REQUEST FOR A SPECIAL PROJECT 2017–2019

MEMBER STATE: Denmark

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Project Title:

Permafrost in the global climate system: EC-Earth and GIPL

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.)	2017	
Would you accept support for 1 year only, if necessary?	YES X	NO ☐

Computer resources required for 2017-2019: (To make changes to an existing project please submit an amended version of the original form.)		**2017**	**2018**	**2019**
High Performance Computing Facility	(SBU)	2,500,000	2,625,000	
Accumulated data storage (total archive volume)[2]	(GB)	4,000	9,000	

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):

Thomas Lorenzen (tl@dmi.dk), 2016-06-30

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.

[2] If e.g. you archive x GB in year one and y GB in year two and don't delete anything you need to request x + y GB for the second project year.

Principal Investigator: Christian Rodehacke

Project Title: Permafrost in the global climate system: EC-Earth and GIPL

Extended abstract

It is expected that Special Projects requesting large amounts of computing resources (1,000,000 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.

Permafrost in the global climate system

As part of our long-standing commitment to the EC-Earth community, we aim to perform simulations between the two-way coupled global climate model EC-Earth and the dedicated permafrost model GIPL.

Permafrost and ice sheets are commonly neglected because they're usually considered as passive parts of the global climate system due to their long memory of past climate conditions. However they may be subject to sporadic changes and/or trigger changes in the remaining climate system. Permafrost as a large cryonic body with a vertical extent of 10tens *m* to more than 100 meter requires a substantial amount of energy to change its state from frozen to thaw. Could this mitigate the "Polar Amplification" over centuries? Permafrost holds vast quantities of various potent greenhouse gases, such as carbon dioxide and methane, that could potentially amplify warming trends if they would be released from thawing permafrost (Schuur et al., 2015). The degradation of organic material in thaw permafrost soil may intensify the release of greenhouse gases further (Elberling et al., 2010). The amplified release of methane may already occur from subsea permafrost located on the continental shelf of Siberia (Shakhova et al., 2013).

Also the interaction between the general climate system on one side and ice sheets and permafrost on the other side could have substantial impacts, as recent model simulation of an EMIC (earth system model of intermediate complexity) has shown, where the interaction between ice sheets and permafrost caused a difference of the global sea level during the Last Glacial Maximum (LGM) of 15 m (Willeit and Ganopolski, 2015).

Model development

As part of Nordic Centre of Excellence DEFROST, the permafrost model GIPL has been almost entirely rewritten in collaboration with the GIPL group (University Fairbanks, Alaska, USA) to parallelize the code and to enable the coupling of GIPL with climate models. Now the code is split into three separate parts, namely

- **GIPL Column:** computation of the vertical permafrost's physical properties; GIPL's core.
- **GIPL World:** representation of individual permafrost columns across any horizontal grid.
- **Driving Force:** the inflow (forcing) and outflow (interaction if applicable) of data. This part shall be taken by the atmosphere/surface model component.

This modular concept allows future developments without extensive code changes and enables us to couple the permafrost model with (nearly) every atmospheric or ocean model. The input/output (IO) interface now supports both classical netCDF-3 and parallel netCDF-4. The code using OpenMP and/or the Message Passing Interface (MPI) parallelization techniques; hence GIPL@DMI shall be ready for coming computer architectures; limited access to computers with an OpenACC capability has prevented us to implement it. Auxiliary tools to prepare initial and boundary files are available, hence our initial focus will be to develop a coupled prototype.

