DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

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

Saša Gaberšek
Naval Research Laboratory
7 Grace Hopper Avenue, Stop 2
Monterey, CA 93943-5502
phone: (831) 656-4882 fax: (831) 656-4769 email: sasa.gabersek@nrlmry.navy.mil

Award Number: N0001415WX00409, N0001415WX00850

LONG-TERM GOALS

The long-term goal of this project is to develop a Numerical Weather Prediction (NWP) model built around a next-generation dynamical core. Its advantages are that it is scalable over a large number of computational cores, highly accurate, and being unified in a sense that the same dynamical core is being used regardless of the temporal and spatial scales.

OBJECTIVES

The main objective is to improve the existing set of basic physical parameterizations, and add the missing parameterization schemes to complete a full, basic suite of parameterizations in NEPTUNE (Navy Environmental Prediction SysTem Utilizing the NUMA corE), built on the Element Based Galerkin (EBG) method. The parameterizations will be tested individually and combined using both idealized and real data case simulations in three dimensions (3D).
The secondary objective is to implement a way to enforce positive definiteness for scalars in NEPTUNE.

APPROACH

NEPTUNE continues to evolve with a goal to become a candidate for the next generation, unified NWP model. The development is performed in conjunction with the Earth System Prediction Capability (ESPC) project work unit 4 (WU-4) in which NEPTUNE is a participating next generation model. NEPTUNE is the first fully three-dimensional spectral element model (SE) for the atmosphere, which is designed for high accuracy and scalability. The EBG models are built by subdividing the computational domain into elements, in which variables forming the governing equations are represented by high-order polynomial basis functions and expansion coefficients. If the points at the element boundaries are shared and continuity is ensured, the formulation is called a Continuous Galerkin (CG), or SE method. If the fluxes between the adjacent elements are shared, but the actual values at the element boundaries are allowed to differ, the formulation is called a Discontinuous Galerkin (DG) method. One of detrimental side-effects of EBG methods is Gibbs effect (ringing), made worse by steep gradients of represented variables. The ringing can yield physically implausible solutions, such as negative moisture. In order to ensure physical plausibility (positive moisture), and tracer mass conservation, positive definiteness needs to be implemented.

The main effort of this project is aimed at completing physical parameterization packages. Once they are implemented in NEPTUNE, they are continually being improved and tested using both idealized and real data cases. The initial physical parameterizations were based on methods used in local area models, thus being designed and developed for finer grid spacing (~10 km) compared to global simulations. Processes like convection cannot be explicitly resolved using coarse grid spacing typically used by global models and as such need to be parameterized. Since our goal is to develop a model with a unified dynamical core that can be used for a wide array of spatial resolutions, the physical parameterizations need to support that and be able to either explicitly resolve or parameterize the driving proceeses.

The ultimate goal of the project is to deliver a mature, next generation NWP model, positioning the US Navy at the leading edge of the existing NWP models used worldwide. NEPTUNE has advantageous and unique characteristics: an ability to efficiently scale over thousands of computational cores, high accuracy, the same dynamical core used over the globe and for local area predictions.

Our approach is two pronged:

1. Physical Parameterization Packages

   We will complete and upgrade the basic set of parameterization schemes describing physical processes. The parameterizations will be tested either indivudually or as a set, and the results will be validated to ensure they are physically consistent and plausible.

2. Positive definiteness

   We will explore options to ensure positive definiteness, focusing on the DG framework, which allows conservation laws to be enforced locally, within elements.

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

WORK COMPLETED

We have implemented or improved the following set of physical parameterizations:

- Ice-permitting microphysics (WRF Single Moment 6-species, WSM6, and WRF Single Moment 3-species, WSM3)
- Deep and shallow convection (Tiedtke cumulus parameterization)
- Boundary layer (YSU BL parameterization)
- Surface energy budget (Deardorff force-restore)
- Radiation transfer (inclusion of moisture in RRTMG)

A viable option to ensure positive defineteness has been tested and implemented within the EBG framework, although still in two dimensions only.

