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Project acronym: ENSEMBLES

Project title: ENSEMBLE-based Predictions of Climate Changes and their Impacts

Instrument: Integrated Project

Thematic Priority: Global Change and Ecosystems

**D2A3.3 Report on 21st century scenario simulations in stream 2 (A1B and E1)**

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Organisation name of lead contractor for this deliverable:
Freie Universität Berlin (FUB), Institut für Meteorologie

Revision [Final]

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Introduction

The study of climate change, its potential impacts, and the possible options to avoid, or reduce, some of its undesirable consequences, requires climate simulations with state-of-the-art earth-system models. In light of emerging climate policy, it seems necessary to consider also more stringent mitigation pathways in climate model calculation. RT2A WP2.3 was focussed on a climate scenario for stabilising the additional anthropogenic radiative forcing at an equivalent carbon dioxide concentration of around 450 ppm during the 22nd Century for attempting to match the European Union target of keeping global anthropogenic warming below 2°C above pre-industrial levels. Thus, a new set of climate simulations over the 21st Century with improved earth-system models has been designed by the RT2A-partners.

The following report describes the models used for production runs, explains the choice of scenarios, gives an overview on the improved forcing and scenario experiments and finally the simulated changes of the surface air temperature, precipitation and sea level pressure and a statistical description of the multi-model ensemble in terms of ensembles mean and standard deviation of the estimated long-term mean changes are described.

Models used for production runs

In the preface of the ENSEMBLES Stream-2, nine coupled atmosphere ocean global circulation models (AOGCMs) used for ENSEMBLES Stream-1 were further developed. Four of them now include a carbon cycle, three have an interactive aerosol transport scheme and six model versions allow for land use changes for crop and pasture.

The Table 1 gives an overview on the models used for the Stream-2 simulations by the different partners. The models including a carbon cycle marked by ● in the column CC, while models including an aerosol transport and chemistry model marked by ● in column AT. Furthermore, all models considering the land use marked by ● in column LU. The vertical as well as the horizontal resolution of the coupled AOGCMs varies considerably between the models.

More details of the employed models and forcing are described in Deliverable D2A.3.4. The contact information of the nine partners is located in the appendix.
### Table 1: Models used for ENSEMBLES Stream-2 simulations: overview about model components and resolutions.

<table>
<thead>
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**Choice of scenarios**

The SRES A1B scenario (Nakicenovic et al. 2001) has been chosen as the baseline scenario for the ENSEMBLES Stream-2 simulations, because the strong increase in emissions is consistent with real emissions growth, and in order to provide overlap with earlier climate modelling work.

The SRES A1B scenario was used in simulations of phase 3 of the Coupled Model Intercomparison Project (CMIP3) and for regional simulations in ENSEMBLES.

Besides the A1B SRES marker scenario, a new stabilisation scenario has been designed to limit the long-term radiative forcing to 450 ppm of CO$_2$-equivalent. This new stabilisation scenario E1 (Lowe et al. 2009) has been developed with the latest version of the integrated impact assessment model IMAGE at Netherlands Environmental Assessment Agency (MNP 2006, van Vuuren et al. 2007), with improvements in the land use representation of the A1B scenario. (Royer et al. 2009)

This policy-relevant mitigation scenario (E1) is a new scenario for stabilisation at 450 ppm CO$_2$-equivalent including several abatement options: reduction measures in energy production, by improving efficiency; reduction of non-CO$_2$ gases (mainly methane) in energy production and agriculture and carbon plantations and increase in agricultural productivity, a slow down of deforestation rates and allowing greater bio-energy production.

Stabilization of greenhouse gas (GHG) concentration is approached after an initial peak in concentrations at 530 ppm CO$_2$-equivalent, as pointed out by Den Elzen and van Vuuren (2007) to be preferable in terms of cost consideration for reaching long-term temperature targets.

The emission reduction in E1 comes from energy system with greatest contribution from energy efficiency improvement and Carbon Capture and Storage (CCS). Furthermore, increased use of bio-energy, nuclear and wind power reduces the CO$_2$ emissions. The reduction of F-gasses (>90%) contribute only a little to the absolute emission reduction.
Improved forcings

The greenhouse gas and aerosol data are produced by Dutch National Institute for Public Health and the Environment (RIVM, Detlef van Vuuren) using the IMAGE 2.4 model (MNP 2006, van Vuuren et al. 2007) and are available as emission data (on a 0.5° Lat/Lon grid) and as concentrations as required for the structure proposed by Hibbard et al. (2007) for the A1B and the E1 scenario. They include the major GHG and air pollutants from energy, industry and land use (change) as vertical integrated values from 1970 to 2100 in time steps of 5 years.

