SPACE SCIENCE AND ENGINEERING CENTER

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September 14, 1995

Ms. Tanga Baylor, Contracts Specialist
U.S. Department of Energy
DOE Chicago Operations Office, Contracts Division
9800 S. Cass Avenue
Argonne, IL 60439

Dear Ms. Baylor:

Enclosed please find three copies of our final report, contract #92ER61474. Please feel free to contact me if you have any questions.

Sincerely,

Dr. John Anderson
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Associate Director, Space Science and Engineering Center
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Enclosures

An Experimental Climate Modeling Laboratory
DOE CHAMMP Program Year 2 Final Report

The major focus of this two year duration CHAMMP science team project is the development and in-model testing of new numerical methods and dynamical algorithms which are particularly well suited to massively parallel computers. The project includes efforts relevant to both global ocean circulation models and atmospheric GCMs.

During the course of our investigations we focused on two basic areas:

The first of these was the implementation and testing of a global non-linear dynamics code using the Local Spectral (LS) formalism. The LS method is of considerable interest for atmospheric GCMs since it has a computational complexity of N^2 as opposed to the $N^3 \log N$ complexity of Spectral Transform (ST) implementations while maintaining many of the same properties of the ST models which have become the dominant method employed for global climate model studies. The LS method is based on a wavelet-like approach to the treatment of the non-linear dynamics and can be shown to asymptotically approach the ST calculations.

We have completed an implementation of the LS system on the CM5 using a semi-spectral partitioning where the convolution sums in the LS kernel are computed using direct convolutions in the meridional direction and FFT based fast convolutions using the Winnograd method in the zonal direction. This implementation seems to offer significant computational advantages over the ST method and similar performance. A significant issue remains which is the generation of LS schemes for use with semi-Lagrangian advection techniques. We plan to address this problem in future work on incorporating the LS technique into existing high performance climate models.

A second element of our investigation has been the evaluation of alternate dynamical systems for use in global ocean circulation models. Some of our investigations have focused on the use of split-explicit hydrostatic models while others have made use of non-hydrostatic dynamics with vertically implicit integrations of equation systems using artificial compressibility. The use of either reduced surface gravity or a slow artificial sound wave allows the generation of very efficient split explicit models which do not require the use of large elliptic solvers; often problematic on massively parallel computers. In addition there are two significant advantages to non-hydrostatic systems for global ocean models.

The first advantage is that the use of a dynamical system of this sort allows the straightforward nesting of mesoscale models to represent deep convection processes in the polar water mass source regions. Since the regions where oceanic convection occurs are quite limited, the use of explicit nested models instead of a convective parameterization appears to be an attractive option which could improve the fidelity of the simulations of the thermohaline circulations at a modest computational cost.

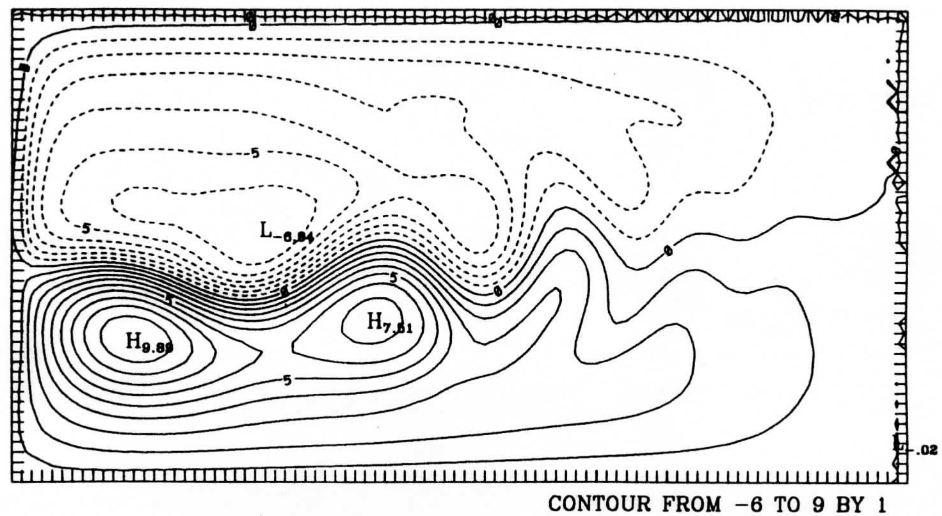
The second advantage of non-hydrostatic systems has been recently discussed by Len Margolin of LANL. He has shown that the commonly used hydrostatic systems are subject to nonlinear instability problems because the hydrostatic system nonlinear internal gravity waves evolve toward a first order discontinuity instead of the soliton-like limit of the non-hydrostatic system.

