Process-based models

Process-based models, or also known as mechanistic models, process models or biogeochemical models, were developed to model key growth processes and fundamental causes of productivity such as photosynthesis and respiration, carbon allocation, nutrient cycles and climate effects. They are mathematical representations of biological systems that incorporate our understanding of physiological and ecological mechanisms into predictive algorithms. They take into account at the physiological level plant responses to site factors either if they are manipulated by humans directly, such as fertility, or indirectly, such as atmospheric carbon dioxide concentrations (Reyer *et al.* 2013).

However this type of model requires high quantity of detailed data which is rarely available at national, regional or even lower scales. This is due to the fact that they were originally designed and used for research purposes only, although these models have been more recently developed for use in practical forest management. Indeed, the models designed to provide predictions for management require simpler and more readily available data than those designed for research (Wamelink *et al.* 2009).

2.2.3. Ecological/Landscape models

Ecological models were developed to model natural and management-induced disturbances in cultivated, semi-natural or natural forests. They model long-term ecosystem dynamics involving spatially explicit information on recruitment, growth and mortality of individual trees. For example, the gap models, which deal with population succession, assess the potential vegetation patterns and changes in the vegetation distribution under the climate change (Bugmann 2001).

Ecological models explicitly assess the impacts of temperature, water and nutrients on the growth and development of trees. However, the main goal of these models is to simulate vegetation patterns over time based on the regeneration, growth and death of individual trees and on the interaction between different tree species (Lischke *et al.* 2006).

Nevertheless, the gap models normally exclude physiological mechanisms linking the growth and development of trees with the climatic and edaphic factors. This may limit their applicability for impact studies compared to process-based models, which include physiological response mechanisms to changes in environmental conditions.

2.2.4. Hybrid models

Hybrid models were developed from complementary merging of well understood processes and reliable tree and stand empiricism aiming to have a process model for the manager in which the shortcomings of both approaches can be overcome to some extent (Crookston *et al.* 2010). The same effort has been done for hybrid models gathering both landscape and process-based models. The improvement of process-based, landscape and empirical models will lead to better hybrid models (de Bruijn *et al.* 2014).

2.3. Investigations

In order to have an idea of the needs and desires of the potential future users of the new component of MOSAICC, discussions were engaged with several national and international institutions and countries (Peru, Morocco, Zambia, Zimbabwe, South Africa, Philippines). The conclusions were basically similar for all the countries and institutions. The principal interests were on the impacts of climate change on wood-productivity and biomass, but also on species range distribution (for all type of forests). Furthermore, most of them wished to have an indication of the impacts of the disturbances as fire, wind and insects on forest dynamics.

Investigations were conducted among several forest modeling expert institutions (Wageningen University, Université catholique de Louvain, Universidad Nacional Agraria la Molina) to discuss the topic and obtain advice.

2.4. Selecting the model

The MOSAICC platform is open-source. To make the use of the models as economical as possible for recipient institutions, the platform uses an open source programming language and free software to solve the models.

The aim was to seek and select a forest model, suitable for a broad type of forests around the world, able to model impacts of climate change and other disturbances as fire, at national level and easy to integrate in open-source software (if not already integrated) with low data inputs

Various models were pre-selected, studied, and discussed with the experts. Although pre-selected models seemed to be good, most of them were not meeting all the criteria as presented below.

One of the candidates was the European Forest Information Scenario (EFISCEN) model. The core of the model is an area-based forest model (or landscape model) and become a hybrid model with the data from the national inventories (empirical model). The model is flexible, not very data intensive and designed for large forest areas, such as provinces or countries and then was a great candidate for MOSAICC. Nevertheless, it is only suitable for even-aged monospecies forests (as most of the other empirical models) and cannot be used for plurispecies forests (Schelhaas *et al.* 2007).

PICUS model was another candidate for MOSAICC. It is a 3D gap model extended with a process-based model (hybrid model). This forest model can assess the impacts of climate change and study the effects of adaptive management alternatives. However, the model is adapted to study the forest dynamics in temperate/alpine forest ecosystems and not yet for others (Seidl *et al*. 2005).

