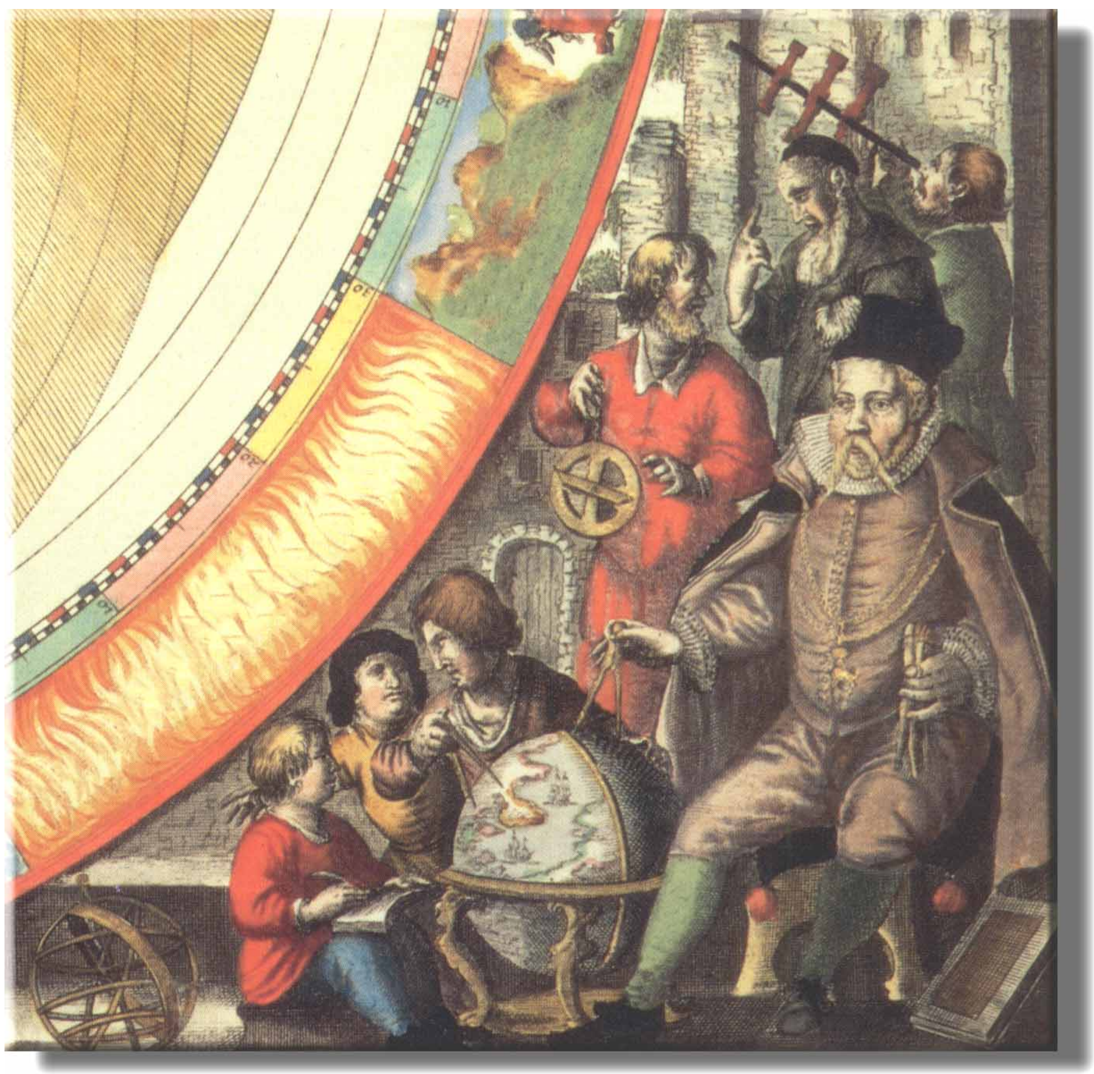
2001 Workshop on the Solution of Partial Differential Equations on the Sphere

May 15-18 2001

Montréal, Québec, Canada



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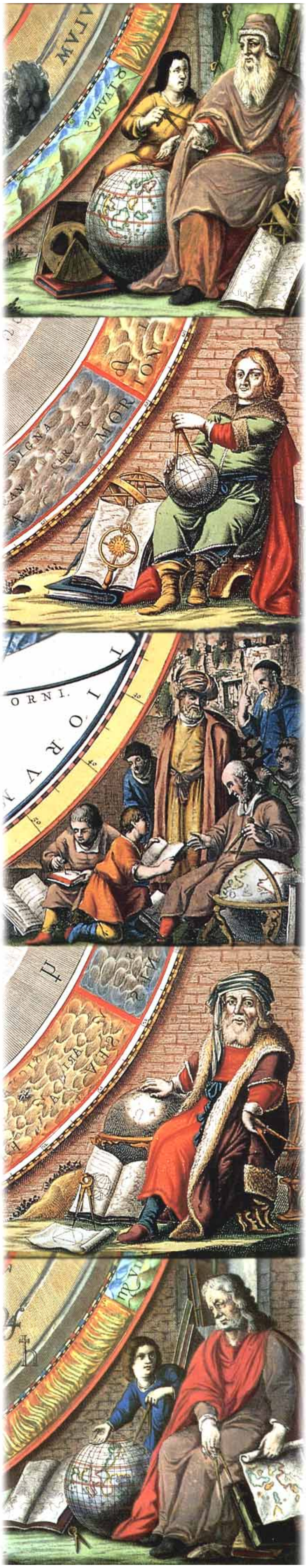


Program

Tuesday May 15th 2001

08:30-09:00	REGISTRATION	
09:00-09:15	WELCOME	
09:15-09:45	Dukowicz	Efficient Discretization of Consistent Friction Operators on a B-Grid in General Orthogonal Coordinates on a Sphere
09:45-10:15	Yeh	Finite-volume dynamics with variable resolution
10:15-10:45	BREAK	
10:45-11:15	Berbery	Impact of regional resolution in stretched-grid GCM simulations of the North American Monsoon mesoscale circulations
11:15-11:45	Fox-Rabinovitz	Regional climate experiments with stretched-grid GCMs
11:45-13:45	LUNCH	
13:45-14:15	Bénard	Study of the robustness of partially implicit temporal schemes in the Euler system
14:15-14:45	Côté	The Global Environmental Multiscale (GEM) Model: recent and future developments
14:45-15:15	Smolarkiewicz	Mesh Adaptivity for Nonhydrostatic Global Models
15:15-15:45	BREAK	
15:45-16:15	Heinze	An Adaptive Mesh Generator on the Sphere for the FEM-Solution of the Shallow Water Equations
16:15-16:45	Fournier	Shallow-water flow with the adaptive multiwavelet/spectral-element method
16:45-17:15	Grabowski	A global cloud model
18:00	NO HOST ICE BREAKER	

Wednesday May 16th 2001

08:45-09:30	Loft	Parallel Spectral Element Atmospheric Dynamical Core Part I: Formulation and Implementation
	Fournier	Parallel Spectral Element Atmospheric Dynamical Core Part II: Standard Test Cases
09:30-10:00	Hortal	A finite-element scheme for the vertical integrations in the semi-Lagrangian version of the ECMWF forecast model
10:00-10:30	BREAK	
10:30-11:00	Temperton	Use of the tangent-linear and adjoint of the semi-Lagrangian dynamics in the ECMWF global spectral model
11:00-11:30	Juang	Implementing a reduced Gaussian grid to NCEP seasonal forecast model
11:30-12:00	Spotz	Performance of the Eulerian Double Fourier Atmosphere Model
12:00-14:00	LUNCH	
14:00-14:30	Tomita	A modified icosahedral grid by using spring dynamics
14:30-15:00	Pudykiewicz	A class of finite difference approximations for conservation laws on icosahedral grids
15:00-15:30	Ringler	A Potential Enstrophy and Energy Conserving Numerical Scheme Suitable for Geodesic Grids
15:30-16:00	BREAK	
16:00-16:30	Majewski	The Global Icosahedral-Hexagonal Gridpoint Model GME of the DWD - Operational Version and Very High Resolution Tests
16:30-17:00	Heikes	Towards a Parallel CSU GCM

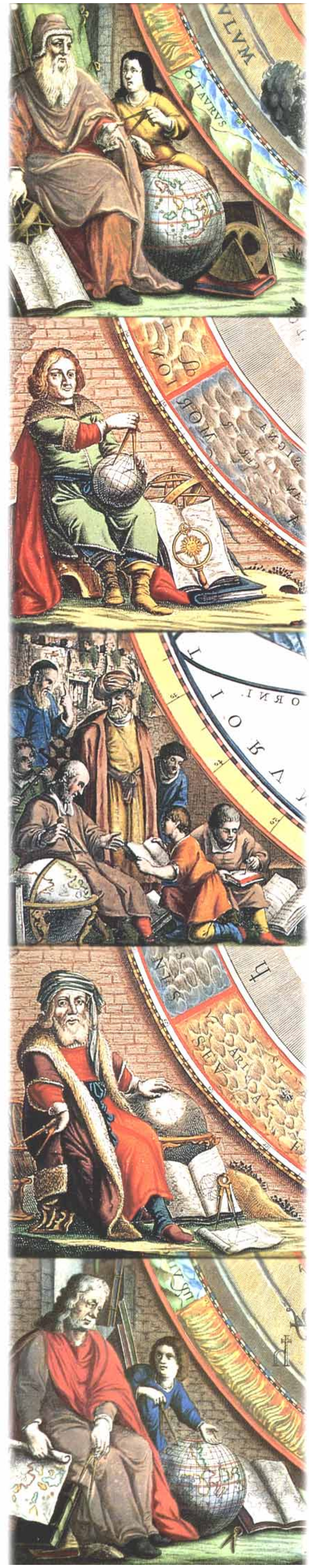
Thursday May 17th 2001

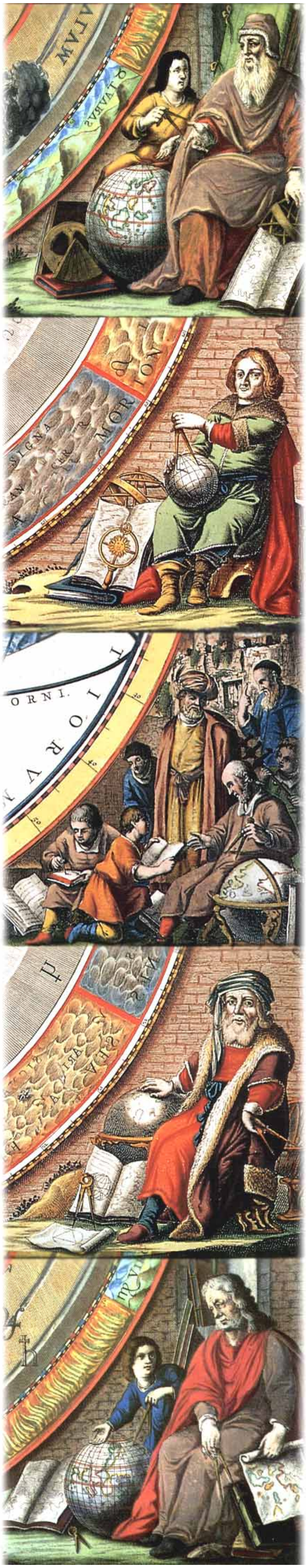
08:45-09:30	Giraldo	A Spectral Element Dynamical Core in Cartesian Coordinates A Discontinuous Galerkin Shallow Water Model on the Sphere
09:30-10:00	Rancic	A Global Version of the NCEP ETA Model on a Cubic Grid
10:00-10:30	BREAK	
10:30-11:00	Rossmanith	A wave propagation method for the solution of PDEs on the surface of a sphere
11:00-11:30	Adcroft	Global Coupled Modeling on the Expanded Spherical Cube
11:30-12:00	Yau	Testing of mass conserving semi-Lagrangian schemes in a vertical updraft
12:00-14:00	LUNCH	
14:00-14:30	Rasch	Mass/Wind consistency requirements for tracer transport on the sphere
14:30-15:00	Layton	An Optimal Quadratic Spline Collocation Method for the Spatial Discretization of the Shallow Water Equations on a Sphere
15:00-15:30	Spotz	Formulation of the Semi-Lagrange Double Fourier Atmosphere Model
15:30-16:00	BREAK	
16:00-16:30	Yoon	Numerical simulation of shallow water equations using CIP method with high order spatial resolution
16:30-17:00	Lanser	Time Integration of Prototype Atmospheric Circulation Models in Spherical Geometry
19:00	BANQUET	

