Visualization of Biosphere Changes in the Context of Climate Change

Thomas Nocke, Ursula Heyder, Stefan Petri,
Katrin Vohland, Markus Wrobel, Wolfgang Lucht
Potsdam Institute for Climate Impact Research (PIK),
Telegrafenberg, 14473 Potsdam, Germany
nocke,heyder,petri,vohland,wrobel,lucht@pik-potsdam.de

Abstract

To bridge the gap between climate impact research on the one hand and decision makers and the public on the other hand, we introduce an new approach visualizing climate driving forces together with their possible impacts onto the biosphere. Therefore, an interactive tool synchronizing multiple-views has been designed and implemented, providing easy-to-use access to simulation results for several driving climate models, emission scenarios, vegetation variables / classifications and statistical derivations. It provides intuitive access to temporal and spatial regions of interest. Furthermore, to deploy this tool in different use cases, a mechanism for fast image pre-calculation in different image resolutions has been implemented.

Keywords: Climate Impact Research, Visualization, Biome Shift, Biodiversity, Ecosystem Services, Uncertainties

1. Introduction

The communication of scientific results in climate change and climate impact research is a challenging problem due the complexity of the applied models and their basics as well as the diversity of research fields involved (meteorology, climatology, biology etc.). Important examples for this complexity are the interrelations of biome shifts with the drivers CO_2, temperature, and precipitation as well as with the main ecosystem services (carbon sequestration, carbon storage and soil water content). On one hand, this complexity hampers the investigation of such interrelations by scientists. On the other hand, communicating scientific results with relation to biodiversity and ecosystem research including their inherent uncertainties to decision makers and to the general public in an easily-understandable way is of growing importance. In this context, interactive visualization and graphical user interfaces can play a key role in analyzing and presenting scientific results on the projected impacts of climate change, bridging the gap between the complexity of climate related scenario analyzes and users [NOC07, WRO08] by supporting various tasks (e.g. analysis of trends / extremes, presentation of changes / uncertainties).

Thus, this paper provides an alternative approach for interactive visualization of biosphere simulation data in climate change context. We introduce a new software tool tailored to represent biosphere change simulation data in combination with their driving forces. This tool is a dynamic and augmented version of the static and exemplary visualization from [LUC06, SCH06] in IPCC AR4 ([FIS07], fig. 4.3.). Using a multi-view environment, new insights about relations in the underlying data (e.g. causes and effects of climate change) as well as an improved communication of uncertainties can be achieved, synchronizing views onto different driving models and scenarios together with representations of different biosphere related variables. Additionally, interactive selection of spatial and temporal regions of interest supports studying details.

2. Background

The value of biodiversity is increasingly acknowledged from different communities, ranging from countries negotiating climate policy to rural communities and farmers which directly rely on natural resources. Climate change impacts biodiversity at various scales, ranging from changes in species distribution and phenology to profound shifts in global biome distribution [LUC06, FIS07].

To project changes of biodiversity due to climate change, meaningful indicators are required. Alternative approaches for investigating biodiversity are (1) the usage of indicators using numbers of species (e. g. a specific taxon such as plants or birds) and (2) the analysis of ecosystem or biome composition on the basis of ecophysiological mechanisms, considering the more complex mechanisms in the biosphere.

For the second approach, LPJmL [SIT03, GER04, SCH06] as a well-validated global dynamic vegetation model of land biogeochemistry (carbon and water fluxes through vegetation and soils) and biogeography (spatial distribution of 9 plant functional types, of which 7 are woody and 2 herbaceous) is suited to project global biome shifts under climate change. LPJmL comprises modules for photosynthesis, evapotranspiration, carbon allocation to several compartments, establishment, mortality and disturbance, as well as quantification of run-off, computed as a function of climate and atmospheric CO_2 composition. The plant functional types differ in their physiological response, and can be classified according to their relative distribution into biome types, such as evergreen tropical forest or savanna.