Another opportunity for the platform was the VEGECLIM project developed by the Université Catholique de Louvain in association with Universiteit Gent and the LSCE (Laboratoire des sciences du climat et l'environnement). The project finalized the development of a Land Use Land Cover Change model based on drivers analysis (10-year daily SPOT VEGETATION time series analysis using) to be coupled with the ORCHIDEE model, a process-driven global ecosystem model (process-based model). Although the hybrid model is promising, it is not precise enough on the differentiation of the tree species and for now, it is not yet validated (Defourny 2014).

JABOWA Forest Computer Models is a well-known forest gap model. It is quite a simple model which can simulate grows of individual trees on small plots and allow changes in almost anything about the forest and its environment, with the full model. Unfortunately, the last versions of the model are non-open-source and as most of the forest gap models are derived from JABOWA it was decided to choose another model using the same assumptions (Bugmann 2001).

Finally, an open source landscape forest model, LANDIS-II, developed among others by Portland State University, met all the specifications required and was selected.

2.5. The model

2.5.1. LANDIS-II Forest Core Model

LANDIS-II simulates forest succession, disturbance (including fire, wind, harvesting, insects), climate change, and seed dispersal across large (typically 10,000 - 20,000,000 ha) landscapes. LANDIS-II tracks the spatial distribution of discrete tree and shrub species and has flexible spatial and temporal resolutions (Scheller *et al.* 2007).

LANDIS-II advances forest modelling in many aspects. Most significantly, LANDIS-II:

1. Is completely open-source at all levels with extensive documentation (http://www.landis-ii.org/),

2. Has a large library of ecological processes to choose from, including many explicitly designed to track landscape carbon dynamics,
3. Has flexible time steps for every ecological process,
4. Uses an advanced architecture that allows rapid model development and easy distribution and installation of model components,
5. Has a large and active community of users and developers (forum).

LANDIS-II manages and executes discrete extensions (modules or plug-ins). Each ecological process is programmed as an independent extension that interacts with the landscape through an explicit interface with the core LANDIS-II program.

The user specifies which extensions would be used to simulate the forest dynamics of interest. LANDIS-II allows scientists to easily develop and share their own extensions. There are many teams currently developing new extensions or revising existing ones.

2.5.2. PnET-Extension

Ecological models built on phenological relationships and behaviour of the past may not be robust under novel conditions of the future because global changes are producing environmental conditions that forests have not experienced historically (de Bruijn *et al.* 2014).

The US forest service and the Purdue University developed a new succession extension for the LANDIS-II forest landscape model, PnET-Succession, to simulate forest growth and succession using physiological first principles.