RESULTS

The unified dynamical core of NEPTUNE supports simulations over a wide array of spatial scales. Using fine grid spacing, however poses a computational challenge when applied uniformly over the entire globe. One possible solution to test the dynamical core at fine spatial scale where non-hydrostatic effects are important is to design a numerical experiment on a reduced-radius sphere. This approach was used when testing the interaction of NEPTUNE's microphysical parameterization packages with the dynamical core, at the average horizontal grid distance of 1 km. Starting from a moist mid-latitude based sounding, meridional gradients of air temperature and vertical wind shear, the convection is triggered by an elevated positive temperature perturbation centered over the Equator. The initial tests were performed using Kessler parameterization which does not include ice species (not shown). Additional tests were performed including the ice-phase in microphysics by using WSM6 (Figure 1) and WSM3 (not shown). After two hours, the initial convective plume can be seen at the back of the storm, with its outflow triggering two new centers of convection, sustained by the vertical wind shear which effectively decouples the inflow of warm and moist air into updrafts, from the precipitation induced downdrafts.

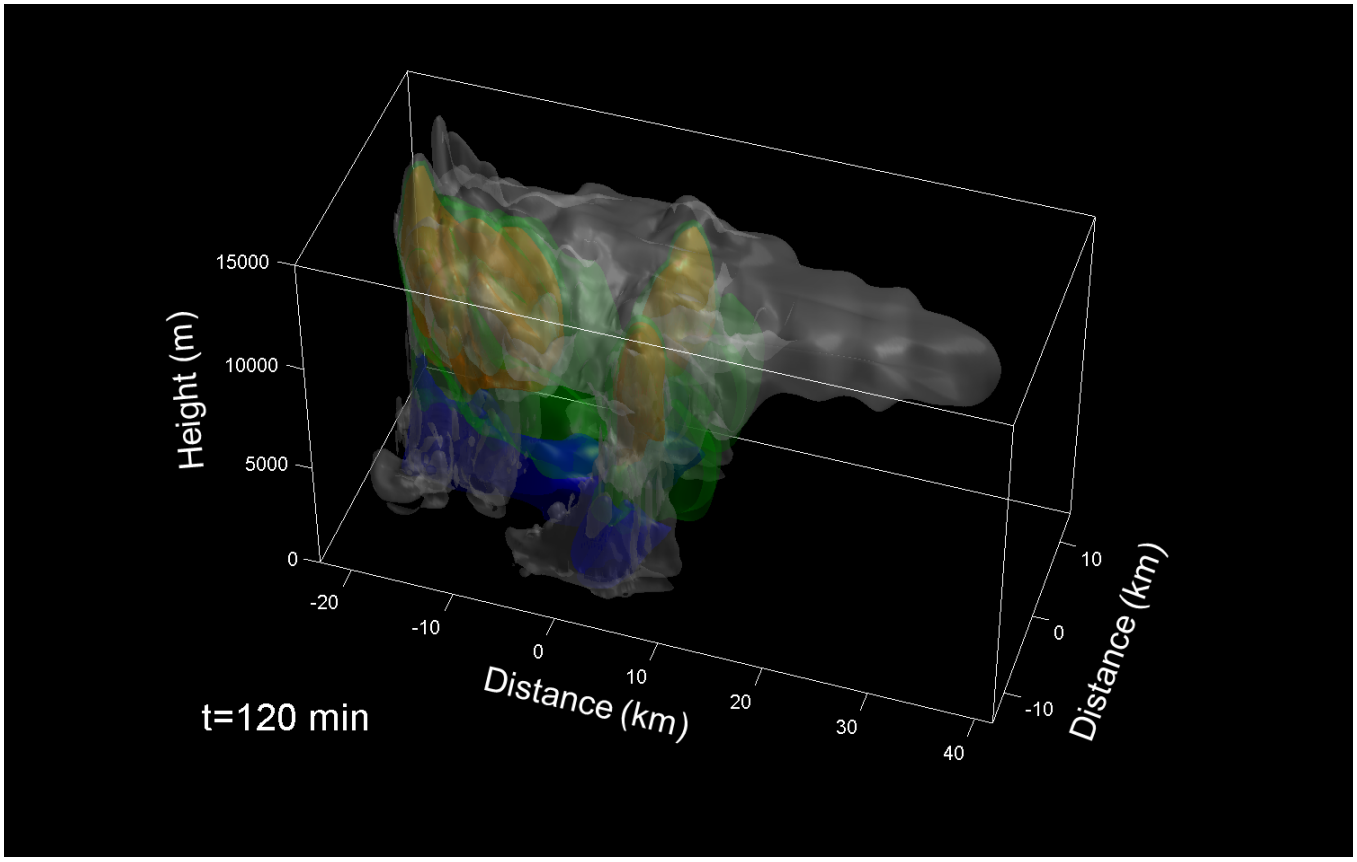

Figure 1: Isosurfaces of rain (blue), cloud (dark gray), snow (yellow), graupel (green) and ice (light gray) for a splitting supercell idealized simulation at t=120 min, when using WSM6.

The second experiment was based on the real data case, hurricane Sandy of October 2012. In order to properly describe the driving physical processes, several new physical parameterizations were implemented: Tiedtke cumulus scheme, YSU boundary layer, Deardorff surface energy budget (slab force-restore), and inclusion of clouds and moisture in RRTMG. In addition to implementing the parameterizations themselves, additional model infrastructure work has been required (e.g. regulary spaced physical grid used by all physical parameterization, onto which model variables are transformed before the physical processes are computed, vertical staggering of regularly spaced grid points for thermodynamic variables).

NEPTUNE was initialized using GFS initial conditions and the length of hindcast was 72 hours. The average horizontal nodal spacing in the example shown (Figure 2) is approximately 13 km, although grid spacing of 5, 26 and 52 km were also tested (not shown). A global distribution of the precipitation accumulation at t=12 h shows the precipitation accumulation associated with hurricane Sandy in the Western Atlantic Basin, in addition to both mid-latitude frontal features and tropical smaller-scale convection (Fig. 1).

