Prospectus:
Summer School & Dynamical Core Model Intercomparison Project (DCMIP) on Future-Generation Non-Hydrostatic Weather and Climate Models

National Center for Atmospheric Research (NCAR), Boulder, CO
7/30-8/10/2012

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Web page:

http://esse.engin.umich.edu/admg/dcmip/index.html

Sponsored by: NCAR (CISL), NOAA, NSF, Department of Energy (DoE), University of Michigan, NASA (inquired)

Endorsed by: WMO Working Group on Numerical Experimentation (WGNE)

Summary:

This multidisciplinary two-week summer school and Dynamical Core Model Intercomparison Project (DCMIP) will be held at NCAR from 7/30-8/10/2012. The event brings together graduate students, postdocs, atmospheric modelers, expert lecturers and computer specialists to create a stimulating, unique and hands-on driven learning environment. It will lead to an unprecedented student-run model intercomparison project, and thereby train the future generation of scientists engaged in global atmospheric model developments. Special attention is paid to the role of emerging non-hydrostatic global atmospheric models. The summer school and model intercomparison project promote active learning, innovation, discovery, mentorship and the integration of science and education. We anticipate testing about 12-15 dynamical cores that represent a broad spectrum of the modeling approaches in the international weather and climate modeling community.

Scope of the 2012 Summer School and Model Intercomparison Project:

The 2-week summer school and model intercomparison project will highlight the newest modeling techniques for climate and weather models. Special attention will be paid to non-hydrostatic global models that are an emerging trend, especially for the climate sciences. These will allow high-resolution simulations and provide a pathway for embedded variable-resolution meshes for regional climate assessments. The objectives of the summer school are (1) to teach a group of about 30 multi-disciplinary students and postdocs how today's and future atmospheric models are or need to be built, (2) to invite about 15 dynamical core model developers to NCAR for a hands-on student-run model intercomparison project, (3) to establish new non-hydrostatic dynamical core test cases in the community and (4) to invite keynote speakers to NCAR that give lectures on modern modeling techniques, uncertainty quantification, the physics-dynamics coupling and innovative computational tools.

The format of the summer school and model intercomparison project mimics our highly successful 2008 NCAR Advanced Study Program Colloquium (http://www.asp.ucar.edu/colloquium/2008/) that the first four members of the organizing team organized in June 2008. The summer school includes morning lectures and afternoon hands-on sessions in small teams in partnership with a modeling mentor. The latter will enable the students to gain an in-depth understanding of the modeling choices available to them in one particular model. These small-team sessions are lively, exciting and relevant, and guarantee the direct scientific feedback about the model results. The students will also immediately share the results with each other through a newly developed shared workspace, developed as a cyberinfrastructure tool (supported through an NSF Cyber-Enabled Discovery and Innovation (CDI) project). Snapshots of the 2008 colloquium are provided at http://www.cisl.ucar.edu/research/2008/0804.ASPcolloq.jsp. Examples of the 2008 presentations are collected at http://esse.engin.umich.edu/admg/ASP_Colloquium.php. The 2012 summer school builds upon this format, but will extend and broaden the scientific scope of both the lectures and hands-on sessions. While the 2008 summer colloquium focused on the numerical aspects and the evaluation of dry hydrostatic dynamical cores, the 2012 event puts emphasis on the newest non-hydrostatic modeling approaches and their interactions with moisture processes. This includes a discussion of the dynamics-physics interplay, the coupling and tuning aspects in both the dynamical cores and physical parameterizations, the assessment and quantification of

uncertainties, the importance of accurate tracer transport, and the use of computational tools. The primary goal of the summer school is to expose the students to the design philosophies in global atmospheric models, and make them aware of the multitude of modeling choices. The lectures are organized as themes (shown below).

