SPECIAL FEATURE: PERSPECTIVE

The Inter-Sectoral Impact Model Intercomparison Project (ISI–MIP): Project framework

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The Inter-Sectoral Impact Model Intercomparison Project offers a framework to compare climate impact projections in different sectors and at different scales. Consistent climate and socio-economic input data provide the basis for a cross-sectoral integration of impact projections. The project is designed to enable quantitative synthesis of climate change impacts at different levels of global warming. This report briefly outlines the objectives and framework of the first, fast-tracked phase of Inter-Sectoral Impact Model Intercomparison Project, based on global impact models, and provides an overview of the participating models, input data, and scenario set-up.

multi-sector | climate data

The Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) fast track took place between January 2012 and January 2013, and was unique in bringing together 28 global impact models from five different sectors (Table 1). During this phase, a common modeling protocol was designed, simulations were performed, and the resulting simulation data were collected in a central archive. Based on these data, an initial round of analysis was carried out, the key outcomes of which are assembled in this special issue of PNAS. The fast-track simulation data will be made freely available for further analysis by the wider research community.

The ISI-MIP fast track pursued several specific goals: (*i*) a quantitative assessment of global climate change impacts at different levels of global warming in a consistent setting across multiple sectors; (*ii*) basic uncertainty estimates based on the quantification of intermodel variations for both general circulation models (GCMs) and global impact models; and (*iii*) to initiate an ongoing coordinated impact modeling improvement and intercomparison program, as well as an impact assessment effort driven by the entire community.

The central motivation for the project can be summarized by the question: What is the difference between a 2 °C, 3 °C, and 4°C warmer world, and how well can we differentiate between them?

The project builds on earlier climate change risk assessments at the global scale, such as the UK Fast Track project (1), the Climate Impact Response Functions (2) initiative, and the more recent investigation by Arnell et al. (3) covering climate impacts in six sectors (water availability, river flooding, coastal flooding, agriculture, ecosystems, and energy demands) using a coherent set of climatic and socioeconomic scenarios. However, all existing cross-sectoral impact studies use only one impact model per sector, and are thus unable to formally assess uncertainties beyond those stemming from climatic and socio-economic input data.

In contrast, there are sector-specific multi-impact-model studies, such as Cramer et al. (4) and Sitch et al. (5) in the biomes sector, WaterMIP (6) in the water sector, and AgMIP (7) in the agriculture sector. In this context, ISI-MIP is intended to address the lack of a cross-sectoral multimodel assessment of impacts of climate change.

The project serves the dual purpose of facilitating process understanding and model development in the scientific community, as well as providing quantitative results that are readily available to stakeholders and society in general. The timeline of the fast track was designed to deliver a first set of results in time for assessment by the Intergovernmental Panel on Climate Change in preparation for the fifth assessment report. To further the above goals beyond this narrow timeline, a second, longer-term phase of ISI-MIP was initiated in May 2013. This second phase is planned to incorporate regional models, as well as additional sectors and systems, enabling both a cross-sectoral and cross-scale synthesis of the impacts of climate change. More information on the project can be found at www.isi-mip.org, including the detailed fast-track modeling protocol.

Impact Models

Global impact models from five different sectors were involved in the ISI-MIP fast track (Table 1) (water, agriculture, biomes, coastal infrastructure, and malaria) as an example of health impacts. In the case of agriculture and water, existing intercomparison efforts AgMIP (7) and WaterMIP (6), respectively, ensured that much of the necessary simulation framework was already in place. The agricultural component of ISI-MIP was coordinated under the umbrella of AgMIP, and an ISI-MIP component was included in the AgMIP agro-economic model intercomparison (comprising the models listed in Table 2).

Each impact model was driven by a common daily, gridded climate dataset and delivered results in the form of a sector-specific set of common output variables at time resolutions ranging from subdaily to monthly. Harmonization across models was limited to the driving climate input data and, where applicable, socio-economic data (population and gross domestic product, GDP). Additional input data were selected according to the default settings of each model, to gain a representative picture of uncertainty across the models using native settings. Further sector-specific details can be found in this special issue.

