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Development of the Navy's Next-Generation Nonhydrostatic Modeling System

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LONG-TERM GOALS

The long-term goal of this project is to maintain the leading edge of the Numerical Weather Prediction (NWP) model by developing the next generation model with an ability for prediction across spatial and temporal scales.

OBJECTIVES

The main objective is to continue development of the next generation model, the Spectral Element (SE) model, built on the Element Based Galerkin (EBG) method and evaluate simulations in both two- (2D) and three dimensions (3D). The primary focus is on completing the set of the basic necessary physical parameterizations, adding the ability to use initial boundary conditions from another global model, and reading the climatological database to provide required surface characteristics.
The overarching objective is to perform a global weather forecast using real data.

APPROACH

The main effort is aimed at the development of the SE model

1. Physical Parameterization Packages

   We will complete the set of basic parameterization schemes describing physical processes. We will add cumulus parameterization, surface fluxes, and radiaton. Each parameterization package will be tested in simplified, single-column mode setting.

2. Climatological database

   Surface characteristics (e.g. surface roughness, land-sea mask, surface albedo) are needed by physical parameterizations. The surface values will be read and interpolated from a global database.

3. Initialization using fields from NAVGEM

   The initial values of variables will be provided by NAVGEM. Fields will be read and interpolated to the SE model nonuniformly spaced nodal points. Special attention will be given

to decomposing the initial state into the hydrostatically balanced background and residual perturbation.

4. Positive definitness

   Gibbs effect (ringing) caused by steep gradients can yield physically implausible solutions, e.g. negative moisture. Decoupling the polynomial order in vertical will allow us to us Piecewise Parabolic Method with flux limiters to remove spurious values.

Key personnel: Saša Gaberšek (Naval Research Laboratory), P. Alex Reinecke (NRL), Kevin Viner (NRL), James D. Doyle (NRL), Dale R. Durran (University of Washington), Peter N. Blossey (UW)

WORK COMPLETED

We have implemented the following parameterizations: i) surface fluxes based on bulk Louis/TOGA-COARE scheme; ii) the convective parameterization based on the University of Washington shallow convection scheme (designed to be scale aware); iii) the radiation scheme based on the Rapid Radiative Transfer Model GCMs (RRTMG). In addition, the subgrid scale mixing has been changed to act in the vertical direction only, in the implicit form.

The global database for terrain, landmask and surface characteristics (e.g. albedo, surface roughness) is now available to the model during the initialization stage.

We have added infrastructure to the model to use NAVGEM fields for initial boundary conditions. Once the fields are read in, they are hydrostatically balanced.

The decoupling of the polynomial order in horizontal and vertical direction has been implemented and tested in two dimensions within the DG framework.

RESULTS

The surface fluxes parameterization was tested in an idealized, two-dimensional setting, with a uniform wind profile of 20 m/s, neutrally stratified atmosphere, and no-slip lower boundary condition. As expected, the mechanical mixing starts evolving the surface boundary layer, which deepens as the simulation progresses (Fig 1). The subgrid scale mixing transfers the momentum vertically throughout the surface boundary layer.

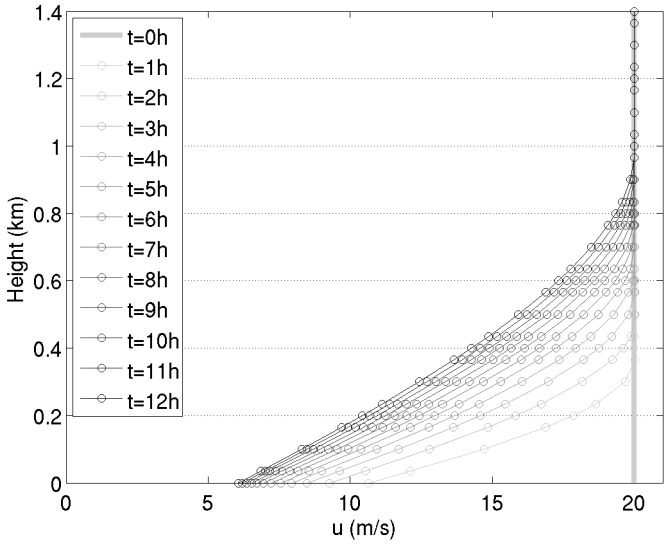

Figure 1: Evolution of the vertical wind profile with time for the first twelve hours with the surface fluxes turned on. The atmosphere is neutrally stratified.

