CLIMATE MODELING WITH SPECTRAL ELEMENTS

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Our primary objective is to create accurate predictions of future climate on decadal to centennial time scales and on a broad spectrum of space scales by improving model-component performance and accuracy, by implementing efficient strategies to couple model components, and by maximizing throughput on state-of-the-art computers capable of exceptional peak speeds. To this end we have developed a climate model entitled Spectral Element Atmospheric Climate Model (CAM_SEM) that includes a unique dynamical core (SEAM) that is currently coupled to both the physics component of the Community Atmosphere Model (CAM) and its the land surface component (CLM). Our primary effort thereto has focused on the dynamical core (dycore) component. Included among the major improvements we hope to provide are a more transparent, efficient and accurate method of producing *regional climate predictions* involving local mesh refinement, improved numerical quadrature, a more comprehensive technique for predicting the overall global climate, and application of computing methodology using the latest in computing hardware most effectively and economically to produce the best predictions/simulations with minimal expenditure of resources.

One signature of climate change may be identified in the frequency and magnitude of deviations from the climate mean, and by the increased frequency of regional events such as hurricanes, or severe storm complexes that have significant impact on relatively short time and space scales. To uncover these phenomena model resolution must be increased, at least locally, with the consequence that processes effecting previously unresolved scales in coarser grained models must then be considered. Including shorter space scales introduces shorter time scales, thereby further increasing computational requirements. This highlights the importance of understanding the impact of the shorter space scales on predictions and how these scales interact with the larger scales in the coarse grained portion of the total domain, and also highlights the need to develop model methodology that optimizes the use of computer resources. Our methodology is formulated to take into account local scaling requirements, and dynamic scalability is achieved without distorting the overall global prediction. We utilize the advantageous features of computers for prediction on any and all space scales deemed significant, and do so in a seamless and rigorously convergent fashion.

Our modeling studies have exploited the spectral-element method. We developed a pioneering dycore for the global atmosphere, which we named the Spectral Element Atmosphere Model (SEAM), summarized in Fournier et al. (2004). Spectral elements have advantageous properties both for global modeling and for inclusion of regional space scales by using local mesh refinement (LMR), providing higher resolution in regions of strong local variability and generating regional predictions within a global model. The model is self-contained and is combined with appropriate physics and other scientific numerical *packages* as noted above.

Based on our runs with SEAM in the shallow water mode using the community test suite, we have established the model's flexibility, its ability to produce regional detail under LMR, its accuracy and computational efficiency when compared to similar models, and its advantages when using parallel processors. We subsequently ran SEAM under various representations as a

3D dycore and have found that in all circumstances it performed well, better or equivalently to competitive models. In this context, we studied the effects of varying resolution with and without the inclusion of the Earth's topography. Additionally, we made predictions with the SEAM dycore and simple Held-Suarez physics applying global and regional scaling concurrently, to check SEAM's skill using local mesh refinement (LMR), primarily over the continental United States. Results from these experiments indicate that LMR is working successfully in our dycore.

To generate a complete climate model, we coupled the state-of-the-art physics package algorithm developed for the CCSM system at NCAR (CAM), as well as the CLM (land model) algorithm to SEAM, creating CAM_SEM. A variety of experiments including the application of LMR were made to test this model. All experiments proved encouraging and culminated with an AMIP run for comparison with the variety of such experiments made available to PCMDI. We ran CAM_SEM with identical initial and boundary conditions to CAM2 (an NCAR submission to AMIP which included the same physics as we used) and we set our grid set as near as possible to T42. Our integration covered the period 1979 to 1998 for which input data were available. We compared CAM_SEM output to the output archives of CAM2 as well as NCAR archives that contain some observational data taken from reanalysis data over that period. The implications of these comparisons indicate that CAM_SEM is running in a stable mode and is producing results that look similar to those of CAM2. Since the integration period is 20 years, it is not possible to achieve identical results from different models, but the similarities noted are highly encouraging. These results have recently been submitted in a paper to Monthly Weather Review that is currently under review (Baer et. al, 2006).

Experiments with CAM_SEM are presently under development to include LMR as a contribution to the Stretched Grid Model Intercomparison Program (SGMIP).

References:

Baer, F., H. Wang, J. J. Tribbia, and A. Fournier, 2006: Climate modeling with spectral elements. *Mon. Wea. Rev.*, under review.

Fournier, Aimé, Mark A. Taylor and Joseph J. Tribbia, 2004: The Spectral Element Atmospheric Model: High-resolution parallel computation and response to regional forcing. *Mon. Wea. Rev.*, **132**, 726-748.