REQUEST FOR A SPECIAL PROJECT 2015–2017

MEMBER STATE: Germany

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Project Title: Potential sea-ice predictability with a high resolution Arctic sea ice-ocean model

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.)	2015	
Would you accept support for 1 year only, if necessary?	YES	

Computer resources required for 2015-2017: (The maximum project duration is 3 years, therefore a continuation project cannot request resources for 2017.)	**2015**	**2016**	**2017**
High Performance Computing Facility (units)	14,594,000	13,784,000	6,892,000
Data storage capacity (total archive volume) (gigabytes)	5,356	7,312	3,656

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): June 20th, 2014

Continue overleaf

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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.

Introduction

Knowing the sea ice conditions becomes increasingly important for Arctic marine operations, but traditional ice state variables such as sea ice thickness and concentration currently provide only crude guidelines. On time scales of hours to days and weeks, ridges form and leads open and close on scales of meters to tens and hundreds of kilometers. These linear kinematic features (LKFs) also emerge in numerical sea ice model simulations as they are pushed to higher and higher resolution (Wang and Wang, 2009), so that sea-ice models may be used to predict sea-ice conditions at these very short scales. The predictive skill for these small scale features, however, is unknown. We propose ensemble simulations with a coupled sea-ice-ocean general circulation model to explore the potential predictability of sea-ice models at very high resolution in the Arctic ocean. The oceanic component is necessary because at very high resolution (4.5 km and higher) the energy spectrum of the ocean reaches to very short scales that cannot be neglected a-priori in the processes of lead opening and closing and ridging. We plan to carry out these simulations with the Massachusetts Institute of Technology general circulation model (MITgcm, http://mitgcm.org), driven by atmospheric fields of the operation ensemble forecasting system of the ECMWF (Buizza et al. 2007). The simulation code has been used successfully at resolutions of 4.5 km and higher (Nguyen et al., 2012, Losch et al., 2014, Figure 1).

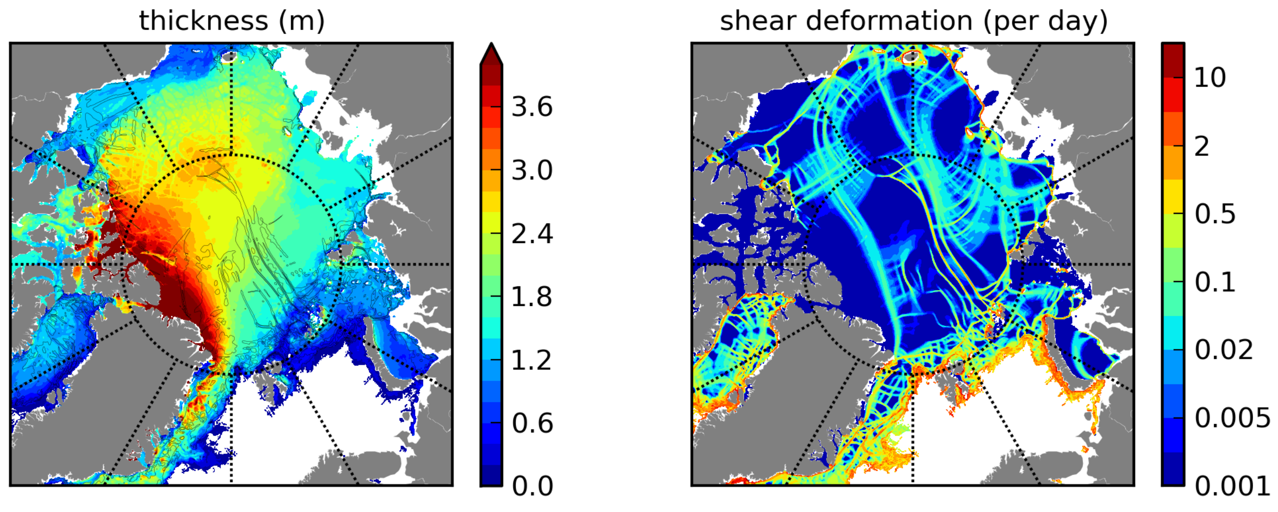

Fig. 1: Example plots of the MITgcm ocean-sea-ice model with a resolution of 4.5 km. Left hand side: Ice thickness (in m, colour) and ice concentration (in %, unlabelled contour lines). Right hand side: Shear deformation (per day, note the logarithmic colour scale), redrawn from Losch et al. (2014).

Fracture zones and leads represent challenges for numerical sea-ice models that generally rely on a quasi-continuity assumption and some form of viscous-plastic (VP) rheology. At coarse resolution there ingredients tend to lead to smooth solutions of ice thickness and concentration with very little detail. As a consequence, predictions can only be made about mean ice conditions and these may be of limited use. At very high resolution the assumption of quasi-continuity needs to be revisited and the realism of simulations at high resolution, while plausible, needs to be established by rigorous comparison to observations. Several model assumptions were made for coarse models and require revisiting and re-interpretation at very high resolution.