Friday May 18th 2001

08:45-09:15	van Leer	PDEs on the Sphere and in the Classroom: Auroral Heating of Jupiter's Atmosphere
09:15-09:45	Davies	Idealised 3d global tests: Comparing pressure-based and height-based models
09:45-10:15	Jablonowski	Towards a standardized test suite for dynamical core intercomparisons: Growing baroclinic waves
10:15-10:45	BREAK	
10:45-11:15	Zerroukat	Idealised models for testing and development of NWP dynamical cores
11:15-11:45	Williamson	Aqua-planet as a test for dynamical cores

End of workshop





Abstracts

Global Coupled Modeling on the Expanded Spherical Cube

Alistair Adcroft[1], John Marshall[2] and Chris Hill[2]
[1]Massachusetts Institute of Technology, [2]MIT

Grid point models built on standard latitude-longitude grids must deal with stringent stability criteria arising from the convergence of meridians at the poles. Gridding the sphere using a conformal mapping (Rancic et al., 1996) provides relatively uniform resolution and overcomes many of the shortcomings of the standard grids. We have taken this grid and re-scaled the coordinates to further improve the uniformity of spatial resolution whilst keeping the grid locally orthogonal.

The expanded cubic grid introduces eight singularities. We discuss how to deal with them in a robust way; adhering to the finite volume paradigm employed in discretizing our model, the weak formulation unambiguously defines quantities at singularities. Careful consideration of the order of discrete operations avoids degeneracy of variables at the singularities. The model can be integrated forward without any spurious problems arising from these singularities or the cubic grid in general.

We describe the implementation of the MIT Isomorphic Dynamical Kernel (Marshall et al, 1997) on the conformal expanded cube, and the subsequent use of this model for coupled global atmosphere-ocean calculations. We have been able to deploy the model on the cubic grid with relatively few and rather minor modifications to the original code which was originally developed on a regular latitude-longitude grid.

Avoiding the extreme stability criteria of the latitude-longitude grid allows the model to take a longer time-step than previously and use less memory at an equivalent resolution, leading to overall improved efficiency. Using the same cubic grid for both the atmosphere and ocean greatly simplifies the coupling procedure and allows for simple and exact conservation of properties including energy.

Impact of regional resolution in stretched-grid GCM simulations of the North American Monsoon mesoscale circulations

Ernesto Hugo Berbery[1] and Michael Fox-Rabinovitz[2]
[1]University of Maryland, [2]ESSIC/Department of Meteorology, University of Maryland

Numerical experiments with a variable resolution general circulation model (GCM) are analyzed to determine an adequate and efficient regional resolution to resolve the meteorologically important mesoscale features of the circulations associated with the North American monsoon. The GEOS (Goddard Earth Observing System) stretched-grid (SG) GCM with enhanced resolution over the U.S. was run with two SG-configurations. The SG-configurations are produced by an SG-generator using different regional and global resolutions. The first configuration is obtained by redistribution of the grid points originally at a global uniform 2x2.5 degree grid, while the second one redistributes a 1x1 degree grid. The stretched grids have approximately 60 km and 40 km uniform resolution over the U.S., and immediate vicinity, for the model dynamics and orography, while physics is resolved at a 2x2.5 and 1x1 degree uniform global resolutions, respectively. Along with higher regional resolution, the 40km/1x1 grid has better resolved the land-sea differences.

The SG-GCM is run in a special integration mode imitating the nested-grid approach. The mode provides the usual SG-GCM simulation inside an area of interest whereas outside the SG-DAS (data assimilation system) analyses are produced. The mode is designed for

consistent comparisons within WMO/WGNE PIRCS (Project to Intercompare Regional Climate Simulations).

It has been shown that mesoscale components (not simulated by typical global models) are critical to resolve the monsoonal circulations over North America. Here, four subregions were identified; they are the core monsoon region in Northwestern Mexico, the Arizona monsoon, the southern Great Plains and the northern Great Plains. The evolution of precipitation during the 1993 warm season for each region was analyzed and compared to high resolution rain gauge observations. The onset of precipitation over Arizona occurred about one month after the onset at the core monsoon region, although this may vary from season to season. The simulation also reproduces the decay of precipitation over the southern Great Plains that has been linked to the onset of the monsoon; over the northern Great Plains, where historical flood records were broken, heavy precipitation was also reproduced, both in intensity and frequency.

Results also indicate that the two configurations adequately represent the main components of the monsoon and its onset, but the 40 km/1x1 version also resolves the low-level jet over the Gulf of California that develops in conjunction with the onset of precipitation over Arizona. On the other hand, this jet was not captured by the 60 km/2x2.5 version. We conclude that the dynamical forcing (including orography) and the physical forcing (including land-sea differences) need to be adequately resolved to reproduce the mesoscale structure of the monsoon. Finally, we find that 40 km/1x1 or finer resolutions are needed for efficient representation of mesoscales in SG-GCM simulations.

Study of the robustness of partially implicit temporal schemes in the Euler system

Pierre Bénard[1], Jozef Vivoda[2] and Petra Smolikova[3]
[1]Météo-France, [2]Slovak Hydrometeorological Institute (SHMI), [3]Department of Applied Mathematics, Charles University, Prague

The Euler Equations (EE) system is the compressible, approximation-free generalization of the widely used Primitive Equations (PE) system. This makes it an attractive candidate for future use in meso-scale operational weather prediction.

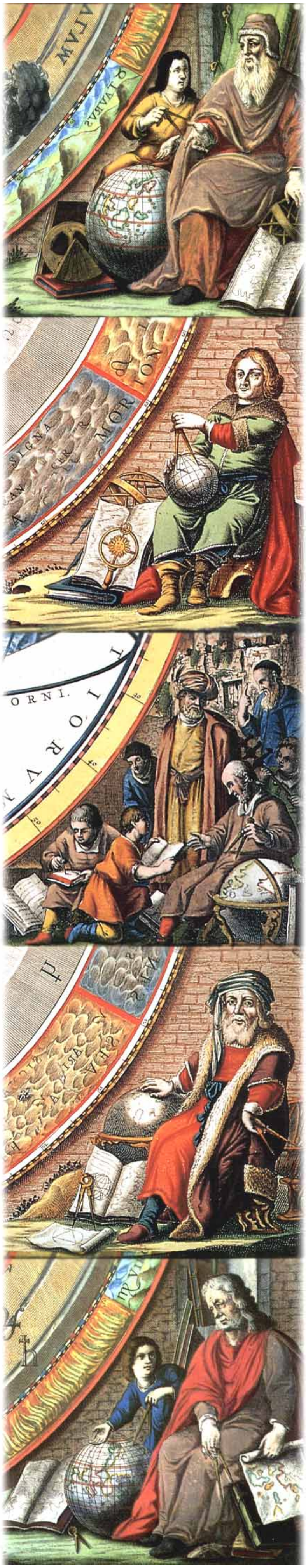
In this contribution, we will examine the stability of semi-implicit (SI) and so-called "trapezoidal" iterated-implicit temporal schemes for the EE system, in comparison to the simpler PE and Shallow Water (SW) systems.

As a necessary condition for robustness in more realistic contexts, the stability of these temporal schemes can first be assessed in simplified, analytically tractable frameworks. In addition to the choice of the vertical coordinate, the choice of the prognostic variables of the system will then be shown to have a large impact on the stability.

This appears to be a distinctive feature of the EE system: the stability for the SW and the PE systems were respectively unsensitive and very weakly sensitive to these choices. An important point to be noted is that these properties are totally independant of the choice of a space discretization since they pertain to the space-continuous context.

Hence these properties are actually general to the considered equation systems "per se", and not specific to a given numerical application. This leads to the idea that for designing a numerical model in the EE system, the choice of the variables should not be done independently of the choice of the temporal scheme.

The above-mentionned simplified framework provides a simple strategy for finding an optimal set of variables for the considered temporal scheme: the number of equations



involved with explicitely-treated non-linear residual terms has to be minimized, since the source of instability lies in these terms.

Of course, the stability of a given model-design in idealised frameworks is not a guarantee of robustness when concrete application to real cases has to be considered.

Hence, in the second part of the presentation, the sensitivity of SI and iterated-implicit schemes robustness to the choice of the prognostic variables will be explored in a numerical implementation of the EE system (namely the NH version of the cooperative Aladin limited-area model), for frameworks with increasing realism:

(i) in a 1D linear (horizontally spectral and monochromatic) version of the discretized model.
(ii) in a 2D non-linear (vertical plane) version. The latter context allows to satisfactorily simulate the conditions of practical NWP, including complex terrain, and non-linear flows.

This study is indirectly linked with the problem of spherical geometry or global modelling through the following remark: if a proper choice of variables allows the target temporal schemes to be robust for EE with a simple and "universal" warm iso-thermal reference-state (as it was the case for PE), then the integration of the EE system on the whole globe will become possible with the same very efficient time-schemes as currently used operationally for PE models (e.g. leap-frog semi-Lagrangian SI, or 2 time-levels semi-Lagrangian iterated-implicit with very few iterations).

The Global Environmental Multiscale (GEM) Model: recent and future developments

Jean Côté[1], Michel Desgagné[2], Sandrine Édouard[2], Abdessamad Qaddouri[2], André Plante[3], Claude Girard[2] and Monique Tanguay[2]
[1]RPN-MRB-MSC, [2]RPN, [3]CMC

The Global Environmental Multiscale (GEM) model has been developed at RPN/CMC for operational weather forecasting, data assimilation, and air quality applications. This model is a non-hydrostatic atmospheric model using an implicit two-time level semi-Lagrangian time marching scheme. All operational deterministic numerical forecasts are currently performed with GEM at the Canadian Meteorological Center (CMC). The paper will present some results and an overview of the current research and development around the GEM model at RPN.

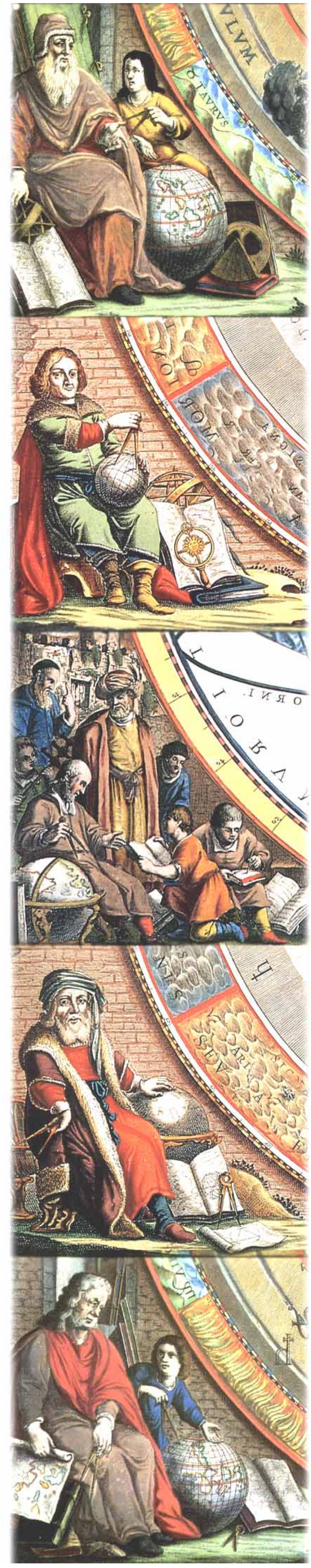
We are currently completing the parallelization of the model in a distributed memory environment with explicit message passing using the Message Passing Interface (MPI). Pre-operational trials should begin soon. The Tangent-linear and Adjoint models have also been recoded with MPI.
Development of the limited area version of GEM, called LEM is also progressing. This version of the code will include all combinations of global/limited-area, uniform-/variable-resolution and hydrostatic/non-hydrostatic.

