MPAS

Model for Prediction Across Scales

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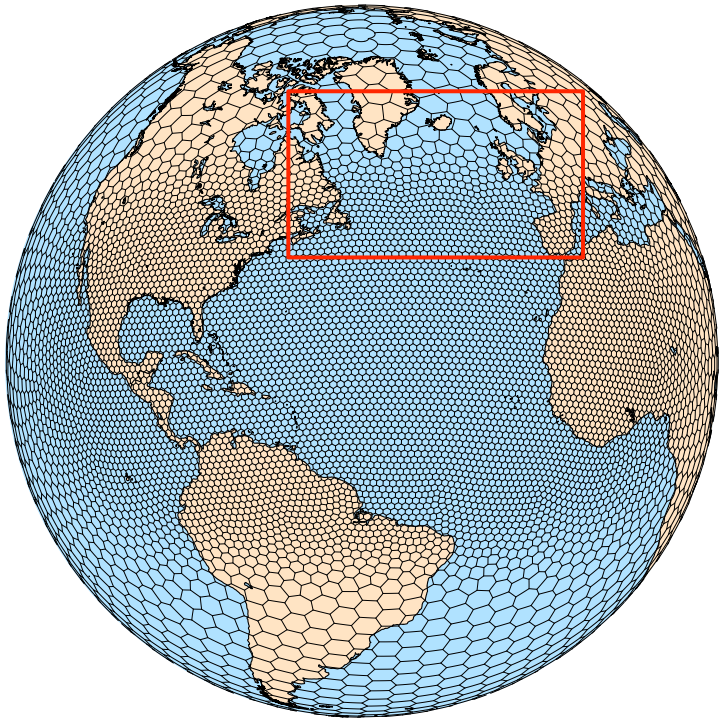
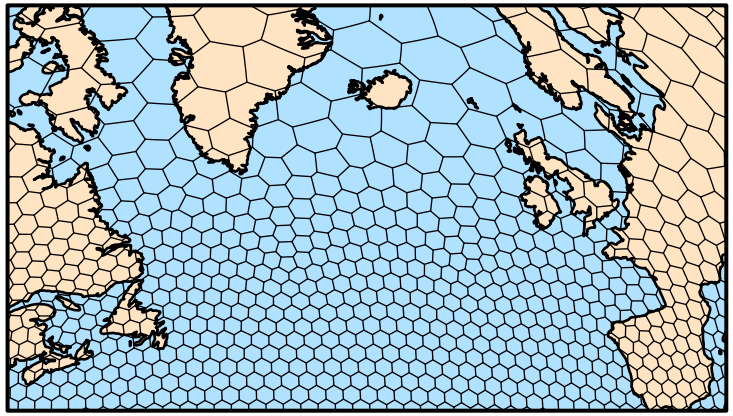
National Center for Atmospheric Research



Based on unstructured centroidal Voronoi (hexagonal) meshes using C-grid staggering and selective grid refinement.



Collaboratively developed, primarily by NCAR and LANL/DOE

MPAS infrastructure - NCAR, LANL, others.
MPAS - Atmosphere (NCAR)
MPAS - Ocean (LANL)
MPAS - Ice, etc. (LANL and others)

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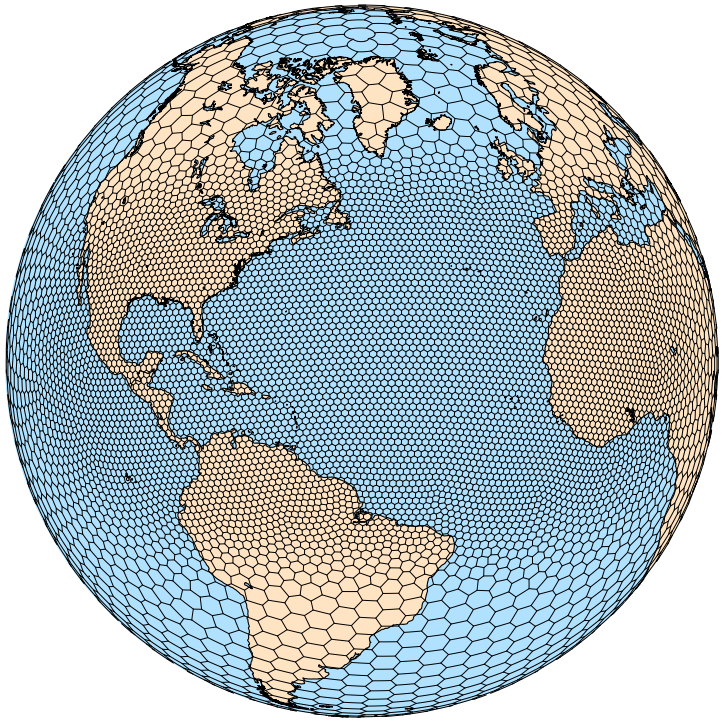

- *Overview*
- Mesh description
- Atmospheric solver, physics
- Registry, installation, running MPAS
- MPAS support, future evolution

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What is MPAS?