3. Related work

Visualization has been established as a method to communicate climate and impacts of climate change. Standard techniques are maps using color mapping with different geographic projections, time charts, bar charts and scatter plots (see e.g. [IPC07], [FIS07]).
The visualization of biosphere changes of indicator based methods faces the challenge of the high numbers of species to be display concurrently. Here, texture-based mapping of driving forces and vegetation classes using gray scale images is a frequently used approach [SCO02, HIC04], however, providing limited distinction of smaller populations. In mechanism based biosphere change research the use of colored maps is wide spread, representing single variables or classifications [SCH06, FIS07, MOR07].
Nowadays, the visual comparison of climate data, in particular for the representation of quality aspects becomes of increasing importance, visualizing uncertainties using multiple images [FIS07, MOR07] or mapping them together with the data in one image (e.g. using textures [IPC07], pp. 76, or transparency [NOC07]). To analyze and mediate such uncertainties of future scenario simulation and to answer specific questions (e.g. regional specifics), an interactive visual inter comparison of different climate forcing scenarios and related biosphere impacts for various variables from different perspectives (e.g. difference vs. absolute plots) is required. However, previous work in this field is mainly restricted either to an inter comparison of different static images side by side or to animations of one single biospheric variable to show temporal trends, or to finer spatial resolution plant functional types representing e.g. single European tree species [HIC09].

4. A visualization approach for biosphere changes

Facing these obstacles, we designed a visualization framework fulfilling the following requirements: easy to use graphical user interfaces, intuitive visualization metaphors, high error tolerance to user inputs and data, high portability for different software platforms and a fast visualization calculation. With regard to these requirements, our framework design is split up into two independent parts: image generation and interactive multi-view image presentation (see fig. 1).

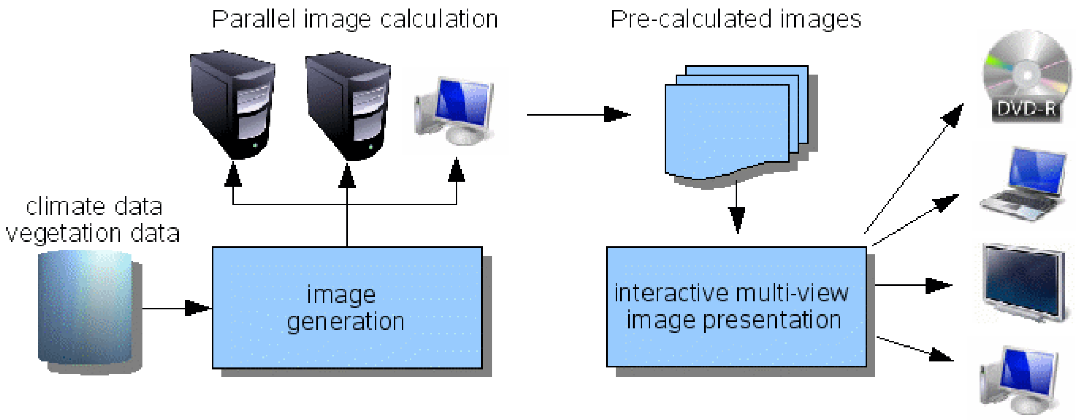

Figure 1: Architecture of the climate and biosphere impact visualization approach

4.1.Interactive, multi-view image presentation

As major part, we developed an easy-to-use Java based image representation tool (PIK Vegetation Visualizer: PVV) which is scalable to be presented in different scenarios: various screen resolutions enable presentation sessions on notebook PCs on scientific conferences, on scientist's workstations in the intranet, on high resolution displays on exhibitions and information events and deployed on DVDs. It provides a graphical user interface to interact with the different visualizations, providing six main parts (see fig. 2): a time chart presenting three CO_2 scenarios (top left), two small maps representing simulated future climate conditions (top center: temperature, top right: precipitation), one larger map representing biosphere changes based on LPJmL output (bottom left), data selection parameters (center right) and an information part (bottom right).

