

cal geometry. The shallow water equations exhibit the major difficulties associated with the horizontal dynamical aspects of atmospheric modeling on the spherical earth. These cases are designed for use in the evaluation of numerical methods proposed for climate modeling and to identify the potential trade-offs which must always be made in numerical modeling. Before a proposed scheme is applied to a full baroclinic atmospheric model it must perform well on these problems in comparison with other currently accepted numerical methods. The cases are presented in order of complexity. They consist of advection across the poles, steady state geostrophically balanced flow of both global and local scales, forced nonlinear advection of an isolated low, zonal flow impinging on an isolated mountain, Rossby-Haurwitz waves, and observed atmospheric states. One of the cases is also identified as a computer performance/algorithm efficiency benchmark for assessing the performance of algorithms adapted to massively parallel computers.

A SUBCELL RESOLUTION METHOD FOR VISCOUS SYSTEMS OF CONSERVATION LAWS. Eduard Harabetian. *Department of Mathematics, University of Michigan, Ann Arbor, Michigan 48109.*

We consider the generalization of scalar subcell resolution schemes to systems of viscous conservation laws. For this purpose we use a weakly nonlinear geometrical optics approximation for parabolic perturbations of hyperbolic conservation laws and the Roe type field by field decomposition. Computations of the reactive Navier-Stokes equations are presented as an application.

AN ALGORITHM FOR DECONVOLUTION BY THE MAXIMUM ENTROPY METHOD WITH ASTRONOMICAL APPLICATIONS. Johann Reiter. *Mathematisches Institut der Technischen Universität München, Arcisstraße 21, D-8000 München 2, Germany.*

The solution of a Fredholm integral equation of the first kind, which is, in general, an ill-posed problem, can be regularized by the maximum entropy method (MEM). With this method the solution is reformulated as a nonlinear optimization problem with one or two nonlinear constraints. In real life applications, however, this optimization problem is a large-scale one with up to 10^6 unknowns to be determined. For the solution of such problems we present a numerical algorithm which is made to work most efficiently on modern multiprocessor, vector computers. The usefulness of the algorithm is illustrated by deconvolving optical pictures of the sky taken with astronomical telescopes.

EXTRACTION OF ACCURATE FREQUENCIES FROM THE FAST-FOURIER-TRANSFORM SPECTRA. Kazuo Takatsuka. *Department of Chemistry, College of General Education, Nagoya University, Nagoya 464-01, Japan.*

The Fast Fourier Transformation (FFT) is well-known to be extremely fast and useful. However, its spectrum is quite often not accurate, because it is a discrete transformation and, further, the effect of finite range of sampling, the so-called Gibbs phenomenon, produces long tails. Here a very simple and efficient method to extract the accurate frequencies and the amplitudes of discrete spectra from FFT data is proposed. No window function is used in the present method. Indeed, our numerical examples show that the resultant frequencies and amplitudes are extremely accurate.

A SPECTRAL METHOD FOR THE NUMERICAL SOLUTIONS OF A KINETIC EQUATION DESCRIBING THE DISPERSION OF SMALL PARTICLES IN A TURBULENT FLOW. Tao Tang and S. McKee. *Department of Mathematics, University of Strathclyde, Glasgow G1 1XH, Scotland; M. W. Reeks. Nuclear Electric plc., Berkeley Nuclear Laboratories, Berkeley, Gloucestershire GL13 9PB, England.*

In this paper we consider numerical solutions to a kinetic equation for the dispersion of small particles in a turbulent flow. The solution represents the probability density that a particle has a certain velocity and position at a given time. These solutions are based on a mixed finite-difference-spectral method. Computational results are presented.

AN ALGORITHM FOR TRACKING FLUID PARTICLES IN A SPECTRAL SIMULATION OF TURBULENT CHANNEL FLOW. K. Kontomaris and T. J. Hanratty. *Department of Chemical Engineering, University of Illinois, Urbana, Illinois 61801; J. B. McLaughlin. Department of Chemical Engineering, Clarkson University, Potsdam, New York 13676.*

The ability to follow individual fluid particles dispersing in a turbulent flow and to collect turbulence information along their trajectories is of key importance in many problems of practical and theoretical significance. With the availability of a direct numerical simulation of turbulence such information can be extracted directly from first principles without resorting to questionable assumptions. In this paper an algorithm for tracking fluid particles in a direct numerical simulation of turbulent channel flow is developed and tested. Fluid particle velocities are computed with an interpolation scheme that employs Lagrange polynomials of order 6 in the homogeneous directions of the channel and Chebyshev polynomials in the inhomogeneous normal direction. Errors in computed particle velocities and trajectories are assessed and it is shown that accurate single-particle Lagrangian statistics can be extracted both in the center and in the wall region of the channel.

