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COLORADO STATE UNIV FORT COLLINS DEPT OF MATHEMATICS
W H SCHUBERT ET AL. 08 FEB 84 N00014-83-K-0068

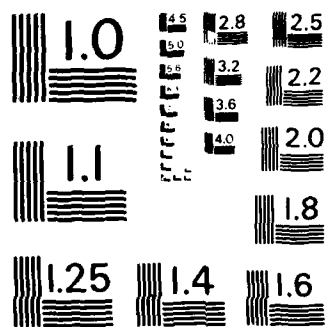
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Annual Report for
ONR Contract N00014-83-K-0068

February 8, 1984

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During the period December 1982 - November 1983 our efforts have been devoted to the study of spectral and multigrid methods.

The following three papers with abstracts describe our work on Chebyshev spectral methods for the marine boundary layer, on Fourier spectral methods for tropical cyclones, and on time differencing problems in Chebyshev spectral models.

1. Schubert, W. H., G. D. Taylor, S. R. Fulton and M. DeMaria, 1984:

A Chebyshev spectral method for boundary layer models. Archives for Meteorology, Geophysics and Bioclimatology, to appear.

Abstract

Boundary layers in the atmosphere and ocean often take on the structure of mixed layers bounded by narrow, highly stable regions. Simulation of the movement of such stable regions is a challenging task for the numerical modeler. Here we explore the use of Chebyshev spectral methods. We compare the results of spectral and finite difference methods for a simple one-dimensional test problem with known analytic solution. The results indicate the usefulness of the spectral method in obtaining accurate solutions to boundary layer problems.

2. DeMaria, M., and W. H. Schubert, 1984: Experiments with a spectral tropical cyclone model. J. Atmos. Sci., 41, to appear in March issue.



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ABSTRACT

The three-layer balanced axisymmetric tropical cyclone model presented by Ooyama (1969a) is generalized to three dimensions and the resultant primitive equations are solved using the spectral (Galerkin) method with Fourier basis functions on a doubly-periodic mid-latitude β -plane. The nonlinear terms are evaluated using the transform method where the necessary transforms are performed using FFT algorithms. The spectral equations are transformed so that the dependent variables represent the normal modes of the linearized equations. For the three-layer model the normal modes correspond to internal or external gravity or rotational modes or to inertial oscillations associated with the constant depth boundary layer. When the governing equations are written in terms of the normal modes, the linear terms can be evaluated exactly and the application of the nonlinear normal mode initialization scheme proposed by Machenhauer (1977) is straightforward.

The model is run with an axisymmetric initial condition on an f -plane and it is shown that many of the results presented by Ooyama (1969a) can be reproduced. The energy of the gravity modes and rotational modes are calculated for this simulation and it is shown that the gravity mode energy is more than an order of magnitude smaller than the rotational mode energy. The model is then run on the β -plane and it is shown that the variation of the Coriolis parameter with latitude causes the tropical cyclone to move towards the northwest at about 2 ms^{-1} , in agreement with several other authors. It is also shown that the dispersion of the rotational modes causes the tropical cyclone to elongate towards the west and develop sharper geopotential gradients towards the east. The model is also run with a basic state wind profile

and it is shown that the motion of the storm produces asymmetries in the boundary layer convergence field.

The effect of initialization procedures on a tropical cyclone simulation is also studied. The results from linear and nonlinear normal mode initialization procedures and results from applying an initialization procedure based on the nonlinear balance equation are compared. It is shown that the nonlinear normal mode initialization procedure results in much smaller track and intensity forecast errors, and prevents the excitation of spurious gravity waves.

3. Fulton, S. R., and G. D. Taylor, 1984: On the Gottlieb-Turkel time filter for Chebyshev spectral methods. J. Comp. Phys., in press.

ABSTRACT

Highly accurate solutions to hyperbolic boundary value problems may be obtained using Chebyshev spectral methods. However, with explicit time differencing the increased resolution of the Chebyshev series near the boundaries necessitates using very small time steps for stability, thus compromising efficiency. Recently, a method of time filtering has been proposed which is claimed to make explicit time integrations unconditionally stable so that time steps may be chosen by accuracy requirements alone. An analysis of this method shows that the filtering can in fact lead to absolute instability for any time step and that it does not relax the stability condition of the unfiltered method in a useful manner.

The following two papers with abstracts describe our work on multigrid methods for elliptic problems with both finite difference and spectral discretization.

