THE ACCIMA PROJECT – COUPLED MODELING OF THE HIGH SOUTHERN LATITUDES

David H. Bromwich[1,2*], Keith M. Hines[1], Le-Sheng Bai[1], David M. Holland[3], John M. Klinck[4], and Michael Dinniman[4]

[1]Polar Meteorology Group, Byrd Polar Research Center, The Ohio State University, Columbus, OH
[2]Atmospheric Sciences Program, Department of Geography, The Ohio State University, Columbus, OH
[3]Department of Mathematics, New York University, New York, NY
[4]Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, VA
*Email: bromwich.1@osu.edu

1. Background

Understanding the mass balance of the Antarctic ice sheet is critical for projecting global sea-level change. Also, Antarctica provides key climate records through deep ice cores, one of which is currently being extracted in West Antarctica. On decadal and shorter timescales, the Antarctic Ice Sheet responds to climate phenomena such as the El Niño-Southern Oscillation, the Southern Annular Mode, and the Pacific Decadal Oscillation. Processes spanning multiple physical disciplines impact the Antarctic Ice Sheet. For example, important mesoscale phenomena in the atmosphere and ocean deliver heat to the bottom of the floating Antarctic ice shelves, such as those in the Amundsen Sea embayment. In response to such influences on the mass balance, a coupled modeling project is initiated on the mesoscale to treat the system processes including those that melt Antarctic ice shelves.

The West Antarctic Ice Sheet (WAIS) loses volume due to outlet glaciers draining into the Amundsen Sea (Thomas et al. 2004; Pritchard et al. 2009) and the rate of loss has been increasing in recent years (Chen et al. 2009). One proposed reason for the supposed increased basal melt of ice shelves in the region (Payne et al. 2004) is a change in either the temperature or circulation of warm Circumpolar Deep Water (CDW) that enters the subglacial area providing heat to increase the basal melt rate. Representing such processes in our coupled model will be a fascinating challenge.

The overarching theme of this project is the expected rise in sea-level due to melting of the Antarctic Ice Sheet; specifically, the fate of that part of the ice sheet floating in the ocean, and its influence on the inland ice. The primary tool is a high resolution coupled regional ice-ocean-atmosphere model to be developed. The coupled model will be capable of receiving forcing boundary data from a coarse resolution climate model and downscaling that forcing to the fine appropriate for a regional model. We include sea-ice, ocean, and atmosphere component models, with the ice sheet being present only in a so-called thermodynamic sense. This project will combine a team of researchers to develop and couple the system model. The component system models include the polar-optimized version of the Weather Research and Forecasting model (Polar WRF) for the atmosphere. The ocean component will be the Regional Ocean Modeling System (ROMS), and the sea ice component will be the Los Alamos sea ice model (CICE). A thermodynamic ice shelf model that is already part of ROMS will be applied. The overall project and the Polar WRF component will be coordinated by David Bromwich of the Polar Meteorology Group (PMG) of The Ohio State University's Byrd Polar Research Center. David Holland of New York University in conjunction with both John Klinck and Michael Dinniman of Old Dominion University will lead the ocean, sea ice, and ice shelf modeling components. Assistance in coupling the different model components through the Community Climate System Model flux coupler CPL7 is provided by Ruby Leung of the Pacific Northwest National Laboratory.

This project will analyze the important mesoscale processes in the ocean, atmosphere and sea-ice that contribute to this basal melting of ice shelves. Relatively coarse resolution coupled ocean-atmosphere simulations forecast or suggest increased ice shelf melting (Overpeck et al. 2006). Furthermore, current observations indicate a reduction in ice volume and increased transport of ice sheets towards the ocean (Pritchard et al. 2009). We will use the mesoscale-resolution coupled model to analyze the processes responsible for increased basal melting, including the southward transport of heat and the northward transport of freshwater in this system. We will also evaluate the extent to which there is meaningful coupling between our component models in the study region, and thus the actual need for coupling in order to understand how Southern Hemisphere ocean, sea ice, and atmosphere impact the ice sheet periphery.

2. Key Questions

The research will address the following specific questions focused primarily on quantification of the amounts and mechanisms of the meridional transport of heat and freshwater in the coupled system:

1) How does the atmosphere over the Southern Ocean affect the transport of heat to the continental shelf either by direct heat advection or indirectly by changing the circulation and variability of the ocean? How does this heat affect continental shelf circulation, sea ice cover and ultimately the basal melt of ice shelves?

