MODELING CLIMATE CHANGES THROUGH DELAYED RESPONSE PLATFORMS

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Recent climate change has affected all sectors of society, from economic to social. There are few methods to assess the potential impacts of climate change as well as the options available to reduce the risks. The development of an integrated platform for assessing the multi-sectorial effects of these changes appears to be a necessity in order to eliminate imminent risks. The novelty introduced in this research article is to provide the opportunity to explore and understand interactions between different environmental sectors through the use of an integrated assessment platform.

Keywords: online platforms, integration, interconnectivity, climate change

1. Introduction

Present climate changes have come to disturb the natural balance and together with it the welfare of people and society as a whole. The need to diminish their effects and adapt to sudden variations are considered crucial to meet the new natural conditions.

Decision-makers often fail to put in balance future climate scenarios, fact which is most likely led by an unsuccessful dissemination of knowledge in the climate change field [1]. In most of the cases, studies and global or continental information exist but are not take into account in the decision-making process at the local level, their focus being centered more on the local and immediate needs [2]. Therefore, for actions to be carried on, decision-makers and stakeholders should be able to access credible scientific information on the risks of climate change impacts in order to take measures to mitigate their effects.

Therefore, there is a need to develop tools to simulate the impacts of climate change in a broad range of sectors of the environment, taking into account their mutual interactions and the climate and socio-economic factors. Such tools are the integrated assessment (IA) platforms that emerged and were first applied in the early 1980s in the field of acid rain [3].

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This article presents and brings into attention the implementation of a delayed response integrated assessment platform: IMPRESSIONS dIAP (dynamic Integrated Assessment Platform) developed within IMPRESSIONS FP7 European project [4] which aims to understand the consequences of disastrous climatic and socio-economic scenarios and to assess how such information can be effectively used and integrated into decision-making and adaptation processes in the future.

IMPRESSIONS dIAP aims to provide relevant scientific information concerning the natural consequences produced due to long-term climate changes.

2. State of the art

As mentioned above the first integrated assessment platform appeared at the beginning of 1980s. As scientists realized the potential of this type of instrument it has been further widely used in a number of projects, platforms and models:

- MEDIATION [5] a FP7 European project developed between 2007-2013 which put in the spotlight climate change and population's vulnerability;
- ClimateCost [6] a FP7 European Project developed between 2008 and 2011 which proposed to develop an economic analysis on the costs brought in by climate change;
- MOTIVE [7] a FP7 European project developed between 2009 and 2013 and was intended to study existing and potential adaptation strategies for changes that occur at climate and soil level and also the influences and impacts of these changes on forests and services provided by them;
- OPERAs [8] a FP7 European project developed between 2012 and 2017 that has attempted to translate the ecosystem theoretical knowledge into practice;
- EKLIPSE [9] a Horizon 2020 European project that is still under development aims to develop a self-sustainable mechanism to answer biodiversity and ecosystem services emerging questions;
- TESSA [10] an information flow assessment developed to provide practical advice on how to assess and monitor ecosystem services;
- OXYGEN [11] a Horizon 2020 European project still under development intends to analyze the evolution of Earth's atmospheric components with the help of newly developed isotope systems;

Although all these models and platforms address the problem of climate change not many of them have an interactive graphical interface to make them available to users. The results of most of these tools are made available in the form of scientific reports. One-way communication with users is preferred over a bidirectional communication. Many of these platforms address the issue of climate change in only some sectors or a suite of sectors without interconnecting and integrating them, but rather looking at and studying impacts of climate change on an isolated sector.

3. IMPRESSIONS dIAP

IMPRESSIONS dIAP is an on-line platform available at all times that enables stakeholders to assess the impact of climate change and vulnerabilities in key natural and anthropogenic sectors such as agriculture, forests, biodiversity, water resources and the urban sector. The platform integrates and interconnects different sectorial models that allow stakeholders to see how their interactions can change the effects of climate change.