Using the selection parameters, the user can change between

- different CO2 emission scenarios: A1B, A2, B1

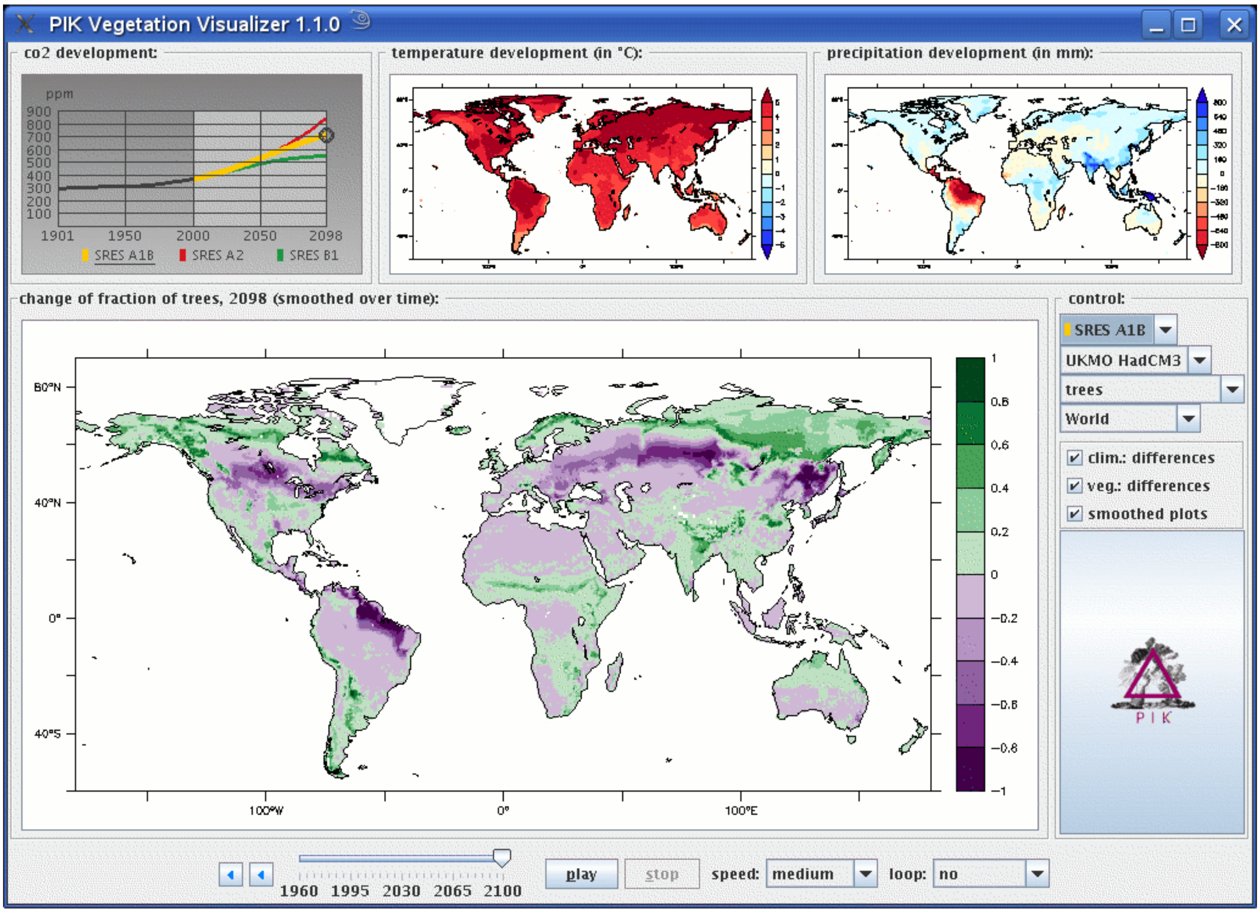

Figure 2: Screen shot of the vegetation visualizer graphical user interface (1024x768 resolution version)

- different climate models: ECHAM (MPI), HadCM3 (UKMO), CCSM-3 (NCAR)
- different vegetation variables: area fraction of trees, grasslands and barren; net ecosystem exchange, carbon sequestration, and two biosphere classifications
- different time steps[1] (1901-2098) and spatial regions (world, continents).

The user can select a certain time step manually or use different animation modes. Further modi enable users to chose between absolute values and changes in reference to the reference time period (1961-1990) and to smooth small changes in time which might confound the user (using a temporal averaging window of ±5 years). As a result, a variety of views onto the data source can be inspected and presented (see fig. 3).

