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The ICLIPS Impacts Tool: Presenting climate impact response functions for integrated assessments of climate change

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Abstract: The ICLIPS model is an integrated assessment model of climate change that links global climate change with regional impacts and mitigation efforts by integrating components from different disciplines and various spatial scales. Its reduced-form impact module consists of climate impact response functions (CIRFs) that depict the regional sensitivity of selected climate-sensitive impact sectors to changes in important climatic and atmospheric drivers. In addition to enabling the specification of maximum “tolerable” impacts of climate change in a tolerable windows analysis with the ICLIPS model, the CIRFs are also a valuable information source in their own right. In this paper, I present the ICLIPS Impacts Tool, a software tool that provides convenient access to a large number (ca. 100,000) of CIRF diagrams for a wide range of impact indicators, geographical regions, and climate projections. The choice of Java as programming language enables the ICLIPS Impacts Tool to run on most computer platforms, including Microsoft Windows, Linux, Solaris and AIX. This paper provides an introduction into the CIRF concept and presents the main features of the ICLIPS Impacts Tool.

Keywords: Climate change, climate impact response functions, integrated assessment model, ICLIPS, graphical user interface

1 CLIMATE IMPACT RESPONSE FUNCTIONS IN THE ICLIPS MODEL

This section introduces the concept of climate impact response functions (CIRFs) as it is applied in the ICLIPS integrated assessment model (IAM). A more detailed explanation of these issues can be found in the cited references. Section 2 describes the main features of the ICLIPS Impacts Tool, and Section 3 concludes this paper.

The ICLIPS IAM implements the tolerable windows approach (also known as guardrail approach), a decision-analytical framework for climate policy that allows a clear-cut separation of normative decisions about the desirability of different policy outcomes on the one hand, and of the scientific analysis of the relevant components of the earth system on the other (see Petschel-Held et al. [1999]; Bruckner et al. [1999]). The core of the ICLIPS IAM combines an efficient global carbon cycle and climate

model with a multiregional economic growth model that includes emission rights trading and dynamic carbon mitigation cost functions in an optimizing framework (see Toth et al. [2002]). This core model is supplemented, among others, by a reduced-form impact model that consists of a large set of regionally and sector-specific CIRFs (see Füssel et al. [2002]).

The CIRFs included in the ICLIPS model link projections about future climate change to their impacts on selected climate-sensitive sectors, and vice versa. They are derived from extensive simulations with spatially explicit, biophysical impact models. Whereas the principal output of the ICLIPS climate model consists of time trajectories for globally averaged changes in surface temperature and sea level for a given scenario of greenhouse gas emissions, the impact models require geographically explicit data for several climate parameters at monthly or even daily resolution. A scaled scenario approach is applied to bridge that gap (see Viner [1994]).

Climate change patterns for surface temperature, precipitation and cloudiness in each month are extracted by principal components analysis from the results of transient simulations with various coupled general circulation models (GCMs). These time-invariant patterns are then scaled to the simulated change in global mean temperature, and superimposed onto the baseline climatology. The regional and seasonal variability in the climate change signal simulated by the GCM is thus included in the impacts analysis even though future climate states are concisely described by the change in global mean temperature. The scientific uncertainty about the future climate evolution is partially accounted for by applying climate projections from different GCMs (see Füssel and van Minnen [2001]).

The CIRFs contained in the present version of the ICLIPS model have a clear focus on biophysical impacts. A modified version of the BIOME 1 model that includes the direct effects of enhanced CO₂ levels on the water-use efficiency of plants is used to compute the global distribution of biomes for a given climate and CO₂ concentration. An adapted version of the FAO crop suitability model determines the suitable area and the potential rain-fed production of the 19 most important food crops worldwide. The global hydrological model WaterGAP 1.1 simulates freshwater availability on the level of river basins (see Füssel et al. [2002]; Alcamo et al. [1998]; Döll et al. [1999]). The spatial resolution of the impact models is 0.5 by 0.5 °.