2) Are there feedbacks among these processes? For example, do these changes on the continental shelf change regional atmospheric circulation? What is the role of sea ice in amplifying or modulating any such feedback?

3) What is the fate of the glacial meltwater? Is it transported northward in the ocean near the surface or through deep export?

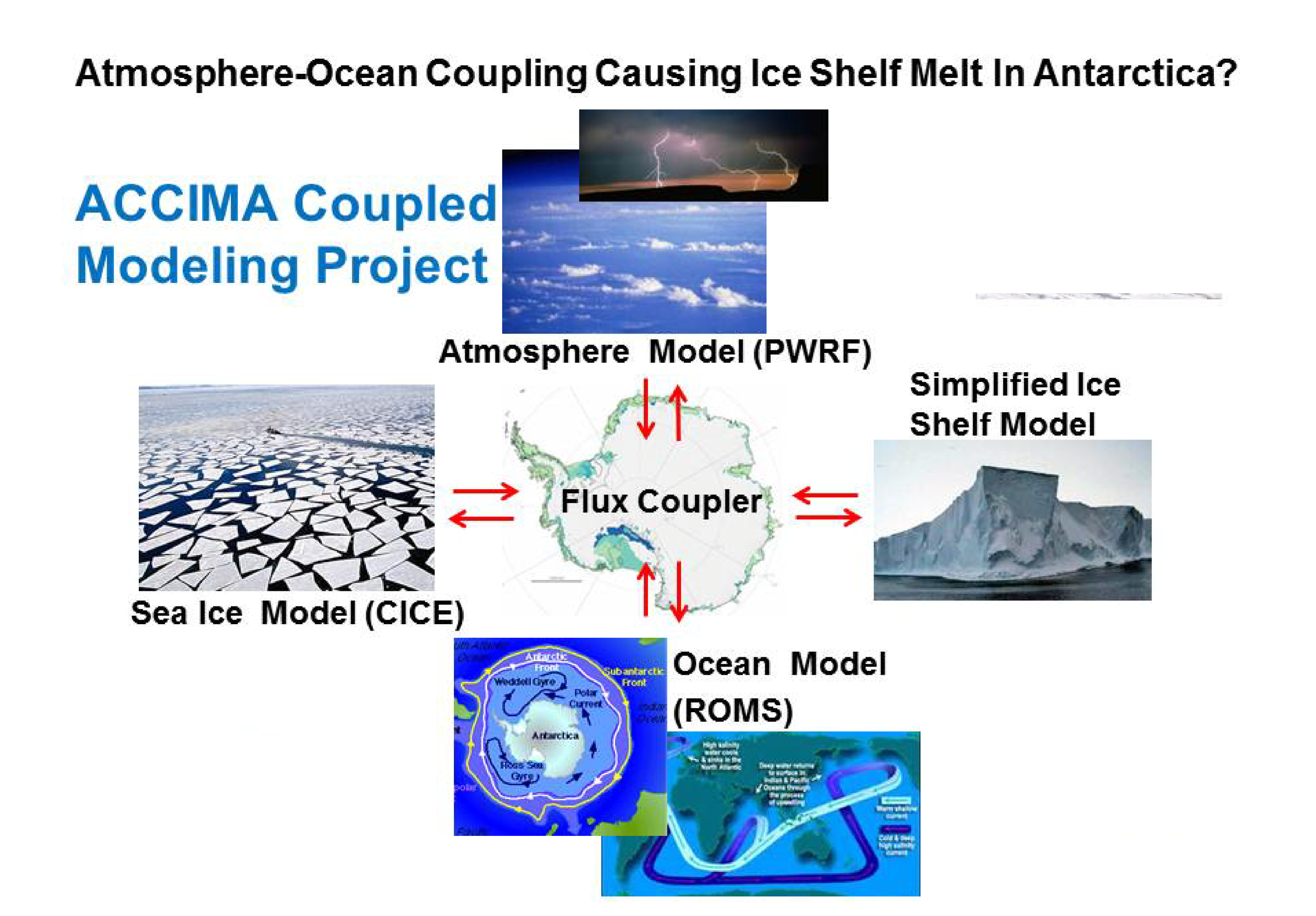

Figure 1. Diagram of the linked ACCIMA components

3. The Component Models

3a. Polar WRF

The polar-optimized version of the Weather Research and Forecasting (WRF, Skamarock et al. 2008), http://www.wrf-model.org) will serve as the mesoscale atmospheric model. WRF, developed for both operational weather forecasting and research simulations, has a portable code that is efficient in various computing environments ranging from massively-parallel supercomputers to laptops. There are now over 10,000 registered users of the model. The modeling system has a flexible, user-friendly WRF Preprocessing System (WPS) for the advanced research formulation of WRF and a much-advanced data assimilation system (WRF-Var). The PMG has provided polar-optimizations previously for the earlier generation Polar MM5 and currently to WRF. The polar-optimized model known is known as "Polar WRF" (http://polarmet.osu.edu/PolarMet/pwrf.html) and intended for a variety of Arctic and Antarctic applications.

Polar WRF has been tested in the Arctic for the Greenland Ice Sheet (Hines and Bromwich 2008), the Antarctic region (Powers 2009; Bromwich et al. 2012), the Arctic Ocean (Bromwich et al. 2009) and Arctic Land (Hines et al. 2011; Wilson et al. 2011). Polar modifications have been shown to improve the performance of the model in the Arctic and Antarctic regions. Polar physics additions are now available to the scientific community for the standard release of versions 3.1.1 to 3.3.1. Additions, including variable sea ice thickness and variable snow cover on sea ice are available to the community in supplemental files provided by PMG. Polar WRF also serves as the atmospheric component for the developing Regional Arctic System Model (Cassano et al. 2011). For Antarctica, Polar WRF is now the only model for operational forecasting in support of National Science Foundation's operations including transportation and field programs. The polar-optimization includes significant updates to the Noah surface package, with a highly-improved thermodynamic treatment over snow and permanent ice surfaces (Hines and Bromwich 2008). Bromwich et al. (2009) added a treatment for fractional sea ice over the oceans.

3b. Ocean Model: ROMS