The models embedded within the platform are representative for each of the above-mentioned sectors. With the help of these models, the platform simulates the impacts of climate change on relevant sectors for a period of time up to 2100. Simulation of results by 2100 is done at decade level (10 years), thus enabling models to take into account the results from previous decades. The results obtained in each decade will be displayed in an interactive manner using a GIS map service.

3.1 Scenarios

Integration of user input in the context of climate change impacts is achieved through customized scenarios, which are consistent and plausible descriptions of the future.

Lately most climate studies and projects were based on the concept of scenarios: global environmental scenarios [12], global ecosystem scenarios [13] and climate scenarios [14]. Thus, within IMPRESSIONS were designed a range of socio-economic (SSPs) and climate (RCP) scenarios according to the IPCC Fifth Assessment Report [15].

In terms of climate scenarios, their development has advanced from the idea of an increase in temperature by 2100 by 2°or less and then a decrease of it, to scenarios where the temperature could rise by 4-5° by 2100 continuing to rise after this threshold.

Similarly, to the climatic scenarios, the socio-economic ones have advanced lately by the development of so-called SSPs. These are a combination of qualitative narrative descriptions of five possible future universes with quantitative data on key factors such as GDP, population etc. These scenarios were chosen so there is no correspondence between them and the existing scenarios.

IMPRESSIONS innovates in terms of climate and socio-economic scenarios by combining SSPs and RCPs and integrating them. By engaging stakeholders, the climatic and socio-economic scenarios are credible and are designed to cover the period from now until 2100.

3.2 Meta-modeling approach

To improve IMPRESSIONS dIAP development process all sectorial integrated models were designed to be modular, independent and capable of replacement with an improved version at any time. The meta-modeling technique was chosen to provide the platform with the necessary computing speed. Meta-models are in fact simplified versions of existing sectorial models, most of them running as desktop software tools. The advantage of using existing models is that they have already been tested and produce credible and up to date results. However, being very complex they could not be integrated the way they are into the platform and were simplified. Thus, it was necessary to develop clear specifications to enable integration and communication between them. These specifications are independent from the algorithm applied in each model.

For a fruitful integration and interconnection, a series patterns and protocols were agreed and developed. These steps are briefly mentioned below:

1. The resolution at which IMPRESSIONS dIAP operates is 10'x10' (16kmx16km) and corresponds to the Climatic Research Unit’s baseline 1961-90 climatology [16]. This resolution includes 24131 European terrestrial cells over which the results obtained in the platform will be mapped and will be displayed to the user in an interactive GIS map.
2. Meta-model input and output identification – the input and output variables of each model had to be prioritized and reduced in order to simplify the algorithm. In order to prioritize the inputs of each model, those inputs that can and are useful in the process of simulating climate change have been considered. For the prioritization of the output variables, were chosen those indicators that were considered useful by stakeholders but also the economically relevant indicators. The list of the interconnected models for IMPRESSIONS dIAP is the following: RUG – Urban Model, WGMM – Water Models, Flood – Flood Model, Crop yields – Crop model, ForCLIM – Forest model, SFARMOD – Agricultural model, SPECIES – Biodiversity model.
3. Identifying links between meta-models which within the platform are represented as data transfers between the targets.
4. Document completion (data dictionaries) - In order to ensure the transparency of all existing data within the project, a prototype of a document was created in which each modeler filled in the data that the

meta-model needs to run smoothly and the output data calculated by the model in order for it to be made public to all the persons involved in the project especially the modelers who will identify that some of their inputs can be fed by the results obtained in other meta-models.