Our target participants are graduate students and postdocs with diverse backgrounds and interests in atmospheric science, applied mathematics and/or computer science. Thus, the summer school will train the future generation of scientists engaged in global atmospheric model developments. Such a task has become a truly multidisciplinary endeavor. The 2008 workshop have had long lasting implications and impacts: (1) the participants of the 2008 colloquium built an online Facebook peer-network that has also been used after the colloquium, (2) Springer approached the organizing team that has now edited and authored a Lecture Notes Book (Lauritzen et al., 2011), (3) the dynamical core intercomparison data (1.3 TeraByte) are public and disseminated through the Earth System Grid, (4) the science results are being published in the reviewed literature (Lauritzen et al. 2010), (5) the test cases (Jablonowski et al, 2008) have the potential to become a community standard. The latter two aspects have integrated science and education in an exemplary way. We envision a similar long lasting impact for the 2012 event. In the fall of 2010 the 2012 model intercomparion project has been endorsed by the WMO / Working Group on Numerical Experimentation (WGNE). It will have a high visibility in the atmospheric modeling community.

The evaluation of the effectiveness of the workshop will be conducted through questionnaires and discussions on the last day of the summer school. In 2008, the organizing team received excellent reviews.

References:

Jablonowski, C., P. H. Lauritzen, R. D. Nair and M. Taylor (2008), Idealized test cases for the dynamical cores of Atmospheric General Circulation Models: A proposal for the NCAR ASP 2008 summer colloquium, Technical report, available online at http://esse.engin.umich.edu/admg/publications.php

Lauritzen, P. H, C. Jablonowski, M. A. Taylor and R. D. Nair (2010), Rotated versions of the Jablonowski steady-state and baroclinic wave test cases: A dynamical core intercomparison, J. Adv. Model. Earth Syst.,Vol. 2, Art. #15, 34 pp.

Lauritzen, P. H., C. Jablonowski, M. A. Taylor and R. D. Nair (Eds.) (2011), Numerical Techniques for Global Atmospheric Models, Lecture Notes in Computational Science and Engineering, Springer, Vol. 80, 556 pp.

Details about the 2012 event (in bullet form):

Date for the 2-week Summer School & Model Intercomparison Project:

July/30-August/10/2012 with arrival date Sunday July/29/2012 and departure date Saturday August/11/2012 for full-time participants

Location:

National Center for Atmospheric Research, Boulder, CO
Foothills Laboratory

- **first week (7/30-8/3/2012), rooms reserved:**
  NCAR Mesa Lab Tree Plaza on 7/30 from 4-6pm for ice breaker reception
  FL2 auditorium
  FL2-1002
  FL2-1003
  EOL Atrium 7/30-8/1, 8/3 (not available on 8/2)
  FL2-3107 7/30-8/2 (not available on 8/3)

- **Second week (8/6-8/10/2012), rooms reserved:**
  FL2 auditorium
  FL2-1002
  FL2-1003
  FL2-2006
  NCAR Mesa Lab Tree Plaza on 8/10, BBQ

NCAR host, providing administrative, computing and other technical support:

- Computational Information Systems Laboratory (CISL), CISL contact: Dr. Richard Loft (Director of CISL's Technology Development Division (TDD))
- Local administrative support: Jennifer Williamson (CISL)

Computing aspects:

- Students and mentors bring laptops for hands-on sessions, used as terminals to access mainframe computer and servers, CISL will provide a limited number of laptops as a backup if participant cannot bring one
- Mainframe: NCAR Bluefire IBM Power6 system and/or CRAY system
- Mentors port their codes to the NCAR systems, prepare the models to run the test suite
- CISL provides modeling mentors with computing support before the workshop
- CISL provides mentors and students with Cryptocards/yubikeys
- CISL provides dedicated queue on Bluefire (and CRAY?)
- CISL provides computing and equipment support during the summer school at the FL lab (general advice how to logon, print, etc., possible installation of extra power strips in FL meeting rooms, advice on visualization software NCL)
- The output data format of the models needs to be NetCDF (on or interpolated to a regular lat-lon grid). Mentors consult with organizing team and CISL support staff before the workshop to find solutions for the interpolation of data, and the conversion to NetCDF (if necessary).

NetCDF file needs to adhere to CF-standard (inclusion of metadata, standard variable names). Output files can also be made CF-conforming via NetCDF operators (NCO). Modeling mentors provide example data sets before the workshop to help organizing team prepare analysis software.