The tool provides both overview and detail, starting with a world map of smoothed images of difference maps, and providing more details about certain continents, the un-averaged and the absolute data values on demand. The synchronization of views on cli-

[1] For the DVD version we restricted the time range to 1960-2098.

mate forcing and biosphere change impact variables in combination with animation enables an improved understanding of causes and effects of climate change in their temporal reference. For instance, in figure 2, a strong reduction of precipitation conditions in northern Brazil may lead to strong future biospheric changes in this region, in particular leading to a deforestation. Furthermore, the tool allows an interactive assessment of differences between models and scenarios, getting an impression on uncertainties in future scenario simulation.

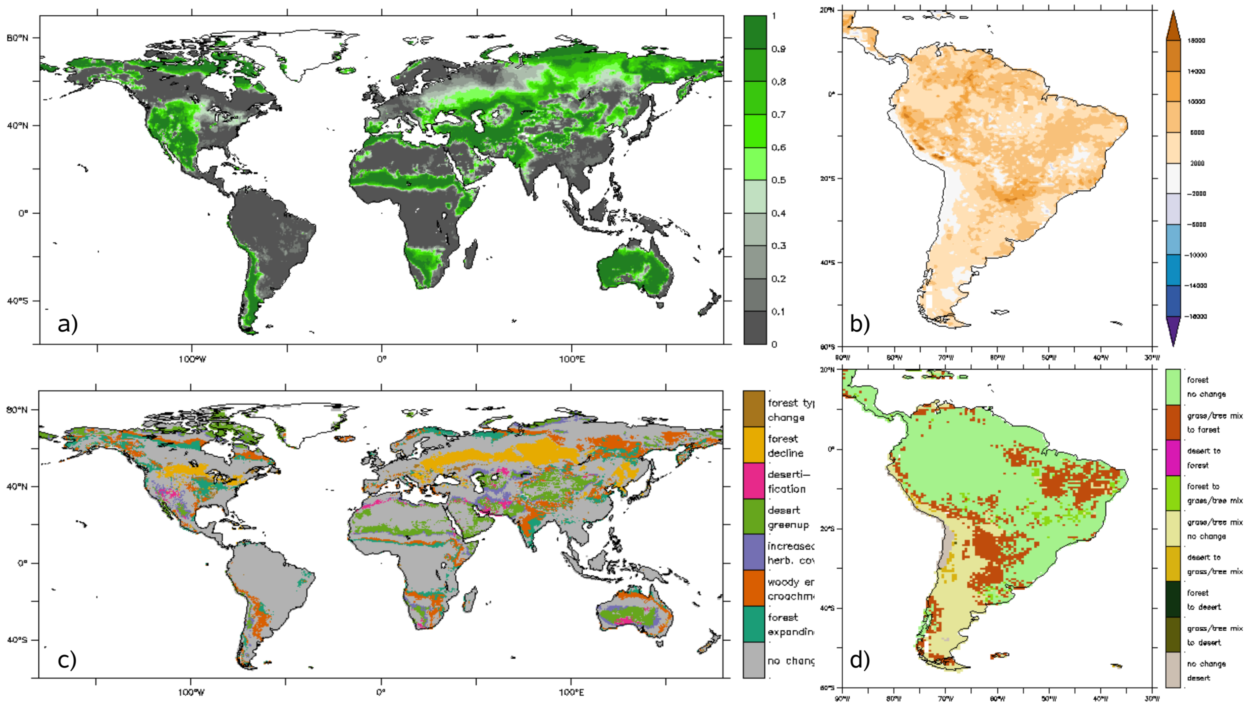

Figure 3: Examples of visualizations of biospheric variables in the PVV tool (CCSM-3 model, scenario A1B, year 2090): a) fraction of grasslands (World); b) change of carbon stocks (South America); c) classification of vegetation class changes (World) d) changes between tree lands, grass lands and barren (South America)

4.2.Image generation

The above described presentation parameters yield a total number of ca. 0.5 million images to be generated, from, currently, ca. 20 GByte of input data. With this amount of data, and considering data privacy, we decided against generating the images on-demand on laptop or workstation computers, as is typically done for visual presentations. Thus, separation between image generation and presentation became necessary.