MPAS Version 2.1:

MPAS infrastructure - NCAR, LANL, others.

Infrastructure for the Voronoi mesh and solvers (data structures; mesh generation, manipulation; operators on the mesh).

MPAS - Atmosphere (NCAR)

Nonhydrostatic atmospheric solver; pre- and post-processors

MPAS - Ocean (LANL)

Hydrostatic ocean solver, pre- and post-processors

MPAS - Ice, etc. (LANL and others)

Land-ice model, pre- and post-processors

These are all stand-alone models – there is no coupler in MPAS

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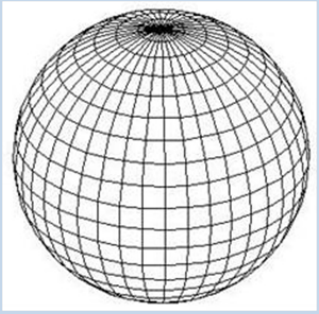
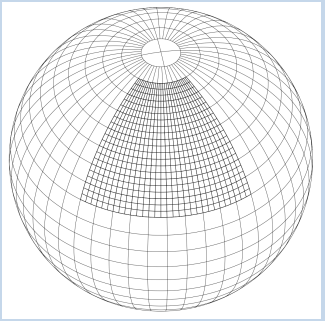
Why MPAS?

Significant differences between WRF and MPAS

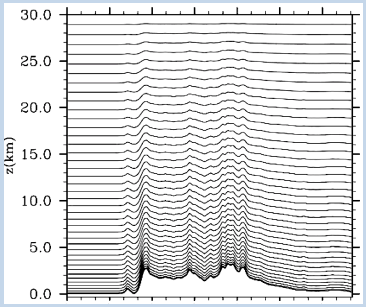
WRF Characteristics



- Lat-Lon global grid
  - Anisotropic grid cells
  - Polar filtering required
  - Poor scaling on massively parallel computers

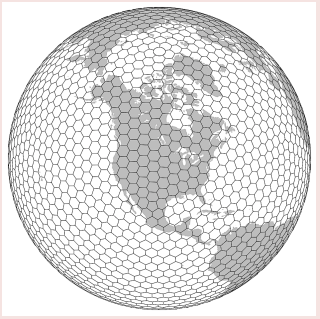


- Grid refinement through domain nesting
  - Flow distortions at nest boundaries

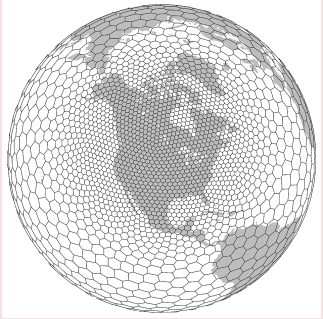


- Pressure-based terrain-following sigma vertical coordinate

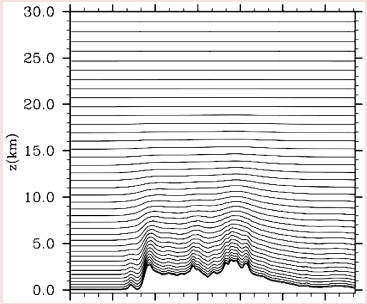
MPAS Characteristics



- Unstructured Voronoi (hexagonal) grid
  - Good scaling on massively parallel computers
  - No pole problems



- Smooth grid refinement on a conformal mesh
  - Increased accuracy and flexibility in varying resolution



- Height-based hybrid smoothed terrain-following vertical coordinate
  - Improved numerical accuracy