A doubling of the efficiency of the variable-resolution solver has been achieved by exploiting the mirror symmetry of the mesh. Iterative solvers are also being investigated.

An implicit high-order horizontal diffusion module has also been developed and optimized. This allows the preservation of good spectral properties of the forecast fields. A study has been initiated to try to develop a sponge layer formulation with a direct control of the gravity wave component of the flow.

The development of a hybrid vertical coordinate where vertical coordinate surfaces tend to pressure surfaces more rapidly than with the Phillips vertical coordinate is completed. This leads to notable improvements in verification scores.

We have also investigated the comparative behavior of the current unstaggered vertical structure of GEM with the Charney-Phillips staggering. This study is performed using a 1D test bed. For the linearized equations, there seems to a small advantage to the staggered formulation.



Idealised 3d global tests: Comparing pressure-based and height-based models

Terry Davies[1]
[1]Met Office

The global dynamical core test proposed by Held and Suarez was cast in pressure-based sigma coordinates. Whereas alternative dynamical formulations in the same coordinates can be readily compared, comparisons between differing coordinate systems (e.g. height-based) need careful consideration. We consider such comparisons and also investigate other full 3d global idealised test problems suitable for benchmarking studies.

Efficient Discretization of Consistent Friction Operators on a B-Grid in General Orthogonal Coordinates on a Sphere

John Dukowicz[1] *and John Baumgardner*[1]
[1]Los Alamos National Laboratory

The use of arbitrary orthogonal horizontal coordinates on a sphere is becoming common for ocean models. We are concerned here with the implementation of horizontal friction operators of either the Laplacian or biharmonic type for such a grid. Consistent friction operators, which are ones derived from a dissipation functional based on deformation rates, thereby ensuring a negative-definite dissipation rate and absence of a checkerboard null-space, are quite costly and complicated to implement, particularly on a B-grid. In this paper we exploit the fact that these operators may be expressed in the form of local, time-invariant matrices which may be precalculated and stored. The application of these matrices resembles a finite element assembly process. This is particularly efficient on current superscalar processors, with the result that the computational performance of the present friction force algorithm ranges from 40% to 60% of the theoretical peak speed on such machines.

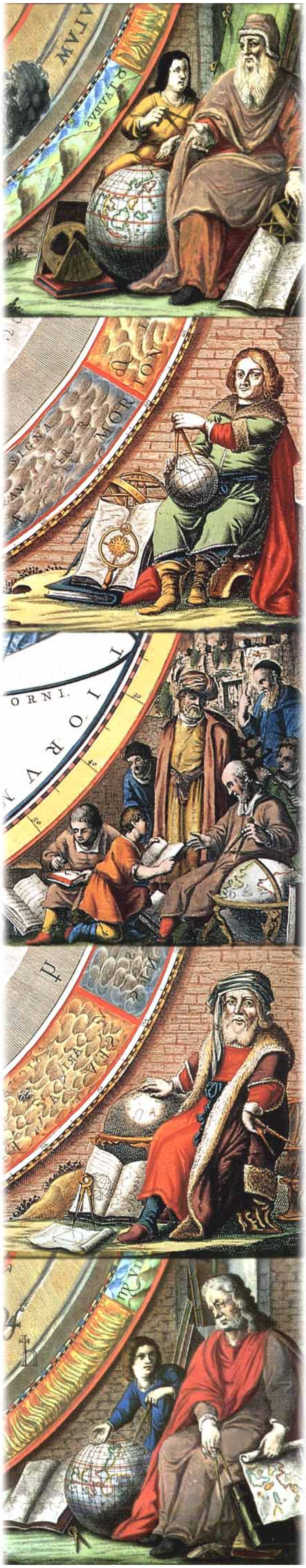
Parallel Spectral Element Atmospheric Dynamical Core Part II: Standard Test Cases

Aimé Fournier[1]*, Joe Tribbia*[2]*, Steve Thomas*[2] *and Rich Loft*[2]
[1]ESSIC, University of Maryland, [2]National Center for Atmospheric Research

The model described in the accompanying presentations is applied to the standard test cases of Williamson et al. (1992) and Held and Suarez (1994). At moderate climate resolutions, performance levels exceeding 100 GFLOPS have been achieved on large SMP clusters. Thus, climate-simulation rates on the order of 100 years per day appear to be within reach.

Shallow-water flow with the adaptive multiwavelet/spectral-element method

Aimé Fournier[1] *and Steve Thomas*[2]



[1]University of Maryland, [2]National Center for Atmospheric Research

The dynamics of the Earth's atmosphere clearly involve multiscale phenomena. Unfortunately, the current mathematical framework for modeling the atmosphere does not permit an easy consideration of scales and their mutual interactions. Moreover, no advantage of the problem's multiscale nature is taken, in order to reduce its computational cost. Therefore a new computational methodology has been introduced to address these issues, based on the spectral-element model described in the accompanying presentations.
The shallow-water equations (SWE) describe the dynamics of a thin incompressible atmospheric layer confined between a rigid bottom and a free surface. The SWE exhibit a rich range of dynamical behavior, due to various effects. In particular, free-surface effects represent the next level of complexity above the barotropic-vorticity-equation dynamics, that had already begun to be modeled using wavelets, e.g., by Farge, Kevlahan, Perrier and Schneider (1999). Wavelet-based methods are even more appropriate for SWE since the free-surface solution can form 2D ``shocks," as shown e.g., by Polvani, McWilliams, Spall and Ford (1994). Also, the simultaneous vorticity field is relatively smoother, except at the vortex edges, implying fewer coefficients for the flow. Thus generalizing the adaptive techniques of Alpert, Beylkin, Gines and Vozovoi (1999) to 2D should provide an efficient representation of such structures (and their interactions) using surface-height and flow coefficients only in the necessary regions. The present talk describes the derivation of an adaptive multiwavelet scheme from the spectral-element scheme, and includes some preliminary results.

Regional climate experiments with stretched-grid GCMs

Michael Fox-Rabinovitz[1]
[1]University of Maryland

A variable resolution GCM using a global stretched grid (SG) with fine resolution over the area(s) of interest, is a viable new approach to regional and subregional climate studies and applications. It is an alternative to the widely used nested grid approach introduced a decade ago as a pioneering step in regional climate modeling.

The SG-GCM based on the GEOS (Goddard Earth Observing System) GCM using a finite-difference approximation, has been developed and thoroughly tested during the last few years. Successful simulations have been performed with the SG-GCM for the U.S. summer anomalous regional climate events of 1988, 1993, and 1998. They have shown the feasibility of the SG-approach for regional climate modeling. The GEOS SG-DAS (Data Assimilation System) incorporating the SG-GCM has also been developed and tested. The assimilated regional fields and diagnostics are used for validating the SG-GCM regional simulations. For both the SG-GCM and SG-DAS the stretched grid design with multiple (four) areas of interest has been introduced. These areas include the major global monsoonal circulations: North American, South American, Indian, Asian, and Australian. Two new SG-GCMs are being developed as a collaborative effort. The first (in collaboration with K.Yeh) is the SG-version of the new NASA/NCAR FV-GCM (with the finite-volume (FV) dynamics), and the second (in collaboration with F.Baer, A.Fournier, J.Tribbia, and M.Taylor) is the SG-version of the new GCM with spectral-element dynamics. Both GCMs use the NCAR CCM4 physics. Using these advanced numerical techniques will provide increased computational efficiency for the new the SG-GCMs, and will allow us to employ more flexible stretching strategies beneficial for the efficient regional down-scaling. The major current developments are focused on studying the efficiency of regional down-scaling in long-term experiments on: simulating the 1997-1999 ENSO cycle and related monsoonal circulations; studying intraseasonal and interannual regional climate variability for the extended multiyear (1988-1998) AMIP-type SG-GCM simulations; and studying the impact of ensemble integrations.

A Discontinuous Galerkin Shallow Water Model on the Sphere

Francis Giraldo[1], Timothy Warburton[2] and Jan Hesthaven[2]
[1]Naval Research Laboratory, [2]Division of Applied Mathematics, Brown University

We present a discontinuous Galerkin shallow water model on the sphere. The equations are written in Cartesian coordinates using the Lagrange multiplier approach of Cote'. In the discontinuous Galerkin method (DGM) each element is completely independent from all the other elements. Thus, each element contains its own elemental approximation to the solution. The elements communicate with their neighbors by virtue of flux exchanges. In fact, the DGM method can be best described as the high order generalization of the finite volume method; however in the DGM the approximation inside each volume cell can be of any order imaginable instead of constant as is typically assumed in the FVM. In this talk we show that the DGM method gives similar results to the spectral element method while being much better suited for distributed memory architectures. We show results for the Williamson et al test case suite. In addition, we show results for test cases containing non-smooth solutions to highlight the power of this new method.

A Spectral Element Dynamical Core in Cartesian Coordinates

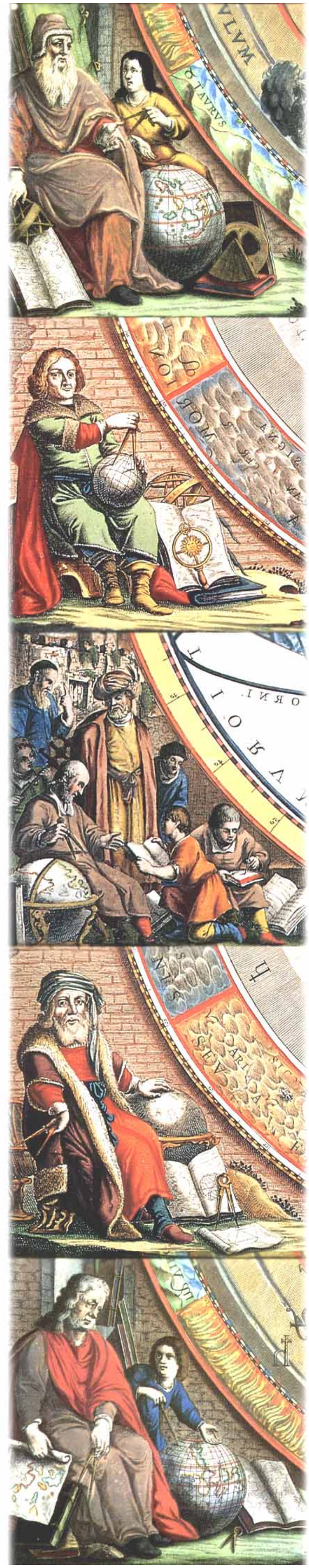
Francis Giraldo[1]
[1]Naval Research Laboratory

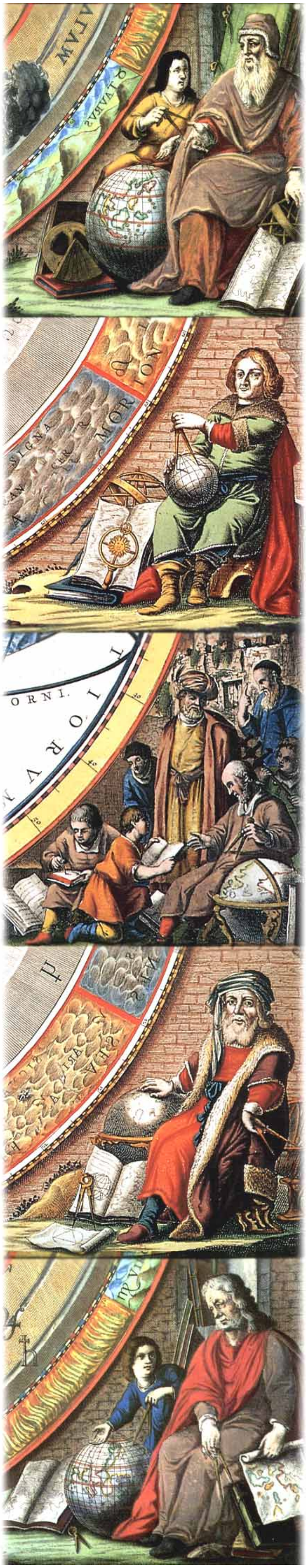
We report on the progress of a spectral element dynamical core. A spectral element shallow water model has been developed at the Naval Research Laboratory. This spectral element model is written completely in Cartesian coordinates using the Lagrange multiplier approach introduced by Cote'. The use of Cartesian coordinates allows for the flexibility of using any type of grid, including: icosahedral and hexahedral grids. This shallow water model has been extended to the 3D atmospheric equations using a similar vertical discretization used by the Navy's global atmospheric model (NOGAPS). In this talk we shall report on the idealized cases used to test the model dynamics. In addition, we report on the semi-implicit and semi-Lagrangian extensions of the model.