The radiation scheme has been tested in a single-column mode, with no clouds (clear sky). After a 24-hour integration, the shortwave radiation is warming up the atmosphere (Fig 2, left panel), while the longwave radiation is cooling it down (Fig 2, right panel)

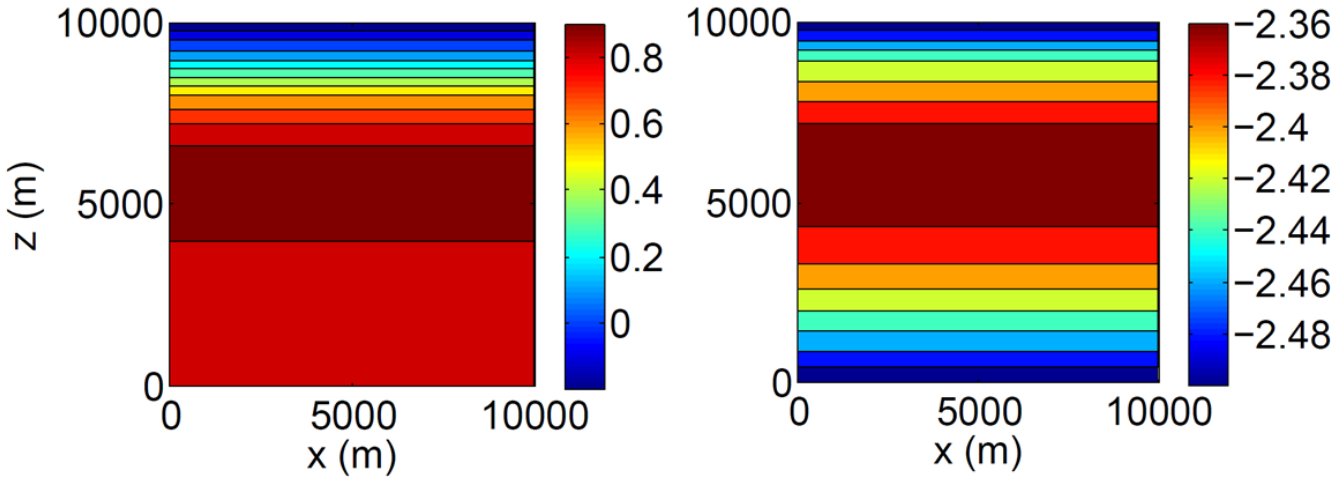

Figure 2: Vertical distribution of the potential temperature perturbation (K) after 24 hours using the radiation parameterization. Effects of the shortwave warming (left panel) and longwave cooling (right panel) are shown separately.

The climatological fields and topography are shown on a grid selected for a global test simulation, with a nominal horizontal grid spacing of 100 km. Note the nonuniform spacing of grid points, representing the cubed sphere with six faces (Fig 3).