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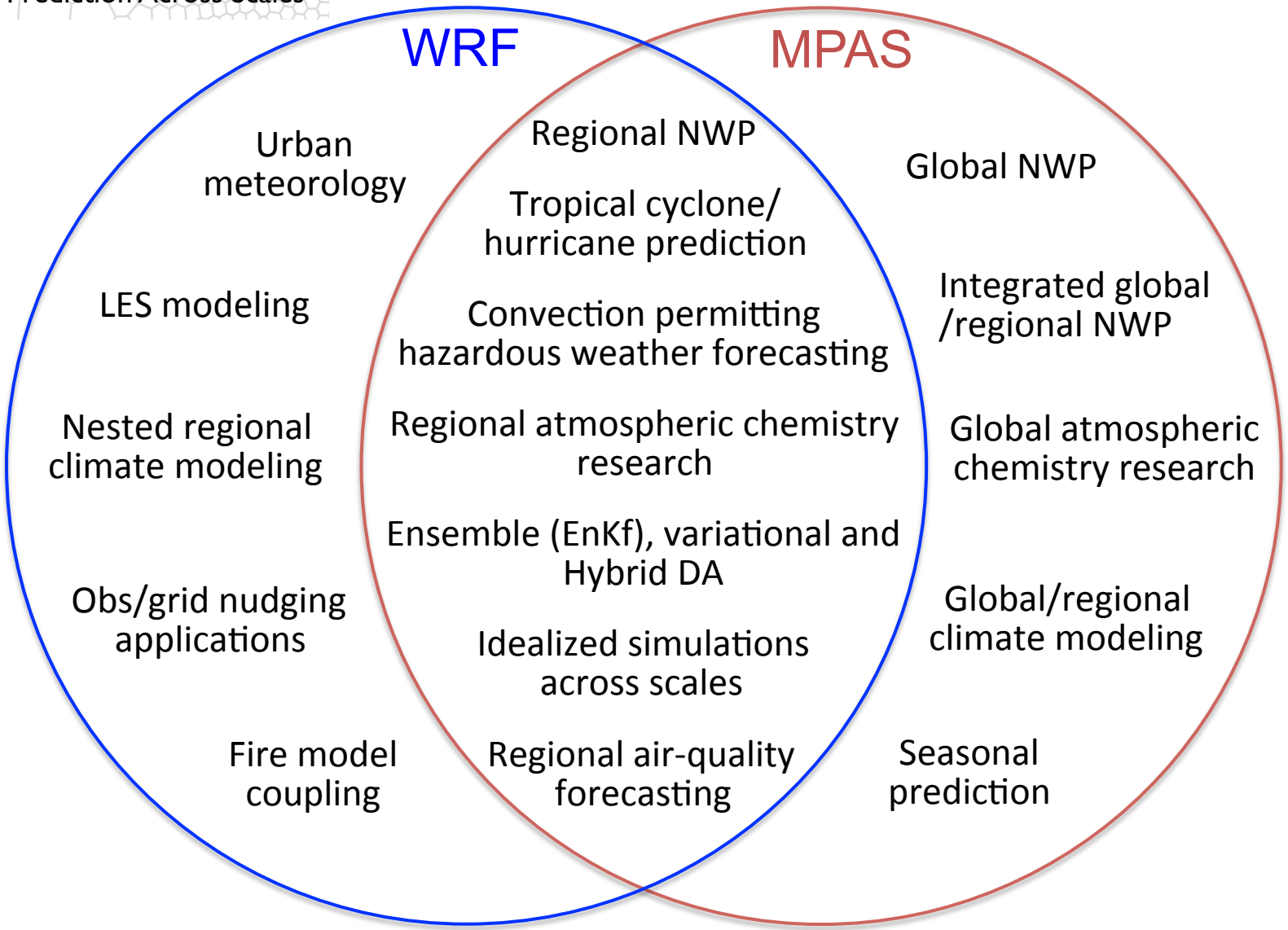
MPAS and WRF Applications



MPAS is not intended to replace WRF!

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MPAS Nonhydrostatic Atmospheric Solver

Nonhydrostatic formulation

Equations

- Prognostic equations for coupled variables.
- Generalized height coordinate.
- Horizontally vector invariant eqn set.
- Continuity equation for dry air mass.
- Thermodynamic equation for coupled potential temperature.