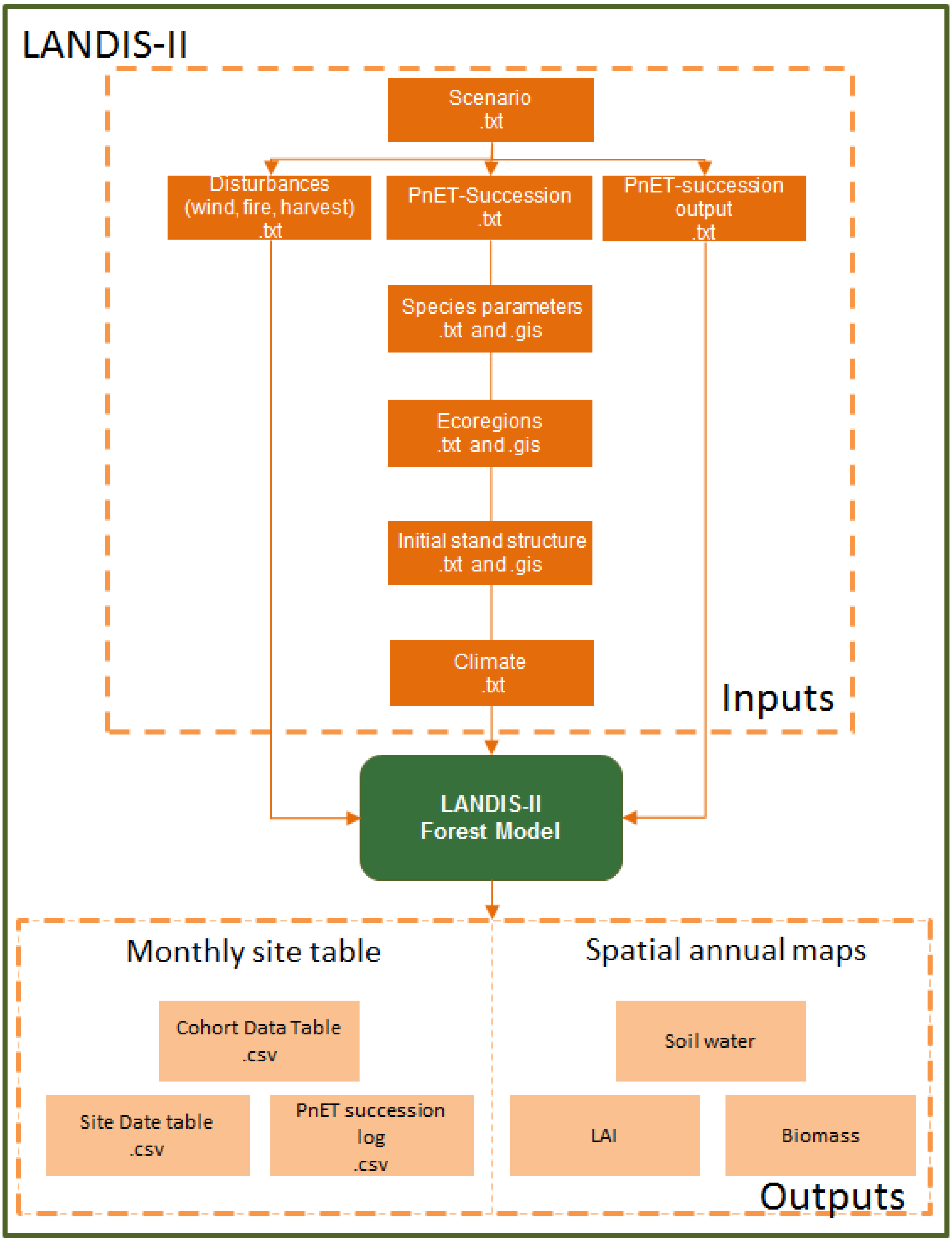
PnET-Succession integrates the tree physiology model PnET-II with the existing LANDIS-II Biomass Succession extension. PnET-Succession simulates the competition of tree species cohorts for water and light as a function of photosynthetic processes driven by foliar nitrogen.

Competition for water is simulated on each grid cell through a dynamic soil-water balance that receives precipitation and loses water through runoff, consumption in photosynthesis, and evapotranspiration. Competition for light is modelled by tracking solar radiation through canopy layers according to a standard Beer-Lambert formula. PnET-Succession requires average monthly photosynthetically active radiation, atmospheric CO_2 concentration, temperature and precipitation as inputs.

The new extension also dynamically calculates species establishment probabilities in each time step as a function of water and radiation stress.

The calibration of PnET-Succession to biomass and LAI measurements was made from the Duke Experimental Forest in North Carolina (USA) and tested the calibrated model against data from the Green Ridge State Forest in Maryland. The new extension shows considerable promise for studying forest response to climate change, including changes in carbon stocks.

2.5.3. Model flowchart



2.5.3.1. Inputs

- Climate data: Temperature, Photosynthetically Active Radiation (PAR), Precipitation and CO_2 concentration by month.
- Species parameters data: Among others: Species Name; Longevity; Sexual maturity; Shade tolerance; Fire tolerance; Seeding distance; Resprouting age; Foliar characteristics (Nitrogen content, turnover, photosynthesis …); Wilting point; Water use efficiency (WUE); Root-stem ratio; Roots turnover.
- Ecoregions data: a map of the different ecoregions of the area studied created from the layers of soils, precipitation and temperature.
- Initial communities' data: List of species present in the study area grouped into cohorts (by span age).
- Disturbances: disturbances as fire and wind, or even harvest (in the case harvested forests) can be added to the model, based on historical data and management policy.