4. Schubert, W. H., P. E. Ciesielski and J. J. Hack, 1983: Response of the tropical atmosphere to convective cloud clusters. Proceedings of the ECMWF Workshop on Convection in Large-scale Models.

ABSTRACT

How does the tropical atmosphere dynamically respond to the release of latent heat in clusters of convective clouds? This depends on several factors, including:

- the latitude of the convective cloud cluster,
- the horizontal scale of the cluster compared to the appropriately defined Rossby radius,
- the time scale of the cluster,
- the "static" and "inertial" stability of the flow in which the cluster is imbedded.

The first three factors have been studied theoretically using the linearized equations for a stratified fluid on an equatorial β -plane. The method of solution involves transforms in all three spatial coordinates -- a finite Sturm-Liouville transform in z , a Fourier transform in x and a generalized Hermite transform in y . The resulting spectral equations can then be solved analytically for a specified forcing. Of particular interest is the case of a Gaussian shaped heat source centered at latitude y_0 and with e-folding radius a . The heat source is transient and has time scale $1/\alpha$. Using the Parseval relation we compute how the

forced energy is partitioned between Kelvin, mixed-Rossby gravity, Rossby and gravity modes as a function of a , y_0 , α . Model results using a heat source centered at 11°S with an e-folding radius of 750 km and a time scale of about a day indicate that many aspects of the summertime upper tropospheric circulation over South America can be explained by the dispersive properties of Rossby and mixed Rossby-gravity waves. These results also show that the transient heat source excites Kelvin waves which propagate rapidly eastward as a nondispersive wave group. The existence of the Kelvin waves has implications for the initialization of tropical forecast models. By applying a nonlinear normal mode initialization procedure in the middle of a model simulation we investigate how the initialization distorts the subsequent evolution. Much of the distortion is associated with the Kelvin wave response.

The last factor mentioned above is more difficult to study but apparently plays a crucial role in hurricane development. It can be studied in a simple context by using the Eliassen balanced vortex model, which is based on hydrostatic and gradient balance and on the conservation of absolute angular momentum $f \frac{R^2}{2} = rv + f \frac{r^2}{2}$. Using the "potential radius" R as an independent variable and the actual radius r as a dependent variable, and introducing transformed components (u^*, w^*) of the transverse circulation we obtain the curved flow analogues of the semi-geostrophic equations. These equations differ from the original ones in the following respects: (1) the radial coordinate is R which results in a stretching of positive relative vorticity regions and a shrinking of negative relative vorticity regions; (2) the thermodynamic equation contains only the transverse circulation component w^* , the

coefficient of which is the potential vorticity q ; (3) the equation for r contains only the transverse circulation component u^* ; (4) the transverse circulation equation contains only two vortex structure functions, the potential vorticity q and the inertial stability s , where $\rho q = \frac{\zeta}{f} \frac{g}{\theta_0} \frac{\partial \theta}{\partial Z}$ and $\rho s = f^2 \frac{R^4}{r^4}$. The form of the transverse circulation equation leads naturally to a generalized Rossby radius proportional to $(\frac{q}{s})^{1/2}$. The fundamental dynamical role of $(\frac{q}{s})^{1/2}$ can be illustrated with simple analytical examples. These lead one to the somewhat surprising conclusion that hurricane development can occur while the net release of latent heat remains approximately fixed, the transverse circulation weakens, and the tangential wind and horizontal temperature gradient increase more and more rapidly.

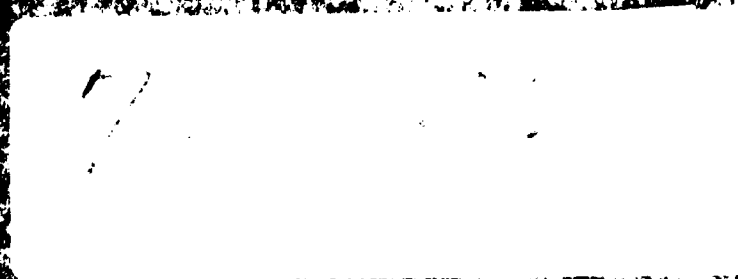
5. Brandt, A., S. R. Fulton and G. D. Taylor, 1984: Improved spectral multigrid methods for periodic elliptic problems. Submitted to J. Comp. Phys.

ABSTRACT

The spectral multigrid method for periodic elliptic problems is examined. Several modifications are introduced, including a new pseudospectral discretization which eliminates the need for filtering the highest Fourier mode and new relaxation schemes for isotropic and anisotropic problems. Numerical results are presented demonstrating substantial increases in efficiency and accuracy over previous methods.

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