Time integration scheme

As in Advanced Research WRF - Split-explicit Runge-Kutta (3rd order)

Variables:

$$(U, V, \Omega, \Theta, Q_j) = \tilde{\rho}_d \cdot (u, v, \dot{\eta}, \theta, q_j)$$

Vertical coordinate:

$$z = \zeta + A(\zeta)\, h_s(x, y, \zeta)$$

Prognostic equations:

$$\frac{\partial \boldsymbol{V}_H}{\partial t} = -\frac{\rho_d}{\rho_m}\left[\nabla_\zeta\left(\frac{p}{\zeta_z}\right) - \frac{\partial z_H p}{\partial \zeta}\right] - \eta\, \boldsymbol{k} \times \boldsymbol{V}_H$$
$$- \boldsymbol{v}_H \nabla_\zeta \cdot \boldsymbol{V} - \frac{\partial \Omega \boldsymbol{v}_H}{\partial \zeta} - \rho_d \nabla_\zeta K - eW\cos\alpha_r - \frac{uW}{r_e} + \boldsymbol{F}_{V_H},$$

$$\frac{\partial W}{\partial t} = -\frac{\rho_d}{\rho_m}\left[\frac{\partial p}{\partial \zeta} + g\tilde{\rho}_m\right] - \left(\nabla \cdot \boldsymbol{v} W\right)_\zeta$$
$$+ \frac{uU + vV}{r_e} + e\left(U\cos\alpha_r - V\sin\alpha_r\right) + F_W,$$

$$\frac{\partial \Theta_m}{\partial t} = -\left(\nabla \cdot \boldsymbol{V}\, \theta_m\right)_\zeta + F_{\Theta_m},$$

$$\frac{\partial \tilde{\rho}_d}{\partial t} = -\left(\nabla \cdot \boldsymbol{V}\right)_\zeta,$$

$$\frac{\partial Q_j}{\partial t} = -\left(\nabla \cdot \boldsymbol{V}\, q_j\right)_\zeta + \rho_d S_j + F_{Q_j},$$

Diagnostics and definitions:

$$\theta_m = \theta[1 + (R_v/R_d) q_v] \qquad p = p_0\left(\frac{R_d \zeta_z \Theta_m}{p_0}\right)^\gamma$$

$$\frac{\rho_m}{\rho_d} = 1 + q_v + q_c + q_r + \ldots$$

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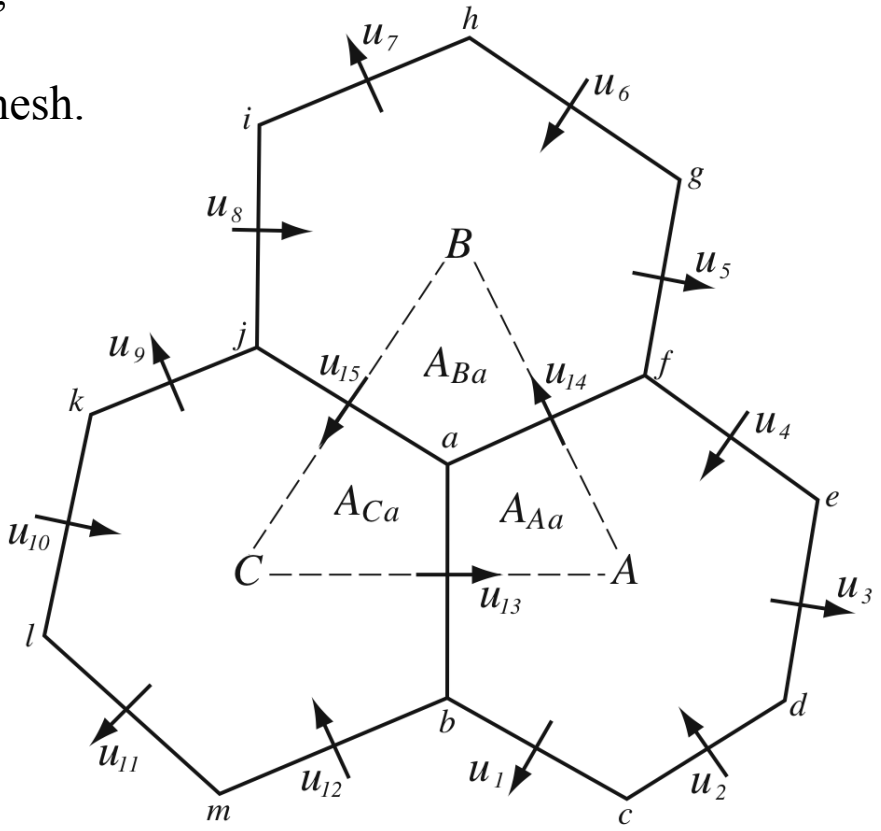
Centroidal Voronoi Meshes

Unstructured spherical centroidal Voronoi meshes

- Mostly *hexagons*, some pentagons and 7-sided cells
- Cell centers are at cell center-of-mass (centroidal).
- Cell edges bisect lines connecting cell centers; perpendicular.
- Uniform resolution – traditional icosahedral mesh.