The image generation also involves interactive work cycles to adapt the visualization to users' demands (color palettes, axis labeling, map projections, etc). Speed-up through parallelization was found essential to manage these work steps in reasonable time. Generating a single image needs only a fraction of a second -- once the visualization software has loaded the required parts of the input data. Each image can be generated independently from all others, enabling master-slave task farming. An MPI wrapper program is used to manage concurrent instances of the sequential visualization environment Ferret (http://ferret.wrc.noaa.gov/Ferret) on supercomputers. To avoid long queue wait times on central compute resources, and to facilitate interactive work flows, also cpu cycle stealing on idle workstations is used. Since task farming does inherent load balancing, even low performance machines can be employed

Some things were found to be important for an efficient visualization work flow:

- The granularity of the farmed subtasks must be coarse enough to rectify the parallelization overhead, but they must not overflow the target machine's memory.
- Data locality should be considered: subsequent jobs that work on the same data subset should be dispatched onto the same machines.
- A checkpoint-restart facility to resume interrupted runs can greatly ease the work.
- Versioning of produced images, to easily identify and distinguish image sets from different generation runs, produced with different parameter sets, also reliefs from sorting out several 1000s of images from different runs by hand.

5. Discussion

The frequent application of the proposed, interactive image presentation tool for both discussions in scientific background and in presenting results of climate change research to decision makers and the general public showed its high usability. Visually linking the temporal dynamics of different climate and biospheric variables, it makes scientific knowledge tangible even for non-expert users. For example, it shows that the different driving climate models predict different changes over time. Temperature and CO2 concentration generally increase, while precipitation shows differing patterns. Subsequently, impacts, as expressed by biome shifts, do not change continuously. It then is a good chance to discuss – or an obligation to describe - the different physiological mechanisms behinds (drought effect, CO2 fertilization etc.).

Further, direct relationships between biome shifts and carbon cycling can be made visible, also to discuss feedback effects. For example, a shift from an evergreen tropical rain forest to a more open vegetation leads to a reduction in soil carbon storage as well as carbon sequestration – both of which are currently acknowledged as ecosystem services to reduce climate change.

However, the provided tool has some limitations. First of all, it can - and possibly as well should not - replace a the scientist's knowledge and presence. This knowledge about the complexity and limitations of the models and the related phenomena can not be represented by a software tool. Interpretation of certain data values, their distributions and related uncertainties are still subject to climate and climate impact experts, for instance considering the complex interactions between carbon and water, nitrogen not yet included, the impact of social systems on land use, or the variability of soil conditions. Furthermore, biome shifts are only an indirect indicator for biodiversity, because neither the depending animals, fungi and plants are considered, nor other concepts such as phylogenetic age to valorize biodiversity shifts.

From a technical perspective, the large number of images to be calculated and distributed limits the number of variables, scenarios, models and visualization options (e.g. using different color mappings). This restricts the approach to a result presentation scenario, being of marginal applicability for an interactive visual data analysis only. Moreover, it bases on an image level comparison, facing the well-known obstacles in comparing smaller regional patterns for multiple variables, models and scenarios. Here, the application of alternative approaches visualizing multi-variate and multi-run climate data [NOC07] for such an presentation oriented scenario needs to be further investigated.

6. Conclusion

Using a multi-view environment, insights about relations in the underlying data (e.g. causes and effects of climate change) as well as an improved communication of uncertainties can be achieved, synchronizing views onto different driving models and scenarios together with representations of different biosphere related variables. Additionally, interactive selection of spatial and temporal regions of interest facilitates studying and discussing details.

Facing the limitations discussed in the previous section, we see three directions for future work to enhance the approach

1. as an **visually-based data analysis tool** supporting model output exploration research: inclusion of further (alternative) visualization techniques used for data exploration and a variety of parameters; provision of direct image interaction techniques (e.g. brushing & linking); combination with statistical filters
2. for an **autonomous use for educational purposes** (schools, etc.): limitation to very few scenarios, models, variables etc.; provision of a multitude of additional multimedia information, reducing possible misunderstanding or wrong interpretation; providing image interaction to get information about certain “events” within the data (e.g. tipping points)
3. for **decision making processes**: inclusion of land use scenarios which are of high importance for decision making (subsidies for specific land uses, EU biofuel quota, etc.); coupling to economic models to assess the (regionalized) impact of different carbon prices or different REDD (Reduced Emissions from avoided Deforestation) schemes.

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