A FAST ALGORITHM FOR CHEBYSHEV, FOURIER, AND SINC INTERPOLATION ONTO AN IRREGULAR GRID. John P. Boyd. *Department of Atmospheric, Oceanic & Space Sciences, and Laboratory for Scientific Computation, University of Michigan, 2455 Hayward Avenue, Ann Arbor, Michigan 48109.*

A Chebyshev or Fourier series may be evaluated on the standard collocation grid by the fast Fourier transform (FFT). Unfortunately, the FFT does not apply when one needs to sum a spectral series at N points which are spaced *irregularly*. The cost becomes $O(N^2)$ operations instead of the FFT's $O(N \log N)$. This sort of "off-grid" interpolation is needed by codes which dynamically readjust the grid every few time steps to resolve a shock wave or other narrow features. It is even more crucial to semi-Lagrangian spectral algorithms for solving convection-diffusion and Navier-Stokes problems because off-grid interpolation must be performed several times per time step. In this work, we describe an alternative algorithm. The first step is to pad the set of spectral coefficients $\{a_n\}$ with zeros and then take an FFT of length $3N$ to interpolate the Chebyshev series to a very fine grid. The second step is to apply either the M th order Euler sum acceleration or $(2M+1)$ -point Lagrangian interpolation to approximate the sum of the series on the irregular grid. We show that both methods yield full precision with $M \ll N$, allowing an order of magnitude reduction in cost with no loss of accuracy.

GLOBAL OPTIMIZATION METHODS FOR HIGHLY MULTIMODAL INVERSE PROBLEMS. John A. Scales, Martin L. Smith, and Terri L. Fischer. *Amoco Research Center, P.O. Box 3385, Tulsa, Oklahoma 74102.*

Global optimization methods such as simulated annealing and genetic algorithms are potentially useful in attacking the multimodal search calculations which arise in a number of geophysical inverse problems. In the one-dimensional waveform inversion problem considered here the optimization method must find a one-dimensional earth structure which produces a seismogram that agrees with an observed seismogram. Both

simulated annealing and genetic algorithms provide satisfactory performance when the earth structure has only 15 free parameters. As this number is increased to 22, and then, 30 parameters both techniques become more costly. Genetic algorithms, however, still yielded accurate solutions for problems with 30 free parameters, a point at which simulated annealing was only marginally useful. The superior performance of genetic algorithms may reflect the non-proximate search methods used by them or, possibly, the more complex and capacious memory available to a genetic algorithm for storing its accumulated experience.

ADAPTIVE REMESHING FOR THREE-DIMENSIONAL COMPRESSIBLE FLOW COMPUTATIONS. J. Peraire and J. Peiró. *Department of Aeronautics, Imperial College of Science, Technology and Medicine, Prince Consort Road, London SW7 2BY, United Kingdom*; K. Morgan. *Department of Civil Engineering, University College, Swansea SA2 8PP, United Kingdom.*

An adaptive mesh procedure for computing steady state solutions of the compressible Euler equations in three dimensions is presented. The method is an extension of previous work in two dimensions. The approach requires the coupling of a surface triangulator, an automatic tetrahedral mesh generator, a finite element flow solver, and an error estimation procedure. An example involving flow at high Mach number is included to demonstrate the numerical performance of the proposed approach. The example shows that the use of this form of adaptivity in three dimensions offers the potential of even greater computational savings than those attained in the corresponding two-dimensional implementation.