All CIRFs presented here use the change in global mean temperature as an input variable. Due to its strong effect on the water-use efficiency and the photosynthesis rate of plants, CO₂ concentration serves as a second input variable in the CIRFs for natural vegetation and crop production. The domain of the CIRFs was chosen in such a way that it includes the trajectories of all SRES emissions scenarios until 2100. Global mean temperature varies between the average of the 1961–1990 baseline climatology and a maximum value that is about 4.5 K warmer (whereby the exact range depends on the climate sensitivity of the respective GCM). The range for CO₂ is from 325 ppm to 1200 ppm. CIRFs are computed by varying global mean temperature and CO₂ concentration in 21 and 23 steps, respectively, within these ranges, and forcing the impact models with the respective local climate data. The model output is further processed to derive various aggregated impact indicators on the level of either individual countries or larger regions (see Table 1).

CIRFs are a useful means for the presentation of

aggregated simulation results on potential climate impacts, and for their inclusion into global IAMs. Some important limitations of the present CIRFs and their application in the ICLIPS model shall also be mentioned. Firstly, the reduced-form climate model, by design, produces smooth climate change projections without any “surprises”. Secondly, all impacts are determined in equilibrium with a changed average climate. For systems with a long memory, such as many ecosystems, the exact timing of a projected impact can thus not be determined. Finally, all impact computations are performed with purely biophysical models that do not adequately consider potential adaptation strategies to mitigate some of the adverse effects.

2 ICLIPS IMPACTS TOOL

This section starts with a presentation of the main features of the ICLIPS Impacts Tool. This overview is followed by a description of the various types of impact diagrams that are used for the graphical display of the CIRFs. The final part of this section discusses technical aspects of the software.

2.1 Main features

The ICLIPS Impacts Tool makes the comprehensive set of CIRFs developed for the ICLIPS model available to a wider community by means of a convenient graphical user interface. It provides a structured and transparent way to access the aggregated simulation results, and to compare results across regions, sub-indicators, and emissions scenarios. In so doing, the ICLIPS Impacts Tool helps to enhance the knowledge about potential climate impacts, including their regional and sectoral diversity and some aspects of uncertainty.

Fig. 1 shows a screen shot of the ICLIPS Impacts Tool that will be used to explain the main features of the program. The central task is the step-by-step selection of an impact diagram from the large database. The respective dimensions are represented by the following menus in the top panel:

Impact indicator: Selection of the impact indicator (see Table 1 for details).

Area coverage: Some indicators are available for the total land surface as well as for subsets that include or exclude agricultural and protected areas.

Diagram type: The different types of impact diagrams are presented in Section 2.2.

Indicator	Explanation
Stable biome area [% of current area]	Percentage of an individual biome's present extent that remains climatically suitable. Newly suitable areas are not taken into account.
Total biome area [% of current area]	Total potential area of an individual biome. Newly suitable areas can compensate for losses within the present range.
Stable forest area [% of current area]	Percentage of the present forest area that remains suitable for forest growth. A change from one forest biome to another one is allowed by this indicator.
Total forest area [% of current area]	Total potential forest area (including newly suitable areas).
Change of present biome [% of specified area]	Percentage of an area where the present biome is no longer viable under altered climate conditions. This indicator is available (1) for the total land surface, (2) for the land surface excluding areas used for agriculture, and (3) for protected areas.
Crop yield [t/ha]	Rainfed yield of a specific crop under given climate and soil conditions.
Suitable area [% of total area]	Area where a specific crop can grow, assuming 10 % of its maximum yield (under optimal climate and soil conditions) as the minimum threshold
Maximum food energy [Gcal/ha]	Indicator aggregated across all regions. In each grid cell, that crop is chosen which maximizes the caloric yield.
Maximum crop performance [% of max. yield]	Indicator aggregated across all regions. In each grid cell, that crop is chosen which has the highest relative performance (measured as the percentage of its maximum yield under optimal climate conditions).
Weighted crop performance [% of max. yield]	Overall performance of present crops. The yield of each crop (within the presently cultivated area) is weighted with its share in the total cultivated area of a country.
Runoff [mm/yr]	Surface runoff and groundwater recharge.

Table 1: Indicators for climate impacts on natural vegetation (top), crop production (center), and water availability (bottom).

Climate model: The scaled scenario approach links CIRFs to climate projections from specific GCMs. The present model version uses climate change patterns from ECHAM3–LSG, ECHAM4–OPYC and HadCM2.

Regional grouping: The grid-based simulation results are first aggregated to the level of individual countries. Due to restrictions on the manageable data volume and the low reliability of some simulation results at that level, most impact indicators are presented for coarser world regions only.