A global cloud model

Wojciech Grabowski[1] and Piotr Smolarkiewicz[2]
[1]NCAR/MMM, [2]NCAR

We present an all-scale (viz. global) cloud model. In technical terms, we extend on moist processes a nonoscillatory nonhydrostatic anelastic solver (Smolarkiewicz et al., 2001, JAS, 58, 349-354) suitable for modeling a broad range of atmospheric flows on scales from micro to planetary. Theoretical formulation of the moist precipitating thermodynamics follows the standard cloud models, i.e., the model evaluates the grid-scale formation of cloud condensate and subsequent development and fallout of the precipitation, in response to resolved motions of the moist air. In order to accommodate a broad range of temporal scales, we merge the explicit scheme for the thermodynamics with the implicit scheme for the dry dynamics, where the latter is essential for the efficacy of the global model. At high spatial resolutions, the new scheme is shown to yield computational results of the same quality as explicit techniques used in traditional small-scale models. At coarse spatial resolutions used in contemporary general circulation models, the posed problem becomes very stiff---a manifestation of the disparity between time scales of the fluid flow and much shorter time scales associated with phase-change processes and precipitation fallout. In order to overcome this difficulty, the moist-thermodynamics scheme is cast in the form of the method of averages (Nadiga et al., 1997, Theor. Comp. Fluid Dyn., 9, 281-291) where





fast processes are evaluated with adequately small time step (and lower accuracy) along flow trajectories to provide an accurate approximation to the large-time-step trajectory integral of the stiff system. Such an approach allows for stable integrations when cloud processes are poorly resolved, and it converges to the formulation standard in traditional cloud models as the resolution increases. The theoretical developments are illustrated with simulations of small-, meso-, and planetary-scale moist atmospheric flows. Results of small-scale simulations demonstrate that the approach reported compares favorably with traditional explicit techniques used in cloud models. Planetary simulations, on the other hand, illustrate the ability of the scheme to capture moist processes in low resolution large-scale moist precipitating flows.

TOWARDS A PARALLEL CSU GCM

Ross Heikes[1], Todd Ringler[1] and David Randall[1]
[1]Colorado State University

We are currently in the process of constructing a parallel version of the CSU AGCM. The model employs a geodesic grid to discretize the horizontal dimensions. We will discuss our approach to decompose the geodesic grid into subdomains. An important feature of our approach allows for the assignment of an arbitrary number of subdomains from arbitrary geographic locations to each process. This feature provides greater flexibility to fine-tune the parallel load balancing. The current version of the model predicts vorticity and divergence. Each timestep it is necessary to solve a set of elliptic equations to get a streamfunction and velocity potential. This is done with multigrid techniques. Since the multigrid methods requires substantial horizontal communication, we have spent considerable effort to efficiently code the elliptic solver. We will show the scalability of this code on various platforms. In addition, we have incorporated the CSU physics package into the dynamical core and have conducted full AGCM simulations. At present, we discretize the Earth's surface using the same geodesic grid as we use for the atmosphere, so the land-atmosphere and ocean-atmosphere coupling is simple. The scalability of the full AGCM will also be shown.

An Adaptive Mesh Generator on the Sphere for the FEM-Solution of the Shallow Water Equations

Thomas Heinze[1] and Jörn Behrens [1]
[1]Chair for Numerical Analysis and Scientific Computing, Munich University of Technology

The latest version of the adaptive mesh generator AMATOS that was developed for 2d-flows in atmosphere and ocean at the Alfred-Wegener-Institute in Bremerhaven is now available. With this release a triangular mesh on the sphere can be generated adaptively. We introduce a properly chosen formulation of the Shallow Water Equations on the sphere. With that we don't have to deal with singularities at the poles and the application to the finite element method on the sphere is straight forward.
One test cases of the NCAR-Shallow-Water-Test-Suite is presented and compared to another shallow water model that was developed at the Meteorological Institute of the University of Bonn. This model refines the sphere regularily. Both models use a semi-implicit two step semi-Lagrangian time step and the finite element techniques for calculating the PDEs.

A finite-element scheme for the vertical integrations in the semi-Lagrangian version of the ECMWF forecast model

Mariano Hortal[1] *and Agathe Untch*[1]
[1]ECMWF

The algorithm for the vertical integration of the continuity and the hydrostatic equations in the ECMWF model is currently based on the Lorentz grid and is only first order accurate in space, whereas the semi-Lagrangian scheme used for the advection is second order.

In this paper we describe a new non-staggered scheme for the vertical integration of the forecast equations, based on the Galerkin method using cubic B-splines both as basis and as test functions.

The results of forecast experiments show a reduction of the "vertical noise" seen in the operational version, mainly in the divergence field in the stratosphere, and the objective scores improve substantially in the lower stratosphere. The smallest eigenvalue of the linearized vertical eigenmodes increases by an order of magnitude compared to the eigenvalue of the finite-difference scheme with the Lorentz staggering, and approaches the value obtained with the Charney-Phillips staggering. This facilitates the inversion of potential vorticity without the draw-backs of the Charney-Phillips staggering found in connection with semi-Lagrangian models.

Results are also shown from analysis/forecast experiments in which the new scheme is used in both the forecast and the variational (4D) data assimilation.

Towards a standardized test suite for dynamical core intercomparisons: Growing baroclinic waves

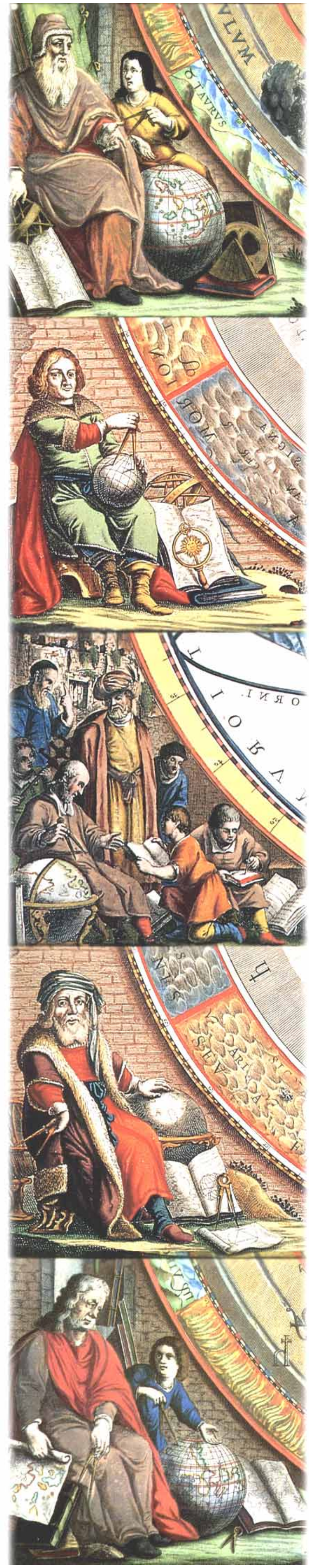
Christiane Jablonowski[1]
[1]University of Michigan

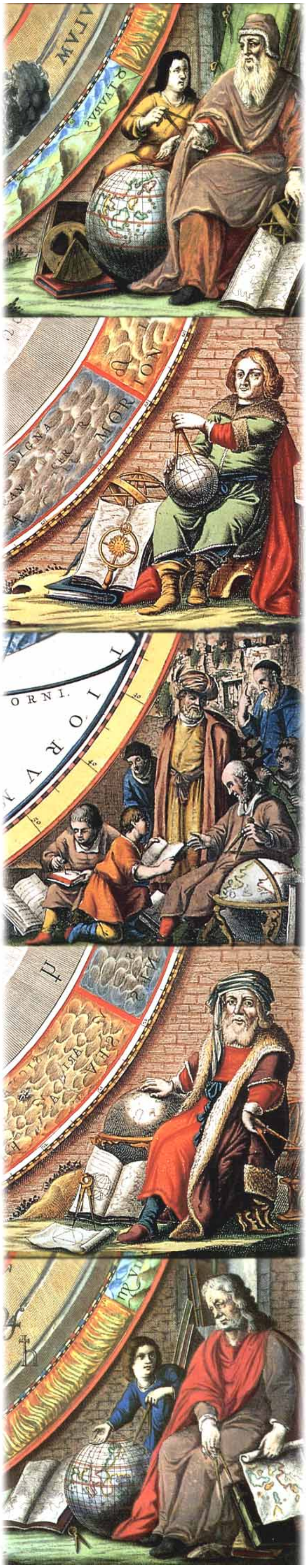
Tests of general circulation models and, in particular, dynamical core tests are an important step towards future model improvements. They reveal the influence of the individual model designs on climate and weather simulations and indicate how representative the circulation is described by different numerical approaches.

Meanwhile, recent efforts aim at establishing a standardized test suite for dynamical core intercomparisons. The deterministic test case presented here is based on this intercomparison idea.

The talk will introduce a newly developed, idealized test case for primitive-equation based dynamical cores. The test analyzes the evolution of baroclinic waves that are triggered by small perturbations within a dynamically balanced initial data field. This initialization represents a steady-state solution to the primitive equations. The initial conditions are specified entirely analytically. Therefore, the test can easily be applied not only to Gaussian or regular grids but also to irregular geodesic or cubic meshes.

In order to trigger the development of growing baroclinic waves, two perturbation patterns will be suggested that overlap the balanced initial conditions. First, the baroclinic wave evolution can be initiated when a single grid point perturbation is included. The resulting flow pattern shows baroclinic wave activity after 10-15 forecast days. In contrast, a wavenumber 8 perturbation can be added to the initial vorticity field that translates into a wavenumber 8 disturbance of the horizontal wind components. This perturbation favors the evolution of even more rapidly growing baroclinic waves.





The test has been applied to NCAR's newest model generation. In particular, the spectral Eulerian and semi-Lagrangian dynamics packages of CCM3.10 were tested and compared to NASA's Lin-Rood dynamical core. This finite-volume model has recently been developed by S.-J. Lin and R. Rood at the Goddard Space Flight Center (NASA/GSFC, Data Assimilation Office). It is based on the conservative and monotonic flux-form semi-Lagrangian advection algorithm.

Besides discussing the test case design, the talk will give an overview of the model results. This includes a convergence study and addresses horizontal diffusion aspects. In addition, suitable test case diagnostics will be proposed.