A CELL-CENTERED LAGRANGIAN-MESH DIFFUSION DIFFERENCING SCHEME. J. E. Morel, J. E. Dendy, Jr., Michael L. Hall, and Stephen W. White. *University of California, Los Alamos National Laboratory, Los Alamos, New Mexico.*

A new cell-centered diffusion differencing scheme for the quadrilateral meshes associated with Lagrangian hydrodynamics codes is described. Computational comparisons of this scheme and existing schemes are given. It is shown that the new scheme is much more accurate than existing schemes when the mesh is significantly skewed. The new scheme is also more costly because there are special cell-edge unknowns in addition to the standard cell-center unknowns, and the associated diffusion matrix is asymmetric. The disadvantages of an asymmetric diffusion matrix are mitigated by a multigrid solution technique that is quite effective.

COMPUTATIONAL IMPLEMENTATION OF A COUPLED PLASMA-NEUTRAL FLUID MODEL. E. L. Vold, F. Najmabadi, and R. W. Conn. *Institute of Plasma and Fusion Research, Department of Mechanical, Aerospace, and Nuclear Engineering, University of California, Los Angeles, Los Angeles, California 90024-1597.*

This paper describes the computational transport of coupled plasma-neutral fluids in the edge region of a toroidally symmetric magnetic confinement device, with applications to the tokamak. The model couples neutral density in a diffusion approximation with a set of transport equations for the plasma density including classical plasma parallel velocity, anomalous cross-field velocity, and ion and electron temperature equations. The plasma potential, gradient electric fields, drift velocity, and

net poloidal velocity are computed as dependent quantities under the assumption of ambipolarity. The implementation is flexible to permit extension in the future to a fully coupled set of non-ambipolar momentum equations. The computational method incorporates sonic flow and particle recycling of ions and neutrals at the vessel boundary. A numerically generated orthogonal grid conforms to the poloidal magnetic flux surfaces. Power law differencing based on the SIMPLE relaxation method is modified to accommodate the compressible reactive plasma flow with a "semi-implicit" diffusion method. Residual corrections are applied to obtain a valid convergence to the steady state solution. Results are presented for a representative divertor tokamak in a high recycling regime, showing strongly peaked neutral and plasma densities near the divertor target. Solutions show large poloidal and radial gradients in the plasma density, potential, and temperatures. These findings may help one to understand the strong turbulence experimentally observed in the plasma edge region of the tokamak.

A CHEBYSHEV COLLOCATION ALGORITHM FOR 2-D NON-BOUSSINESQ CONVECTION. P. Le Quéré, R. Masson, and P. Perrot. *LIMSI-CNRS, BP 133, 91403 Orsay Cedex, France.*

A Chebyshev collocation algorithm is developed to integrate the time-dependent Navier-Stokes equations for natural convection flow with large temperature differences. The working fluid is assumed to be a perfect gas and its thermophysical properties vary with temperature according to Sutherland laws. The governing equations do not allow for acoustic waves. The Generalized Helmholtz and Uzawa operators which arise from time discretization are solved iteratively and the performances of several types of preconditioners and iterative schemes are examined. The algorithm is validated by computing almost Boussinesq flows and by comparing with previous results obtained with a finite difference algorithm. We investigate the effects of the temperature difference and of total mass contained within the cavity on the transition to unsteadiness in a cavity of aspect ratio 8. It is shown that these parameters have indeed a significant effect on the value of Rayleigh number at which unsteadiness is triggered. We also discuss the nature of the time-periodic solution which is obtained for Ra values slightly supercritical.

A PRIMITIVE VARIABLE METHOD FOR THE SOLUTION OF THREE-DIMENSIONAL INCOMPRESSIBLE VISCOUS FLOWS. F. Sotiropoulos and S. Abdallah. *Department of Aerospace Engineering and Engineering Mechanics, University of Cincinnati, Cincinnati, Ohio 45221.*

In this paper we present a new primitive variable method for the solution of the three-dimensional, incompressible, Reynolds averaged Navier-Stokes equations in generalized curvilinear coordinates. The governing equations are discretized on a non-staggered grid and the discrete continuity equation is replaced by a discrete pressure-Poisson equation. The discrete pressure equation is designed in such a way that: (i) the compatibility condition for the Poisson-Neumann problem is automatically satisfied, and (ii) the discrete incompressibility constraint is satisfied to, at least, truncation error accuracy while the computed pressure is smooth. The momentum equations are integrated in time using the four stage Runge-Kutta algorithm while the pressure equation is solved using the point successive relaxation technique. The method is applied to calculate the turbulent flow field over a ship model. The computed results are in very good agreement with the experimental data.