Region/ Sub-indicator/ Impact guardrail/ Emissions scenario: Most types of impact diagrams require that values for two out of those four dimensions are specified. The last two menus thus change depending on the chosen diagram type.

The selected impact diagram is displayed in the central part of the screen. The bottom panel allows the user to choose emissions scenarios whose time tra-

jectories will be displayed in certain diagram types (see Section 2.2), and to specify graphical properties of the displayed impact diagrams (see Section 2.3). The toolbar to the left allows, among others, to print and export impact diagrams in different file formats, and to simultaneously display multiple diagrams. The toolbar to the right gives access to the user help system of the ICLIPS Impacts Tool. The help system consists of an overview of the program, a guided tour, an illustrated explanation of the choices to be made in each menu (such as the different impact indicators and diagram types), and a context-sensitive help for the user interface.

2.2 Types of impact diagrams

Results of impact model simulations can be aggregated along various dimensions and presented in many different ways. The following categories of impact diagrams cover the most important cases:

Response surface diagrams depict the response of

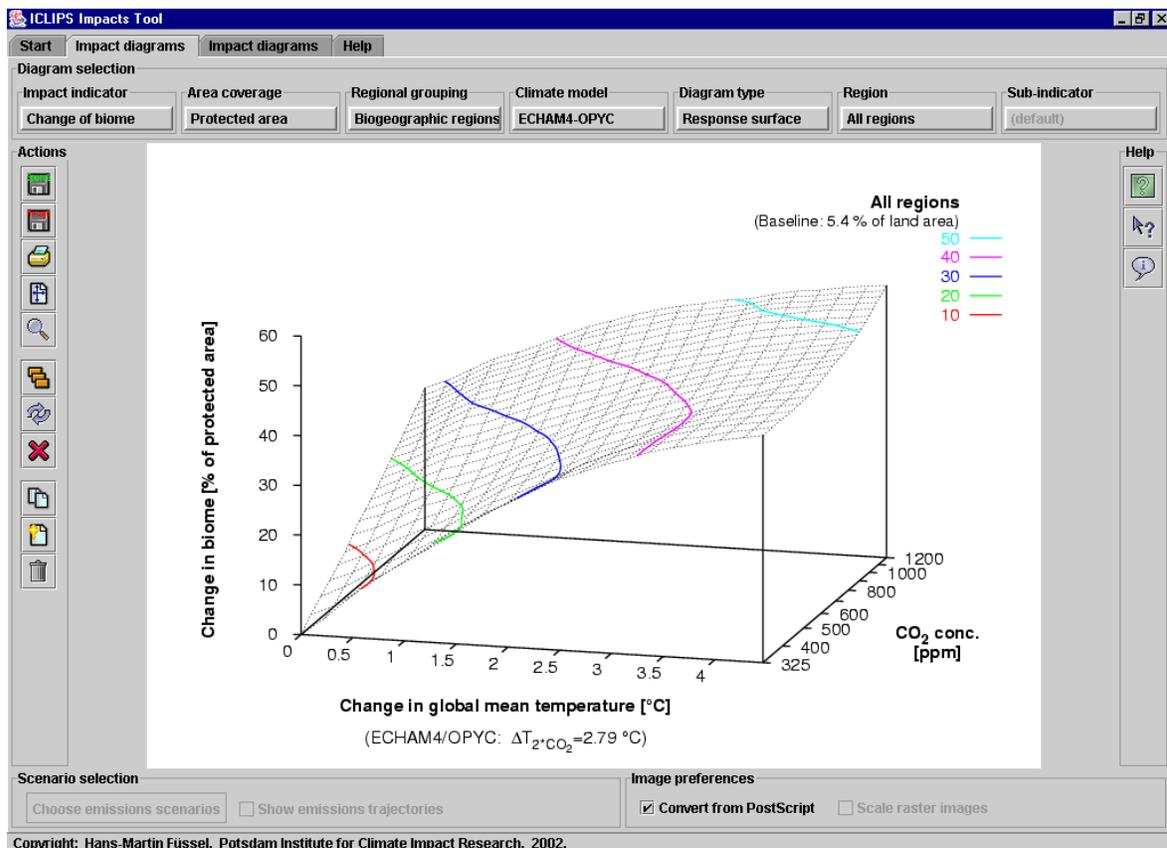


Figure 1: Screen shot of the main page of the ICLIPS Impacts Tool. (Details are explained in the text.)

an impact indicator in a region across the whole domain of the CIRF. These 3-dimensional diagrams give an overview of the sensitivity of the impact indicator to individual and combined changes in its input variables. Isolines connect all points on the response surface for which the impact indicator takes some pre-defined value (a so-called impact guardrail). Fig. 1, for instance, shows the fraction of the world's protected areas where the current biome (a broad vegetation category) becomes nonviable for all combinations of global mean temperature and CO₂ concentration based on climate change patterns from ECHAM4.