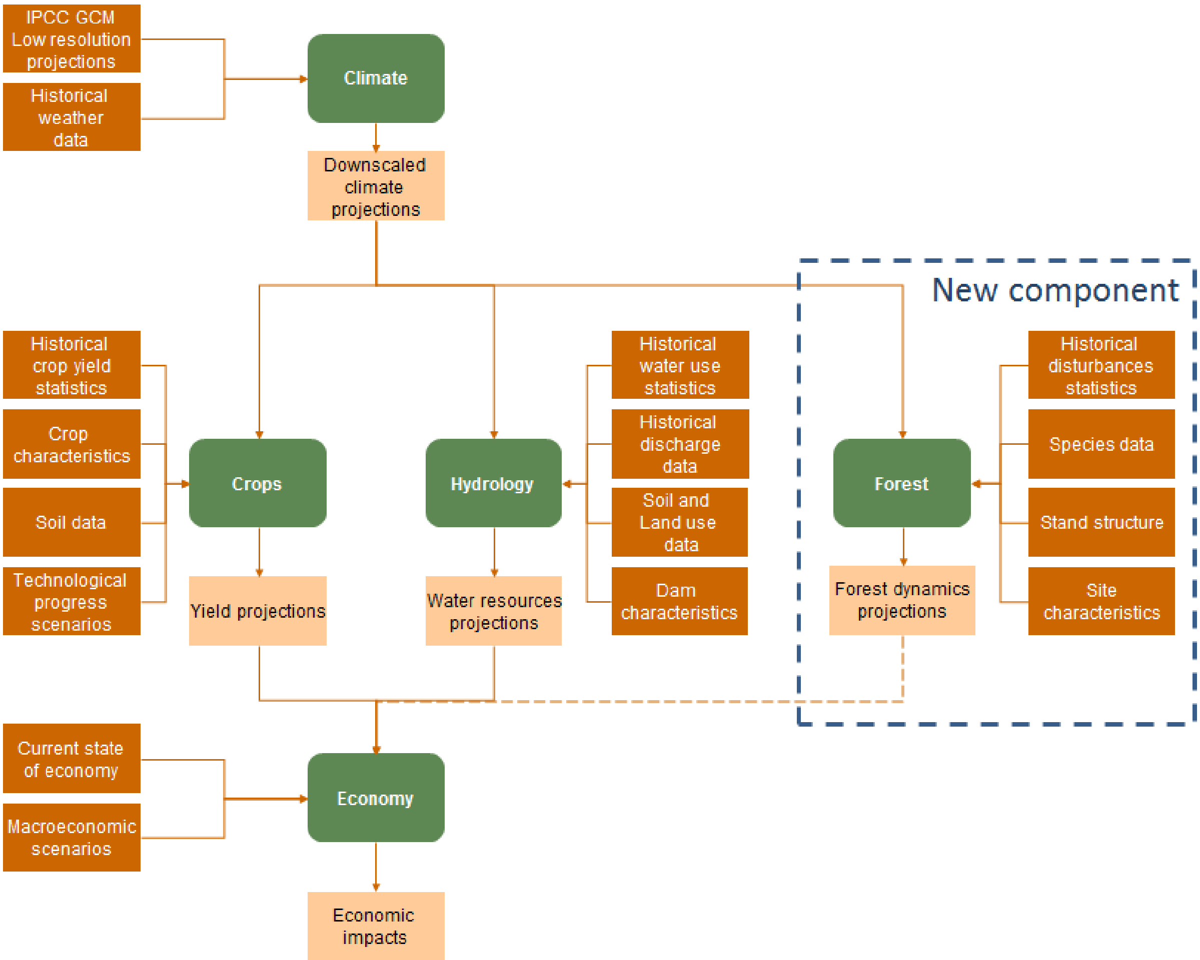
2.5.3.2. Outputs

The outputs are of two types:

- Spatial annual output (maps): Set of maps of the evolution in time of the Biomass, Leaf Area Index (LAI), Litter, Soil water, (…) by species.
- Monthly output (tables):
    - *Cohort Data* - Among others: Cohort net photosynthesis, Cohort mean WUE, Biomass of the cohort foliage/root/wood pool.
    - *Site Data* - Among others: Monthly transpiration, Net photosynthesis for all species combined, Total aboveground woody/root/foliage biomass of all species.