Using the gridded emissions of black carbon and precursors of sulphates from the IMAGE scenarios Olivier Boucher has used the same chemistry-transport model as used for IPCC (Boucher and Pham 2002) to compute the 3-D sulphate aerosol concentration maps. Black carbon is not computed in IMAGE but has been scaled on sulphur emissions.

Sulphur emissions are reduced strongly in the E1 scenario as side-effect of the assumed climate policy.

The ozone concentrations were generated with the Oslo CTM2 chemistry transport model (Sovde et al. 2008). They have been computed with emissions from the A1B and E1 scenarios, fixed transport specified from ECMWF reanalyses and temperature correction using EGMAM-Stream1 upper air temperatures for A1B and scaling for E1.

Historical reconstructions for cropland (in percentage of each grid cell yearly from 1700 to 1992, Ramankutty and Foley 1999) and pasture from the HYDE dataset (in absence or presence, i.e. 0% or 100% per grid cell 1700 to 1990, every 50 years from 1700 till 1950, and every 20 years afterwards; Klein Goldewijk 2001) are used by Nathalie de Noblet (IPSL/LSCE) to produce a fraction of grid-cell covered by crop and pasture on a 0.5x0.5° global grid for each year from 1700 to 1992.

Changes in future crop and pasture extent is derived from the IMAGE 2.4 scenarios using an anomaly procedure to ensure consistency between past and future changes.

Scenario experiments

For ENSEMBLES Stream-2 experiments with the AOGCMs were run for the SRES A1B scenario. Furthermore, the within des ENSEMBLES project developed scenario E1 and the A1B_IMAGE (D2A.0.4) were simulated.

In total, for Stream-2 17 SRES A1B, 17 E1 and 4 A1B_IMAGE simulations were carried out.

In Table 2 the ENSEMBLES Stream-2 scenario simulations of the various partners are shown with their corresponding CERA-model-acronym and run-number as well as the associated historical run.

Monthly, daily, 6h- and 3h-data are available at CERA database. As in ENSEMBLES Stream-1 soil/ice data (3), dynamical output data (7), fixed fields (7), near surface data (54) and atmosphere data (7 variables on 13 levels) are stored and available for the community.
In Stream-2 additional output variables from the aerosol transport schemes and carbon models, were applicable were provided.

A detailed list of variables stored in CERA database with their respective time resolution and their units can be found at http://www.mad.zmaw.de/projects-at-md/ensembles/output-variables/.

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Table 2: Overview of scenario simulations and the associated historical runs
* - these runs include additional aerosol variables
** - this run also includes natural forcing (solar + volcano) in addition to GHG

Statistics

In this report for all figures the differences of the climatologies for the years 2080-2099 and for the years 1980-1999 are considered.
To achieve compatibility data from different models are spatially interpolated to a common grid with the resolution of 2.5° longitude x 2.5° latitude.
The model ensemble mean is calculated by giving each model the same weight except for models BCM2 and BCM2C, both getting half of the weighting factor, because they differ only in the carbon feedbacks. To account for multiple realisations (BCM2C, CNRM-CM3, ECHAM5/MPI-OM, EGMAM2 (for E1), HADGEM2, IPSL_CM4), single realisations from intra-model n-member ensemble are weighted with 1/n. This
guarantees that all contributing models have the same weight with the single exception discussed above.
The multi-model standard deviation is analysed as it is a measure of ensemble spread due to different model formulations and hence a measure of model uncertainty.

Temperature

The global mean temperature increases with the concentration of the GHGs for both scenarios (Fig. 1 - top).

For all models the temperature response by the end of the 21st century with respect to pre-industrial conditions (1860-1890) is much smaller in E1 than in the A1B scenario. In most models the global mean temperature change stays below 2°C in the E1 scenario. However, this is not true for all models. Two models (HadGEM2, IPSL) show warming between 2°C and 3°C at the end of the 21st century. But again, the warming is much smaller than the warming in the A1B scenario when simulated with the same models.

