Documentation Templates for Dynamic-core Test Group 2015 (DTG-2015)

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Based on collection using

- Common Information Model from Earth System Documentation (ES-DOC) https://www.earthsystemcog.org/projects/dcmip-2012/metadata as configured for

- The 2012 Dynamical Core Model Intercomparison Project https://www.earthsystemcog.org/projects/dcmip-2012/

For the dynamical core that is chosen for the Next Generation Global Prediction System (NGPPS) a full technical documentation is required. Examples of such documentation are, "A Description of the Advanced Research WRF Version 3," (http://www2.mmm.ucar.edu/wrf/users/docs/arw_v3.pdf) or the suite of documents for the Community Atmosphere Model (CAM, http://www.cesm.ucar.edu/models/cesm1.2/cam/).

Part 1: Overview

Project	DTG-2015
Name of dynamical core	MPAS-MMM
Long Name of dynamical core	Model for Prediction Across Scales
Date this document created	1 February 2016
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Part 2: Documents and Citations

- List the governing equations and the approximation made to the equations.

MPAS integrates the fully compressible nonhydrostatic equations as given in

Skamarock, W. C, J. B. Klemp, M. G. Duda, L. Fowler, S.-H. Park, and T. D. Ringler, 2012: A Multi-scale Nonhydrostatic Atmospheric Model Using Centroidal Voronoi Tesselations and C-Grid Staggering. Mon. Wea. Rev., 140, 30903105. doi:10.1175/MWR-D-11-00215.1

equations (3)-(7). We are using the shallow atmosphere approximation in our integrations, that is, the terms removed with this approximation are disabled in the horizontal and vertical momentum equations (3) and (4) in the MPAS integration.

- Include a description and figure of the vertical structure of the dynamical core as well as the prescription of the vertical coordinate, e.g. hybrid sigma-pressure.

The hybrid vertical coordinate used in MPAS is pictured and described in

KLEMP, J. B. (2011). A Terrain-Following Coordinate with Smoothed Coordinate Surfaces. *Monthly Weather Review*, *139*(7), 2163–2169. doi:10.1175/MWR-D-10-05046.1

Available at http://dx.doi.org/10.1175/MWR-D-10-05046.1

- Peer-reviewed journal articles:

There are a number of published papers documenting the formulation of the nonhydrostatic solver in MPAS. Links to these papers from Bill Skamarock's web page are provided.

(1) The primary reference is

Skamarock, W. C, J. B. Klemp, M. G. Duda, L. Fowler, S.-H. Park, and T. D. Ringler, 2012: A Multi-scale Nonhydrostatic Atmospheric Model Using Centroidal Voronoi Tesselations and C-Grid Staggering. Mon. Wea. Rev., 140, 30903105. doi:10.1175/MWR-D-11-00215.1

http://www2.mmm.ucar.edu/people/skamarock/Papers/cv_49.pdf

The description of MPAS-Atmosphere is reasonably up-to-date. The rationale for the MPAS modeling approach is described in section 2d (Discretization considerations). The discretization of the explicit spatial filters are described in section 2c, and the discretization of the kinetic energy, needed in the vector invariant formulation of the horizontal momentum equation, is also described in section 2c. Discretization of the so-called nonlinear Coriolis term, arising from our use of the vector invariant formulation of the horizontal momentum equation, is not described in this paper; the Ringler et al 2010 JCP paper (see below) contains this description. Also, we are solving the shallow atmosphere equations, but there are terms associated with the deep atmosphere equations found in the momentum equations (equations 3 and 4 in the paper). The terms are not evaluated in our current MPAS-A configuration.

(2) The paper describing the transport scheme used on the unstructured Voronoi mesh to transport scalars (moist species, etc), potential temperature, and vertical momentum, is

Skamarock, W. C. and A. Gassmann, 2011: Conservative Transport Schemes for Spherical Geodesic Grids: High-Order Flux Operators for ODE-Based Time Integration. Mon. Wea. Rev., 139, 2562-2575, doi:10.1175/MWR-D-10-05056.1

http://www2.mmm.ucar.edu/people/skamarock/Papers/cv_47.pdf

We are using the third-order variant of the scheme with an unwinding coefficient of 0.25 (see equation 11 in the paper - beta is the coefficient). The monotonic limiter used in the scheme (essentially that of Zalesak) is described in references found at the end of section 2 in the paper.

(3) Much of the Voronoi-mesh-specific discretization is described in

Ringler,T. D, J Thuburn, J.B Klemp, W. C Skamarock, 2010: A unified approach to energy conservation and potential vorticity dynamics for arbitrarily-structured C-grids. J. Comp. Phys., 229, 3065-3090.

http://www2.mmm.ucar.edu/people/skamarock/Papers/cv_44.pdf

This paper is fairly dense - it presents a derivation of the discretization for the shallow water equations on the Voronoi mesh and a derivation the conservation properties of the discrete solver (mass, energy, enstrophy and PV). Of note, we have modified the computation of the kinetic energy at the cell centers (we are using Skamarock et al 2012 equation 13).

(4) MPAS uses a split-explicit time integration scheme for the fully compressible system cast in conservative form. The scheme is described in

Klemp. J. B., W. C. Skamarock, and J. Dudhia, 2007: Conservative Split-Explicit Time Integration Methods for the Compressible Nonhydrostatic Equations. Mon. Wea. Rev., 135, 2897-2913, doi:10.1175/MWR3440.1

http://www2.mmm.ucar.edu/people/skamarock/Papers/cv_36.pdf

There are a number of ways to cast the governing equations, and while the implementation of the perturbation equations for the acoustic integration in MPAS is slightly different than that presented in the paper, the general aspects of the implementation are the same. The paper also
presents a discussion of 3D divergence damping (i.e. acoustic mode damping) used in MPAS and other compressible nonhydrostatic models

(5) The general 3rd-order Runge-Kutta time-split integration used in MPAS-A is described in

Wicker, L. J., and W. C. Skamarock, 2002: Time Splitting Methods for Elastic Models Using Forward Time Schemes. Mon. Wea. Rev., 130, 2088-2097

http://www2.mmm.ucar.edu/people/skamarock/Papers/cv_30.pdf

This reference is included because the Klemp et al (2007) paper does not specifically address the main time integrator in its discussion of splitting.

(6) MPAS is cast in a generalized hybrid terrain-following geometric height coordinate – the first equation set discussed in the paper. The MPAS implementation of the height coordinate follows the description of the height coordinate in

KLEMP, J. B. (2011). A Terrain-Following Coordinate with Smoothed Coordinate Surfaces. *Monthly Weather Review*, *139*(7), 2163–2169. doi:10.1175/MWR-D-10-05046.1

Available at

http://dx.doi.org/10.1175/MWR-D-10-05046.1

(7) The gravity-wave absorbing layer used in MPAS is described in

KLEMP, J. B., Dudhia, J., & Hassiotis, A. D. (2008). An Upper Gravity-Wave Absorbing Layer for NWP Applications. Monthly Weather Review, 136(10), 3987–4004. doi:10.1175/2008MWR2596.1

available at

http://journals.ametsoc.org/doi/abs/10.1175/2008MWR2596.1

- Technical documentation: See the MPAS website and the MPAS-Atmosphere download page at http://mpas-dev.github.io/

- User's guide:

  http://www2.mmm.ucar.edu/projects/mpas/mpas_atmosphere_users_guide_4.0.pdf

- Software repository, management (e.g. GitHub): GitHub -

  http://mpas-dev.github.io/

- Open source? YES. If yes, license:

MPAS license:

Part 3: Summary of Technical Details:

Accompanying Spread Sheet