REQUEST FOR A SPECIAL PROJECT 2017–2019

MEMBER STATE: The Netherlands

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Project Title: Towards Cloud-Resolving Climate Simulations

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	

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)	10 MSBU	15 MSBU	15 MSBU
Accumulated data storage (total archive volume)[2]	(GB)	5000 GB	100000 GB	100000GB

***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): 22-06-2016…

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: Daan Crommelin

Project Title: Towards Global Cloud Resolving Modeling

Extended abstract.

Scientific Motivation

Atmospheric convection and cloud processes are of major importance for weather and climate modeling. They constitute a key element in the response of the climate system to increasing CO2 levels (cloud-climate feedback), as well as in the global hydrological cycle (vertical transport of moisture in the atmosphere). A good representation of these processes in climate models is very challenging because of the multi-scale character of the atmosphere and the climate system. Resolving clouds and convection explicitly in numerical models requires extremely high model resolution (ca. 50-100 meters horizontally) and a very small integration time step (ca. 1 second).

It is currently computationally infeasible to simulate with such high resolution over the entire earth. The atmospheric components of climate models have (horizontal) resolutions of ca. 100 km and up (and an integration time step on the order of 15 minutes). Current global (i.e., covering the entire earth) operational weather forecasting models have resolutions of ca. 10-20 km, also still far from convection-resolving.

Because of these computational limitations, comprehensive global atmosphere models (so-called General Circulation Models or GCMs) employ so-called parameterizations: simplified representations of the effect of convection on the GCM-resolved scale. It is well known that conventional convection parameterizations have serious shortcomings that hold back the performance of GCMs, forming one of the greatest obstacles to a major improvement of weather and climate models [1,2,3]. According to the IPCC: "cloud feedbacks remain the largest source of uncertainty in climate sensitivity estimates" (AR4 report, 2007) and "there remains low confidence in the representation and quantification of [cloud and aerosol] processes in models" (AR5 report, Summary for Policy Makers, 2013) [4].

The overarching goal of this project is to come to a better understanding of cloud-climate feedbacks, leading to reduced uncertainty in climate sensitivity estimates. To achieve this, we will pursue a new computational strategy by embedding 3d-Large Eddy Simulation models in each grid column of the global model that replaces traditional parameterization package. When successful this may become a computationally extremely desirable pathway toward global cloud resolving modeling and such a model configuration might be informative in the quest toward constraining uncertainty of climate sensitivity.

Methodology

Our approach will be to develop a 3-dimensional *super-parameterization* (3dSP) with Large Eddy Simulation (LES) models: two-way nesting of 3-dimensional convection-resolving models within a global circulation model. The resulting multi-model will be accelerated with appropriate algorithmic and computing technologies.

The key idea of super-parametrization (SP) for convection is to nest a separate convection-resolving model (e.g. LES model) in each vertical model column of an atmospheric GCM [2,5,6,7]. It is a two-way nesting (or two-way coupling): the GCM column state drives the LES model, and the LES feeds back to the GCM. Until now, the convection-resolving models used for SP have been 2-dimensional or quasi-3-dimensional to reduce computational cost [8]. A major innovation in this project is to nest fully 3-dimensional LES models inside the GCM grid columns.

Regarding the LES-scale boundaries, we will use periodic conditions for each single LES instance, which makes the computational problem massively parallel. Due to the relatively large time step of the GCM and the fact that the GCM only requires mean tendencies of the LES model, thdata transfer between embedded LES models and the climate model shall remain very limited. Strong numerical acceleration will be achieved by implementing sparse space-time algorithms of [9,10] and applying mean state acceleration techniques [15]. The approach has besides computational also conceptual advantages. In the case of a fully global cloud resolving model, compressible equations are needed for the entire range of spatial scales, from small-scale turbulence to synoptic- and planetary-scale circulations, which are cumbersome because of the presence of sound waves that are marginally (if at all) relevant for weather and climate. In the case of 3d Super-Parameterization (3dSP), the outer model can simply apply hydrostatic equations while the embedded LES models can be made anelastic, thereby eliminating the need for compressible equations. Another numerical advantage is that it is extremely suitable for massive parallel computer architectures, since the LES models can act almost independently of each other with only a limited amount of data transfer between the LES model and the outer model.