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Table 1. Participating impact models

Model (source)	Sector
LPJmL (15, 16)	Water/agriculture/ biomes
JULES (17, 18)	Water/biomes
VIC (19)	Water
H08 (20)	
WaterGAP (21)	
MacPDM.09 (22)	
WBM (23)	
MPI–HM (24)	
PCR–GLOBWB (25)	
MATSIRO (26)	
DBH (27)	
ORCHIDEE (28)	Biomes
Hybrid4 (29)	
SDGVM (30)	
JeDi (31)	
VISIT (32)	
GEPIC (33)	Agriculture
EPIC (34)	
pDSSAT (35)	
PEGASUS (36)	
GAEZ-IMAGE (37)	
LPJ-GUESS (38)	
MARA (39)	Health (malaria)
Umea statistical model (40)	
LMM 205 (41)	
MIASMA (42)	
VECTRI (43)	
DIVA (44)	Coastal infrastructure
AIM (45)	(Agro-) economic effects
ENVISAGE (46)	
EPPA (47)	
GTEM (48)	
FARM (49)	
MAGNET (50)	
GCAM (51)	
GLOBIOM (51)	
IMPACT (53)	
MAgPIE (54)	

CO_2 and Climate Data

Atmospheric CO_2 concentrations were prescribed according to the four representative concentration pathways (RCPs) (8) also used to drive the GCMs within in the latest, fifth phase of the Climate Model Intercomparison Project (CMIP5) (9) (see Table 2 for model names and climate variables). To provide the associated climate information for ISI-MIP, five of the CMIP5 GCMs were selected to span the space of global mean temperature change (ΔGMT) and relative precipitation changes as best as possible, albeit with the limited available data in the CMIP5 archive at the relevant stage of the project (March 2012).

The ISI-MIP climate dataset covers the period from 1960 through to 2099 on a horizontal grid with 0.5° × 0.5° resolution; where necessary, climate model output was spatially interpolated. Further details of this procedure are given in Hempel et al. (10). The data were bias-corrected to ensure long-term statistical agreement with the observation-based watch forcing data (11) over the period 1960–1999. Projected absolute trends in temperature and relative trends in precipitation and all other variables (Table 2) were preserved by the bias-correction method, which was developed specifically for this project (10). Preservation of the temperature trends in each grid cell also implies that the global warming trend and thus, in particular, the climate sensitivities of the GCMs, are preserved.

Of the 20 combinations of four RCPs and five GCMs considered, three exhibit ΔGMT greater than 4 °C above present day (1980–2010) for the highest concentration scenario RCP8.5 in 2099 (Fig. 1*A*). Note that the 1980–2010 reference period was also chosen as a baseline for the quantification of future climate impacts. This baseline period is ∼0.7 °C warmer than preindustrial conditions. A set of 16 GCM-RCP combinations surpasses a warming of 1.3 °C above 1980–2010, which corresponds to the internationally accepted threshold of 2 °C above preindustrial. To illustrate the projected evolution of land-averaged precipitation, relative changes compared with the historical period ($\Delta P/P$) are quantified in terms of ΔGMT (Fig. 1*B*). Both variables are filtered by a 30-y moving average.

The spatial patterns of (bias-corrected) temperature and precipitation changes by the end of the 21st century cover a range of different states (Figs. 2 and 3, respectively).

A spin-up dataset was also produced by detrending the climate data for the period 1951–1980 from each GCM, and copied in a series for impact models needing a long spin-up time (see simulation protocol for details). The length of the spin-up was determined individually according to the needs of each impact model. For those impact models requiring subdaily climate data, the native disaggregation scheme of the respective model was used. Results from the impact models were then provided at the highest time resolution available.

Socio-Economic Data

ISI-MIP aims to use the recently developed shared socio-economic pathways (SSPs) (8, 12) as the basis for socio-economic input for the impact models. For the fast track, the preliminary version of population and GDP projections published in May 2012 was used (13). The final versions of these data are expected to be released in the second half of 2013. The SSPs provide population and GDP at the country scale at 5-y intervals. Based on this, a grid-level population dataset was developed, scaling up the 2010 Gridded Population of the World (GPWv3) dataset (14) by the SSP country totals (neglecting changes in population distribution within countries), and interpolating linearly in time to yield annual values. United Nation World Population Prospects population and World Bank GDP were used for the historical period.