Given the potential advantages of using the non-hydrostatic equations for the ocean models, one of our first efforts in the ocean modeling area was to demonstrate that systems of this sort are in fact at least as accurate as hydrostatic systems and that they are computationally competitive with traditional ocean model systems. We have implemented a non-hydrostatic system using artificial compressibility techniques in conjunction with sub-cycled time integration and mode splitting methods which achieves computational efficiencies at least as good as the hydrostatic system.

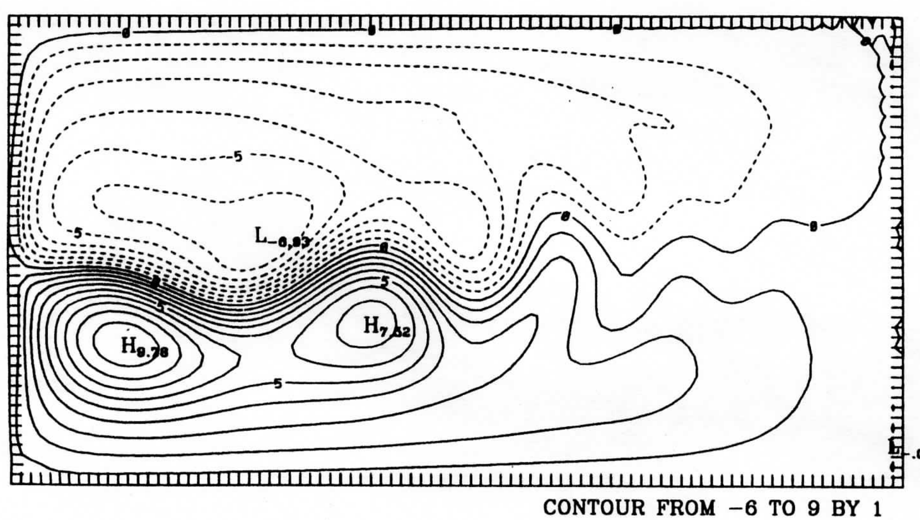
Our validation testing for the new method began with a set of test calculations employing a simple rectangular basin originally studied by Holland and Lin(HL). The HL problem is an integration of the ocean which develops baroclinc eddies and provides a good test for exploring the accuracy of the non-hydrostatic system for a physical problem. These results are summarized in Figures 1 and 2. The results were very encouraging and led us to the next step of implementation of the non-hydrostatic model in a realistic global geometry.

A major element of the testing for either method is understanding the effects of the reduced phase velocity for the barotropic gravity waves and Rossby waves. In particular, we need to determine to what extent the external mode propagation velocity can be reduced without impacting the transient forced response of the model system. We have addressed this problem by exploring the behavior of the H-L system where the driving wind stress is moved northward and southward in an annual cycle. These results are summarized for the H-L domain in Figure 2. From these results it is apparent that very high fidelity results can be achieved with surface gravity reductions of a factor of 64 corresponding to a reduction in the surface wave speed and external mode time step of 8.