- variable type: input / output
- for input data, the date source will be specified:
  - from the user interface (via dIAP)
  - from the platform's common database
  - from the meta-model internal database
  - from another meta-model
- for output data must be specified if the variable will be passed to the user interface or if it can be used by other meta-models
- the name of the variable as used in the meta-model
- the full name of the variable
- brief definition of the variable
- data type: Integer, Single, Float, Double etc.
- measurement unit: meters, hectares, 1000 people
- spatial resolution

5. Data dictionaries standardization

The meta-models were implemented in the form of DLLs (Dynamic-Link Libraries), therefore various programming languages were used such as Microsoft C++, Microsoft C# and Microsoft VB. They were interconnected within the platform and work as a whole. The computational part of the platform provides the necessary data to the DLLs, it runs them in a predetermined order, gather data outputs and stores them. In the final step an e-mail will be sent to the user with the results obtained from running the desired scenario. All these meta-models interact with each other, the output indicators of some of them are inputs for the other. The interaction scheme between IMPRESSIONS dIAP models is depicted in Fig. 1.

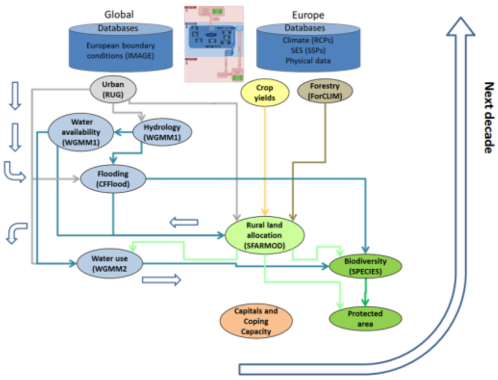

Fig. 1 Linked-models structure within IMPRESSIONS dIAP

4. Client/Server architecture

From the technical standpoint dIAP platform is built on Client/Server architecture keeping in mind the advantages of accessibility, scalability and the possibility of upgrading the platform whenever it is needed.

In dIAP the **Client** side and the **Server** sides are separated, thereby allowing sufficient running times for the computational part located on the **Server**. dIAP disconnected the **Client** from the **Server** in order to get more time for running meta-models. Therefore, the **Client** includes the input and output interfaces of the tool and the **Server** its computational one. Because of this disconnection, the user interaction with the instrument will not be a real-time one.

IMPRESSIONS dIAP platform architecture was synthesized in Fig. 2.

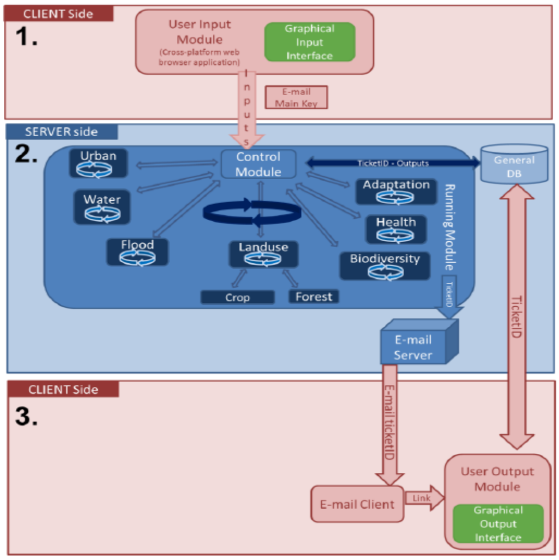

Fig. 2 Schematic of the dIAP software architecture

4.1 Model-View-Controller architectural pattern

For the development of the platform, MVC (Model-View-Controller) architectural pattern was used. This pattern is widely used in the development of graphical platforms in which the three components (Model, View and Controller) are separated to allow parallel development and reuse of the required sections. The meaning of the three components is as follows:

- *Model* - is the component that describes the logic of the architecture. In most cases, it is implemented as classes that manipulate the logic of the application. The connection to the databases used in the application is done through this component. The Model component interacts directly with the Controller.

- *View* - is the graphics component through which the application interacts with the user. It is basically the component that is responsible for displaying information in an interactive graphic way. This component sends the data to the Controller and retrieves the results from it. The View component interacts directly with the Model.
- *Controller* - is the most important component of the architecture in which the computational phase takes place. The data flow within this architecture begins with the requests received by the Controller, which in turn sends some of them to the Model. The information obtained by the Controller is sent to the View component and thus reaches the user. This component acts as a communicator between Model and View.