Scenarios

The scenario suite for the ISI-MIP fast track was designed to allow for quantification of the uncertainty in the impacts of climate change—both across climate models and across impact models—at different levels of global warming. The list of chosen scenarios represents a balance between ensuring harmonization across the sectors and exploring the sector-specific modeling uncertainties.

A subset of the scenario set, the minimal setting, was defined as a minimum requirement for all participating models, whereas modeling groups with sufficient resources were

Table 2. Global climate models and climate variables included in the ISI-MIP climate dataset

Climate model	Climate variables
GFDL-ESM2M	Surface air temperatures (Tavg, Tmin, Tmax)
HadGEM2-ES	Precipitation
IPSL-CM5A-LR	Surface radiation (short- and longwave downwelling)
MIROC-ESM-CHEM	Near-surface wind speed (east- and north-ward)
NorESM1-M	Near-surface wind speed (total)
	Surface air pressure
	Near-surface relative humidity
	CO_2 concentration

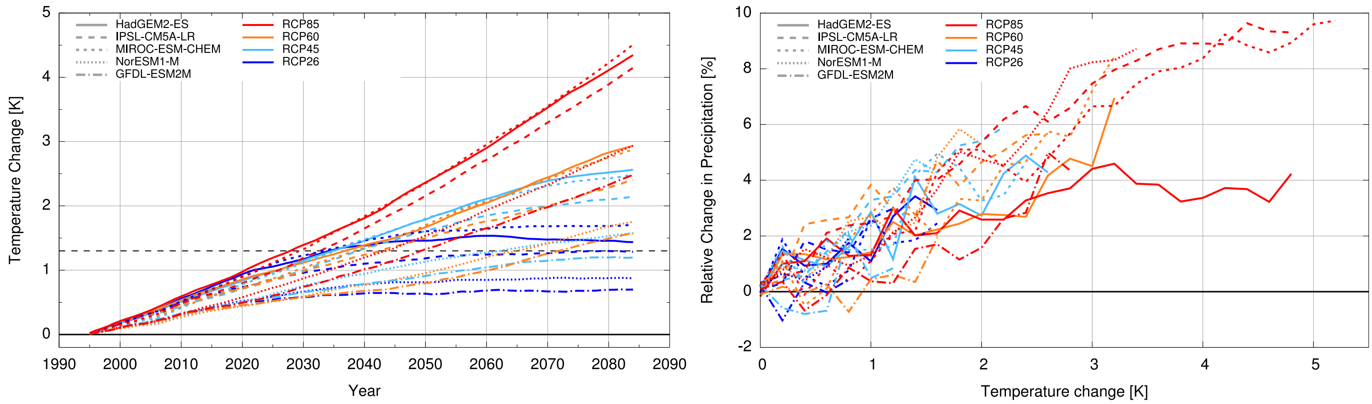

Fig. 1. (*Left*) GMT change (in degrees centigrade) with respect to the 1980–2009 average, averaged over 30-y window, centered on year shown. (*Right*) Relative change in land-averaged precipitation with respect to the 1980–2009 average, in terms of GMT change above present day (average of a 7-y interval around the year in which a given temperature change occurs). Each line represents one GCM and RCP.

encouraged to run the full scenario set. The minimal setting was chosen to span both the climate model and the RCP space to a basic extent and comprises all four RCPs for one global climate model (HadGEM2-ES). These four runs enable comparison of climate impacts at different levels of global warming out to $\Delta GMT = 4°$, as well as identification of potential scenario dependencies, such as the effects of different rates of warming or different CO_2 concentrations at a fixed level of warming. Additionally, the remaining four GCMs were considered together with those RCPs producing the highest and lowest end-of-century forcings (RCP8.5 and RCP2.6, respectively). Where applicable, only the middle-of-the-road socio-economic scenario SSP2