Impact isoline diagrams (see Fig. 2, top left panel) show the projection of impact isolines from a response surface diagram onto the 2-dimensional domain of the CIRF. Each isoline separates those climate regimes where the simulated impacts lie below the associated guardrail from those regimes where they lie above. This feature is utilized in tolerable windows analyses with the ICLIPS model. The climate evolution for selected emissions scenarios can be shown by superimposing the associated time trajectories onto the isoline diagram.

Multi-regional isoline diagrams (see Fig. 2, top right panel) also show the projection of isolines onto the domain of the CIRF. In contrast to the former diagram type, the isolines do not refer to different impact guardrails for one region but to the same impact guardrail for different regions. These diagrams facilitate cross-regional sensitivity analyses of an impact indicator.

Multi-category isoline diagrams show isolines for different sub-indicators (where they exist) in a region. They facilitate cross-category analyses of an impact indicator.

Scenario trajectories (see Fig. 2, bottom left panel) show the time path of an impact indicator in one region for different emissions scenarios.

Multi-regional trajectories (see Fig. 2, bottom right panel) show the time path of an impact indicator in different regions for one emissions scenario.

Multi-category trajectories show the time path of different sub-indicators within a region for one emissions scenario.

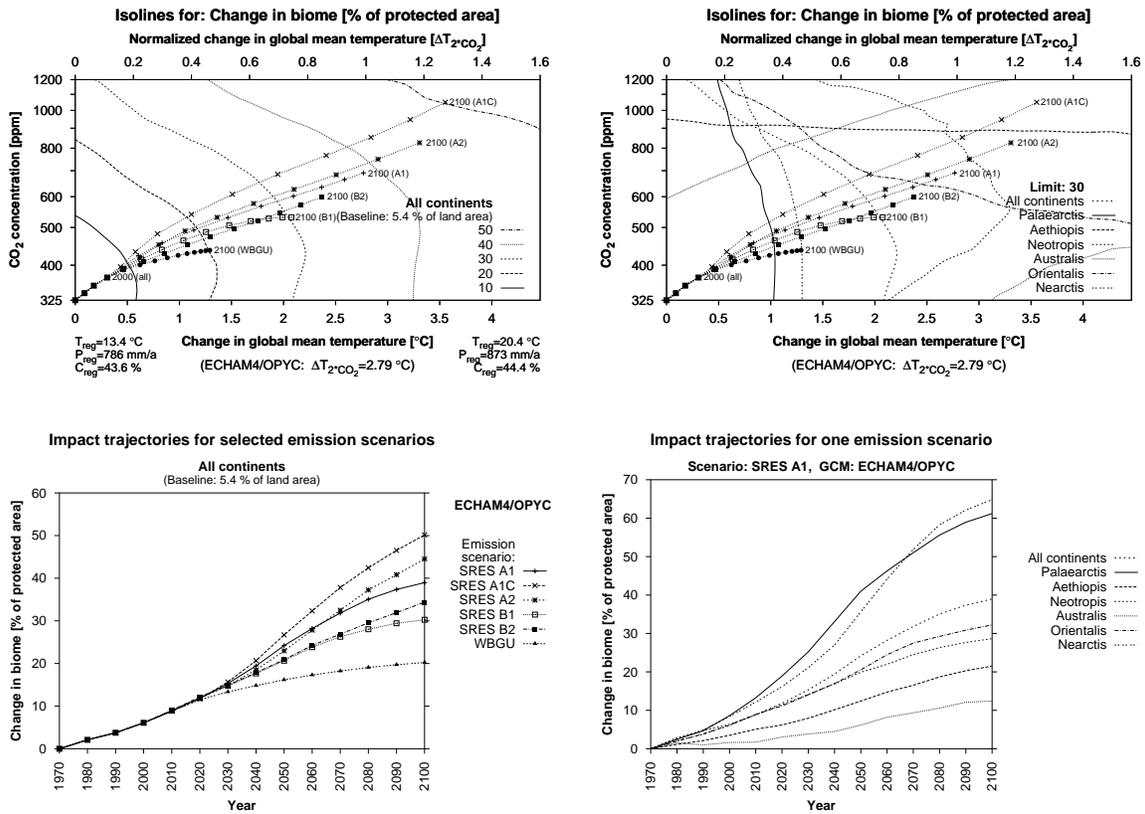


Figure 2: Different types of impact diagrams. Top left: impact isoline diagram; top right: multi-regional isoline diagram; bottom left: scenario trajectories; bottom right: multi-regional trajectories. (Individual isolines may be difficult to distinguish in the black-and-white reproduction.)

Some of these diagram types are not relevant for CIRFs with only one input variable, e. g. for water availability. An additional category, the so-called area balance diagrams, is omitted here (see Füssler and van Minnen [2001]).

2.3 Technical aspects

The ICLIPS Impacts Tool is written in Java 2. It runs on all platforms for which the appropriate Java Runtime Environment (JRE) is available (including Microsoft Windows, Linux, Solaris, and AIX).

The considerable number of dimensions in the simulated impacts results in a large set (about 100,000) of impact diagrams. These diagrams are available as Encapsulated PostScript (EPS), Graphics Interchange Format (GIF), and Portable Network Graphics (PNG) files. The EPS format combines an excellent output quality with low file size, and it can be scaled without quality loss. The Java Virtual Machine, however, only supports the display of raster graphics like GIF and PNG (whereby the latter re-

quires JRE version 1.3 or higher). The ICLIPS Impacts Tool is thus equipped with two different display modes. In basic mode, the raster format files are displayed directly. In advanced mode, the program calls ImageMagick, an external image handling tool, to perform an on-the-fly conversion of the EPS files into a raster format. ImageMagick is freely available for many operating systems, including Microsoft Windows. It is already contained in standard Linux distributions.