- CISL installs NetCDF CF-compliance checker on glade server
- GAUs, needs reallocation: our original September 2011 GAU proposal had been awarded with a total of 540k GAUs:
  - 450k GAUs on the new Wyoming supercomputer
  - 40k GAUs on bluefire,
  - 50k GAUs on the Janus cluster (NCAR & CU)
- Communication between NCAR/CISL - NOAA ESRL software/computing specialists:
  - data handling and storage during the summer school on NCAR's glade server, estimate: 10 TB
  - disk space, visualization capabilities on the glade server, NCL,NCO available?
  - organizational aspects of the data storage on glade: directory structure, accessibility by all participants during the workshop
  - data transfer to a NOAA server (Boulder) during and after the summer school, is 'rsync' possible?
  - transfer speeds between NOAA (Boulder) and NCAR
- Long-term open-access archive of the model intercomparison data on the Earth System Grid Federation (estimated 10 TB), entry point and storage provided by NOAA ESRL
- Cyberinfrastructure support through the NSF-funded project *'CDI-Type II: Scaling up: Introducing commoditized governance into community Earth science modeling'* conducted by NOAA's Environmental Software Infrastructure and Interoperability group, the University of Michigan and the University of Colorado.
  We are building cyberinfrastructure tools / shared workspaces, to be used as prototypes during the workshop. The cyberinfrastructure supports data (Earth System Grid Federation), searchable metadata for models and data, remote visualization and analysis capabilities through NOAA's Live Access Server (LAS), a communication platform for participants (Wiki functionality) and adheres to standards like the netCDF data format (CF-compliant).
  Entry points for DCMIP and the 2012 summer school activities:
  http://earthsystemcog.org/projects/dcmip/
  http://earthsystemcog.org/projects/dcmip-2012/
  (project pages currently under construction)

Technical support (NCAR CISL), outreach, broader participation, dissemination:

- Videotape presentations, mixed with slides for online web release (NCAR CISL)
- Highly desirable: life-stream the talks on the internet (NCAR CISL)
- Intercomparison project has been endorsed by the WMO / Working Group on Numerical Experimentation (WGNE), since Fall 2010, confirmed Fall 2011
- Plans for scientific papers

Participants: (fully funded)

- Approx. 30 graduate students & postdocs from the international community
- About 12-15 international and domestic model developers with particular expertise in dynamical cores for weather and climate models, serving as mentors for the hands-on

afternoon sessions during the 2-week time period, additional domestic modeling mentors are local Boulder/Colorado residents and might not require travel assistance
- Organizing team
- Lecturers that give tutorial-like 50-minute lectures, designed for non-expert audience

Format of the summer school and model intercomparison project:

- Morning lectures and hands-on afternoon sessions that let the students run and explore the newest generation of hydrostatic and nonhydrostatic dynamical cores via idealized test cases
- Focus of the test cases: nonhydrostatic tests, inclusion of simple moisture feedbacks, advection with tracer correlations (see more specifics below)

Ideas for test cases: beyond dry dynamical core tests (all exact specifications will be available by the end of April 2012)

- Passive 3D advection tests with prescribed wind fields, reversing in time
  Assessments of consistency, monotonicity and convergence rates:
    - test of the correlation among multiple tracers, developed by James Kent, test is a 3D extension of the tests by Nair and Lauritzen (2010), Lauritzen and Thuburn (2012), Kent et al. (2012)
    - non-divergent flow resembling the Hadley and Ferrell cells, developed by Paul A. Ullrich
    - Under debate: Horizontal advection in a 3D model in the presence of orography suggested by Bob Walko
- Small-Earth experiments with radius a_e/X, discriminating between hydrostatic and non-hydrostatic responses
  - Non-rotating (X=500):
    - Schaer-type mountain waves with and without wind shear, newly formulated, based on approaches by Schär et al. (2001), Wedi and Smolarkiewicz (2009), Wedi et al. (2009)
    - Propagating gravity waves, newly formulated, based on approaches by Skamarock and Klemp (1994), Tomita and Satoh (2004), Jablonowski et al. (2008)
  - Rotating with increased angular velocity (ΩX)
    - Under debate: Mid-latitudinal mountain in an isothermal hydrostatic atmosphere at rest: Accuracy of pressure-gradient calculation and choice of vertical coordinate in the presence of steep terrain, based on approaches by Lin (1997)
    - Baroclinic waves at extreme km-scale resolutions with X=1000, based on Jablonowski and Williamson (QJ, 2006)
- Full-size Earth baroclinic waves with dynamic & passive tracers and simplified moisture (built upon Jablonowski and Williamson, QJ 2006)
    - Dry baroclinic wave with dynamic tracers: potential vorticity and potential temperature (Whitehead et al., in preparation for QJ)
    - Moist variant of the JW baroclinic wave (newly developed variant of Jablonowski and Williamson (QJ, 2006))
      - moist initial conditions without condensation (matching the dry case)
      - with only large-scale condensation and condensational heating