C-grid

- Solve for normal velocities on cell edges.
- Gradient operators in the horizontal momentum equations are 2nd-order accurate.
- Velocity divergence is 2nd-order accurate for edge-centered velocities.
- Reconstruction of full velocity requires care.



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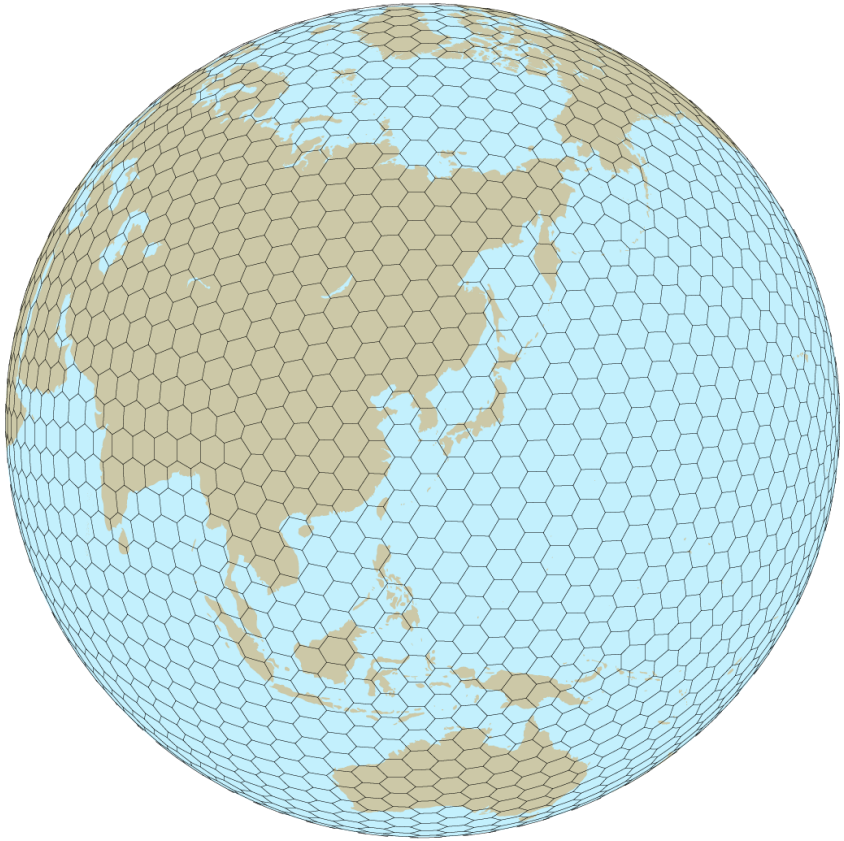
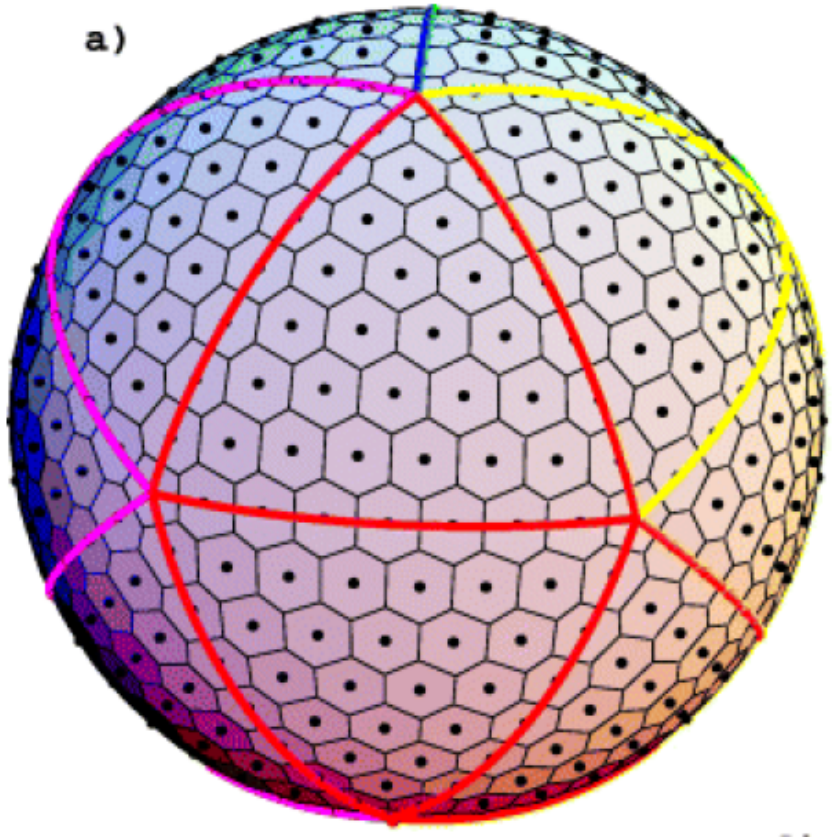
Global Meshes