Proposed Work

We will start the project by simulating a cold air outbreak such as observed during the CONSTRAIN measurement campaign . This case has been subject of the WGNE Grey Zone Project (http://projects.knmi.nl/greyzone/) and has been simulated by global models on a 3 km resolution and by mesoscale models on a 1 km resolution.

In the first phase (2017) of the project we will the run open-IFS at a resolution of O(100 km) and use the Dutch Atmospheric LES Model (DALES) [12] as 3dSP for the area where cold air outbreak develops. This area covers an area of 750 by 1500 km for a period of 36 hours. This implies that around 100 grid boxes of the open-IFS need to be "super-parameterized". As a reference this will be done without any sparse space-time algorithms: each grid box will be equipped with a "LES-copy" that will operate at a turbulent-permitting resolution of 200 m and therefore will have a domain of 500 by 500 grid points. So effectively this will create a high resolution run over the whole cold air outbreak area. The only approximation is that the communication between the 100 LES-copies is done by the outer model at a coarser resolution of 100 km. This "Big_Brother-experiment" will serve as a reference run for all the acceleration techniques that we will explore subsequently. Based on the literature we anticipate to gain at least factor 50~100 without serious degrading the results of the benchmark.

In the second phase (2018) we will employ the accelerated version where the acceleration gain will be applied by using 3dSP on continental spatial scales and on seasonal time scale. This essentially will produce two-nested regional downscaling. The results will be compared with reference runs of the open-IFS with conventional parameterizations.

Finally in the third phase we will explore the possibilities of global 3d superparameterisation. This will be done by using a rather coarse resolution version of open-IFS of 2.5^0 x 2.5^0 for a simple aquaplanet set-up. This will require arounf 10^4 grid points that need to be super-parameterized which can be done by spatial (very) sparse algorithms. Effectively LES with only 10 by 10 grid points will be used. The vertical resolution will not be sacrified and the number of vertical levels will remain large at a typical number of 200. This way it will be possible to make multi-annual runs.

Involved Software

The two-way coupling will be designed on a level of abstraction that allows some degree of flexibility in the choice for the GCM and the LES model. In the proposed implementation, we plan to use ECMWF's OpenIFS for the former and DALES [11,13,14] (Dutch Atmospheric LES) for the latter, which is developed and maintained by KNMI and TU Delft. Both OpenIFS and DALES will be modified to compile as stateful libraries that can be controlled by a master coupling process that is responsible for the two-way nesting. This work is reusable for any future project that aims to couple these codes in an explicit scheme. We also consider to implement the global coupling to the LES models within the OMUSE framework, a generic platform for coupling ocean, coastal and atmosphere models, which is to be published soon.

The plan is to begin by embedding a single DALES instance into the single-column OpenIFS. Once scaling up the embedding to many LES models, testing the performance and validity will require a large amount of compute resources and sufficient storage facilities – although data produced by the individual LES models will not be stored permanently. This is planned to be operational in the beginning of 2017. In a final stage, we plan to implement the embedding of DALES in the EC-Earth system [12].

Justification of Resources

For most of the runs the 3dSP is the computationally most demanding tool. On the host machine of KNMI (Bull) DALES has a good weak scaling up to (at least) 10.000 cores. The typical performance is 2.5 10^{-6} CPU seconds per grid point per timestep per core. The Big Brother reference experiment of the cold air outbreak will therefore require 4 MSBUs which will take up most of the budget of the first year. In 2018 seasonal runs superparameterized on a continental scale of 2000 by 2000 km is foreseen. Here the focus will be on the representation of (subtropical and tropical clouds in the Walker and Hadley circulation). Anticipating on an acceleration of a factor of 100, this will require 5 MSBU per 3 months (season). So in 2018 we anticipate 3 seasonal runs for different regions. Finally the spatial very sparse algorithm allows global 3dSP at a resolution of 2.5x2.5 degrees at the costs of around 250 kSBUs per simulated month. So the budget of 2019 allows global simulations over a period of 5 years (or shorter if less sparse spatial algorithms are required.

Connection with other Projects

The anticipated developed runs and software development is part of a funded joint project of the Dutch Escience Center, the center of mathematics and informatics, KNMI and the Technical University Delft. When successful further hardware acceleration by employing GPU's is also foreseen as part of this project.

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