The ensembles mean shows stagnation in the temperature development in the second half of the 21st century. It is below 2°C in 2100 respective the 1860-1890 mean. Therefore, according to these models the E1 scenario seems suitable to achieve the EU-2°C-target of temperature changes respective to pre-industrial times (Huebener et al. 2009).

For the middle of the 21st century, when the GHG concentration peaks (2040-2059), the models show a change in the warming rate: most models display a slower warming during the second half of the century, some models simulate nearly constant temperature after the peak period, and two models (EGMAM, CNRM) show a slight cooling after the peak (Huebener et al. 2009).

Moreover the ensemble mean warming in the first half of the 21st century in the E1 scenario exceeds the warming signal in the A1B scenario. This may be due to a cooling response to aerosols, i.e. this is related to the fact that the aerosol concentrations in E1 diverge from those in the A1B scenario already during the first half of the century (D2A.3.4).

The late 21st century ensemble mean response (Fig. 2g, 2h) in surface air temperature illustrates the well-known northern hemispheric high-latitude enhancement of warming, and the marked land-sea contrast, although somewhat less pronounced in E1. The intra-ensemble standard deviation is largest in the Arctic Ocean, Labrador Sea, Amazonia and Southern Ocean (Johns et al. 2009).

The seasonal ensemble mean temperature change pattern (Fig. 2g, 2h) reveals that the enhancement of the high-latitude northern hemispheric surface warming is most pronounced in boreal winter.

In light of the 2°C-warming goal of the Copenhagen Accord, note, that in scenario E1 despite of a global mean warming lower than or just slightly above 2°C in all models there are still areas where the temperature change exceeds 2°C. (Figure 2a-2f)
Precipitation

Regarding global mean changes (Figure 1) in line with Meehl et al. (2007), precipitation increases due to the GHG increase in the 21st century. In the A1B scenario, the precipitation increases until the end of the 21st century except for one simulation (EGMAM2). In the E1 scenario, in analogy to the global mean temperature, the slope is smaller in the second half of the century. However, precipitation increase in E1 is higher than in A1B in the first two-thirds of the century. The multi-model ensemble spread of global mean precipitation change for 2080 to 2099 w.r.t. 1980 to 1999 between A1B and E1 overlaps more than for temperature, pointing out the larger uncertainty of precipitation projections previously shown by Douville et al. (2006) for the CMIP-3 models. This is mainly due to uncertainty in tropical precipitation changes, as illustrated by the pattern of the inter-model standard deviation in Figures 3g and 3h. The patterns of precipitation changes for single models are shown in Figure 3a-3f. Figure 4 shows the number of models, which agree in a precipitation increase. The pattern is similar to this in Stream-1 (D2A3.3). Models agree in a precipitation increase at mid and high latitudes and in Pacific and Indic tropics, which may be related to a change in the monsoon, in scenario A1B as well as in E1 for projected changes between 2080-99 and 1980-99. In the E1 scenario fewer models agree with an increase over the southern ocean. While most models show no precipitation increase in the Mediterranean, the picture is less clear in E1, with about 50% of the models simulating a precipitation increase. Especially in E1 the strengthening of the Hadley cell on the southern hemisphere is indicated by more models than on the northern hemisphere.

Sea Level Pressure

The patterns of the change in mean annual sea level pressure as well as for boreal summer (JJA) and boreal winter (DJF) for scenarios E1 and A1B are shown in the Figures 5a-5h in the appendix. The projected changes are weaker in E1 than in A1B. Consistent with Stream-1 simulations of scenario A1B (D2A3.2) the sea level pressure decreases over polar regions of both hemispheres, more on the southern than on the northern hemisphere. For A1B this is a consistent feature across all models.

