Advanced Scientific Computing Research
Applied Mathematics
FY 2007 Accomplishment

“Numerical Strategies for Reduced Dynamics for Models of Geophysical Flows”

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Summary

The main objective of this project is to develop novel computational techniques for describing evolution of essential variables in geophysical systems. In particular, this work targets applications in weather/climate prediction where it is necessary to resolve accurately only the large-scale bulk quantities of interest (e.g. mean seasonal temperature) and accuracy of the small-scale physical processes can be sacrificed in order to boost the performance of numerical methods. In the previous work of the PI a stochastic mode-reduction approach has been developed. In this approach the computational complexity is reduced by eliminating the non-essential variables which leads to derivation a low-dimensional stochastic effective equation for large-scale quantities. Unfortunately, the resulting effective equation contains many unknown coefficient. One of the goals of the current project is to develop reliable numerical techniques for estimating these unknown coefficients from the time-series of the large-scale (essential) variables alone. In the second approach, the non-essential variables are kept in the equation, but their dynamics is systematically modified to allow for a bigger time-step in direct numerical simulations. In addition, a particular emphasis is placed on underlying predictability properties of geophysical systems.

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Reduced stochastic models can be utilized in atmosphere/ocean science in several ways. One of the most interesting and practical issues is the development of so-called reduced models or parameterizations for atmosphere/ocean processes. For example, it would be extremely useful to develop an accurate reduced model for a few leading patters in the global ocean circulation. Such model can then be coupled with an atmospheric model and utilized to drive the atmosphere and study the climate change on decadal time-scales. This research is geared toward understanding underlying mathematical difficulties in such examples and developing novel analytical and computational approaches for use in atmosphere/ocean applications.

Several methodologies for estimating parameters in stochastic differential equations from the time-series of the dynamical variables have been compared. In particular, the two most popular techniques – the Bayesian approach and the Maximum Likelihood approach yield similar estimates for various simple test problems. Nevertheless, the Bayesian approach seems

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to more robust and less sensitive to the sampling frequency. Currently, we are implementing a general Bayesian framework for realistic geophysical problems. A general C code has been written to treat multi-dimension and multi-parameter cases. In addition, this code can treat time-series with variable time-step and incomplete data. One of the main computational difficulties in the Bayesian approach is calculation of high-dimensional integrals. Parallel architecture can be utilized naturally for this task and currently we are working on porting this code to use a modern NVIDIA video card technology. In particular, we plan to utilize a recently released CUDA programming environment for computing on NVIDIA graphics processing units to accelerate calculations of multi-dimensional integrals and develop fast numerical codes for next-generation computers.

Often, the main goal of numerical studies in the atmosphere/ocean community is to understand the statistical behavior of large-scale structures (averaged wind-speed, mean temperature, etc.), but the limiting factor in selecting the time-step of numerical integration is, typically, the behavior of the small-scale variables. Therefore, we seek a systematic modification of the underlying dynamical equations, such that the statistics of the large-scale data is preserved, but the equations can be integrated faster.

A novel methodology for systematic modification of the right-hand side for the non-essential variables has been developed and tested on a simple prototype system. In this methodology, the statistical properties of the fast variables are sacrificed in order to accelerate the direct numerical calculations. In particular, modified equations can be integrated with a time-step which is approximately two or three times bigger than the time-step in the original model. While the behavior of the small-scale variables is modified considerably, the statistics of the essential large-scale components is similar to the behavior of these modes in the original system. Therefore, the new approach has a potential to accelerate the numerical computations of certain types of geophysical problems. In addition, we also verified that the predictability of large-scale modes in the modified system is comparable with the predictability of the original system. Currently we are investigating the optimal structure of the modified equations and proper analytical justification of the modification procedure.

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