2.6. Integration in MOSAICC

2.6.1. The new forestry component of MOSAICC



The new forestry component is the fifth component being integrated in the platform. It gets the climatic input from the statistical downscaling portal of MOSAICC.

This new component will be a useful tool to:

- Assess the impacts of climate change on wood productivity (and its influence on economy).
- Assess biomass in forest under climate change regarding the UNREDD Programme and the voluntary carbon market.
- Assess the impacts of climate change on tree species range distribution.
- Asses the impacts of disturbances as fire, wind or harvest on forest dynamics.
- Decision support tool for policy makers in accordance with climate change previsions.

In the future, a possible link with the economic model is considered.

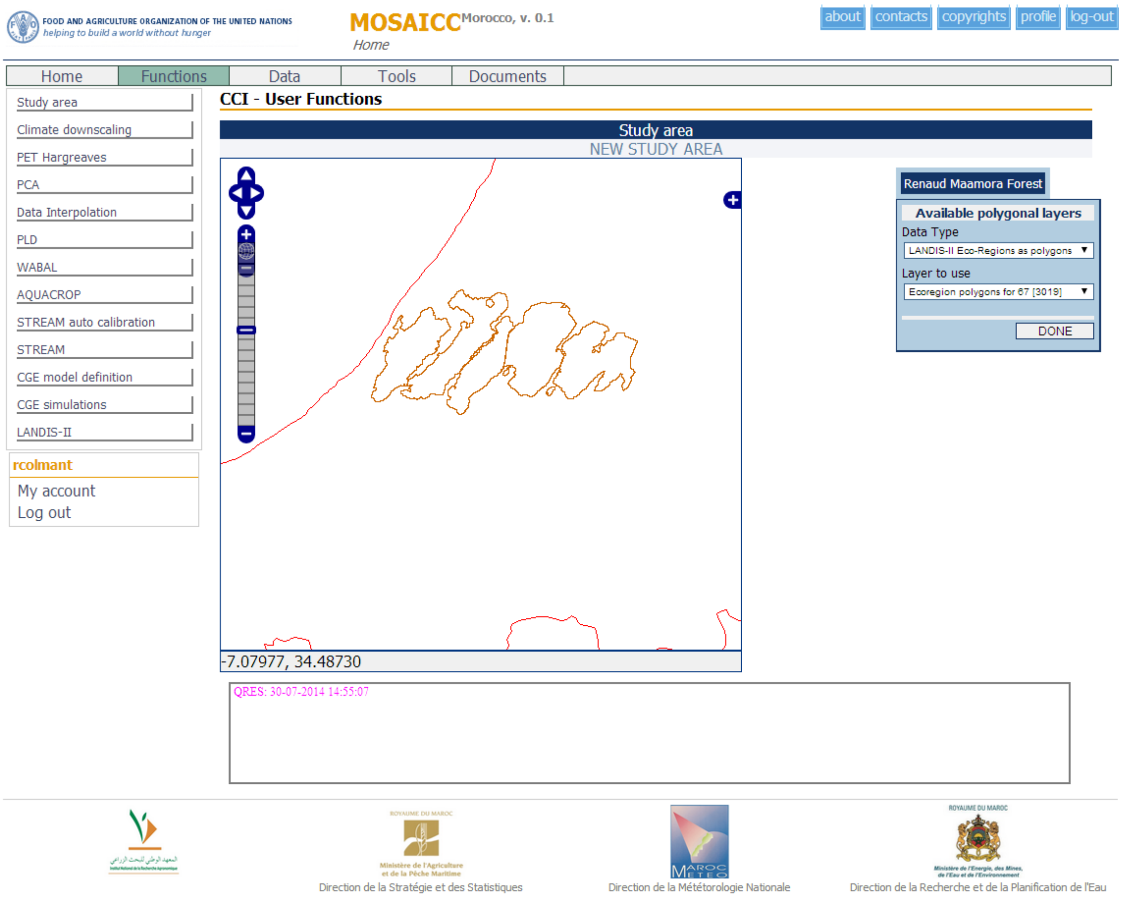
2.6.2. Software installation

See Landis-II documentation (http://www.landis-ii.org/)