        - with large-scale condensation and condensational heating and additional surface fluxes and boundary layer diffusion (so-called simple-physics package as described in Reed and Jablonowski (2012))
- Idealized moist tropical cyclone simulation with simple-physics package (Reed and Jablonowski, 2011, 2012)
- Optional, climate-mode experiments: newly-developed moist-variant of the Held-Suarez test with large-scale condensation

References:

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Jablonowski, C., P. H. Lauritzen, R. D. Nair and M. Taylor (2008), Idealized test cases for the dynamical cores of Atmospheric General Circulation Models: A proposal for the NCAR ASP 2008 summer colloquium, Technical Report, available at http://esse.engin.umich.edu/groups/admg/publications.php

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Lauritzen, P.-H. and J. Thuburn (2012): Evaluating advection/transport schemes using interrelated tracers, scatter plots and numerical mixing diagnostics, Quart. J. Roy. Meteorol. Soc., in press (early release online)

Lin (1997): A finite-volume integration method for computing pressure gradient force in generalized vertical coordinates, Quart. J. Roy. Met. Soc., Vol. 123, 1749-1762

Nair, R. D. and P.-H. Lauritzen (2010): A class of deformational flow test cases for linear transport problems on the sphere, J. Comput. Phys., Vol. 229, 8868–8887

Reed, K. A. and C. Jablonowski (2011a) : An analytic vortex initialization technique for idealized tropical cyclone studies in AGCMs, Mon. Wea. Rev., Vol. 139, 689-710

Reed, K. A. and C. Jablonowski (2012), Idealized tropical cyclone simulations of intermediate complexity: A test case for AGCMs, J. Adv. Model. Earth Syst., Vol. 4, M04001, doi:10.1029/2011MS000099, open access, available at http://www.agu.org/pubs/crossref/2012/2011MS000099.shtml

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Skamarock, W., and J. B. Klemp, 1994: Efficiency and accuracy of the Klemp-Wilhelmson time-splitting technique. Mon. Wea. Rev., Vol. 122, 2623-2630

Tomita, H. and M. Satoh, 2004: A new dynamical framework of nonhydrostatic global model using the icosahedral grid, Fluid Dyn. Res., 34, 357–400

Wedi, N. P., K. Yessad and A. Untch (2009): The nonhydrostatic global IFS/ARPEGE: model formulation and testing, European Center for Medium-Range Weather Forecasts (ECMWF), Technical Memorandum No. 594, 34 pp., http://www.ecmwf.int/publications/library/do/references/list/14

Wedi, N. P. and P. K. Smolarkiewicz (2009): A framework for testing global non-hydrostatic models, Quart. J. Roy. Meteorol. Soc., Vol. 135, 469–484

Whitehead, J. P., C. Jablonowski, J. Kent and R. B. Rood (2012), Potential vorticity: A diagnostic tool for general circulation models, Quart. J. Roy. Meteorol. Soc., in preparation

Invited modeling groups:

Nonhydrostatic global models (confirmed participation, status 4/16/2012):