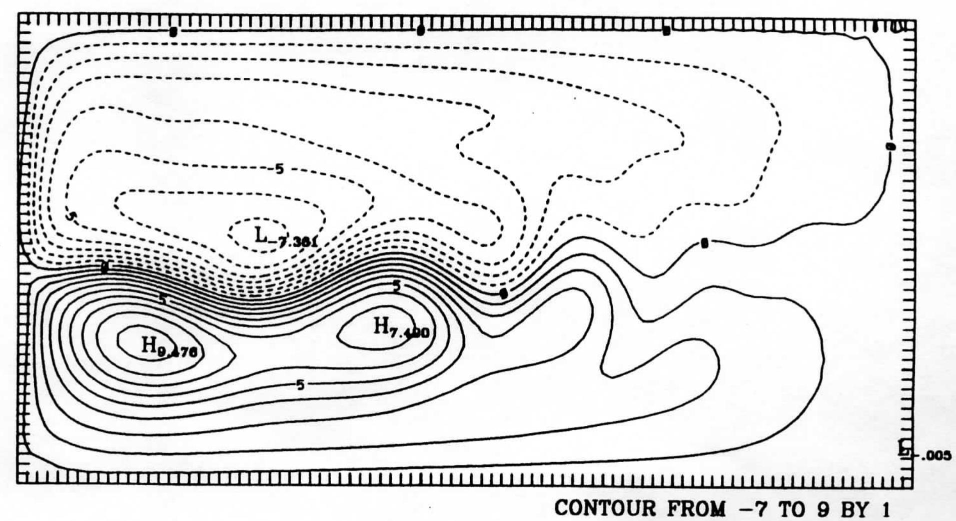
Two global models, one hydrostatic and one non-hydrostatic, were constructed which use the slow external wave mode technique. We have attached Figures 3 and 4 which show the model topography and the surface pressure field from a 10 year integration on a global 256x512 point domain. This model has now been implemented on both the Thinking machines CM5



Mean surface pressure field for years 10-20, normal g.

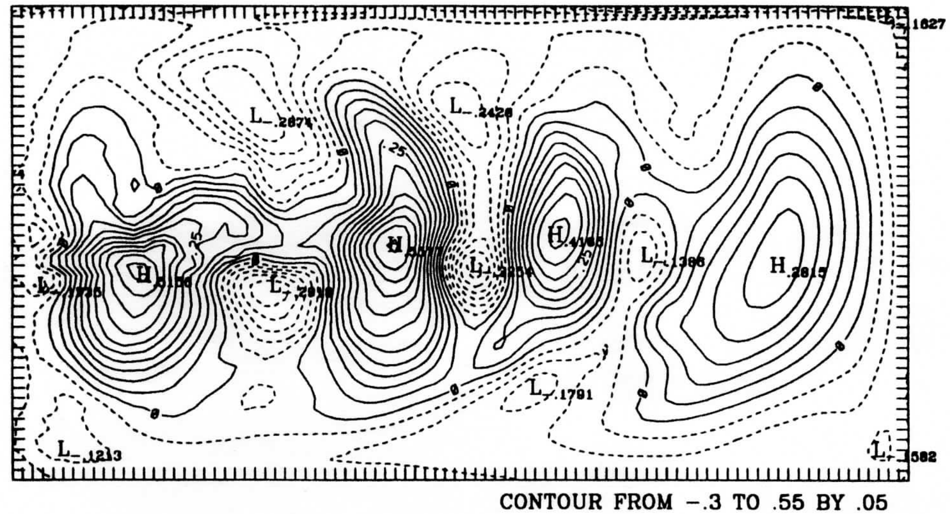


Mean surface pressure field for years 10-20, g/64.