2.6.3. Creation of the interface

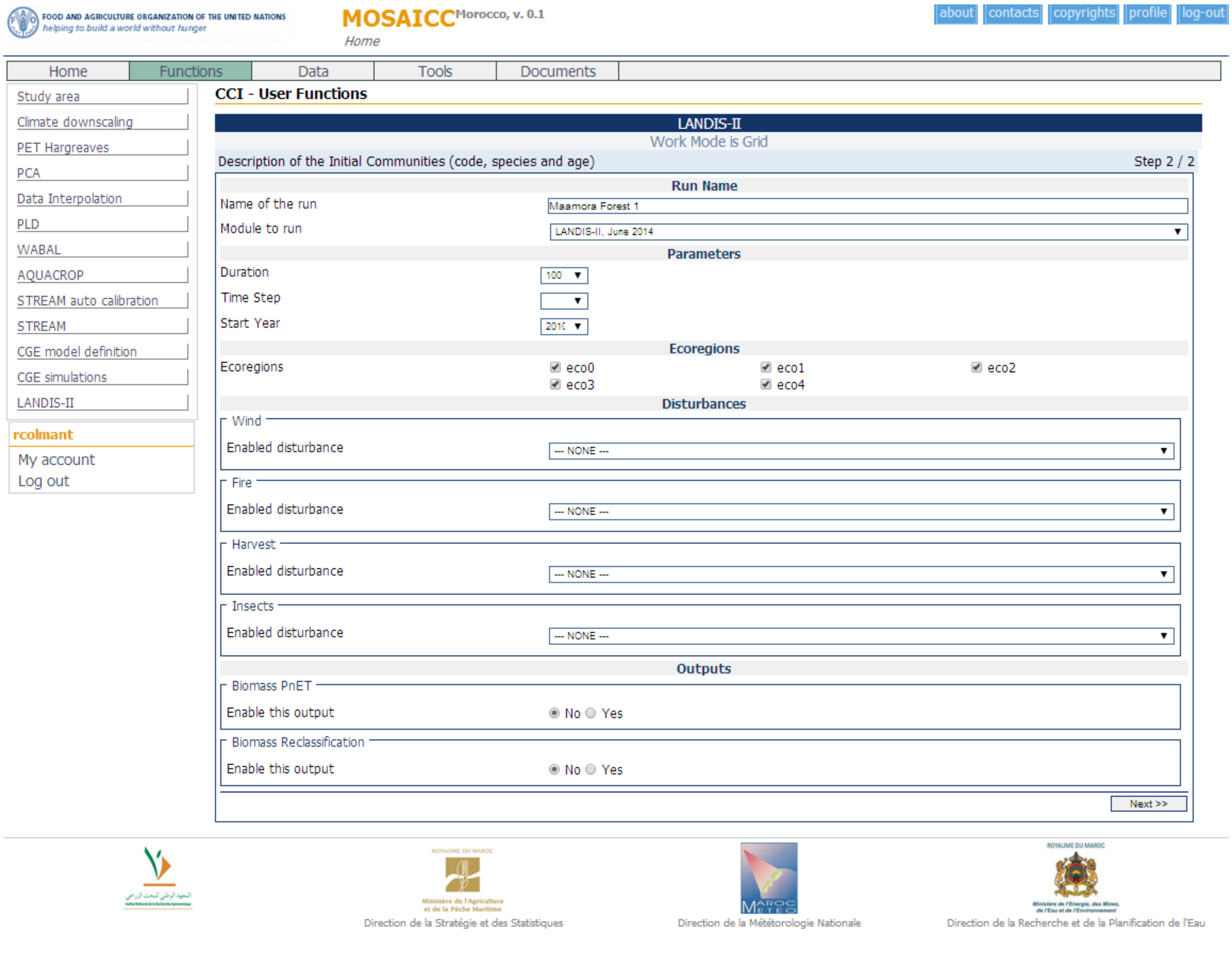
LANDIS-II doesn't have any interface; the model is used through a command prompt. We had to produce a brand new interface for the new component of MOSAICC.