- **I**ntegrated **F**orecasting **S**ystem (**IFS**), European Centre for Medium-Range Weather Forecasts, Reading, U.K.
  Mentor: Sylvie Malardel
- **EndGame**, UK Met Office, Exeter, U.K.
  Mentors: Tom Melvin, Markus Gross (at NCAR during the first week, remotely from the U.K. during the second week)
- **CSU** Vorticity-Divergence Dynamical Core, unified equations, Colorado State University, Fort Collins, CO
  Mentors: TBD, Ross Heikes and/or Celar Konor?
- **M**odel for **P**rediction **A**cross **S**cales (**MPAS**), NCAR & Los Alamos National Laboratory, possibly with nested grid option
  invited scientists: Bill Skamarock, Joe Klemp, Todd Ringler, Sara Rauscher, Sang-Hun Park, Laura Fowler and Michael Duda
  Mentor: TBD
- **FVcubed**, Geophysical Fluid Dynamics Laboratory (GFDL) and NASA, possibly with variable-resolution (stretched) grid, possible frameworks:
  1) NASA's framework
  2) GFDL's modeling framework
  Mentor: Lucas Harris (GFDL), pending decision: Bill Putman (NASA)
- **N**onhydrostatic **IC**osahedral **A**tmospheric **M**odel (**NICAM**), possibly with variable-resolution (stretched) grid, RIKEN Advanced Institute of Computational Science (AICS) & Japan Agency for Marine-Earth Science and Technology *(*JAMSTEC*)* & University of Tokyo, Japan
  Mentors: Hiroaki Miura (University of Tokyo), Ryuji Yoshida (Riken)
- **N**on-hydrostatic **I**cosahedral **M**odel (**NIM**)*,* NOAA Earth System Research Laboratory, Boulder, CO
  Mentor: Jin Lee?
- Flow-Following **F**inite-Volume **I**cosahedral **M**odel (**FIM**)*,* NOAA Earth System Research Laboratory, Boulder, CO
  Mentor: Stan Benjamin
- **O**cean-**L**and-**A**tmosphere **M**odel (**OLAM**), non-hydrostatic, possibly with variable resolution (nested) grid, University of Miami, FL
  Mentor: Robert Walko
- **MCore**, High-order finite-volume model on the cubed-sphere grid, University of Michigan
  Mentor: Paul Ullrich

- **ICO**sahedral **N**on-hydrostatic General Circulation Model (**ICON)**:
  - Icosahedral-triangular grid version, Max-Planck Institute for Meteorology, Hamburg & German Weather Service, Frankfurt, Germany
    Mentors: Marco Giorgetta, Levi Silvers (MPI), Daniel Reinert (DWD)
- **ICO**sahedral **N**on-hydrostatic General Circulation Model (**ICON)**:
  - Hexagonal grid version, Leibniz-Institute of Atmospheric Physics at University of Rostock (IAP), Kuehlungsborn, Germany
    Mentor: Almut Gassmann

Nonhydrostatic global models (final decision pending, 4/16/2012):

- **LMD**/École Polytechnique model DYNAMICO (3D available?), Paris, France, highly interested, decision by end of May/mid June 2012, possibly hydrostatic version only, Mentor: Thomas Dubos
- **G**lobal **E**nvironmental **M**ultiscale Model (**GEM**), Environment Canada, preferred on the Yin-Yang grid (very interested)
  contacted scientists: Abdessamad Qaddouri, Vivian Lee, Gilbert Brunet and Ayrton Zadra

Nonhydrostatic global models (not available on the sphere yet, declined):

- **ASUCA**, new finite-volume nonhydrostatic model of the Japan Meteorological Agency (JMA), contacted scientist: Chiashi Muroi

Hydrostatic global models:

- **CAM – Spectral Element (SE)** (with & without variable resolution), NCAR & Sandia National Laboratories
  Mentors: Mike Levy ?, Mark Taylor ?, Kevin Reed

Hydrostatic global models (participating remotely, not actively featured during summer school):

- **CAM Finite-Volume** model on latitude-longitude grid, NCAR,
  Participating group: University of Michigan Team and NCAR(?)
- **PUMA,** Eulerian spectral transform dynamical core based on ECHAM (MPI), part of the University of Hamburg's Planet Simulator, final decision pending,
  Participating group: Thomas Frisius, University of Hamburg, Germany
- Others?

