Summary description of the project context and the main objectives

The general goal of the COMBINE project is to advance the capabilities of climate prediction and projection based on comprehensive Earth system models. The project brings together the leading European centres in Earth system modeling thus making use of an ensemble of seven Earth system models.

The general goal has three major foci: Firstly COMBINE includes research on critical dynamical, physical and biogeochemical processes in the Earth system and the related feedbacks, which eventually determine the amplitude of natural climate variability and anthropogenic climate change. For this goal the COMBINE project develops new model components for selected processes and assesses the sensitivity of feedbacks and climate change in Earth System models to such added processes, using standardized Coupled Model Intercomparison Project Phase 5 (CMIP5) experiments. The processes selected for this project represent: C- and N-cycle; aerosols coupled with clouds and chemistry; stratospheric dynamics; and ice sheets, sea ice and permafrost for the cryosphere.

Secondly COMBINE investigates the potential predictability of climate on time scales up to a decade and the development of initializations and correction methods to practically realize this potential. This research aims at a better quantification of the potential predictability based on an ensemble of Earth system models and standardized CMIP5 experiments, and at the development of procedures to exploit this potential in current Earth system models, using ocean and sea ice analyses and accounting for systematic biases of models.
The project assesses the sensitivity of decadal predictions to the choice of the initialization and correction methods, as well as to adding selected new components to the Earth system models.

Thirdly COMBINE aims at linking Earth system simulations for the past and future to global and regional impacts with focus on water availability, and to feed the climate change simulations back to the development of new scenarios, thus closing the circle between the development of socio economic scenarios and the projection of climate change by comprehensive Earth system models. The latter is of particular interest as Earth system models, as used in COMBINE for the CMIP5 scenarios, include the carbon cycle and thus can simulate simultaneously the evolution of temperature and alternatively CO2 concentration or implied anthropogenic CO2 emissions.

Overall the COMBINE project addresses research current questions related to climate change, making use of an ensemble of comprehensive Earth system models developed in Europe. The research goals are well aligned with the international research activities, in particular the simulations made in this project have been selected from the CMIP5 protocol, and a major part of these simulations will be disseminated to the international scientific community through the CMIP5 Earth System Grid. Thus the project will not only generate results from its own analysis of the Earth system model simulations, but it will also broadly support international climate research, and thus the climate change assessment conducted under Intergovernmental Panel on Climate Change (IPCC).

Description of the work performed since the beginning of the project and the main results achieved so far

The work performed since the beginning of the project and the main results achieved so far is summarized as follows:

New components for the representation of carbon and nitrogen cycle, aerosols, clouds and chemistry, stratospheric dynamics, cryosphere: ice shields, sea ice, permafrost, have been developed and tested by means of new methodologies. Main results include: reduction in methane lifetime with global warming; reduction in ocean denitrification in response to reduced productivity of the marine ecosystem; stronger troposphere-stratosphere coupling; more accurate simulation of the Arctic sea ice cover; Greenland ice-sheet simulation for a pre-industrial control run, for which the ice-sheet volume remains stable, compared to an abrupt 4xCO2 simulation in which this volume is clearly decreasing. The construction of "new" Earth system models based on the "new components" is in an advanced state. For some models the production of stream 2 simulations has begun.

Ocean initialization: New ocean re-analyses have been conducted, with improved methodology and observational datasets. These new analyses are used in decadal predications. Major advances are reported on sea-ice initialization and predictability, a novel research field.

Stream 1 simulations: The CMIP5 experiments planned in COMBINE are completed and disseminated. The data can be accessed through the Earth system grid. These simulations are analyzed with regard to decadal predictability, predictive skill, and climate feedback parameters related to physical and carbon cycle processes.

Predictions: Predictive skill of surface temperature is largely driven by trends in radiative forcing, but significant residual skill is found in the North Atlantic area. The Atlantic Multidecadal Oscillation (AMO) appears to be predictable in the near-term (2-5 yrs) as well as in the longer (6-9 yrs) term. A near-term forecast initialized on year 2005 shows a general consensus across models on the AMO persisting in a positive (warm) phase. Predictive skill is generally low over most of the continental areas in the 2-5 years range, with notable exceptions for Scandinavia, Northern Europe and parts of Australia and North America.

Climate feedbacks: A model inter-comparison based on the partial radiative perturbation method applied to idealized 1% per year CO2 increase experiments, has been carried out. For the model considered, it is found that the inter-model spread in cloud radiative feedbacks is not substantially larger than in other feedbacks like the water vapor or the lapse rate feedback, in contrast to previous works. The diagnostic of radiative fluxes against changes in near surface temperatures in an experiment where CO2 is instantaneously quadrupled from pre-industrial levels suggests that the strength of fast tropospheric adjustment processes in different CMIP5 models varies significantly. This could substantially contribute to differences in the climate sensitivity of the models. The sensitivity of the Earth system models with respect to physical and biogeochemical forcing was assessed. For the COMBINE models, about the same sensitivities were obtained for both categories of forcing as previously found. Partially coupled experiments were also made, to assess the linearity in the physical and biogeochemical feedbacks. It turns out that linearity is not valid for every model, hence it is not a general assumption and the derivation of the carbon cycle climate feedbacks using separate runs is not fully adequate.

Impacts and Scenarios: Contribution to the development of the Representative Concentration Pathways (RCPs); developing a modeling framework for the impact assessment; preliminary results indicate a clear acceleration of the hydrological cycle as a consequence of climate change.

Description of the expected final results and their potential impacts and use (including socio-economic impact and the wider societal implications of the project so far).

The COMBINE project generates new knowledge in the field of fundamental climate research through the development and use of an ensemble of European Earth system models. The final results will consist in advanced understanding of the role of selected processes for feedbacks in the climate system. The project analyses the changes in climate feedbacks and climate related to the addition of new process models to Earth system models. The final outcome of the project will consist of two kinds of products:

Simulations: The project generates a substantial number of climate simulations for its own research. As these experiments were chosen to follow the CMIP5 protocol, the simulations have been disseminated to the CMIP5 archive, which is accessible to climate researchers worldwide through the Earth System Grid. These data contribute significantly to a broad multi model ensemble that will be analyzed by a large number of scientists for many aspects of climate variability, climate change and climate predictability, beyond the lifetime of the COMBINE project. These data will not only be analyzed with regard to the physical and biogeochemical functioning of the Earth system, but will also be invaluable for the investigation of socio-economic impact and the wider societal implications of different climate change scenarios.

Publications: Scientific results from the research pursued in the COMBINE project are mainly disseminated to the international research community by peer-reviewed articles. Those articles submitted and published before the cut-off dates for the 5th assessment report (AR5) of the IPCC (31.7.2012 and 15.3.2013, respectively) can be reflected and assessed for the AR5. Through the provision of the AR5 authors with most up-to-date knowledge on the functioning of the Earth system and climate change studies, the COMBINE researchers support indirectly the decision makers, who base their decisions on the IPCC assessments.