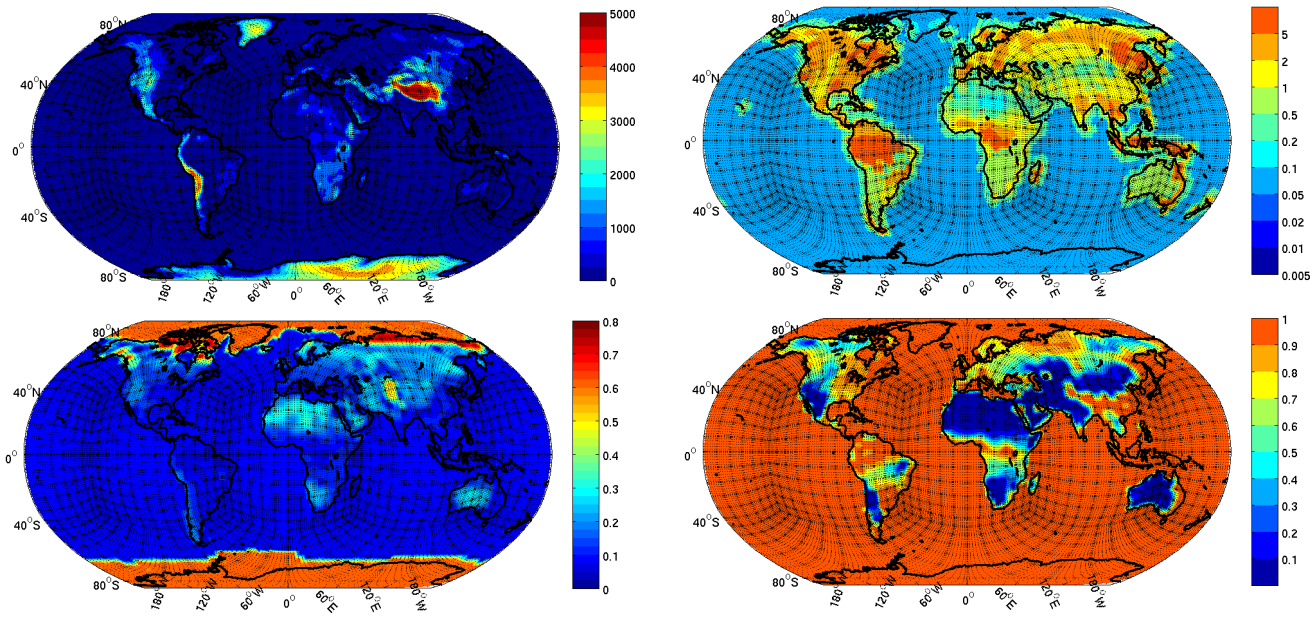

Figure 3: Topography (top left, in meters), surface roughness (top right, in meters), albedo (bottom left, no units), and ground wetness (bottom right, no units) on a cubed-sphere mesh. The average horizontal spacing of nodal points (black color dots) is approximately 100 km.

The first tests were conducted with no topography and the atmosphere at rest to ensure that it remains hydrostatically balanced with no spurious motions evolving. After 12 hours of integration using ark2 time integrator, with a 60 s time step, the atmosphere remains at rest. There is some very low magnitude noise (grid imprint) visible in the vertical velocity field, at the height of ~2.5 km (Fig 4).

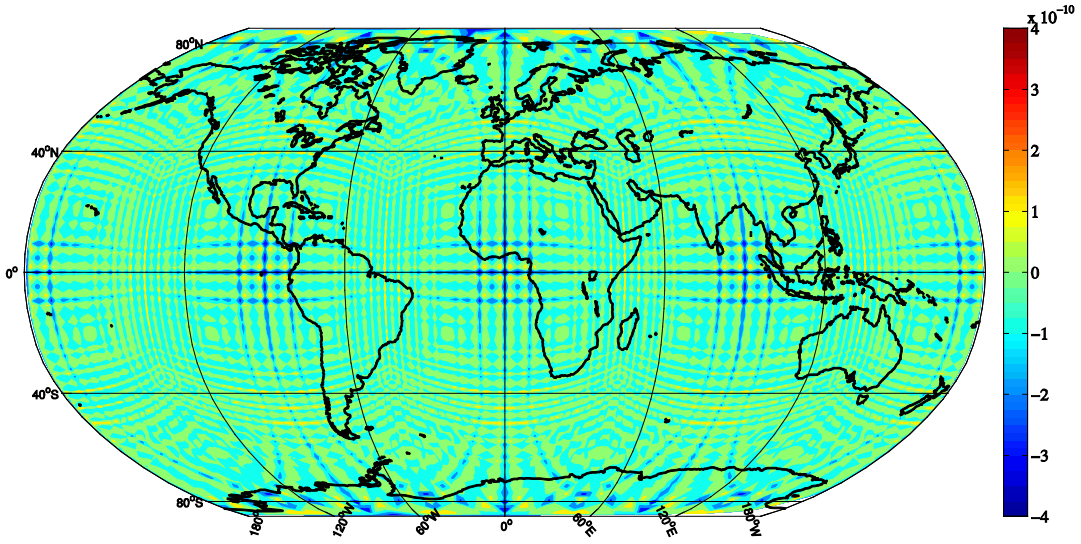

Figure 4: Vertical velocity (m/s) at a height of ~2.5 km after 12 hours of integration. The atmosphere is initially at rest, with no topography.