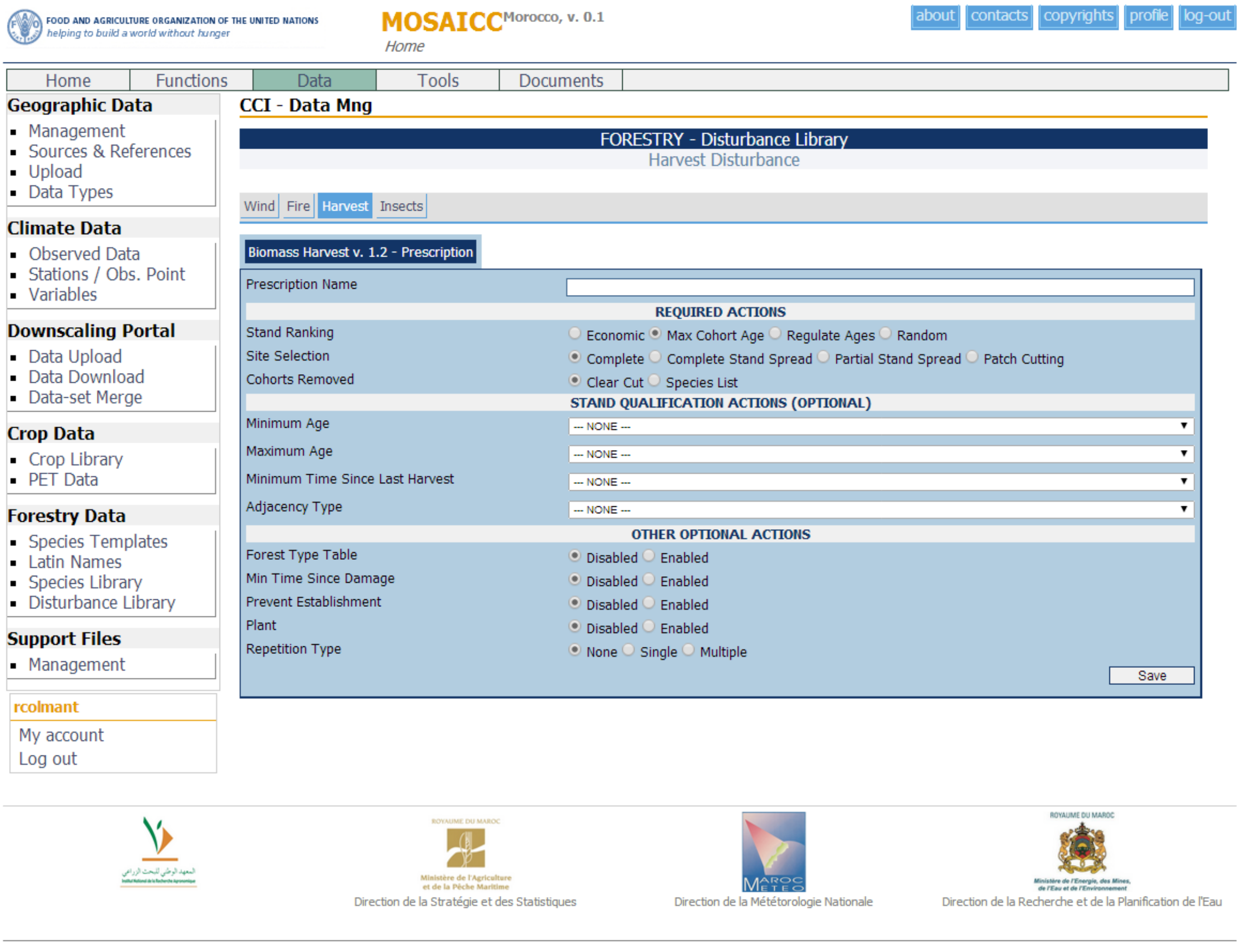
The creation of the interface was done in cooperation with the IT developer, Mr. Mauro Evangelisti, who developed the MOSAICC interfaces from the very beginning. We attempt to create the most user-friendly interface, with the fewer steps possible by simulation in order to allow the user to make multiple simulations in a short time period.



The simulation is done in a few steps with the possibility for the user to upload own maps of the study area on the platform, but also to create several libraries (species library with species names and parameters, disturbances libraries for wind, fire, and harvest).