The main advantages of using the Model-View-Controller pattern are as follows:

- Decoupling the three components enables parallel development of the application facilities
- Easily implementation of changes
- Application structure
- Multiple View implementations for the same Model.

For IMPRESSIONS dIAP the Controller and the Model are the components running on the **Server**, and the View component is the one running on the **Client** side.

IMPRESSIONS dIAP was organized in three components: two modules located on the **Client** side: User Input Module and User Output Module and one located on the **Server**: Running Module.

Using the platform consists of three steps:

1. First the user selects the desired climatic and socio-economic scenario chosen. According to the chosen scenarios the user can also modify the input variables specific to the models integrated within the platform. This choice will be made in the User Input Module which will then submit the information to the **Server**. This input module is part of the View component.
2. The Running Module on the server should perform the following:
    - process the input data received from the User Input Module - part of the Model component
    - interrogate the databases for the additional data that is needed - part of Controller
    - run the chain of meta-models - the main core of Controller
    - store the output data in the correspondent files - part of Controller
    - notify the user by email that the run was completed and how he can access the results - part of Controller

3. Users can graphically view on a GIS map the results by accessing User Output Module via the web address received by e-mail or directly download the results that they are interested in.

4.2 Client Side

The **Client** Part including User Input Module and User Output Module (View component) has been developed with the help of web technologies including HTML, CSS, Javascript, JQuery. These technologies have been used widely given their vast spread, ease of use and updating, availability of running in any browser. The User Input Module captures user inputs specific to each meta-model and sends them to the **Server** side (Controller and Model). The User Output Module displays the results obtained and saved on the **Server** side by plotting them on a GIS map.

From a technical point of view, the User Input Module is made up mainly of CSHTML files:

- one file for each meta-model through which the user can run its standalone version
- two files for the graphical interface of the platform where the integrated meta-models flow can be run.
- other files for the auxiliary pages of the platform

4.3 Server Side

The **Server** contains the following components:

- dIAP central database that stores the climatic and socio-economic datasets and other data needed for running the meta-models. The connection between this database and the platform is managed through the Model component. The database is a SQL database with a list of 22 tables:
  - 12 climatic tables
  - 4 tables containing socio-economic quantifications for each indicator in the User Input Interface
  - 6 tables containing data necessary when running the meta-models
- The Model Component is made up of 11 models of which:
  - 7 for each meta-model
  - one for e-mail
  - one for the integrated structure that contains one model corresponding to each meta-model
  - one for a mediator structure required in IMPRESSIONS dIAP to interchange information between meta-models

    - one containing structures for all the tables in the database. Through this model the necessary information is obtained from the tables.
- Sectorial meta-models which were designed as DLLs (Microsoft Dynamic-Link Libraries). Some of them use their own databases to store internal data, some are fed with information from the general database and some meta-models will establish direct links with each other.
- The Running Module is based on ASP Framework and is part of the Controller component. The programming language that was used is C#. It receives the requests from User Input Module, analyses them and interrogates the database to extract the main information needed to run the desired simulation. Next, it prepares the data for the meta-models, runs them in an optimized way according to the default flow, stores the results in correspondent files and sends the user who initiated the run an email with the links where results can be viewed or downloaded. The Controller component contains 3 controller files:
    - one in which the information in the databases is actually obtained by means of the corresponding model of each of the tables in the database
    - one for meta-models through which they are run standalone. This controller is based on a number of other useful computational files designed for each meta-model in which the necessary input data are prepared, run and the output data are retrieved.
    - one through which the platform is integrated with the whole suite of meta-models. Within this controller are used the computational files corresponding to each meta-model mentioned above. These were designed not to load the code within the integrated controller and to have a modular file structure to allow the running of each meta-model separately. The general functions made available within each file of this type are:
        - readMediator() – populates the input indicators required by the meta-model from the mediator which is populated with information that come from other meta-models or even from model itself (results obtained during the previous decade)
        - writeMediator() - populates the mediator variable with the meta-model own output indicators that will be used by other modules or even by itself in the next decade