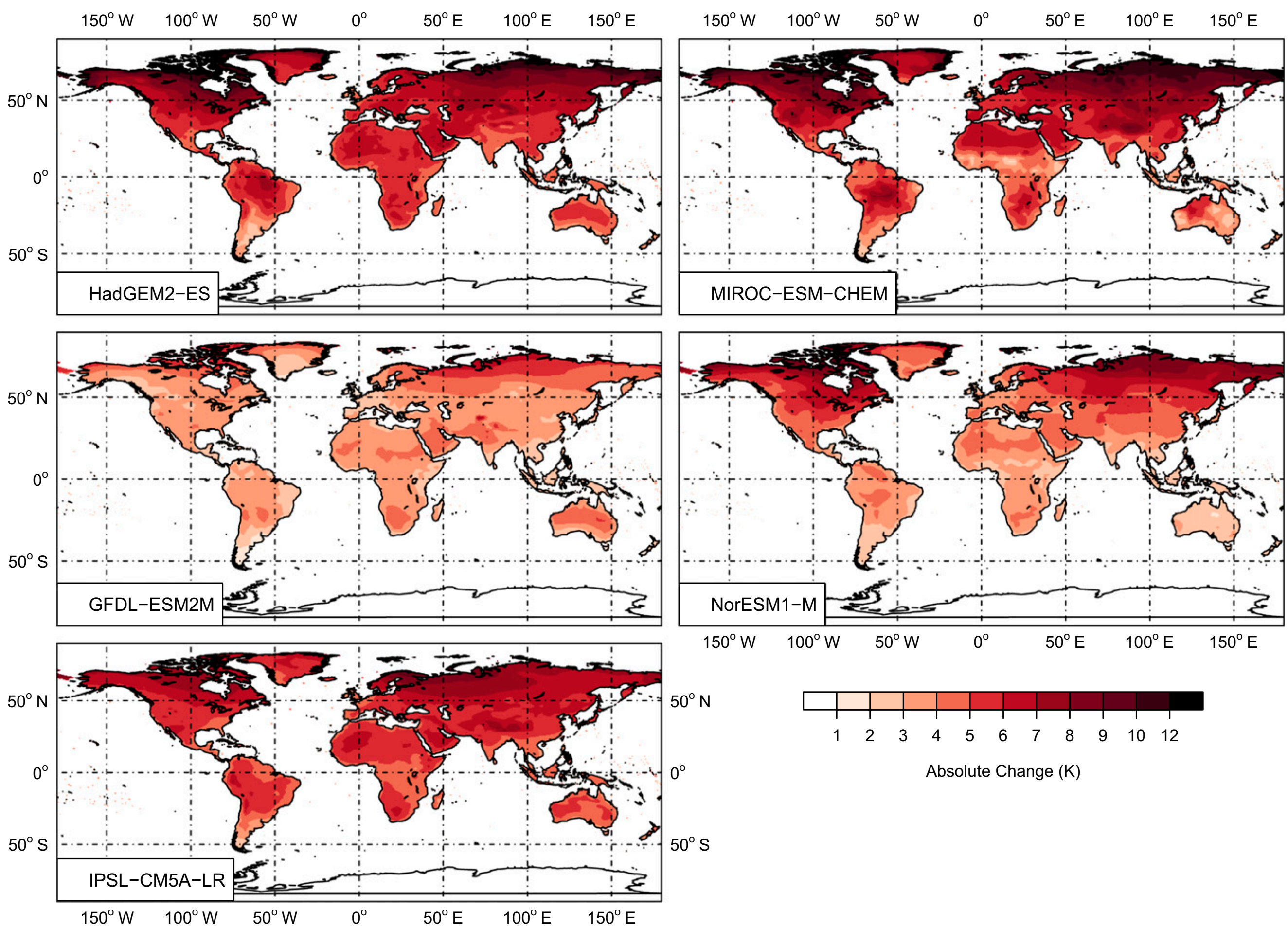

Fig. 2. Difference in bias-corrected, average surface air temperature over land between end of the century (2070–2099) and present-day (1980–2010) under RCP8.5 in the five climate models used in the ISI-MIP.