The initial conditions are interpolated from NAVGEM fields onto the nonuniform mesh, in both horizontal and vertical direction. To reduce spin-up time, the imported fields are split into the

hydrostatically balanced portion which is used as a reference state, and the residual which is treated as a perturbation. An example provided shows the wind speed and geopotential height at 500 hPa interpolated from NAVGEM fields from 2013062500 (Fig 5).

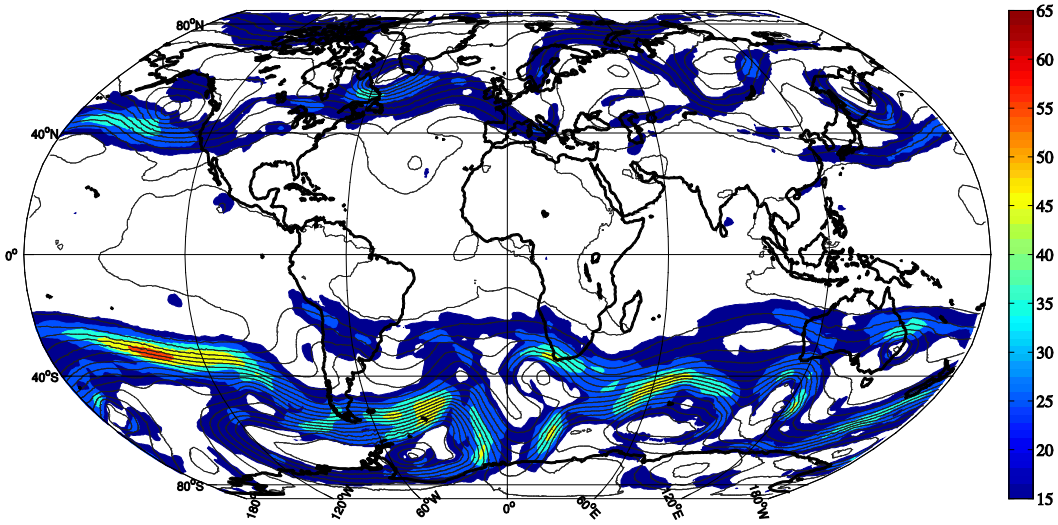

Figure 5: The wind speed (filled contours, starting at 15 m/s, c.i. 10 m/s) and geopotential height (black contours, c.i. 60 m) at 500 hPa at the initial time. Fields are interpolated from 2013062500 NAVGEM fields.

The initial tests of polynomial order decoupling in horizontal and vertical direction are encouraging. Note that the tests were performed with the Discrete Galerkin formulation, not the Continuous Galerkin formulation (also known as SE). The swirling tracer test starts with an initial concentric tracer distribution, stretches it out and returns to the initial position (with no deformation). With no modifications, the test reveals ringing (Gibbs effect) throughout the domain at both half-time and final time (Fig 6).