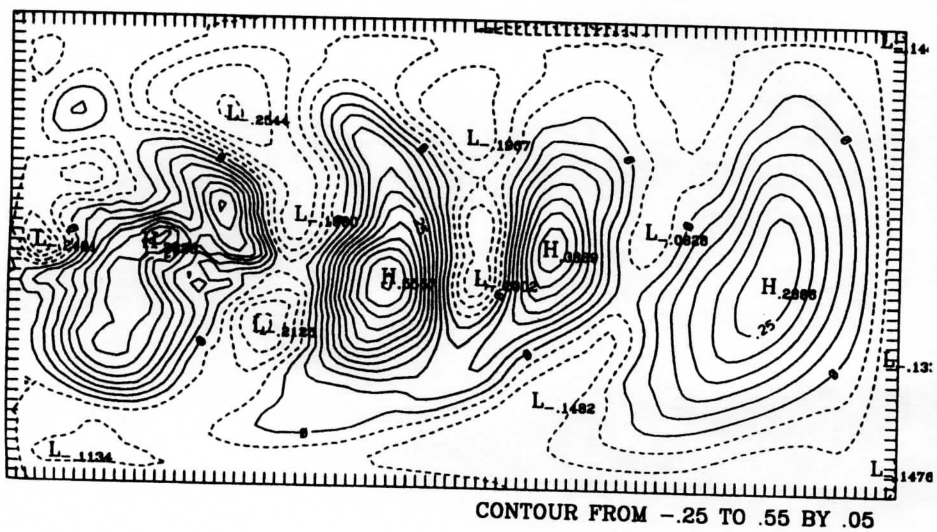


Mean surface pressure field for years 10-20, g/256.

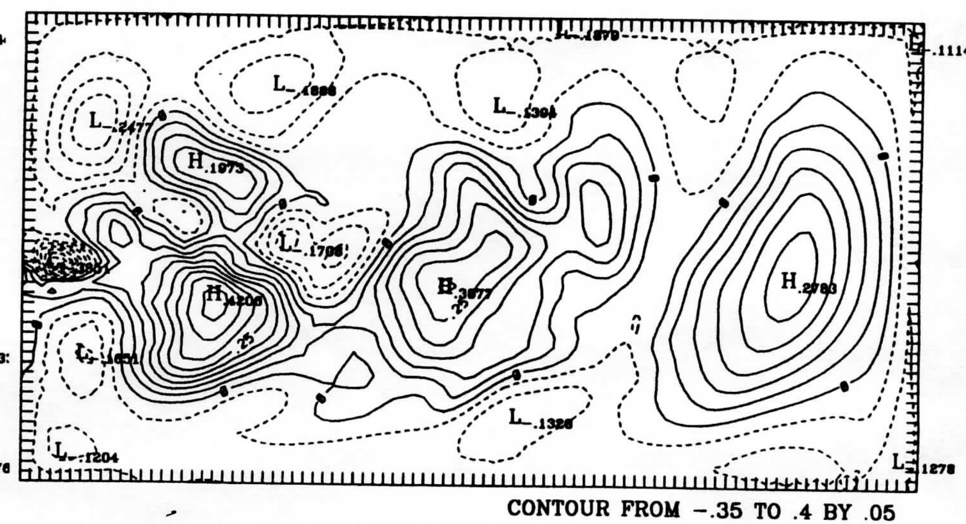
Figure 1. Steady State Ocean Response



Annual cycle for years 10-20, normal g.



Annual cycle for years 10-20, g/64.



Annual cycle for years 10-20, g/256.

Figure 2. Annual Cycle Ocean Response

Figure 3. Global Model Topography

Figure 4. Global Model Surface Pressure

and the IBM SP-2 computers and has proved to provide reliable performance with an efficiency significantly higher than traditional surface solver formulations such as those used in the GFDL MOM system. Since the completion of the original CHAMMP project the hydrostatic model has been coupled with the parallel CCM2 in a joint effort with Argonne National Lab and is being used in an ongoing study of the behavior of coupled ocean/atmosphere systems on century time scales.

The CHAMMP project has supported a PhD thesis by Michael Tobis who will complete his degree in summer 1995. His thesis is based on the evaluation of the ocean dynamics methods described above. Two papers describing these results are also in preparation. A second PhD student, Robert Jacob, was supported under the second year of this project. He is now continuing the work by studying the dynamics of the coupled atmosphere/ocean system as part of the new CHAMMP funded collaborative project with Argonne.