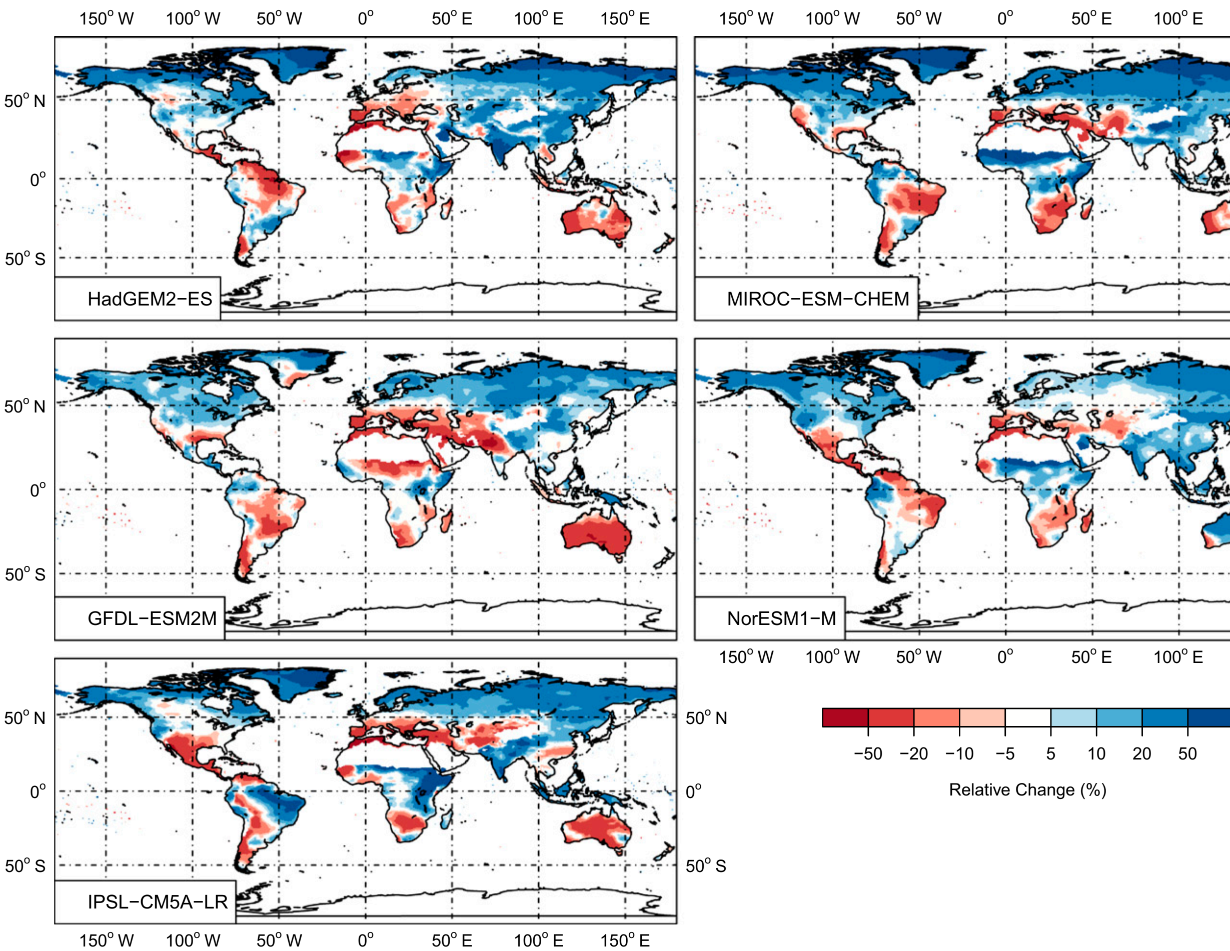

Fig. 3. As in Fig. 2 but for relative difference in average annual rainfall (in percent). Desert regions with present-day annual rainfall below 100 mm are masked.

was used in the minimal setting. Highly relevant sector-specific sensitivities (e.g., CO_2 fertilization for biomes and agriculture) were also considered in the minimal setting as a additional "fixed present day CO_2" experiment based on the RCP climate input. In cases where climate-induced impacts and (direct) human impacts are coupled, the minimal setting includes control runs, which allow these effects to be disentangled in postprocessing. Specific details of the runs performed in each sector are provided in the respective papers in this special issue of PNAS, and a comprehensive overview of the scenario suite can be found in the simulation protocol.

The results of the ISI-MIP fast track presented in this special issue provide a unique systematic overview of the state-of-the-art of climate impact research across sectors. In addition to reports describing the main results in each of the individual sectors, a concerted effort has been made to make use of the unique cross-sectoral set-up to address the vital question of how impacts in different sectors may interact. All modeling data will be made available to the wider research community, facilitating ongoing analysis and further cross-sectoral considerations.

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