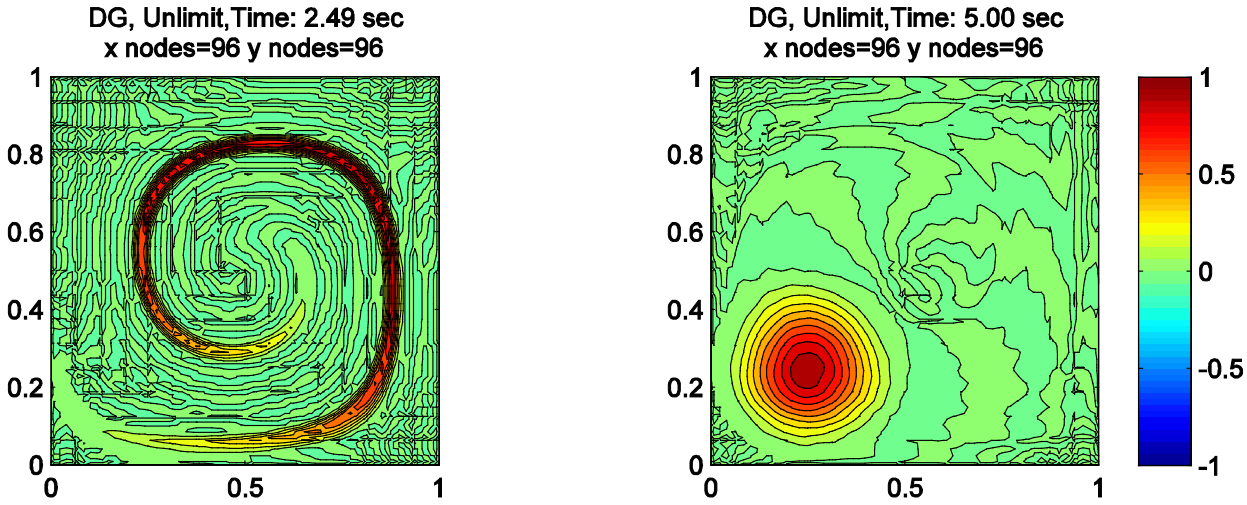

Figure 6: Tracer concentration at half time (left panel), when it is maximally stretched, and final time (right panel). Courtesy of prof. Dale Durran (UW).

When the polynomial order is decoupled and reduced to the second order in vertical, a Piecewise Parabolic Method (PPM) with flux limiters can be used. The ringing at both the half- and final time is virtually eliminated (Fig 7).

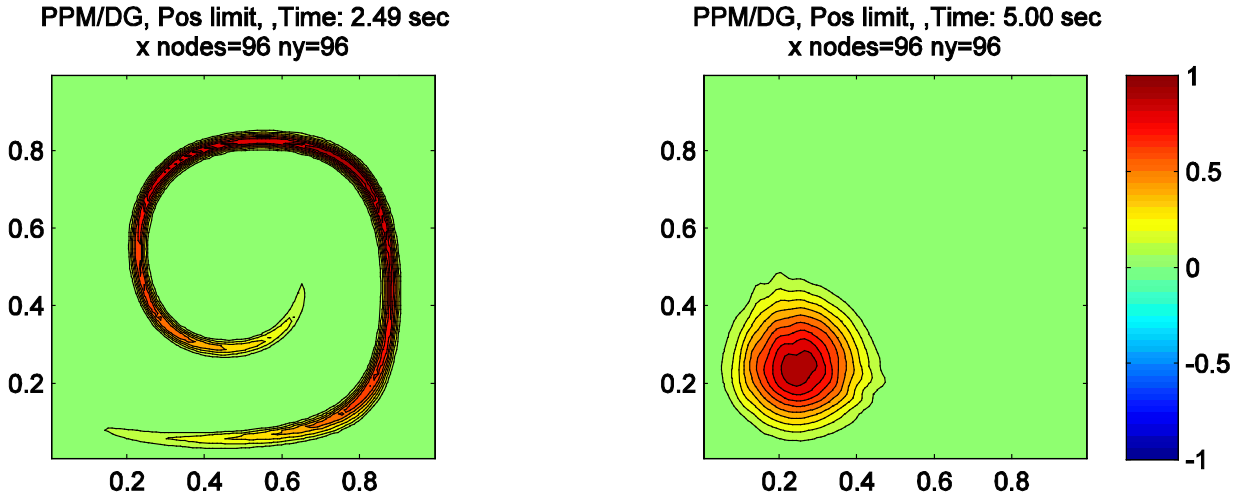

Figure 7: Tracer concentration at half time (left panel), when it is maximally stretched, and final time (right panel), when using PPM in the vertical direction. Courtesy of prof. Dale Durran (UW).

IMPACT/APPLICATIONS

The SE model could become the unified dynamical core for both global and mesoscale weather forecasts across spatial and temporal scales for the US Navy. The design of the model and its structure yield excellent scalability that can take a full advantage of available computational cores as they become readily accessible in large numbers (~100000) in the near future.

TRANSITIONS

The next generation COAMPS system will transition to 6.4 projects within PE 0603207N (SPAWAR, PMW-120, ESPC Dynamical Core project)

RELATED PROJECTS

NUMA will be used in a related 6.2 project within PE 0602435 for an intercomparison of dynamical cores aimed at prediction across scales.

COAMPS will be used in related 6.1 projects within PE 0601153N that include studies of air-ice, air-ocean and air-wave coupling, boundary layer studies, and topographic flows and in related 6.2 projects within PE 0602435N that focus on the development of the atmospheric components (QC, analysis, initialization, and forecast model) of COAMPS.

PUBLICATIONS

Gaberšek, S., J.D. Doyle and F.X. Giraldo, 2012: Dry and Moist Idealized Experiments With a Two-Dimensional Spectral Element Model, *Mon. Wea. Rev*.,**140**, 3163–3182.