Global Quasi-Uniform Mesh
(SCVT)



Many models use an icsoahedral mesh
(NICAM, BUGS, FIM, NIM, OLAM, etc.)

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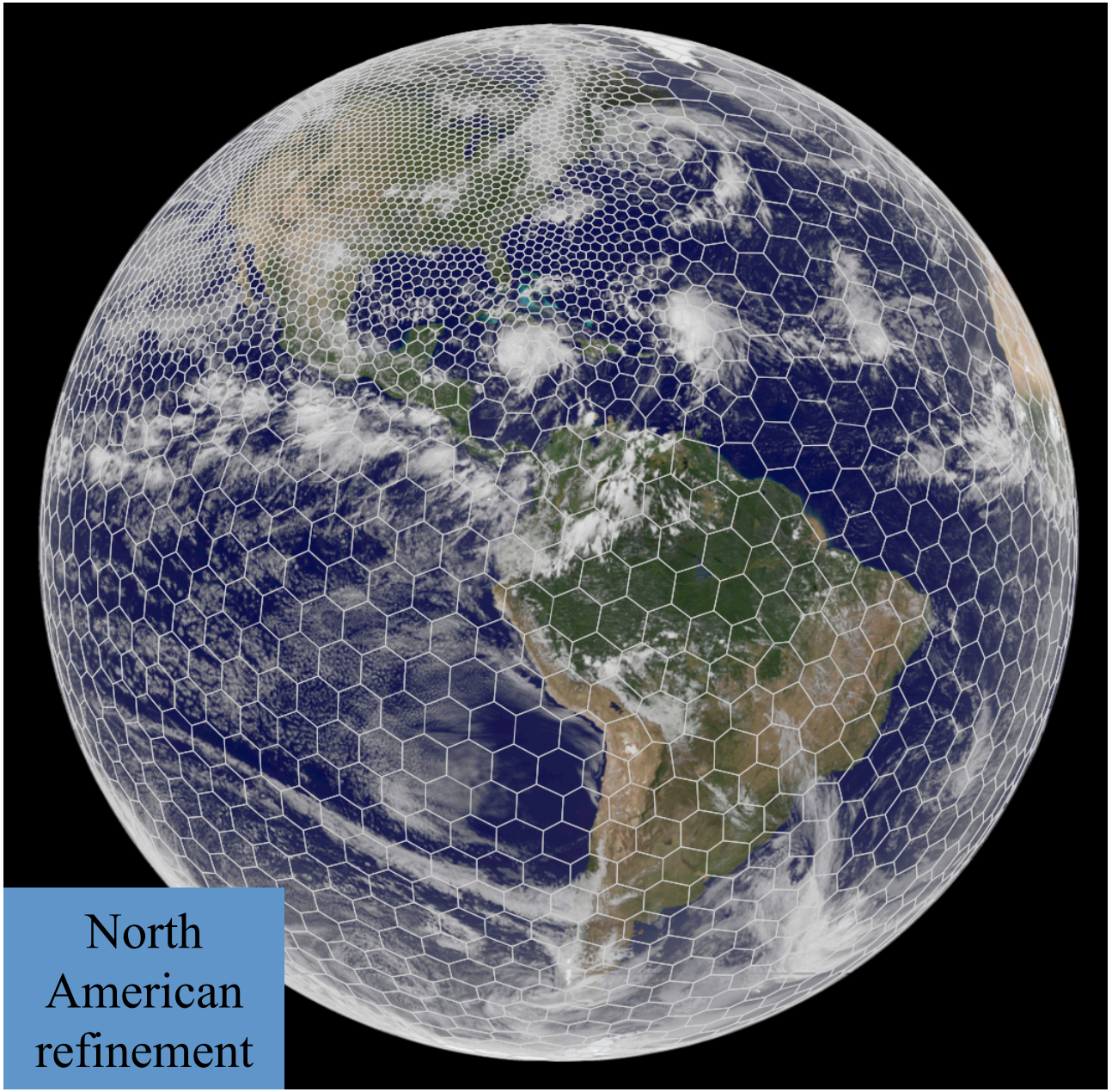
Mesh generation

