REQUEST FOR A SPECIAL PROJECT 2012–2014

MEMBER STATE: Netherlands

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Project Title: Modelling interactions between atmospheric composition and climate changes with the Earth system model EC-Earth

If this is a continuation of an existing project, please state the computer project account assigned previously.	**SP** _____	
Starting year: (Each project will have a well defined duration, up to a maximum of 3 years, agreed at the beginning of the project.)	2012	
Would you accept support for 1 year only, if necessary?	YES ☒	NO ☐

Computer resources required for 2012-2014: (The maximum project duration is 3 years, therefore a continuation project cannot request resources for 2014.)	**2012**	**2013**	**2014**
High Performance Computing Facility (units)	3500,000	3800,000	3000,000
Data storage capacity (total archive volume) (gigabytes)	6000	6500	5000

*An electronic copy of this form **must be sent** via e-mail to:* *special_projects@ecmwf.int*

Electronic copy of the form sent on (please specify date): 26 April 2011

Continue overleaf

[1] The Principal Investigator will act as contact person for this Special Project and, in particular, will be asked to register the project, provide an annual progress report of the project's activities, etc.

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Extended abstract

It is expected that Special Projects requesting large amounts of computing resources (500,000 SBU or more) should provide a more detailed abstract/project description (3-5 pages) including a scientific plan, a justification of the computer resources requested and the technical characteristics of the code to be used. The Scientific Advisory Committee and the Technical Advisory Committee review the scientific and technical aspects of each Special Project application. The review process takes into account the resources available, the quality of the scientific and technical proposals, the use of ECMWF software and data infrastructure, and their relevance to ECMWF's objectives. - Descriptions of all accepted projects will be published on the ECMWF website.

This project focuses on the simulation of changes in the atmospheric composition and interactions between atmospheric chemistry and climate. The modelling system that will be used is the Earth system model EC-Earth with online coupling to the atmospheric chemistry and transport model TM5. Simulations will be performed in the context of a number of projects funded by national or international research programs. The national projects are two PhD projects part of the program 'Feedbacks in the climate system' of the Netherlands Organisation for Scientific Research (NWO). The international projects are the CLIMBAIR Marie Curie Fellowship that was recently granted to Dr. B. Monge-Sanz, and the Ozone_cci project carried out in the framework of the Climate Change Initiative of the European Space Agency.

Modelling system

The modelling system to be used in all of these projects is EC-Earth with online coupling to TM5. EC-Earth (Hazeleger et al., 2010) is an atmosphere-ocean general circulation model that has been developed from ECMWF's Seasonal Forecast System 3. The atmospheric model of EC-Earth version 2, which is the current reference version, is based on ECMWF's Integrated Forecasting System (IFS), cycle 31r1. Some aspects of a more recent IFS cycle have also been implemented, including a new convection scheme and the land surface scheme H-TESSEL. The standard configuration runs at T159 horizontal spectral resolution with 62 vertical levels. In this special project we will also use the 60-layer version, which has more levels in the stratosphere. The ocean component is based on version 2 of the NEMO model with a horizontal resolution of nominally 1 degree and 42 vertical levels. The sea ice model is the LIM2 model. The ocean/ice model coupled to the atmosphere/land model through the OASIS 3 coupler.

TM5 is the atmospheric chemistry and aerosols module of EC-Earth. In this project we will use the tropospheric chemistry version of TM5 (Huijnen et al., 2010), but coupled to the aerosol microphysics scheme M7 (Vignati et al., 2004; Aan de Brugh et al., 2011). A linearized scheme for stratospheric ozone chemistry can optionally be applied (Cariolle and H. Teyssèdre, 2007). The standard configuration uses a global horizontal resolution of 3x2 degrees (longitude x latitude) with 34 vertical levels. Like the ocean-ice model, TM5 is coupled to IFS through the OASIS coupler. The next versions of the EC-Earth model will contain active coupling of TM5 with the radiation. The EC-Earth simulations carried out in this project will use either one-way or two-way coupling between TM5 and IFS. Besides, simulations with TM5 in stand-alone mode driven by the ECMWF's ERA-Interim reanalysis will also be performed.

