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Project Title: Two-Way Integration of WRF and CCSM for Regional Climate Simulations

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Under the support of the DOE award DE-SC0004670, we have successfully developed an integrated climate modeling system by nesting Weather Research and Forecasting (WRF) model within the Community Climate System Model (CCSM) and the ensuing new generation Community Earth System Model (CESM). The integrated WRF/CESM system is intended as one method of global climate modeling with regional simulation capabilities. It allows interactive dynamical regional downscaling in the computational flow of present or future global climate simulations. This capability substantially simplifies the process of dynamical downscaling by avoiding massive intermediate model outputs at high frequency that are typically required for offline regional downscaling. The inline coupling also has the advantage of higher temporal resolution for the interaction between regional and global model components. With the aid of the inline coupling, a capability has also been developed to ingest other global climate simulations (by CESM or other models), which otherwise may not have necessary intermediate outputs for regional downscaling, to realize their embedded regional details. It is accomplished by relaxing the global atmospheric state of the integrated model to that of the source simulations with an appropriate time scale. This capability has the potential to open a new venue for ensemble regional climate simulations using a single modeling system. Furthermore, this new modeling system provides an effective modeling framework for the studies of physical and dynamical feedbacks of regional weather phenomena to the large scale circulation. The projected uses of this capability include the research of up-scaling effect of regional weather system, and its use as an alternative physical representation of sub-scale processes in coarser-resolution climate models.

The integrated system has been validated for the simulation of a mid-latitude cyclogenesis event over the Southern Great Plains of the United States (He et al., 2013). The global atmospheric model CAM4 at T42 resolution in the CESM would miss this cyclogenesis, while the nested WRF at 30-km grid spacing (or finer) that was initialized with the CAM4 condition and laterally forced by the CAM4 successfully simulated the deepening mid-tropospheric trough and associated cyclogenesis. An analysis of the potential velocity evolution and sensitivity experiments further shows that it is the higher WRF resolution that allowed the realistic sharpening of the Ertel's Potential Vorticity (EPV) gradient and the ensuing cyclogenesis. The terrain resolution and the physical parameterizations, however, play little role in the difference between the CAM4 and the WRF in the CESM. This case study serves as a verification of the system through comparisons with observations and standalone WRF simulations forced by operational analyses.

In parallel to the software engineering for integrating two sophisticated community models WRF and CESM, a conservative and accurate data remapping method is developed for data transfer between the grids of the component models (in this case, WRF and CAM) that are in general non-matching (Chen 2011, Chen et al. 2011). The data transfer between non-matching grids should be both physically conservative and numerically accurate. Our method contains two parts: the common refinement and the L-2 minimization. The former computes the grid intersections and provides the necessary data structures for the latter. The grids of WRF and CAM are first projected onto a plain surface using their corresponding map projection methods. The common refinement method then locate the edge intersection points of the two projected meshes, and determine the sub-facets to create a new mesh based on the union of the intersection points and the vertices of the original two meshes within the overlapping area. After obtaining the common refinement mesh, a weighted-residual formulation, which minimizes the L-2 norm of the error, is used to complete the data transfer. The L-2 minimization method satisfies physical conservation and at the same time ensures the accuracy of the remapping.

Publications

He, Juanxiong, Minghua Zhang, Wuyin Lin, Brian Colle, Ping Liu, and Andrew M. Vogelmann, 2013: The WRF nested within the CESM: Simulations of a mid-latitude cyclone over the South Great Plains. ***JAMES***, accepted.

Chen, Ying, 2011: Conservative and accurate data remapping for coupling climate models (WRF and CAM), Ph.D. Thesis, Department of Applied Mathematics and Statistics, Stony Brook University.

Chen, Y., X. Jiao, W. Lin, M. Zhang, and J. He, 2011: Conservative and noise resistant data remapping for coupled regional climate modeling. SIAM Conference on Computational Science & Engineering 2011, Feb 28 - Mar 4, 2011, Reno, Nevada.