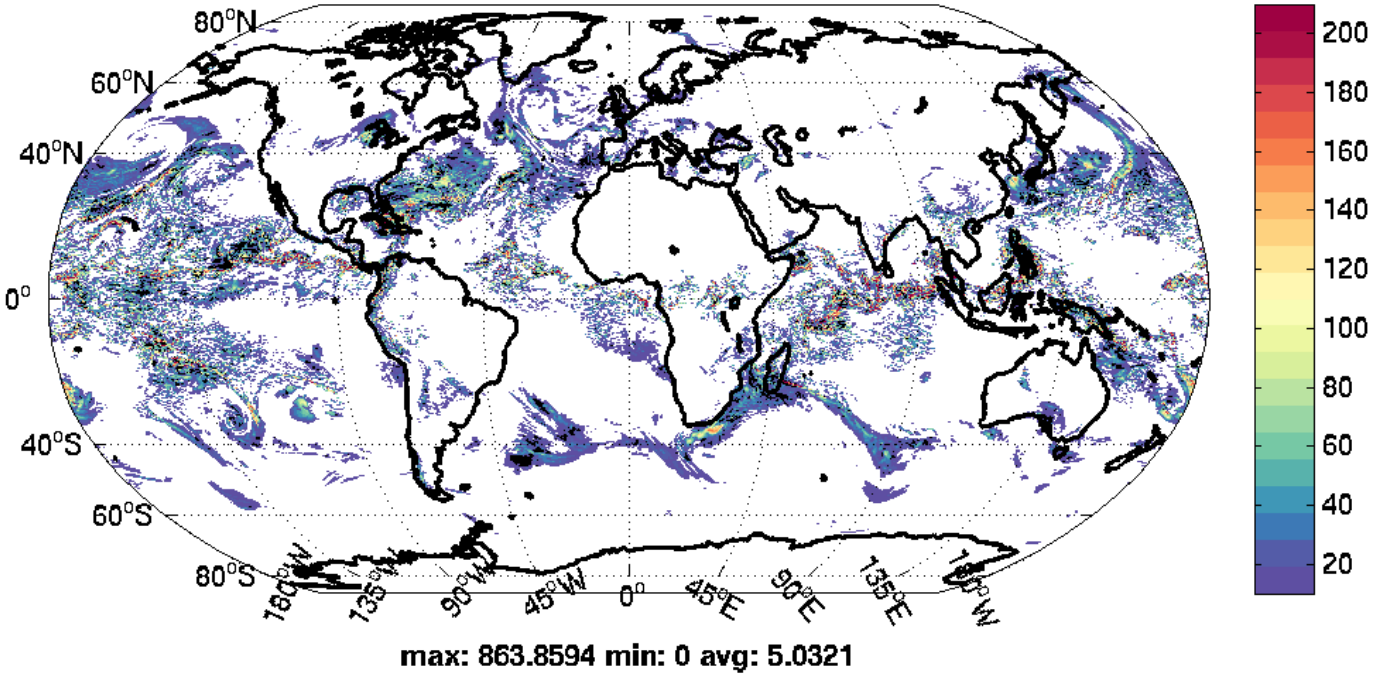

Figure 2: Total precipitation accumulation (mm) at t=12 h for hurricane Sandy. The hindcast was initialized on Oct 24th 2012 at 18Z.

A closer look over the Caribbean reveals a developing tropical storm with rain bands wrapping around its center (Fig. 3). Note that the average horizontal spacing is relatively coarse (13 km), in addition to the earlier time of the storm development, so that the eye is not resolved and visible.