The program documentation is in HTML format. On Windows systems, the contents of the appropriate help file are displayed in the standard browser. On Unix systems, the Netscape browser is used for that purpose.

Due to the large number of impact diagrams and the associated data volume, the standard distribution medium for the ICLIPS Impacts Tool is a CD-ROM that comprises

- the platform-independent Java code,

- all impact diagrams (in compressed EPS and PNG files),
- the user help system (in HTML format),
- JRE 1.4 for Windows and Linux, and
- ImageMagick for Windows.

This CD-ROM allows to run the program in advanced mode on all 32-bit Windows and Linux platforms. Users of other platforms need to have JRE 1.3 (and ImageMagick for the advanced mode) installed. A web browser is required to view the program documentation.

The ICLIPS Impacts Tool CD-ROM can be obtained free of charge from the author of this paper. The other software packages are available for download at no cost on the Internet.

3 SUMMARY AND CONCLUSIONS

In this paper, I have presented the ICLIPS Impacts Tool, a graphical user interface that provides convenient access to about 100,000 impact diagrams. These diagrams present different views on the climate impact response functions (CIRFs) that have been developed for the ICLIPS integrated assessment model. CIRFs bridge the gap between changes in globally averaged climate parameters and selected impacts on the regional level, using maximum information from complex climate models. An important component of the ICLIPS model is now available to the public.

The ICLIPS Impacts Tool can be used to get an overview of potential climate impacts as simulated by biophysical impact models, and to explore their sensitivity along different dimensions. The impact diagrams cover a wide range of sectors, aggregated indicators, regions, climate models, and emissions scenarios. The modular structure of the ICLIPS Impacts Tool provides maximum flexibility to include new results as they become available.

The limitations of the ICLIPS Impacts Tool are two-fold. Firstly, the impact models applied to determine the CIRFs ignore some important factors, for instance concurrent socio-economic developments, dynamic processes, and interannual climate variability. Secondly, the computer tool covers only the impacts part of the ICLIPS integrated assessment model.

While the inclusion of additional features into the ICLIPS Impacts Tool appears desirable at first sight,

this would also increase its complexity. Potential users might no longer be able to manage the program and understand all assumptions that exert influence on the model results. The ICLIPS Impacts Tool thus represents a compromise between flexibility, realism and comprehensibility, and the resources available for its development.

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