Implementing a reduced Gaussian grid to NCEP seasonal forecast model

Hann-Ming Juang[1]
[1]NOAA/NWS/NCEP/CPC

The NCEP seasonal forecast model (SFM) is a global atmospheric spectral model, which is a previous version of the NCEP operational MRF model. It has been modified to be suitable for seasonal forecast purpose for more than two years. The idea of digital accuracy of a reduced Gaussian grid, which is originally developed by Williamson and Rosinski (2000), has been implemented into current SFM. A minor modification is applied to the original design. Due to the requirement to have reproducibility for restart and to un-disturb other utilities, such as preprocessor as well as postprocessor, the method of 'pick- the nearest-point' was used instead of interpolation for the surface fields. 50 year of integration with and without reduced grid was performed to investigate the climatological impact, and others.

Time Integration of Prototype Atmospheric Circulation Models in Spherical Geometry

Debby Lanser[1], *Joke Blom*[2] *and Jan Verwer*[2]
[1]Centre of Mathematics and Computer Science (CWI), [2]CWI

The Shallow Water Equations in spherical geometry provide a prototype for developing and testing numerical algorithms for atmospheric circulation on the globe. In previous work we studied a spatial discretization of these equations based on an Osher-type finite-volume method on stereographic and (reduced) latitude-longitude grids. Recent work concerns time-integration of the resulting semi-discrete system.

We will discuss a third-order A-stable Runge-Kutta-Rosenbrock method. To reduce the costs related to the linear algebra operations, this linearly implicit method is combined with Approximate Matrix Factorization. Its efficiency is demonstrated by comparison with a classical third-order explicit Runge-Kutta method. For that purpose, we use the SWE test set. The comparison shows that the Rosenbrock method is by far superior.

Currently, we are investigating an extension of this method to 3D. To test our 3D method, we have developed a new global 3D test case, viz. an instationary variant of the Ekman boundary layer.

We will also present results for this new test case.

An Optimal Quadratic Spline Collocation Method for the Spatial Discretization of the Shallow Water Equations on a Sphere

Anita Layton[1], Christina C. Christara[2] and Kenneth R. Jackson[2]

[1]National Center for Atmospheric Research, [2]University of Toronto, Department of Computer Science

We present new numerical methods for the shallow water equations on a sphere in spherical coordinates. In these algorithms, the equations are discretized in time with the two-level semi-Lagrangian semi-implicit (SLSI) method, and in space on a staggered grid with an optimal quadratic spline collocation (OQSC) method. A member of the class of finite element methods, the quadratic spline collocation method approximates the solution of a differential problem by a C^1 quadratic spline. In the standard formulation, the quadratic spline is computed by making the residual of the differential equations zero at a set of collocation points. The resulting error is $O(h^2)$, where h denotes the mesh size. In the one-step OQSC method, the discrete differential operator is perturbed to eliminate low-order error terms, and then a higher-order optimal solution is computed using the perturbed operator. In the two-step OQSC method, a second-order approximation is generated first, using the standard formulation, and then a higher-order approximation is computed in a second phase by perturbing the right side of the equations appropriately. The resulting error of the numerical solution of both OQSC methods can be shown to be $O(h^4)$ locally at the nodes and midpoints of a uniform partition, and $O(h^3)$ globally. When compared to standard second-order spatial discretization methods, the OQSC methods require less computation time to reach the same accuracy, and give rise to smaller approximation errors at the same computational cost.

We also show that, when applied to a simplified version of the shallow water equations, each of the algorithms yields a neutrally stable solution for the meteorologically significant Rossby waves. Moreover, we demonstrate that the Helmholtz equation associated with the shallow water equations should be derived algebraically rather than analytically in order for the algorithms to be stable with respect to the Rossby waves. These results are supported by numerical experiments using Boyd's equatorial wave equations with initial conditions to generate a soliton.

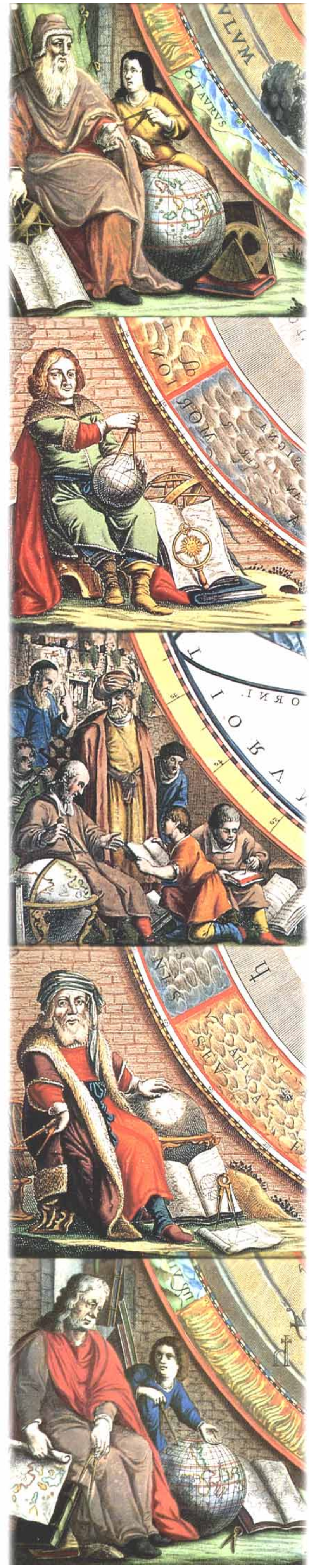
We then analyze the performance of the methods on various staggered grids --- the A-, B-, and C-grids. From an eigenvalue analysis of the simplified version of the shallow water equations, we conclude that, when discretized on the C-grid, the algorithms faithfully capture the group velocity of inertia-gravity waves. Our analysis suggests that neither the A- nor B-grids will produce such good behaviour. The theoretical results are supported by numerical experiments, in which we discretize Boyd's equatorial wave equations using different staggered grids and set the initial conditions for the problem to generate gravitation modes instead of a soliton. With both the A- and B-grids, some waves are observed to travel in the wrong direction, whereas, with the C-grid, gravity waves of all wavelengths propagate in the correct direction.

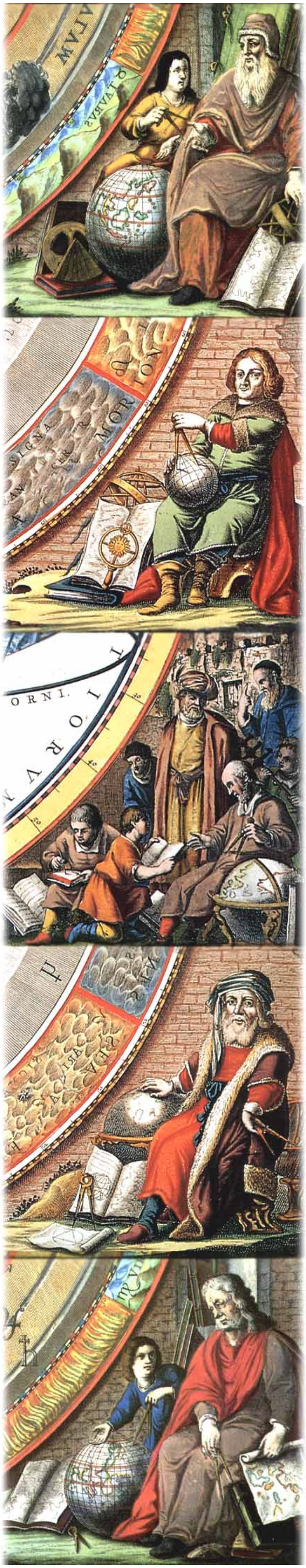
Parallel Spectral Element Atmospheric Dynamical Core Part I: Formulation and Implementation

Rich Loft[1], Steve Thomas[2], Joe Tribbia[3] and Aimé Fournier[4]

[1]Computational Science Section, [2]National Center for Atmospheric Research, [3]National Center for Atmospheric Reseach, 4Earth System Science Interdisciplinary Center, University of Maryland

In this talk we present a high-performance dynamical core for an atmospheric general-circulation model based on the global spectral-element atmospheric model of Taylor, Iskandarani and Tribbia (1997). This core is intended for long-term climate integrations





and geophysical-turbulence studies. Algorithmic modifications include staggered Gauss-Legendre-Lobatto and Gauss-Legendre spectral-element grids in the horizontal for velocity and pressure respectively, and a hybrid pressure coordinate in the vertical. The staggered grid reduces communications and enables the construction of a stable semi-implicit formulation. We find that a block-Jacobi preconditioned conjugate-gradient solver accelerates the simulation rate of the semi-implicit relative to the explicit model, for practical climate resolutions, by about a factor of three.

The new model formulation has been implemented in Fortran 90, and is capable of executing as a message-passing, multi-threaded or hybrid parallel program. Careful attention has been paid throughout the code to improving efficiency on RISC/cache microprocessors. Scalability of the semi-implicit time-stepping scheme has been improved by using a latency-tolerant form of the conjugate-gradient algorithm. The resulting code has performed well on large Compaq and IBM symmetric multiprocessor (SMP) clusters. We will also describe our current efforts to write cache-friendly physical parametrizations in order to build a scalable climate model for tera-scale computers.

The Global Icosahedral-Hexagonal Gridpoint Model GME of the DWD - Operational Version and Very High Resolution Tests -

Detlev Majewski[1]
[1]Deutscher Wetterdienst

Since December 1999 the DWD operates the global icosahedral-hexagonal gridpoint model GME for weather forecasts up to 174h. The average mesh size of the model is 60 km and the number of layers is 31. Operationally, GME uses 13x13 processors of a Cray T3E1200 to compute a a 24-h forecast in less than 15 min. A 7-day forecast produces more than 12 GByte of data. The design and numerical implementation of the model as well as some diagnostic results will be presented. On the Fujitsu VPP5000 GME has been tested for a wide range of mesh sizes from 150 km down to 15 km. The evaluation of these forecasts concentrated of the convergence of the solution with increasing resolu- tion and on the computational requirements and performance.

A class of finite difference approximations for conservation laws on icosahedral grids

Janusz Pudykiewicz[1]
[1]MSC

The system of conservation laws for fluids is approximated on an icosahedral grid defined in Cartesian coordinates. The spatial discretization is accomplished using the finite difference operators defined on an unstructured triangular mesh. The system of ordinary differential equations obtained following the approximation of space derivatives is solved using several different methods including 4-th and 5-th order Runge-Kutta schemes with variable time step. The issues related to the monotonicity of the proposed scheme are discussed in detail and a flux correction procedure on geodesic grid is introduced.

The algorithm is initially evaluated using the simple advective test for a passive tracer in a rotational velocity field on the sphere. Following this simple test, a more complex case of the reactive flow is analyzed. The representation of the tracer transformation is performed using both the linear and non-linear relations. In both cases, the solution of the problem is accomplished without operator splitting. The terms representing chemical reactions and/or condensation are included explicitly in the operator obtained following the discretization of advective terms.

The applications of the method are illustrated using two examples. The first is the simulation of transport of water vapour in the troposphere and the second is the formation of ozone in the stratospheric polar vortex.

The presentation will be concluded by the information about the application of the presented method to problems of fluid dynamics such as shallow water system and propagation of infrasound and gravity waves in geophysical fluids.

A Global Version of the NCEP ETA Model on a Cubic Grid
Miodrag Rancic[1]
[1]GEST/UMBC/GSFC

This paper reports the latest progress on a project which ultimate objective is to develop a universal framework for expansion to global coverage of the contemporary regional models of the atmosphere by employing the concept of quasi-uniform grids. As the first step toward such a "globalization framework", the regional ETA model, which is taken as a prototype within this project, is ported on a cubic grid suggested by Rancic at al. (1996). The paper discusses the underlying rational for this development effort, summarizes the related problems, and presents the first preliminary results.