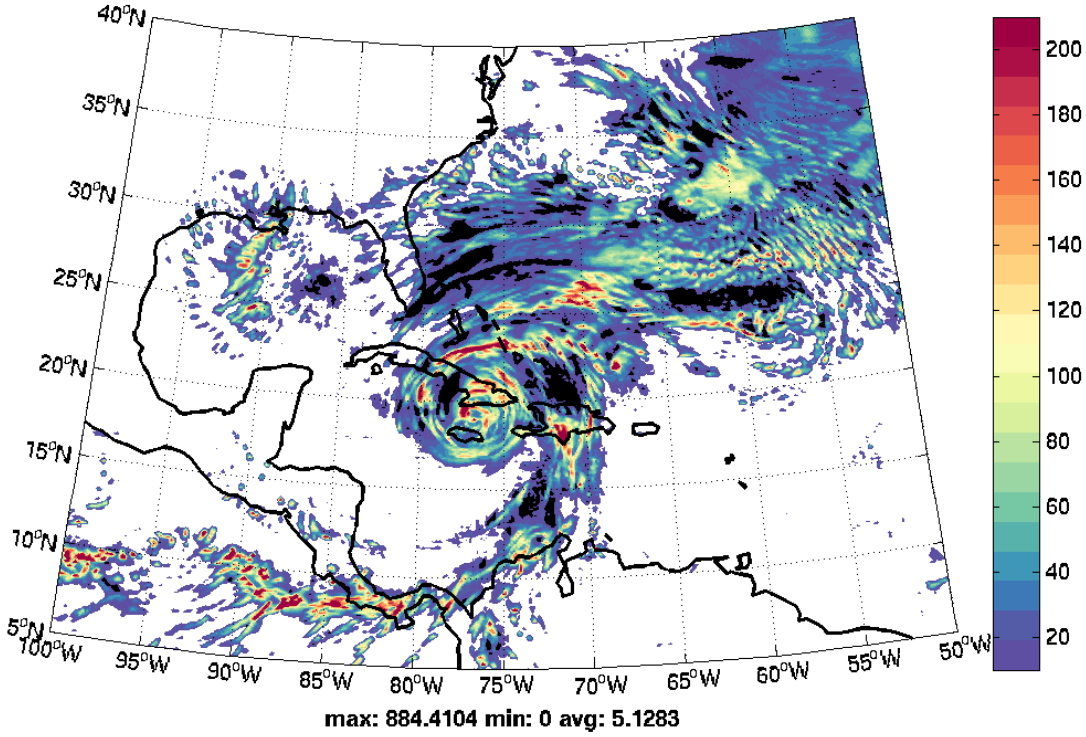

Figure 3: Total precipitation accumulation (mm) at t=12 h for hurricane Sandy. The hindcast was initialized on Oct 24th 2012 at 18Z.

This was the very first fully three-dimensional spectral element model simulation of a real data case with all physical parameterizations activated, putting NEPTUNE and US Navy at the leading edge of the new generation NWP models.