Proposed science foci of the lectures: Organized as themes (in no particular order)

Theme 1: Trends in Dynamical Core Modeling

- Overview of a GCM:
  building blocks dynamics and physics, dry equation sets for dynamical cores: review of the primitive equations, and how to extend them to non-hydrostatic equations, deep and shallow atmosphere approaches, spherical geopotential approximation versus elliptical shapes of the Earth, choices of the prognostic variables

- Evolution of computational grid, grid resolutions, multi-scales and variable resolution approaches for climate models with regional focus areas, contrasts to traditional limited area models
- Towards seamless predictions across many scales

Theme 2: Numerical Methods in Dynamical Cores
- Review of spatial (horizontal) discretizations
- Review of vertical discretizations
- Review of time stepping schemes, numerical stability

Theme 3: Connecting the Dynamical Core and Physical Parameterizations
- How to include moisture, moist equation sets, what are the moisture feedbacks, how do they drive the dynamics?
- How to couple dynamics and physics: grids, physics time steps and update intervals, process-split versus time-split, intrinsic time-scale dependencies in the physics, what are the sensitivities, sensitivities to resolutions?
- Which types of physical parameterizations are present in weather and climate models? What are their high-level design philosophies?
- Are physical parameterizations becoming obsolete in non-hydrostatic models and if yes, at which scale? What are the pros and cons of superparameterizations? How to think about scale-aware physical parameterizations suitable for models with variable-resolution grids?
- Principles of stochastic physical parameterizations, what is their promise?

Theme 4: Tracers in Atmospheric Models and their importance for climate models
- Tracer transport, design philosophies of advection schemes
- Numerical methods for tracer advection
- What does tracer advection tell us about the general circulation of the atmosphere (e.g. utilizing the conservation of potential vorticity), how well do we model tracer advection today?

Theme 5: Evaluating dynamical cores and General Circulation Models (GCMs), Uncertainty Quantification (UQ)
- Overview of structural and parameter uncertainty in dynamical cores. How do we test dynamical cores and full-physics weather and climate models: overview of the test hierarchy including the Atmospheric Model Intercomparison Project (AMIP) and Aqua-Planet Experiments
- Sources of uncertainty in model simulations (structural, parameter, boundary data uncertainty), physical and mathematical principles behind uncertainty characterization and quantification
- Use of ensembles: multi-model ensembles and weighting of models, perturbed parameter ensembles, single-model ensemble with different physics/dynamics components, multi-resolution ensembles, pros and cons of ensembles
- Model validation and verification
- Intergovernmental Panel on Climate Change (IPCC) Coupled Model Intercomparison Project (CMIP5), overview of re-analysis data, control or high-resolution simulations

Theme 6: Emerging computational aspects

- Cyberinfrastructure for atmospheric modeling, Earth System Grid (ESG), Live Access Server (LAS), Metadata, demonstrations of cyberinfrastructure tools
- Trends in parallel computing, Graphical Processing Units (GPUs) as accelerators, co-design of models and hardware, how do we need to design atmospheric models (grids, domain decompositions, parallel communication, load balancing) to maximize performance

Theme 7: Diversity in Dynamical Cores participating in DCMIP

- Design philosophies of dynamical cores with specific examples from the models that participate in the workshop (presentations by modeling mentors)

Theme 8: Tuning of dynamical cores and physical parameterizations

- Filtering and diffusion in the dynamical cores, what are resolvable and unresolved scales?
- What are the empirical physics tuning parameters in GCMs and how are the valid ranges determined? Principles of tuning (who does it, what are the physical principles behind it?), tuning for high resolutions? What works, what doesn't?

Theme 9 (last day): Dynamical Core Model Intercomparison, what did we learn?

- Student presentations: Results of the DCMIP Model Intercomparison Project
- Skype sessions with remote participants, possibly remote presentations
- Perspective of the Modeling Mentors: Results of the Model Intercomparison Project
- Interactive 'Question & Answer' session with experts (modeling mentors, organizers, NCAR scientists)
- Review of the workshop

Planned social activities:

- Daily refreshment breaks at NCAR's FL lab in the mornings and afternoons
- Sunday (7/29/2012) evening, informal get-together at a Boulder pub near hotel
- Monday (7/30/2012) early evening 4-6pm, welcome & ice breaker reception, NCAR Mesa Lab Tree Plaza
- Friday pizza lunch (8/3/2012), discussion of the current status of intercomparison project, results and feedback from participants and mentors
- Saturday morning hike (8/4/2012), Mesa Lab-Chautauqua, catered box lunch
- Friday evening: Farewell BBQ, NCAR Mesa Lab Tree Plaza, concludes the summer school (8/10/2012)