Lloyd's method
(iterative)
using a user-supplied
density function



North American refinement

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Model for Prediction Across Scales

Mesh generation

Lloyd's method
(iterative)
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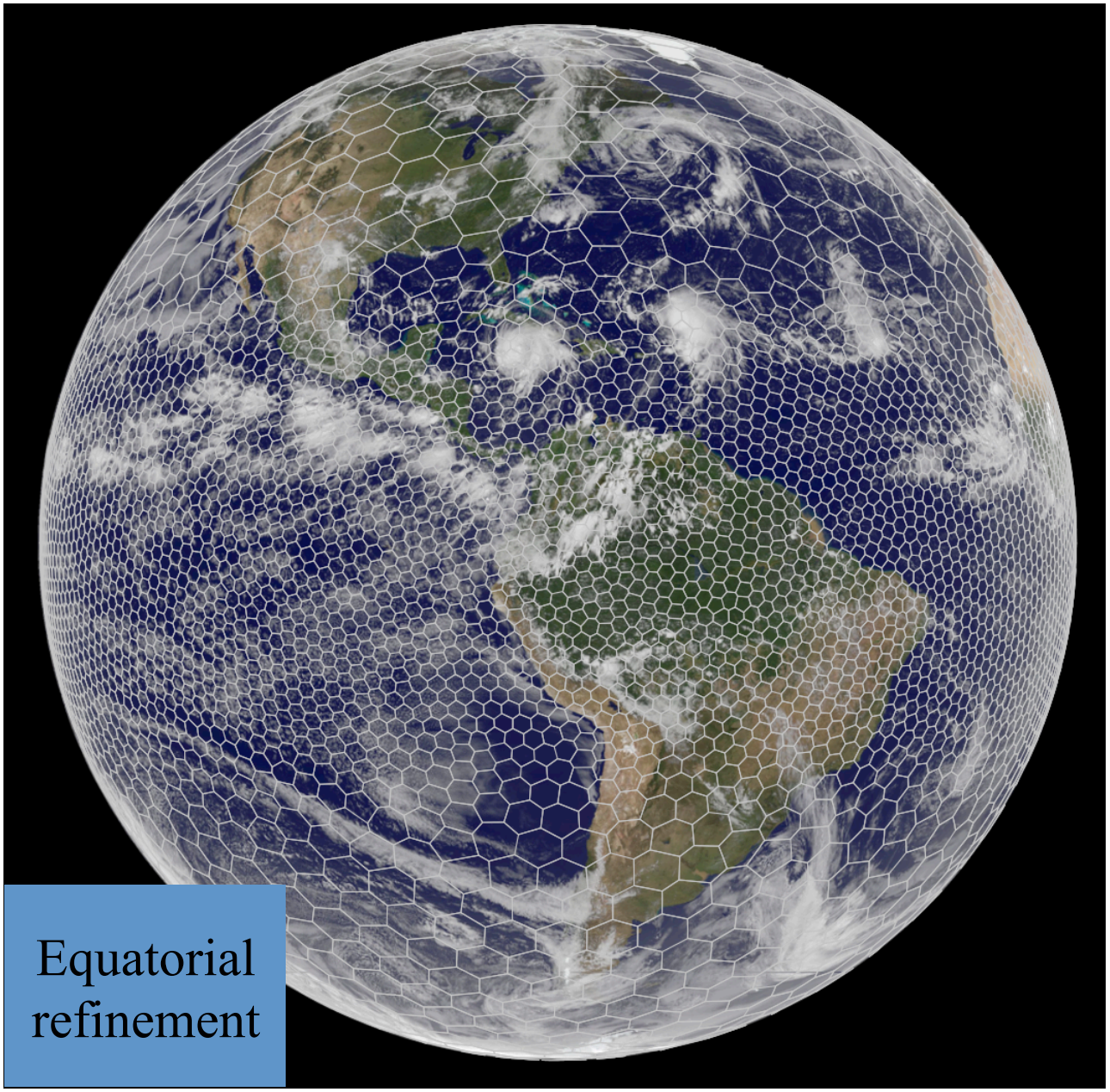
density function