Other Earth system components are currently being added. Most important for this project is the coupling with the dynamic global vegetation model LPJ-Guess that is currently being implemented (see description of the CLIMBAIR project below).

Research projects

As stated above the research carried out within this special project is related to different scientific projects. These are listed below:

1. “Understanding the interaction between climate and the methane budget: analysis of the 1991 eruption of Mount Pinatubo”

This is a 4-year PhD project funded by NWO. It is a collaboration between KNMI and the Institute for Marine and Atmospheric research Utrecht (IMAU) of Utrecht University. The research will be carried out by N. Banda, who is supervised by dr. T. van Noije and dr. M. van Weele (both KNMI) and by prof. M. Krol and prof. T. Röckmann (both Utrecht University). The project started in November 2010.

This research will focus on the well-documented natural experiment that was provided by the eruption of Mt. Pinatubo in June 1991. The scientific objective is to simulate the chemical composition of the atmosphere after the eruption starting from the sulfur dioxide (SO_2) emissions, to disentangle the observed growth rate variations in methane via changes in emissions and changes in lifetime, to simulate the climate impact of the eruption in EC-Earth.

In the first part of the project we will use TM5 driven by the ERA-Interim reanalysis. The stand-alone mode will be used for process studies that do not directly involve the feedback of atmospheric chemistry (including aerosols) on dynamics and temperature. These include the UV absorption by the SO_2 emitted into the stratosphere, the subsequent oxidation of SO_2 to sulphate aerosols, their impact on photolysis rates, and the enhanced stratospheric ozone destruction. The use of TM5 in stand-alone mode allows for more controlled experiments and a more detailed evaluation against chemical observations.

In a later stage TM5 will be used as a module inside EC-Earth, both in an atmosphere-only configuration driven by observed sea surface temperatures and with a coupled ocean. Using the coupled ocean configuration we will carry out two three-member ensemble simulations for the five years after the eruption, with and without the effects of Pinatubo respectively. The goal of these simulations is to evaluate the climate impacts of the eruption, in particular the tropospheric temperature response and the effects on the methane emissions. The initialization of the ocean model will be the same as in the simulations that are carried out for the Coupled Model Intercomparison Project (CMIP5).

To properly capture the effect of the Pinatubo eruption it is important that we use a sufficiently high vertical resolution up to the middle stratosphere. For this reason TM5 in stand-alone and coupled mode will be run at the 60- layer vertical resolution of the ERA-Interim reanalysis.

2. “Feedbacks between climate and human systems assessed with a coupled integrated assessment – climate modeling system” (EC-IMAGE)

EC-IMAGE is a 4-year research project funded by NWO, in which KNMI collaborates with the Netherlands Environmental Assessment Agency (PBL). The simulations included here are part of the PhD project of C.D. Chuwah, who is supervised by dr. T. van Noije and dr. D. van Vuuren (PBL). Promotor is prof. W. Hazeleger (KNMI/Wageningen University). The project started in August 2010.

In recent years there is increasing interest in coupling different disciplines involved in climate research. In this project, we attempt to bridge the gap between natural and human model components by coupling EC-Earth to the integrated assessment model IMAGE (Bouwman et al., 2006). IMAGE describes socio-economic, physical and biological factors to make projections of future changes of the world economy, agriculture, land use, emissions, climate and ecological values. In this project we aim to improve the couplings between emissions (IMAGE), atmospheric chemistry (TM5) and the physical components of the climate system (EC-Earth). We will explore feedbacks such as the impact of changes in nitrogen deposition on reactive nitrogen emissions and the impact of changes in surface ozone concentrations on CO_2 uptake by vegetation, crop yield and growth of natural vegetation.

In this project different types of simulations will be performed. TM5 will be applied to calculate future concentrations of reactive gases and aerosols using input on emission scenarios from IMAGE. Emissions are provided for reactive gases (methane, carbon monoxide, non-methane volatile organic compounds, nitrogen oxides, ammonia, and sulfur dioxide), as well as for primary aerosols (black carbon and particulate organic matter). First a number of time slice simulations will be performed using TM5 in stand-alone mode driven by offline meteorological fields from the European Centre’s ERA-Interim reanalysis. In a next step feedbacks will be included, and eventually climate impacts will be evaluated by running TM5 as a module in EC-Earth.