In most parts of the Southern hemispheric subtropical subsidence zone the sea level pressure increases. Moreover, pressure patterns indicate a pole-ward shift and a strengthening of the Antarctic Circumpolar Westerly’s. The high inter-model standard deviation values over the Antarctica and mountain areas are partly due to the model dependent orography representation and pressure reduction procedure.
References


Deliverable D2A.0.4 “Report on the Stream Two experimental Design”

Deliverable D2A.3.2 “Data and report of stream one simulations for the prediction of future climate”

Deliverable D2A.3.4 “Report or paper on preliminary results of 21st century E1 scenario simulations including simple climate model output”


Appendix

Fig. 1: Time series of globally averaged surface air temperature change in K (top) and precipitation change in % (bottom) from the various coupled models of ENSEMBLES - RT2A for the scenarios A1B (dashed lines) and E1 (solid lines). Numbers in parentheses following the scenario name represents the number of simulations shown. Values are annual means, relative to the 1980-99 average from the corresponding 20th-century simulations. A three-point-smoothing was applied. The multi-model (ensemble) mean series are shown in black.
Fig. 2a: Annual mean temperature response (K) in the 8 models for the time period 2080-99 relative to 1980-1999 mean for scenario A1B.
Fig. 2b: Mean temperature response (K) for December-January-February (boreal winter) in the 8 models for the time period 2080-99 relative to 1980-1999 mean for scenario A1B.
Fig. 2c: Mean temperature response (K) for June-July-August (boreal summer) in the 8 models for the time period 2080-99 relative to 1980-1999 mean for scenario A1B.
Fig. 2d: Annual mean temperature response (K) in the 8 models for the time period 2080–1999 relative to 1980–1999 mean for scenario E1.
Fig. 2e: Mean temperature response (K) for December-January-February (boreal winter) in the 8 models for the time period 2080-99 relative to 1980-1999 mean for scenario E1.
Fig. 2f: Mean temperature response (K) for June-July-August (boreal summer) in the 8 models for the time period 2080-99 relative to 1980-1999 mean for scenario E1.
Fig. 2g: Multi-model mean (left) and standard deviation (right) of mean temperature response in K for June-July-August, December-January-February and annual for the time period 2080-99 relative to 1980-1999 mean for scenario A1B.
Fig. 2h: Multi-model mean (left) and standard deviation (right) of mean temperature response in K for June-July-August, December-January-February and annual for the time period 2080-99 relative to 1980-1999 mean for scenario E1.
Fig. 3a: Annual mean precipitation response (mm/day) in the 8 models for the time period 2080-99 relative to 1980-1999 mean for scenario A1B.
Fig. 3b: Mean precipitation response (mm/day) for December-January-February (boreal winter) in the 8 models for the time period 2080-99 relative to 1980-1999 mean for scenario A1B.
Fig. 3c: Mean precipitation response (mm/day) for June-July-August (boreal summer) in the 8 models for the time period 2080-99 relative to 1980-1999 mean for scenario A1B.
Fig. 3d: Annual mean precipitation response (mm/day) in the 8 models for the time period 2080-99 relative to 1980-1999 mean for scenario E1.
Fig. 3e: Mean precipitation response (mm/day) for December-January-February (boreal winter) in the 8 models for the time period 2080-99 relative to 1980-1999 mean for scenario E1.
Fig. 3f: Mean precipitation response (mm/day) for June-July-August (boreal summer) in the 8 models for the time period 2080-99 relative to 1980-1999 mean for scenario E1.
Fig. 3g: Multi-model mean (left) and standard deviation (right) of mean precipitation response in mm/day for June-July-August, December-January-February and annual for the time period 2080-99 relative to 1980-1999 mean for scenario A1B.
Fig. 3h: Multi-model mean (left) and standard deviation (right) of mean precipitation response in mm/day for June-July-August, December-January-February and annual for the time period 2080-99 relative to 1980-1999 mean for scenario E1.
Fig. 4: Number of models that project increases in precipitation between the periods 1980-99 and 2080-99 for scenario A1B (top) and E1(bottom) for boreal summer (JJA), boreal winter (DJF) and annual (ANN).
Fig. 5a: Annual mean changes in sea level pressure (hPa) in the 8 models for the time period 2080-99 relative to 1980-1999 mean for scenario A1B.
Fig. 5b: Mean changes in sea level pressure (hPa) for December-January-February (boreal winter) in the 8 models for the time period 2080-99 relative to 1980-1999 mean for scenario A1B.
Fig. 5c: Mean changes in sea level pressure (hPa) for June-July-August (boreal summer) in the 8 models for the time period 2080-99 relative to 1980-1999 mean for scenario A1B.
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Fig. 5h: Multi-model mean (left) and standard deviation (right) of mean changes in sea level pressure in hPa for June-July-August, December-January-February and annual for the time period 2080-99 relative to 1980-1999 mean for scenario E1.
Contact information of partners

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