If the model's representation of linear kinematic features (leads) turns out to be sufficiently realistic, then the potential predictability of sea ice features at the kilometre-scale will be assessed by carrying out ensemble integrations with the MITgcm using forcing data from the ECMWF VarEPS. Our hypothesis is that these features are predictable several days in advance given the predictive skill of atmospheric low pressure systems that are known to determine leads and linear kinematic features.

This first estimate of predictability of leads and fracture zones on short and medium range time scales in the Arctic is a milestone of the Polar Prediction Project (http://polarprediction.net)—one of the new beacons of the World Weather Research Programme of the WMO for the coming 10 years. The simulation and prediction of small-scale sea ice features at the kilometre-scale will also be a significant contribution to the development of WMO's Global Integrated Polar Prediction Systems (GIPPS).

The MITgcm is a portable open source code for sea ice-ocean (and atmosphere) simulations on massive parallel architectures with MPI and multi-threading (Hill et al., 2007). The code also vectorizes very well (there is ample experience on an NEC-SX8R system). The sea-ice model is closely coupled to the ocean component of the MITgcm. It consists a thermodynamic part with a choice between Semtner (1976)'s zero-layer and 3-layer thermodynamics (Winton 2000). The sea-ice dynamics are based on Hibler (1979)'s viscous-plastic (VP) rheology, and different solver strategies are implemented (Losch et al. 2010, 2014). Losch et al. (2014) demonstrated high scalability of the sea-ice code to 1000 cores and more for the domain to be used here (1680x1536 horizontal grid points) on a computer at HLRN with Intel 268 Xeon Gainestown processors (X5570 @ 2.93 GHz) (Nehalem EP). The PI Losch is an active member of the development team of the MITgcm and has worked with the code for over 12 years.

Experimental Design

First, the MITgcm will be configured to cover the entire Arctic Ocean and parts of the North Atlantic Ocean and the Bering Sea (Figure 1 shows only part of the domain). Potential predictability will be estimated with the help of ensemble simulations that are driven by the atmospheric fields of the Variable Resolution Ensemble Prediction Systems (VAREPS) of the ECMWF (Buizza et al. 2007). From a control run of more than 22 years, we will select two summer seasons (JJA) and two winter seasons (DJF) and start bi-weekly ensembles with 20 members each to obtain forecasts for up to 15 days. We propose the years of 2007 and 2012 because they are two years with very low ice concentrations that are expected to be typical in the near future. One of the ensemble members will be selected as a reference ("truth") and the deviations of the remaining members will be used to estimate the level of potential predictability. This plan requires 4 x 3 x 8 x 20 x 15 days = 28,000 days of simulation. The control run will require 22 x 365 = 8,030 days of simulation.

Based on experience on the NASA-AMES Computer "Pleiades" (SGI Alit, http://en.wikipedia.org/wiki/Pleiades_(supercomputer)) with a computing grid of 1680x1536x50 = 129 Mio. grid points and a time step of 240sec we assume 16h of cpu time in 1920 CPUS for one model year (131400 time steps) (Gunnar Spreen, pers. communication). With this we estimate 16*3600/131400 ~ 0.438 sec per time step and 1920*0.438 CPUsec = 0.234 CPUh per time step, 84 CPUh per model day, and 30720 CPUh per model year. The SBU in table 1 are computed from CPUh (in seconds) * p, with p = 32634000 /(3480 * 24 * 86400).

We plan to use a new efficient method recently implemented in the MITgcm (blank listing) in order reduce CPU requirements. In this method, subdomains that are completely "dry" after domain decomposition can be dropped. The method requires a restructuring of the MPI-topology because now the domain contains “holes”. With our planned configuration, we expect to be able to drop about 30% of the subdomains, and thus expect to be able to reduce the CPU requirements by 30%.

Single precision 2D-fields are on the order of 10MB (1680x1536x4 bytes), one restart-file (double precision and many 3D-fields) requires 10GB of disk space.

Table 1: Estimated resource requirements for high resolution pan-Arctic simulations

experiment	Integration in model time	SBU (kilo units)	Archive (GB)	comment
spin-up simulation	22 years	7,702	960	production of bi-weekly restart files
reference/control run	simultaneously with spin-up		800	daily 2D-fields and grid information
Ensemble Experiment I, Winter 2007	24 x 20 x 15 days	6,892	3,656	15 days per ensemble member, 20 ensemble members, 3x8 start times, 2D-fields
Ensemble Experiment II, Summer 2007	24 x 20 x 15 days	6,892	3,656	15 days per ensemble member, 20 ensemble members, 3x8 start times, 2D-fields
Ensemble Experiment III, Winter 2012	24 x 20 x 15 days	6,892	3,656	15 days per ensemble member, 20 ensemble members, 3x8 start times, 2D-fields
Ensemble Experiment IV, Summer 2012	24 x 20 x 15 days	6,892	3,656	15 days per ensemble member, 20 ensemble members, 3x8 start times, 2D-fields
Sum:		**35,270**	**16,384**	

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