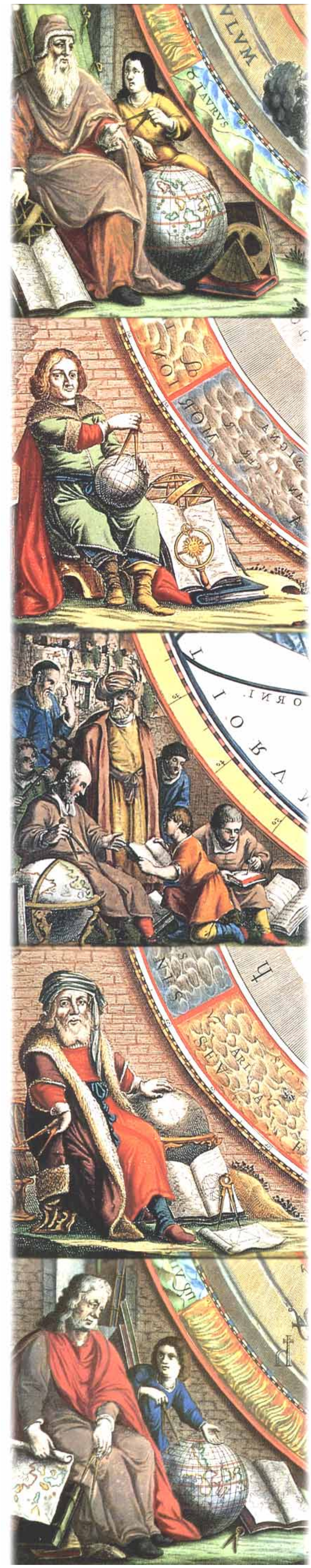
Mass/Wind consistency requirements for tracer transport on the sphere.
Phil Rasch[1]
[1]NCAR

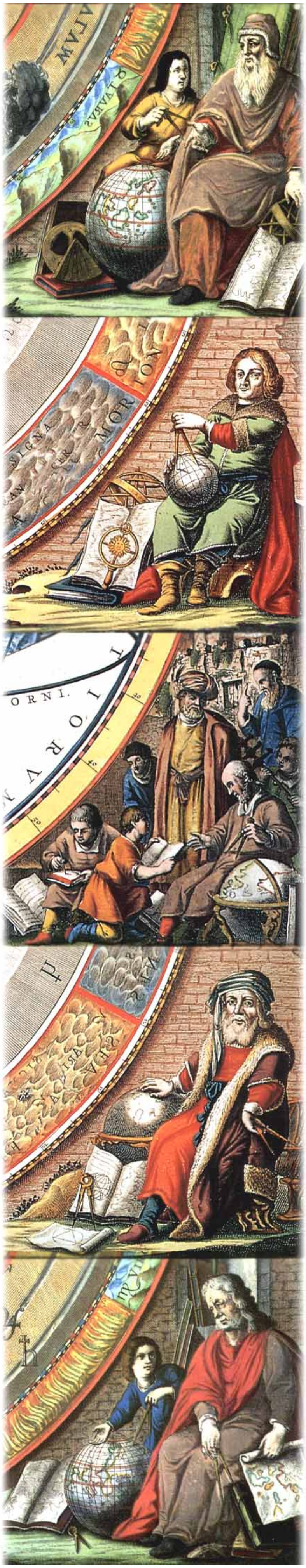
Numerical Methods play an important role in the modeling of transport of trace species in the atmosphere. The conservation of tracer mass is strongly influenced by the consistency between air mass and wind fields used to drive the tracer evolution equations. Furthermore, vertical transport in the vicinity of the tropopause is also strongly influenced by the consistency between wind and mass fields above and below this interface. The upper troposphere and middle atmosphere receives less attention from forecast and climate modeling efforts than regions at lower altitudes, but an accurate characterization of transport across the tropopause is important to for many problems.

In this talk I will describe how the inconsistencies manifest themselves in tracer problems using meteorological fields from a variety of atmospheric models (ECMWF, NCEP, NCAR CCM, perhaps others), and my attempts to remedy the situation.

A Potential Enstrophy and Energy Conserving Numerical Scheme Suitable for Geodesic Grids
Todd Ringler[1] *and David Randall*[1]
[1]Colorado State University

We will present a numerical framework built on a perfect hexagonal grid that conserves the globally-integrated quantities of mass, potential vorticity, potential enstrophy, and total energy in the shallow water equations. In terms of simulating geostrophic adjustment, this scheme is equivalent to the Z-grid. This work also elucidates the relationship between the Z-grid discretization of the vorticity-divergence equations and its momentum equation analog.





A wave propagation method for the solution of PDEs on the surface of a sphere
James Rossmanith[1] and Randall LeVeque[1]
[1]University of Washington

Large-scale geophysical flows are governed by partial differential equations on the surface of a sphere. Numerical solutions to these equations may suffer from singularities introduced by laying down a computational grid on the sphere. We consider a class of finite volume methods in conjunction with a special logically Cartesian grid mapping to numerically approximate the solution of various partial differential equations on the sphere. The mapping we consider is known as the gnomonic grid mapping and was first developed in the early 1970's. The main advantage of this mapping is that it results in a grid spacing that keeps the area of the smallest grid cell at about seventy percent of the largest grid cell, independent of the resolution of the grid. The mapping, however, is non-orthogonal and thus complicates the form of the equations. Furthermore, in the strict mathematical sense, the gnomonic mapping, sometimes referred to as a cubed sphere mapping, results in eight grid singularities corresponding to the eight corners of a cube. The numerical method we consider in conjunction with the gnomonic grid mapping is a Riemann solver based finite volume method. This method is designed to solve hyperbolic equations on arbitrary metrics. The philosophy is to solve locally Cartesian Riemann problems to piece together the global solution on the curved manifold. With this solver it becomes possible to preserve the form of the Cartesian equations despite the non-orthogonal gnomonic grid mapping. Furthermore, this framework allows us to avoid the deterioration of the solution near the grid singularities. To demonstrate the accuracy of the method a variety of test problems are solved including passive tracer advection, the linear wave equation, and the shallow water equations.

MESH ADAPTIVITY FOR NONHYDROSTATIC GLOBAL MODELS
Piotr Smolarkiewicz[1] and Joseph Prusa[2]
[1]National Center for Atmospheric Research, [2]Iowa State University

We have developed an adaptive grid-refinement approach for the nonoscillatory forward-in-time (NFT) nonhydrostatic global model. The major focus in this effort was the design of a generalized mathematical framework for the implementation of deformable coordinates and its efficient numerical coding in a generic Eulerian/semi-Lagrangian NFT format. The key prerequisite of the adaptive grid is a time-dependent coordinate transformation, implemented rigorously throughout the governing equations of the model. It results in the appearance of numerous Christoffel symbols, or grid metric terms in the equations. These terms arise due to the motion, non-orthogonality, and curvature of the deformable coordinate system. By design, the zonal and meridional coordinates of the grid points do not depend on altitude. This greatly reduces the number of metric terms and has the benefit of keeping vertical columns vertical (useful, e.g., for various bookkeeping computations such as column mass of water). Test results to date have clearly established the efficiency and accuracy of the new deformable grid code. A particular benefit of the adaptive mesh, is an optional meridional stretching that clusters grid points near the equator while moving them further away from the poles (useful, for instance, for studies of tropics). This can reduce the condition number of the elliptic operator significantly, thereby leading to a substantially faster code.

Formulation of the Semi-Lagrange Double Fourier Atmosphere Model

William Spotz[1] *and Anita Layton*[1]
[1]NCAR

The Eulerian Double Fourier Atmosphere Model has demonstrated some initial success in reducing the number of floating point operations per timestep in a spectral shallow water solver. As Clive Temperton speculated at the June 2000 ECMWF Workshop on Developments in Numerical Methods for Very High Resolution Global Models, even greater efficiencies may be possible in a semi-Lagrange (SL) formulation. The associated Legendre projection used to stabilize the Eulerian double Fourier model may not be required in an SL implementation, in the same manner as the SL linear advection removes the need for a 2/3 truncation rule. The result would be a truly fast spectral model. This talk covers our initial efforts at formulating a Semi-Lagrange Double Fourier Atmosphere Model.

Performance of the Eulerian Double Fourier Atmosphere Model

William Spotz[1], *Paul Swarztrauber*[1] *and Richard Loft*[1]
[1]NCAR

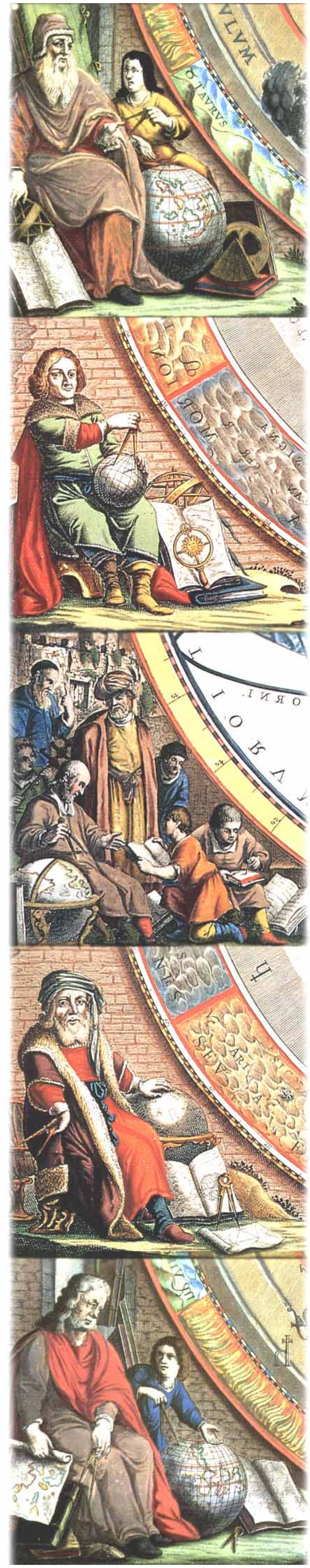
The spherical double Fourier epansion is a set of basis functions which serves as an alternative to the standard spherical harmonics. The obvious attractiveness is that fast Fourier transforms can be used in the latitude direction, thus speeding the computation. Unfortunately, this basis admits nonisotropic and unstable wave modes into the Eulerian form of the shallow water equations. We address this problem by projecting the prognostic variables onto the space of spherical harmonics using an associated Legendre projection, which both stabilizes the model and gives identical numerical results to the spherical harmonics. This approach is $O(N^3)$, as is the spherical harmonic method, but the double Fourier model results in a 42% savings in Legendre transform floating point operations per timestep. This savings has the potential of being quite significant for very high resolution models. The rest of the model is directly analogous to standard spherical harmonic shallow water solvers. Some $O(N^2)$ overhead is unavoidable; for example, the elliptic operator to be inverted is a tridiagonal matrix as opposed to a diagonal matrix for the spherical harmonics. The current version of the Eulerian Double Fourier Atmosphere Model (EDFAM) is a vorticity-divergence shallow water solver, parallelized with 1D decompositions and nine data transpositions per time step, which can use either explicit or semi-implicit time stepping. This talk will cover recent performance results, both of the associated Legendre projection and the full shallow water model.