The Regional Ocean Modeling System (ROMS) will be used as the numerical model for the ocean. ROMS is a three-dimensional, primitive-equation, finite-difference model that uses a terrain-following vertical coordinate system (Haidvogel et al. 2008). This model has been extensively restructured to allow sustained performance on parallel computing platforms. It includes a number of choices for advection algorithms, turbulence models including surface and bottom layer formulations; as well as procedures for data assimilation. Numerical details can be found in Shchepetkin and McWilliams (2009), Haidvogel et al. (2008), as well as on the ROMS web site (http://marine.rutgers.edu/po/index.php?model=roms). The ROMS user community now numbers more than 2000 scientists worldwide. Both groups at NYU and ODU have experience with ROMS, especially in high latitude regional domains (Dinniman et al. 2011; Reddy and Holland 2011).

3c. Sea-Ice Model: CICE

The comprehensive Los Alamos Community Ice CodE (CICE: Hunke and Dukowicz 1997) coupled to ROMS has been used by Old Dominion University and New York University. CICE is a free-standing program to calculate sea-ice processes. CICE includes multiple ice categories, a remapping scheme for advection, and runs separately from ROMS with the models communicating through a flux coupler. Mechanical forcing for the sea ice includes wind stress on the ice surface, stress on the ice base applied by the ocean, Coriolis force, pressure due to the tilting ocean surface and the internal ice forces due to strain. Model simulations for the Ross Sea using CICE and ROMS coupled through the WRF I/O API MCT (Michalakes et al. 2004) have already been carried out at ODU (Haidvogel et al. 2008).

CICE (version 4.1) was developed at Los Alamos to be used with global climate simulation models. It represents thermodynamics, dynamics and horizontal transport of sea ice over a grid of points. The computer code is vectorized to be run on a distributed memory parallel computer cluster. Model code and an extensive user manual are available at the CICE web site (http://climate.lanl.gov/Models/CICE/).

The ice model uses four layers of ice and one layer of snow in each of five ice thickness categories (and one category for open water) to represent different types and ages of sea ice. The thermodynamics model (Bitz and Lipscomb 1999) calculates the local growth rate of snow cover and sea ice. The ice rheology is the elastic-viscous-plastic model (Hunke and Dukowicz 1997). Ice advection is represented by the incremental remapping scheme (Lipscomb and Hunke 2004).

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