The time-slice simulations will be performed for a number of discrete years, including 2005, 2010, 2020, 2030, 2040 and 2050. For some scenarios we will possibly extend the horizon to 2100. Since time slices do not allow the continuous simulation of the evolution of relatively long-lived gases as methane, in these simulations the methane concentration will be prescribed based on the values simulated in the IMAGE model. These simulations will be carried out with meteorological fields for the year 2005. The production runs will be preceded by a spinup of (about) three months, also using 2005 meteorological fields. The year 2005 will only be simulated for a single scenario.

Different Representative Concentration Pathways (RCPs) will be considered, e.g. the IMAGE RCP3-PD that is used in the Coupled Model Intercomparison Project (CMIP5) and the IPCC Fifth Assessment Report (AR5). We will also make projections for alternative RCPs, e.g. IMAGE variants of the RCP4.5 and RCP6.0. In addition we will consider alternative IMAGE scenarios with less air pollution measures included than assumed in the RCP scenarios.

In a next step the simulated changes in nitrogen deposition and surface ozone will be fed back to IMAGE to estimate the strength of the individual feedback processes. Finally, one or more continuous simulations will be carried out with EC-Earth for the 21st century. Chemistry and aerosols will be simulated interactively by running TM5 as a module inside EC-Earth, while the coupling to IMAGE will be done offline. The considered feedbacks that contribute significantly to the climate forcing will be included. The setup of these simulations will depend on ongoing efforts to improve the performance and scalability of TM5. If computationally feasible we will perform an ensemble of EC-Earth simulations consisting of two or more members. Climate simulations will be performed for one or more of the considered future scenarios, which are to be selected during the course of the project. Note that we will not use ECMWF's computing facilities for the IMAGE runs.

3. "Coupled model simulations of global climate, terrestrial biosphere and atmospheric composition focused on global and European air quality" (CLIMBAIR)

CLIMBAIR is a Marie Curie fellowship that will enable dr. B. Monge-Sanz to spend 24 months at KNMI, where she will be working with dr. T. van Noije and colleagues. The project will be carried out in collaboration with dr. A. Arneth and dr. B. Smith from the Department of Earth and Ecosystem Sciences of Lund University. The expected starting date is January-March 2012.

The CLIMBAIR project focuses on the study of the impact of climate change on atmospheric composition, incorporating feedbacks from vegetation and land surface cover. The project will quantify the impacts of climate change, and the associated changes in natural emissions from the terrestrial biosphere (biogenic emissions from vegetation, soils and wildfires) on atmospheric composition and European air quality.

In this project EC-Earth will be applied with the LPJ-Guess vegetation module. LPJ-GUESS (Smith et al. 2001) is a detailed dynamic vegetation-ecosystem model, which simulates vegetation distribution and carbon and water cycles within vegetation and soils. It includes interactive emission modules for biogenic volatile organic compounds such as isoprene from vegetation (Arneth et al., 2007) and methane from wetlands, as well as trace gas emissions from biomass burning and fires. LPJ-GUESS has recently been integrated into EC-Earth in a collaborative effort by KNMI and the LPJ-Guess group at Lund University. This involves couplings to TM5 and the H-TESSEL land surface module (H- TESSEL). This project will contribute to the further development of the couplings between TM5 and LPJ-Guess and evaluate their impacts on the simulation of atmospheric composition.

The research objectives of the CLIMBAIR project are to evaluate EC-Earth using TM5 with high-resolution two-way nested zoom over Europe, to make air quality projections of the atmospheric composition and the European air quality in the 21st century, and to estimate the impacts of future changes in biogenic emissions, wildfires and future land use management on global and European air quality.