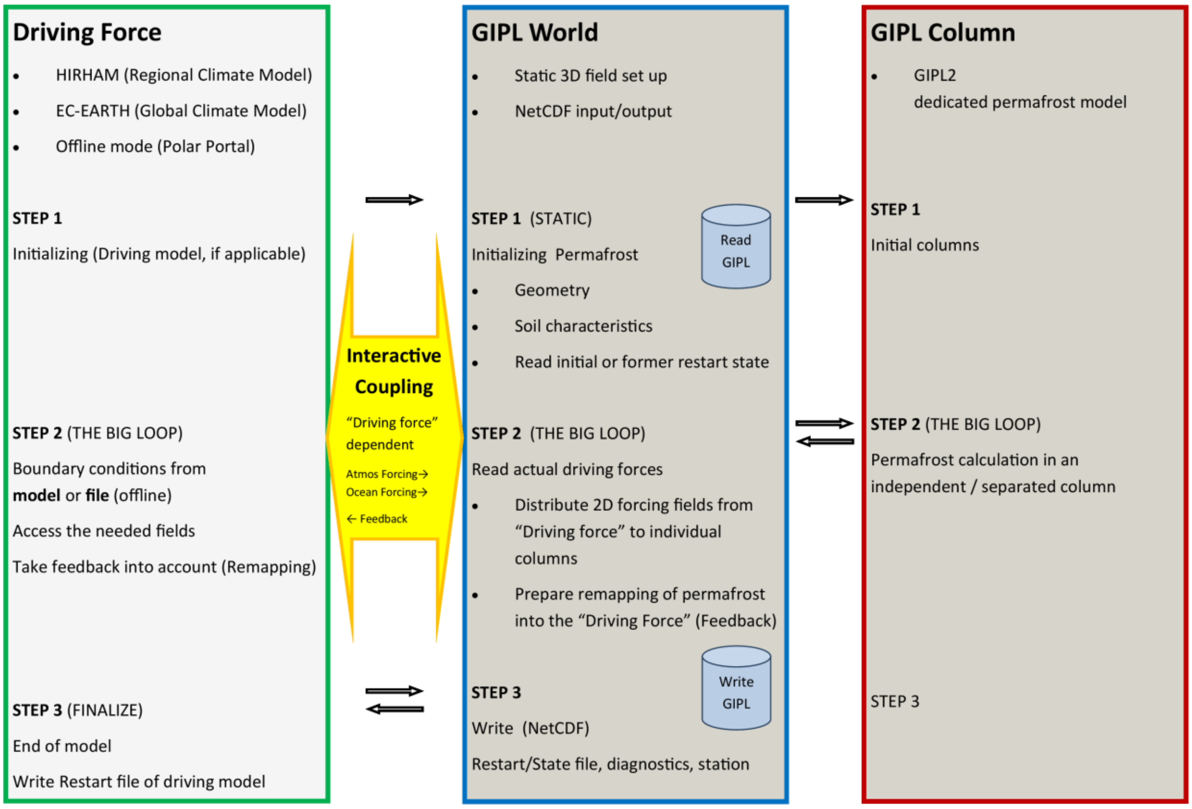

Figure 1 Code structure of the permafrost module GIPL@DMI, which will be coupled with the atmospheric/land module of the global climate model EC-Earth. The left column "Driving force" wiil be EC-Earth.

Working plan

The working plan comprises the following parts:

- Porting of the GIPL@DMI FORTRAN code to the ECMWF’s HPC system.
- Idealized only GIPL@DMI simulations
    - Check if the code has as expected.
    - General code optimizations
- One-way coupling EC-Earth to GIPL@DMI
    - Identification of code locations within EC-Earth to call
        - GIPLinitialize to initialize GIPL@DMI (read GIPL input files, …)
        - GIPLworld to drive GIPL@DMI with EC-Earth forcing
        - GIPLfinalize to finalize GIPL@DMI (close files, …)
    - Preparation of the translation table between EC-Earth surface tiles and the soil classes used in GIPL@DMI
    - Perform simulations of the prepared system
- Two-way coupling between EC-Earth and GIPL@DMI
    - Identification, where the temporal evolution of the soil temperature profile shall influence the original soil scheme of the EC-Earth system
    - Perform simulation with the two-way coupled system

Requested HPC resources

CPU resources

The requested HPC resources in the following are based on our Eemian experiments with EC-Earth under the special project SPDKLANG. We have not yet set up the latest version of the EC-Earth model in the low-resolution paleoclimatic configuration. Moreover, the latest upgrade of the HPC to Broadwell nodes will also influence the resource usage. Here, we base our estimates on our runs with the EC-Earth v.3.1 at T159 (1 deg ocean) on the CCA cluster where colleagues spent about 4500 SBUs per model year.

Unfortunately we currently do not have estimates about computational expense of the GIPL@DMI model component. We expect that it will increase the computational demand by 11% (495 SBU per model year). For the fully coupled model we expect 5000 SBU per model year.

	EC-Earth	GIPL@DMI	Coupled EC-Earth-GIPL@DMI
CPU (SBU/ year)	4500	500	5000
Disk (GB/year)	10	1	11

Initially the permafrost model needs to be spun up by the climate coming from EC-Earth. We will utilize for that existing forcing of the control state (piControl). We plan to run the offline GIPL@DMI for 125,000 model year offline, where the forcing will be adjusted by temperature anomaly estimates originating from ice cores in Greenland. This time period represents the last glacial-interglacial cycle. For these spin-up we will keep data every 1000 years and only for selected time periods we have a high writing frequency to analyse the changes during rapidly changing climates. To reduce the computational coast, we would use an acceleration technique where we could increase the time step from a day to a week, which would reduce the expense by 240 to 1500. We expect numerical stable results for an acceleration of 500. We have performed such simulations for small test cases and, hence, we are familiar with this technique.

*Requirement offline spin up: 500 SBU/year*100,000year / 500 acceleration = 125,000 SBU.*

Afterwards expect to perform one-way coupling experiments, which comprises development activities and first "real" experiments of about 250 years.

*Requirement one-way coupling: 5,000 SBU/year * 250 year = 1,250,000 SBU*

Finally we plan to perform two-way coupling experiments, which again require some development but is predominately directed toward numerical simulation experiments of combined about 750 years. It will include first sensitivity experiments, where we change the soil type descriptions of the permafrost either to once that amplify permafrost degradation (high heat conductivity) or damp it (low heat conductivity) under typical climate change scenarios (such as RCP 8.5)

*Requirement two-way coupling: 5,000 SBU/year * 750 year = 3,750,000 SBU*

The above described 1,000 EC-Earth model years and 125,000 GIPL@DMI model years require in total 5,125,000 SBU.

Storage resources

Each pure EC-Earth model year produces about 10 GB per year, while the coupled system may use 20% more since we plan to use 24 soil types in 120 soil layers for the upper 100 m. With more aggressive clean-up during the 125,000 years GIPL@DMI offline spin-up 1 TB and afterwards keep only the essential data. For the coupled run we estimate about 12 GB per model year. Since we expect that roughly 1/3 of the runs are used for extensive testing, we would actually storage about 2/3*1000 coupled years * 12 GB = 8 TB.

The total storage need is 9 TB for the project life time.

2 year project 2017-18	
Sum of GIPL@DMI model years:	126,000 years
Sum of EC-Earth model years:	1,000 years
Total billing units:	5,125,000 units
Storage pr. coupled model year:	12 GB
Total storage:	9 TB

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