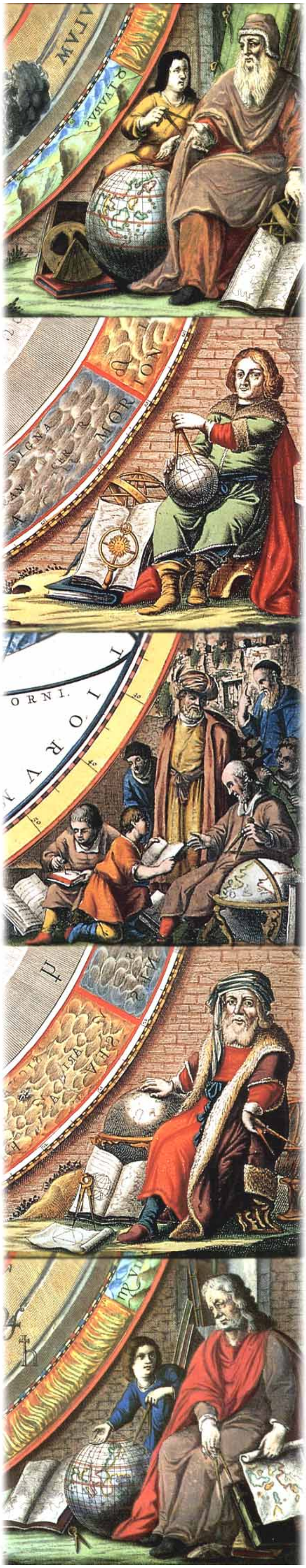
Use of the tangent-linear and adjoint of the semi-Lagrangian dynamics in the ECMWF global spectral model

Clive Temperton[1]
[1]ECMWF

The ability to run high-resolution forecasts efficiently at ECMWF depends crucially on the use of a semi-Lagrangian integration scheme to permit long timesteps. Until recently the tangent-linear and adjoint were only available for the Eulerian version of the dynamics, thus restricting for example the resolution at which the inner loops of the incremental 4D-Var data assimilation scheme could be run.

The tangent-linear and adjoint of the semi-Lagrangian dynamics have now been coded and are being used in 4D-Var, and tested in other applications (e.g., the computation of singular vectors used to generate perturbations for the ensemble prediction system). Coding the adjoint in particular yielded some interesting problems both in vectorization and in





implementation on a distributed-memory computer. Lessons learned from this exercise will be presented, together with examples of results.

A modified icosahedral grid by using spring dynamics

Hirofumi Tomita[1], Masaki Satoh[2], Motohiko Tsugawa[2] and Koji Goto[3]
[1]Frontier Research System for Global Change(FRSGC), [2]FRSGC, [3]NEC

The icosahedral grid has the desirable property for construction of high resolution geophysical models, that is, the spherical homogeneity of grid size. However, there still remain some problems to be overcome. One of the problems in the use of icosahedral grid is convergence problem of solution, that is, whether the numerical solution reasonably converges to the exact solution or not as the resolution increases.

In order to improve the numerical accuracy and stability for the icosahedral grid models, we propose several grid modifications as follows. From the viewpoint of numerical accuracy of operators, we propose to relocate the variable-defined grid points from the standard positions to the gravitational centers of control volumes. Ordinarily, the standard grid is obtained by recursive grid division starting from the lowest order icosahedral grid. From the other viewpoint of numerical stability, we modify the standard grid configuration by employing the spring dynamics, namely, the standard grid points are connected by appropriate springs, which move grid points until the dynamical system calms down. We find that the latter modification dramatically reduce the grid-noise in the numerical integration of equations. The reason for this is that the geometrical quantities of control volume such as its area and distortion of its shape exhibit the monotonic distribution on the sphere. By the combination of the two modifications, we can integrate the equations both with high accuracy and stability.

In order to demonstrate the effectiveness of those modification, we develop a shallow water model on the icosahedral geodesic grid modified by the above method. Discretizations of differential operators in the equations are based on the finite volume method, so that the global integrations of transported quantities are numerically conserved. The performance of our model is examined by the standard test cases of shallow water model proposed by Williamson et al.(1992, J. Comput. Phys., 102, 211). To investigate the convergence properties against resolution, we perform simulations from grid division level 4 (approximately 4.5X4.5 grids) to 7 (approximately 0.56X0.56 grids). The obtained results clearly indicate the advantage of use of our modified grid over the standard grid for the numerical accuracy and stability.

The computational performance of icosahedral models on vector-parallel super-computers, i.e., Earth Simulator, is also discussed. The tests of scalability of parallelization and efficiency of vectorization indicate the advantage of using the icosahedral grid for high resolution computations.

PDEs on the Sphere and in the Classroom: Auroral Heating of Jupiter's Atmosphere

Bram van Leer[1], Hunter Waite[1] and Nathan Schwadron[1]
[1]University of Michigan

In the Department of Aerospace Engineering, University of Michigan, an advanced, research-oriented CFD course is taught that attracts students from various departments interested in simulating compressible flows. The course is project-based; the largest computer project is a simulation of 2-D steady or unsteady flow, not necessarily taken from aerospace engineering. The students in this computational class are already highly

motivated (they have to be: it's considered the toughest class offered by the department), but injecting actual research into the classroom experience gives them an additional boost.

In the current term (Winter 2001) the project is: "Auroral heating of Jupiter's atmosphere", an actual research subject in the Space Physics Research Laboratory.

A heating function is prescribed, representing the effect of plasma raining down onto Jupiter's atmosphere at high latitudes, and its dynamical impact on the atmosphere is followed in an inviscid compressible flow description. For simplicity Jupiter's magnetic and rotational axes are assumed to coincide, and the flow is taken to be independent of longitude, allowing a 2.5-dimensional description (2 space coordinates, 3 velocities).

The hope is to find a flow mechanism that can explain the unexpectedly high atmospheric temperatures observed down to Jupiter's equatorial zones. At the time this presentation will be given, the term is over and preliminary results should be available

Aqua-planet as a test for dynamical cores

David Williamson[1]
[1]NCAR

Hoskins and Neale have proposed a series of aqua-planet experiments as a test-bed for the interaction of parameterizations with each other and with the dynamical core. The "correct answers" are not known, but sensitivities and interactions can be investigated with such tests. We apply their tests to the NCAR CCM with Eulerian and semi-Lagrangian dynamical cores. Surprisingly, with the standard CCM3 parameterization suite, the Eulerian core generates a single ICTZ on the equator, but the semi-Lagrangian core generates a double ITCZ straddling the equator. We have performed a large number of experiments to attempt to identify the cause of this unexpected behavior. We will present these results and any explanations we develop at the workshop.

Testing of mass conserving semi-Lagrangian schemes in a vertical updraft

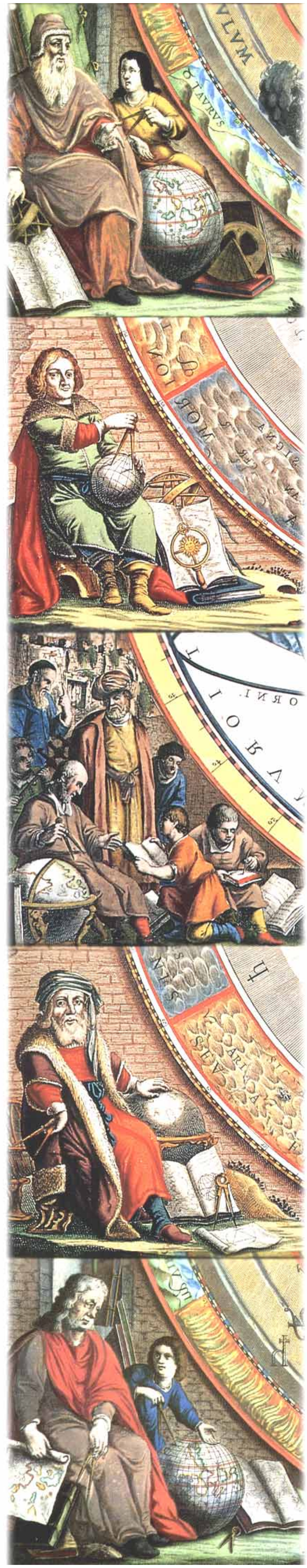
Peter Yau[1], *Abdessamad Qaddouri*[2], *Feng Xiao*[3], *Jean Côté*[2] *and Takashi Yabe*[3]
[1]McGill University, [2]Recherche en prévision numérique, Meteorological Service of Canada., [3]Tokyo Institute of Technology

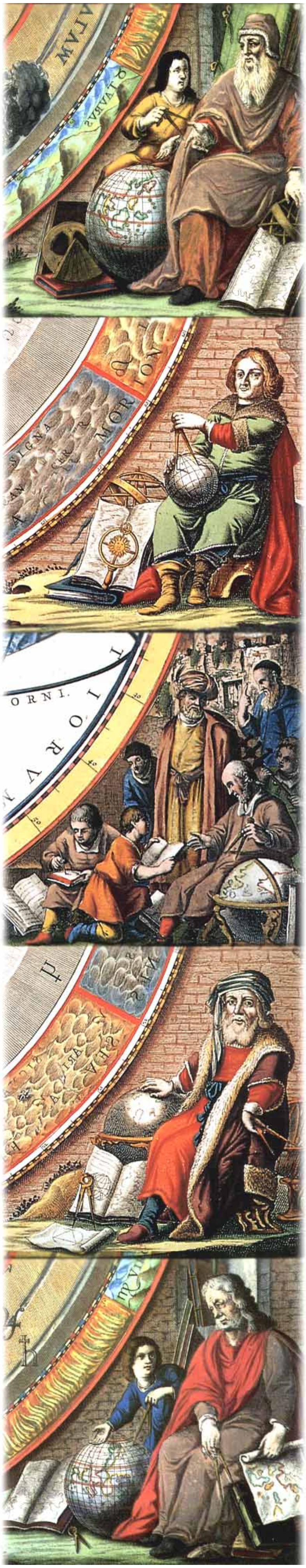
For study of the water budget in the atmosphere, it is important to conserve the mass of the water substances due to advection. Since the original semi-Lagrangian scheme lacks formal conservation, various variations have been proposed to enforce conservation and monotonicity. In this paper, we compare the performance of a number of such algorithms, including the constrained interpolated profile (CIP) method, in the context of a sinusoidal vertical updraft including sources and sinks of water substances. The scalar quantities advected consist of cloud water, rain water, ice/snow, and graupel. A large number of warm and cold rain microphysical processes are also included.

Finite-volume dynamics with variable resolution

Kao-San Yeh[1], *Michael Fox-Rabinovitz*[1] *and Shian-Jiann Lin*[2]
[1]ESSIC/Univ of Maryland & DAO/GSFC/NASA, [2]Data Assimilation Office/GSFC/NASA

Variable resolution is being implemented on the NASA finite-volume dynamics to extend the application of the NASA/NCAR GCM for regional climate simulation and data assimilation. As its original uniform- resolution version, the air mass, angular momentum





and potential internal energy are conserved both locally and globally to maintain the integrity of the flow. The intrinsic monotonicity of finite- volume transport is also preserved to produce noise-free solutions. A semi-stretched grid is introduced to reduce the excessive diffusion of finite-volume schemes in coarse-resolution areas, and therefore promote the overall accuracy with little extra cost compared to fully stretched grid. The semi-stretched grid also reduces significantly the amplitude of dispersion due to resolution variability. Preliminary tests on the properties of wave propagation have been conducted in the context of passive advection and shallow-water dynamics. Satisfactory accuracy is obtained with good flow characteristics.

Numerical simulation of shallow water equations using CIP method with high order spatial resolution

Seong Young Yoon[1], Yukio Tanaka[1], Feng Xiao[2] and Takashi Yabe[2]
[1]Frontier Research System for Global Change, [2]Tokyo Institute of Technology

The high order spatial discretization method based on semi-Lagrangian scheme is presented to solve the shallow water equations on sphere. The governing equations are approximated on longitude-latitudinal coordinate system. To avoid problems resulting from convergence of the meridians toward high-latitude and singularities on the poles, the special attentions are paid around the poles. For treating the advection terms more accurately, the CIP method (cubic interpolated propagation) is employed. The method has inherently properties of semi-Lagrangian method and uses the interpolation function constructed by a cubic polynomial in which the first derivative of dependent variable is used besides the value itself. According to problems to be solved and method to determine the coefficients of the polynomial function, many kinds of interpolation functions can be adopted. Because the method uses the first order spatial derivatives in addition to the value of dependent variables to construct the interpolation function unlike conventional semi-Lagrangian method, it requires the less stencils to determine the polynomial function. This property also allows the polynomial function to be very compact formulation. Recently, the family of CIP method considering the monotone and conservation in constructing the interpolation function are proposed and then the new version of CIP method is implemented in this calculation.