In this project EC-Earth will be run in atmosphere-only mode. A number of time-slice simulations will be carried out for the present day (2001-2010), mid century (2046-2055) and the end of the century (2091-2100). In these simulations the sea surface temperatures and sea ice distribution will be based on an EC-Earth simulation performed for the Coupled Model Intercomparison Project (CMIP5), in particular the one corresponding to the high forcing scenario RCP8.5 (~8.5 W/m2 in 2100). Future changes in greenhouse

gases and aerosols will be accounted for in IFS by prescribing their concentrations to the values used in the CMIP5 simulation. Anthropogenic emissions of ozone and aerosol precursors in TM5 will be held fixed to the RCP8.5 levels for the years 2005, 2050 and 2100, depending on the simulations. The two-way nested zooming option available in TM5 will be tested and exploited within EC-Earth. This will allow us to increase the resolution from 3x2 degrees in the global domain to 1x1 degrees over Europe.

Couplings between IFS, TM5 and LPJ-GUESS will be activated in a stepwise approach, including an uncoupled configuration with only one-way coupling from IFS to TM5 and a 'vegetation-coupled' configuration with two-way coupling between IFS and LPJ-GUESS, and one-way coupling from IFS and LPJ-GUESS to TM5. The uncoupled configuration will be run with and without zoom to estimate global and local impacts of future changes in anthropogenic emissions and climate change on European air quality. It will also provide the reference for evaluating the coupled configuration runs. The vegetation-coupled mode will be used to estimate future biogenic and wildfire emissions and their effects on global and European air quality under changing climatic conditions, as well as for sensitivity studies. In total we plan to do 14 10-year simulations, 5 of which with a zoom over Europe.

4. Ozone_cci

The Ozone_cci project is part of the ESA Programme on Global Monitoring of Essential Climate Variables (ECV), better known as the Climate Change Initiative (CCI), initiated in 2010 for a period of 6 years.

In the Ozone_cci project consistent total column ozone data products will be operationally produced from ERS-2/GOME, SCIAMACHY and GOME-2 over the period from 1995 until at least 2011. Ozone profiles will be derived over the period from 1995 until at least 2010 from ERS-2/GOME, SCIAMACHY, GOME-2 and OMI instruments using a new algorithm, and merged ozone concentration profiles will be generated from the ENVISAT MIPAS, GOMOS and SCIAMACHY instruments, for at least two contiguous years in the period from 2002 until 2010. In addition, ozone data products from other sensors (TPM or non-ESA) will be used for intercomparison and validation. High quality correlative data sets from the GAW/WMO/NDACC networks will be used as independent validation means.

The chemistry-climate modelling in the project is performed by dr. M. van Weele. This work is part of the Climate Research Group (CRG) within Ozone_cci. The CRG consists of climate research experts specialised in the modelling of global climate and its feedback with chemistry. The CRG contains the core users of the data products developed in the project.

Both in 2012 and in 2013 long-term simulations will be performed against which the newly developed Ozone_cci products will be evaluated. TM5 will be used both in offline mode (driven by ERA-Interim meteorological and surface fields) and in online mode driven by EC-Earth. TM5 will be using the linearized ozone chemistry scheme of Cariolle and Teyssèdre (2007) in the stratosphere and a comprehensive chemistry scheme in the troposphere. The evaluation focuses on the stratospheric ozone distribution as well as on tropospheric ozone, and on the chemistry and dynamics in the UTLS region, which control the ozone stratosphere-troposphere exchange.

Explanation of the requested budget

A 10-year run of EC-Earth at the standard resolution without atmospheric chemistry costs about 15 kSBU in atmosphere-only mode or 30 kSBU with coupled ocean. A 10-year run of TM5 at the default global resolution of 3x2 degrees costs about 200 kSBU. With zoom over Europe we estimate that the model will become about twice as expensive. With 60 vertical levels instead of 34 the costs will also be proportionally higher. Based on these numbers we estimate that the Pinatubo project will require about 1500 kSBU, with the highest use in 2013 and 2014. For EC-IMAGE we require about 500 kSBU in 2012 and 2013 and about 2500 kSBU in 2014. The estimated numbers for CLIMBAIR are 2000 kSBU in both 2012 and 2013. Ozone_cci will require about 500 kSBU in both 2012 and 2013. With some margin for model development, testing and spinup we arrive at the total numbers requested.

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