Positive definiteness (PD) of scalars has been demonstrated within a DG framework. The new scheme favorably compares with the existing schemes to preserve PD. In essence, the element average remains the same, while the possible negative values are set to zero, borrowing from the positive values. The scheme has been tested with a rising thermal bubble, containing a tracer with the initial values of concentration between 0 and 1. A solution without any limiter is compared to the new approach (Mass Weighted PD), and another possible candidate (Zhang-Shu PD). After 800 seconds the new method remains positive, with sharp features (Figure 4).

In order to implement the Mass-Weighted PD method in NEPTUNE, scalars need to be treated separately within the DG framework. The splitting of scalar treatment will be implemented as the next and necessary step to achieve positive definiteness in NEPTUNE.

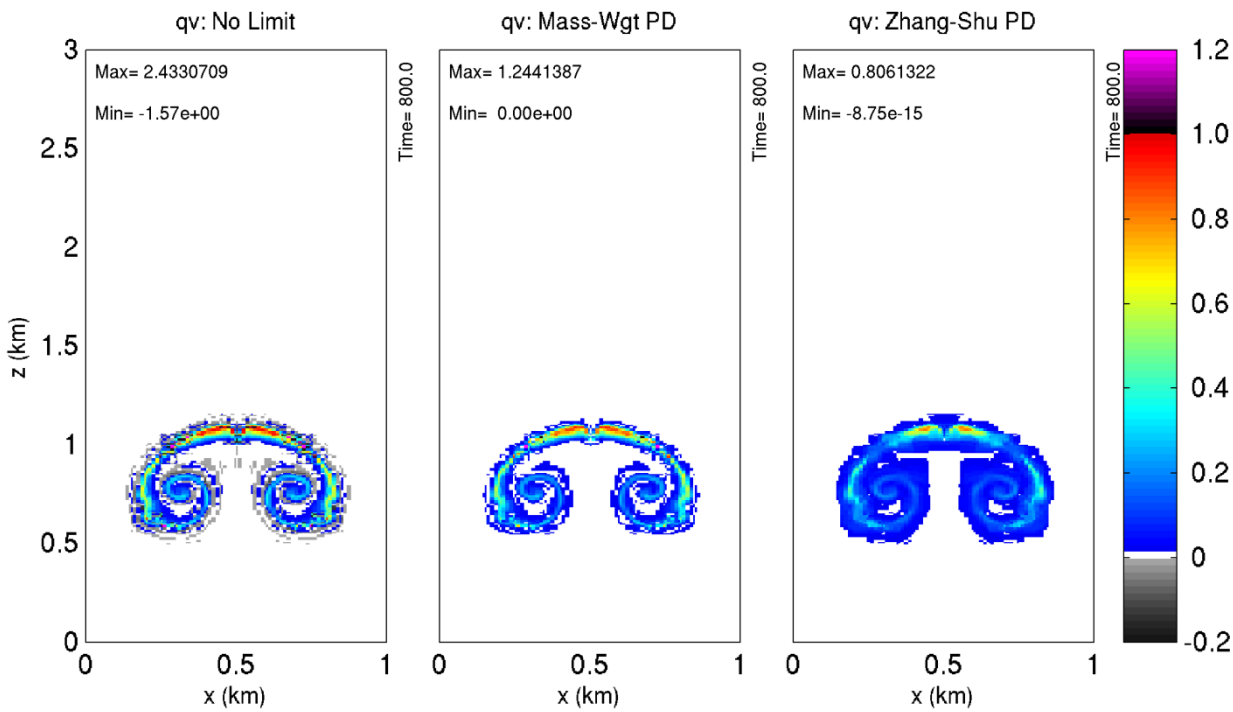

Figure 4: Passive tracer concentration embedded in a thermal bubble, after 800 s. The left panel is for a simulation with no limiter, the center panel uses Mass-Weighted Positive Definiteness method, and the right panel is for Zhang-Shu PD method.

IMPACT/APPLICATIONS

NEPTUNE could become the unified dynamical core for both global and mesoscale weather forecasts 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. The advantage of using a unified model can be exploited to study phenomena spanning various spatial and temporal scales, e.g. Madden-Julian Oscillation and extra-tropical cyclones.

TRANSITIONS

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

RELATED PROJECTS

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