The platform allows the user to define new species and even several sub-species grouped under one Latin name (e.g. when the species parameters tend to be different for one species following the region). Disturbances are defined in libraries to allow the user to store them and call them or not in the simulation.





2.6.4. Advantages and limitations

One of the limitations of this type of model is the complexity of the parameters of each species. The species has to be well known or well documented and if not, studies have to be conducted on the field before using the model.

In order to reduce the complexity of the species parameters for the user, we gathered the parameters in groups following the type of trees (drought tolerant, shade tolerant …). Default values are available for each group created and the user can choose to modify them or not. All the parameters for a specific tree species are saved into a Species library. Each species is named with a Latin name but also with a name characterising the area. The user can then use the parameters for a species in the simulation by calling the species name. The users can chose to share their parameters and experiments with the community and then facilitate the work of others.

The main advantages of the integration of LANDIS-II in MOSAICC are to share information, to reduce the model's complexity but also to enable the user to make the most simulations he can in a given time, using readily available climate time series from the climate module of MOSAICC.

3. Next steps and recommendations

In order to make the tool more user-friendly and more useful, a few steps are still needed to be done.

3.1. User guide

A user guide will be made to ease the learning of the users. This user guide will describe the new component's interface in details. For a better understanding of the core model and its extensions, the users would also have access to the LANDIS-II user guides.

3.2. Implementation

To make the model realistic and validated on the field, the tool must be implemented in a forest with well-known species (species parameters) and field data available (stand, region and climate data) which represent well enough the conditions of interest for the country or region. This work would have to be done with existing data and in collaboration with local experts.

3.2.1. Morocco

A contact is already established with the Moroccan national institution in charge of forests (Haut Commissariat aux Eaux et Forêts et à la Lutte Contre la Désertification), and the institution of research on agronomy in Morocco (INRA Morocco). The first implementation of the tool would have to be established in this country. MOSAICC is already installed in Morocco (Crop model) thereby facilitating the future implementation of the new Forestry component.

3.2.1.1. Mamora Forest

The first implementation will take place in the Mamora Forest in the Province of Rabat in collaboration with a project funded by the French Global Environment Facility (FFEM).

3.2.1.2. Tensift basin

Another option in the near future would be to implement MOSAICC in the Tensift basin in collaboration with the Association Marocaine des Sciences Régionales (AMSR).

3.2.2. Mediterranean countries

The FFEM project aims to maximize the production of goods and services of Mediterranean forest ecosystems in the context of climate change in six countries in North Africa (Algeria, Morocco, Tunisia) and the Near East (Lebanon, Syria and Turkey) which represent a forest cover of nearly 19 million hectares. In this context, we could imagine in the future to implement the new Forestry component of MOSAICC in the five other countries (out of Morocco).

3.2.3. Peru and Philippines

MOSAICC is also installed in Peru and Philippines. A survey in those countries showed that there is an interest for the forestry tool. Thus, the implementation of the tool in those countries in the future can be considered.

3.2.4. Southern Africa

Another survey was made in Southern Africa through the FAO Regional Officer, Mr. Marc Dumas Johansen. Thirteen countries from Southern Africa took part in a workshop in 2013 to discuss the current efforts related to forests, rangelands and climate change and to identify priorities for cooperative work in adaptation aimed at addressing gaps and common needs through a sub-regional programme.

Following the FAO Regional Office, in this perspective, some of the countries could be interested in the use of new forestry component of MOSAICC.

3.3. Link with the economic model

If the tests of the model with real data prove to be successful, the forest model will be linked with an economic model in the future like the other models in MOSAICC. The existing CGE (Computable General Equilibrium) model in MOSAICC can be extended to ingest data on forest productivity changes under climate change scenarios and simulate its impact on the national economy, combined with those of crop yield and irrigation availability changes. This economic model will be chosen among various existing forest economic models and will be used to evaluate the impacts of changing yields on national economies.

3.4. Other forest models and extensions

LANDIS-II forest model extensions are continuously revisited and improved. Regular updates with the new extensions on the MOSAICC platform as soon as they become available will improve simulations and results.

It is also well conceivable to add another forest model to the platform. This could allow the user to compare the models' results between one another and choose the most suitable model to given locations and environmental conditions.

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