Adding embedded simulation to the parallel ice sheet model

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ADDING EMBEDDED SIMULATION TO THE PARALLEL ICE SHEET MODEL

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ABSTRACT

Understanding the impact of global climate change on the world's ecosystem is critical to society at large and represents a significant challenge to researchers in the climate community. One important piece of the climate puzzle is how the dynamics of large-scale ice sheets, such as those covering Greenland and Antarctica, will respond to a warming climate. Relatively recently, glaciologists have identified *ice streams,* which are corridors of ice that are flowing at a much higher rate than the surrounding ice, as being crucial to the overall dynamics and stability of the entire ice sheet. However, ice stream dynamics are not yet well understood, and it is thus important to develop simulation models through which we can develop deeper insight into their behavior and their interactions with the large-scale ice sheet. In this extended abstract, we present our novel approach to developing such simulation models.

1 Problem Statement

Ice streams are fast-moving corridors of ice that originate in the interior of an ice sheet and drain into the sea through what are termed *outlet glaciers.* They have very different dynamics than the rest of the ice sheet, and need to be modeled at a much higher resolution. The problem is that even small increases in resolution often result in massive increases in the number of grid points and the size of the input/output data sets. For example, modeling the Greenland ice sheet at a resolution of 5-km requires on the order of 34 million grid points and data sets on the order of 1-GB. Increasing to the 1-km resolution, however, increases the number of grid points to over 1.6 billion and pushes the size of the data sets to over 28-GB. Our goal is to develop simulation models of ice streams/outlet glaciers at a resolution on the order of meters rather than kilometers, which, if applied to the whole ice sheet, would become largely intractable. Thus new approaches are needed to capture the full dynamics of both physical processes and the critical feedback loops between them.

2 Approach

The Center for Remote Sensing of Ice Sheets (CReSIS [1]), is developing high-resolution data sets for areas of the ice sheet undergoing rapid change (e.g., ice streams/outlet glaciers). As noted, it is not practical to model the entire ice sheet at such resolutions because of the massive computational resources it would require and because such data is not available for large portions of the interior. In fact, it is more intuitive to view the whole ice sheet in terms of multiple physical processes, executing at different spatial and temporal resolutions, each of which can interact with and impact the behavior of the other physical processes.

We are basing our approach on the Parallel Ice Sheet Model (PISM, [2]), which is a widely used parallel simulation model for the study of large-scale ice sheets. It should be noted that PISM does provide techniques for regional modeling (e.g., the Jakobshavn outlet glacier), but these models run in isolation and thus cannot capture the important feedback loops between them and larger ice sheet. To address this issue, we are augmenting the basic PISM system with the ability to create *embedded simulation models,* which can communicate and synchronize their activities to maintain a coherent view of the entire ice sheet and to capture the feedback between them.

3 Communication and Synchronization

Consider a simulation of the whole Greenland ice sheet executing at a resolution of 1km (call it simulation S1), with an embedded model of an outlet glacier at a resolution of, for example, 500 meters (call this simulation S2). Logically, S1 and S2 are implemented as two independent instantiations of the PISM model, each of which is fully parallelized and, in isolation, correctly synchronized by their respective runtime systems. However, they share a border and have overlapping regions of the grid. It is in these areas that one simulation can *directly* impact the model state of the other, thus requiring careful synchronization to correctly capture their interactions while maintaining coherence of the overall simulation.

We use a two-phase synchronization protocol. In the first phase, the low-resolution model (S1) is executed for one complete time step, say from some logical time T1 up to T2. Once completed, the model state of the low-resolution grid nodes *bordering* the embedded simulation are provided to S2. The idea is to use these values for the ice flow and stress boundary conditions for the high-resolution simulation.

In the second phase, simulation S2 is executed from time T1 to T2. However, because it is being modeled at a higher resolution, it typically takes several, much smaller time steps, to model its evolution over the same time interval. Ideally, we would use the values of the bordering grid points (from the low-resolution model) in the computation of the boundary conditions at each time step, but such information is only available for logical times T1 and T2. We therefore use a linear 2D interpolation between the values at T1 and T2 for this purpose. Once the high-resolution simulation reaches logical time T2, it provides similar information to the low-resolution model, which utilizes it in a similar fashion. We note without further explanation that values for the low-resolution grid points that logically fall within the high-resolution grid are also updated and provided to S1.

Thus in our approach, the feedback loop between the models is captured via the exchanged state information. The impact of this feedback on the dynamics of each model is captured through PISM's normal execution of the subsequent time steps.

4 Research Results

We have implemented a prototype embedded simulation model on the Stampede supercomputer housed at the Texas Advanced Computing Center [3]. In the final poster, we will provide visualizations of the ice thickness and velocity fields generated by our embedded simulation model and compare them with values obtained via direct observation and measurement. We are also investigating the allocation of available computational resources between the two simulation models, with the goal of minimizing overall wait time. These results will also be presented in the poster.

REFERENCES

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