- use_Meta-model_name() - populates the input structure with data from the general or internal database model and runs the DLL. In the event of an error, the function will return the error
- set_result() - returns a file with the data obtained by running the DLL

The integrated controller can be schematically synthesized as follows:

- set the general indicators of the run - some of them are the ones taken from the user interface
- calculate based on the exact date and time a unique indicator to identify the run that will be used in establishing the access path where the results will be stored
- write an Input/Output file containing the input indicators of the current run and a list of all the output indicators to be computed, a brief description of each of them and the files in which they will be stored
- set the relative paths on the server from where the data from internal files of the meta-models will be read and where the results will be written
- for each decade from 2010 to 2100:
    - for each meta-model (further referred to as meta):
        - readmediator ()
        - set the relative access path for meta
        - use_meta ()
        - writeMediator ()
        - set_result()
        - verify if each mea-model has successfully finished running
- send an email to the user with the location where results can be viewed and downloaded.

5. Results

The following results present important meta-model results depicting combinations of some customized and predefined scenarios: increase in winter and summer precipitations by 10% for each decade, CO_2 set to 300 ppm and SSP1 socio-economic scenario and increase in mean annual temperature by 2° Celsius for each decade, CO_2 level set to 400 ppm and SSP5 socio-economic scenario.

Under these two scenarios combinations water availability (output within the hydrological model) is:

1. increasing in the first scenario combination, the biggest recorded values are in Northern and Central Europe – Fig. 3. These increased results are consistent with the increased winter and summer precipitation correspondent to the selected scenario.

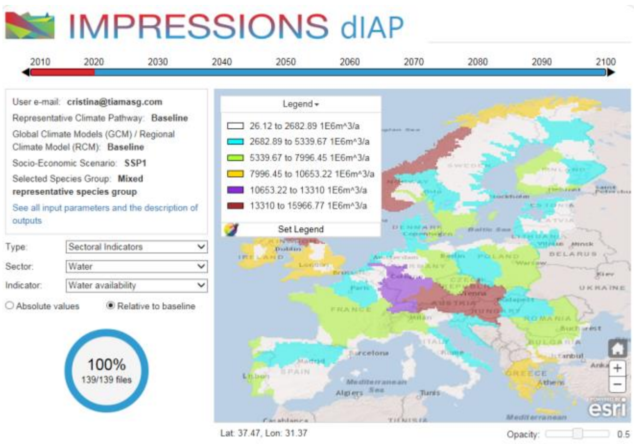

Fig. 3 WGMM: 2010: Water availability for increase in winter and summer precipitations

2. decreasing in the second scenario combination. A decrease in water availability is recorded in most European regions. Due to the location of the river basins, the most affected areas are Northern and Central Europe. The decrease of water availability output is due to the increase in mean annual temperature specific to the second scenario.

6. Conclusions

Although high-end scenarios are extremely plausible, there are relatively few studies or tools to evaluate their possible effects and provide solutions to reducing or adapting to these impacts. Given the fact that current methods and modeling tools meet many limitations and problems in running in terms of a disastrous scenario it appeared the need to develop a calibrated system to operate in extreme conditions, thus enabling decision-makers to have access to credible scientific information.

IMPRESSIONS dIAP is an integrated assessment platform which offers the user the possibility to simulate and visualize nowadays situation but also future high-end scenarios in the context of climate change. Unlike other existing assessment platforms IMPRESSIONS dIAP innovates by being available online, interactive and also broadly accessible. The platform brings novelty into the research field by integrating different sectorial models and linking them together in order to act as a whole. The results are displayed on a GIS map enabling stakeholders and decision-makers to evaluate the impacts of climate change and take actions in order to reduce or stop them.

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