To verify the adaptability of present scheme to atmospheric problem, the advection problem proposed by D.Williamson is first solved and the results are compared with that of conventional semi-Lagrangian one. The results show good properties in preserving shape of solution and shortening the computation time. The overshooting and undershooting in the vicinity of a discontinuity is effectively suppressed by introducing a rational function as interpolation function.

As second calculation, the reduced grid model for shallow water problem is incorporated. Since the CIP method uses the less stencils to construct interpolation function, it can be easily applied to reduced grid model. In this calculation, the cosine bell advection problem is solved on full and reduced grid system. In reduced grid system, the number of grid in longitudinal direction is reduced at four positions in high latitude by fact of two. This reduced grid model allows more increased time step than full grid one and it eventually results in saving executing time with maintaining solution accuracy comparable to that in full grid system.

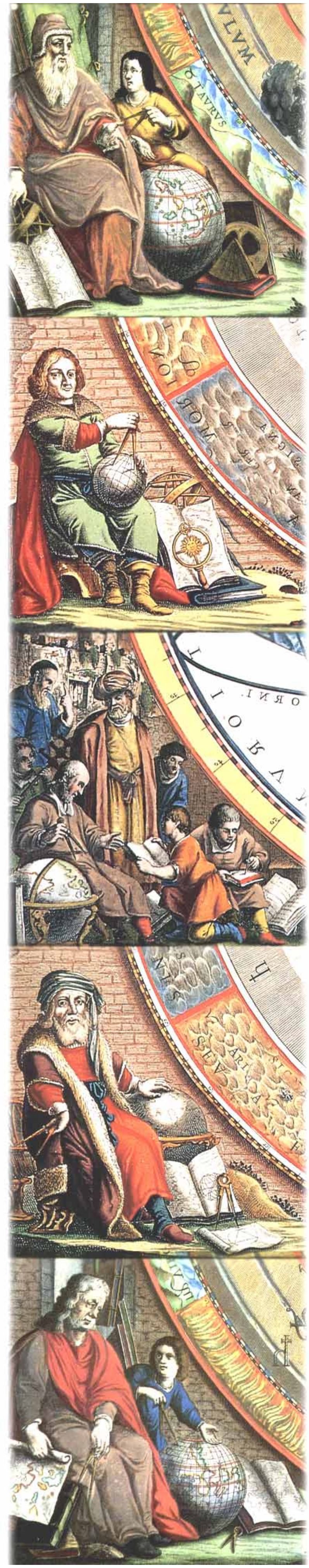
Finally, present method is implemented in global steady state nonlinear zonal geostrophic flow and steady state nonlinear zonal geostrophic flow with compact support etc. and the variations of normalized mean, variance, maximum values with time are compared with that of other method. From the comparison results with conventional grid method, the present model gives a promising prospect with view of a solution accuracy and computational performance.

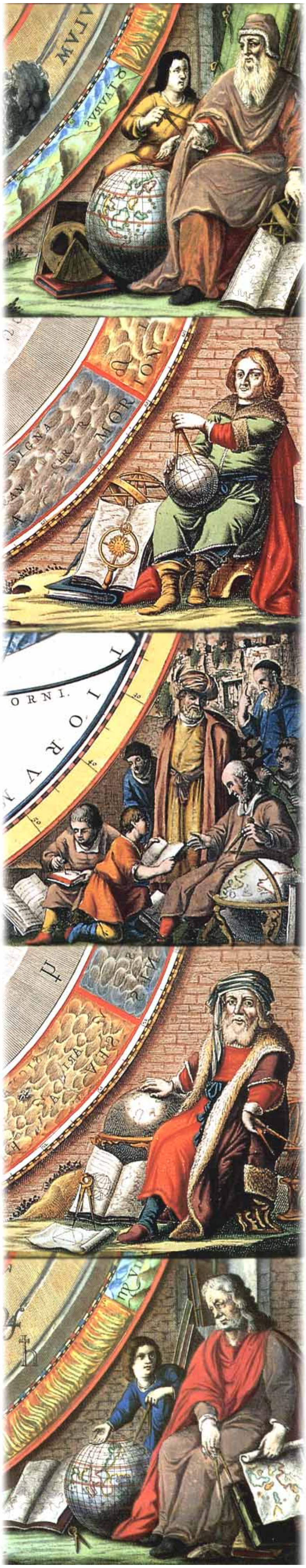
Idealised models for testing and development of NWP dynamical cores

Mohamed Zerroukat[1], Nigel Wood[1], Terry Davies[1] and Andrew Staniforth[1]
[1]Met Office (UK)

At the UK Met Office a number of idealised models have been developed for research and development purposes. These include 1D column, 2D vertical slice, shallow water and 3D limited area and global models to be used for the testing and development of the dynamical core of the Met Office next generation NWP model. These are based on the non-hydrostatic, unapproximated spherical primitive equations.

In this presentation we briefly outline the work undertaken in this regard and in particular the simulation and analysis of flow over a hill/ridge in a three-dimensional idealised setup.





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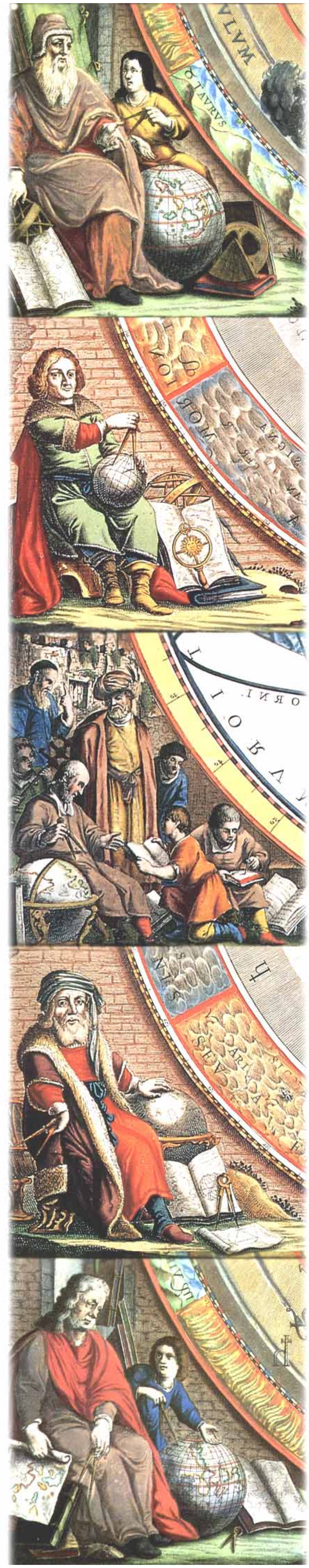

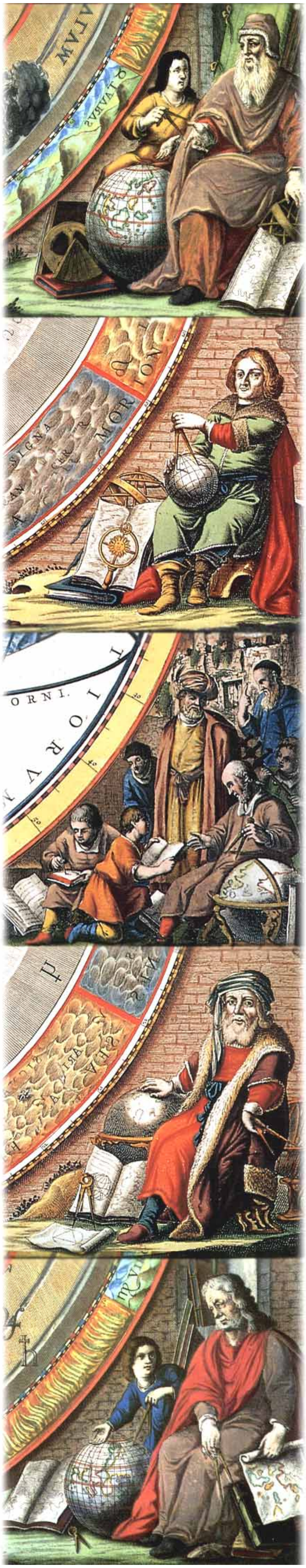

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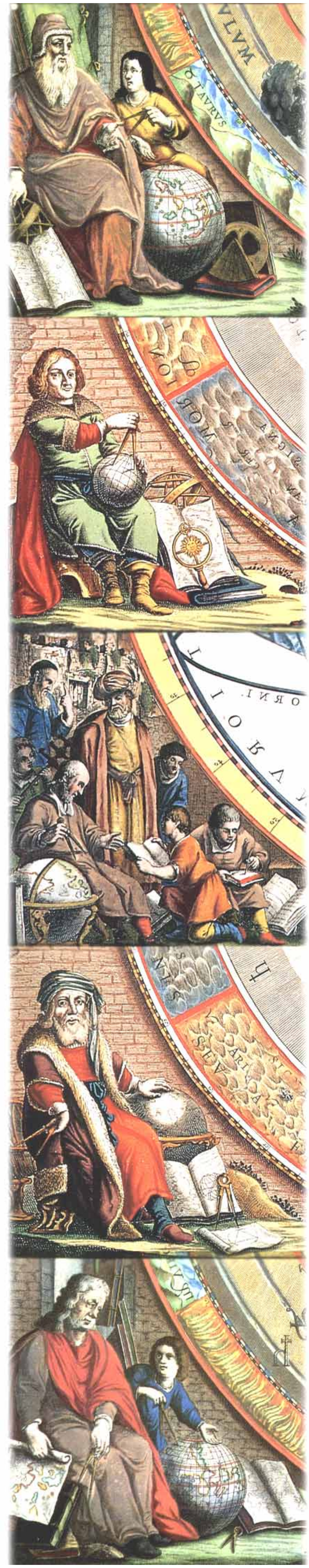

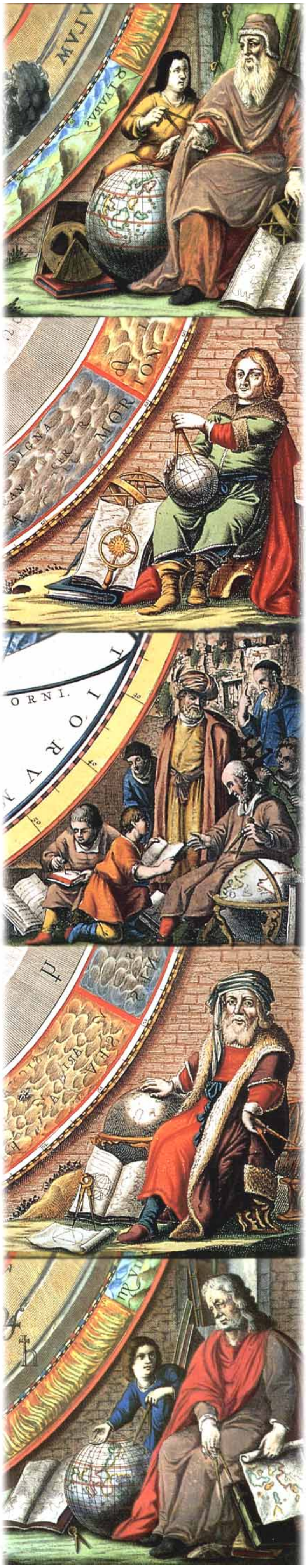

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