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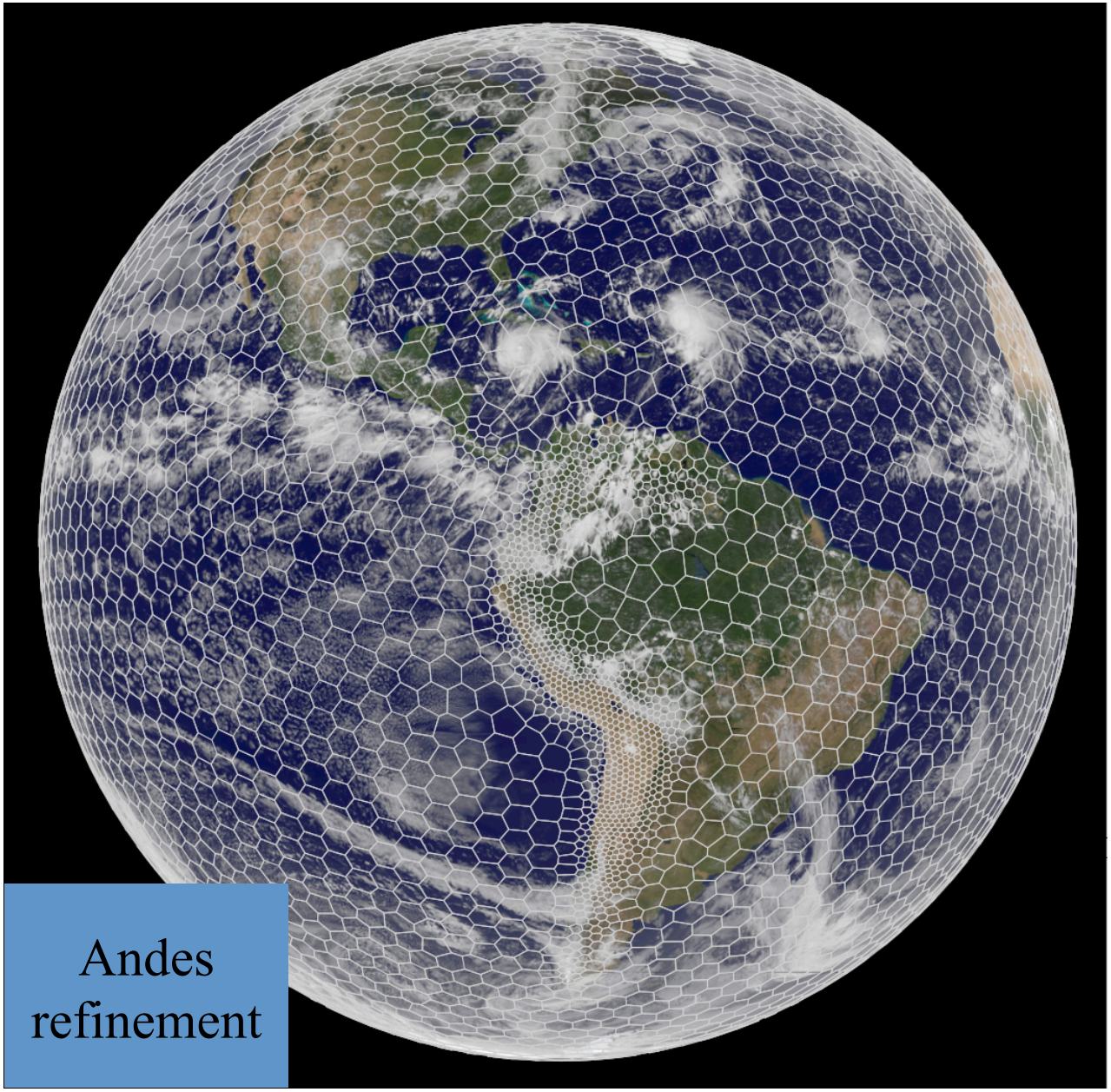

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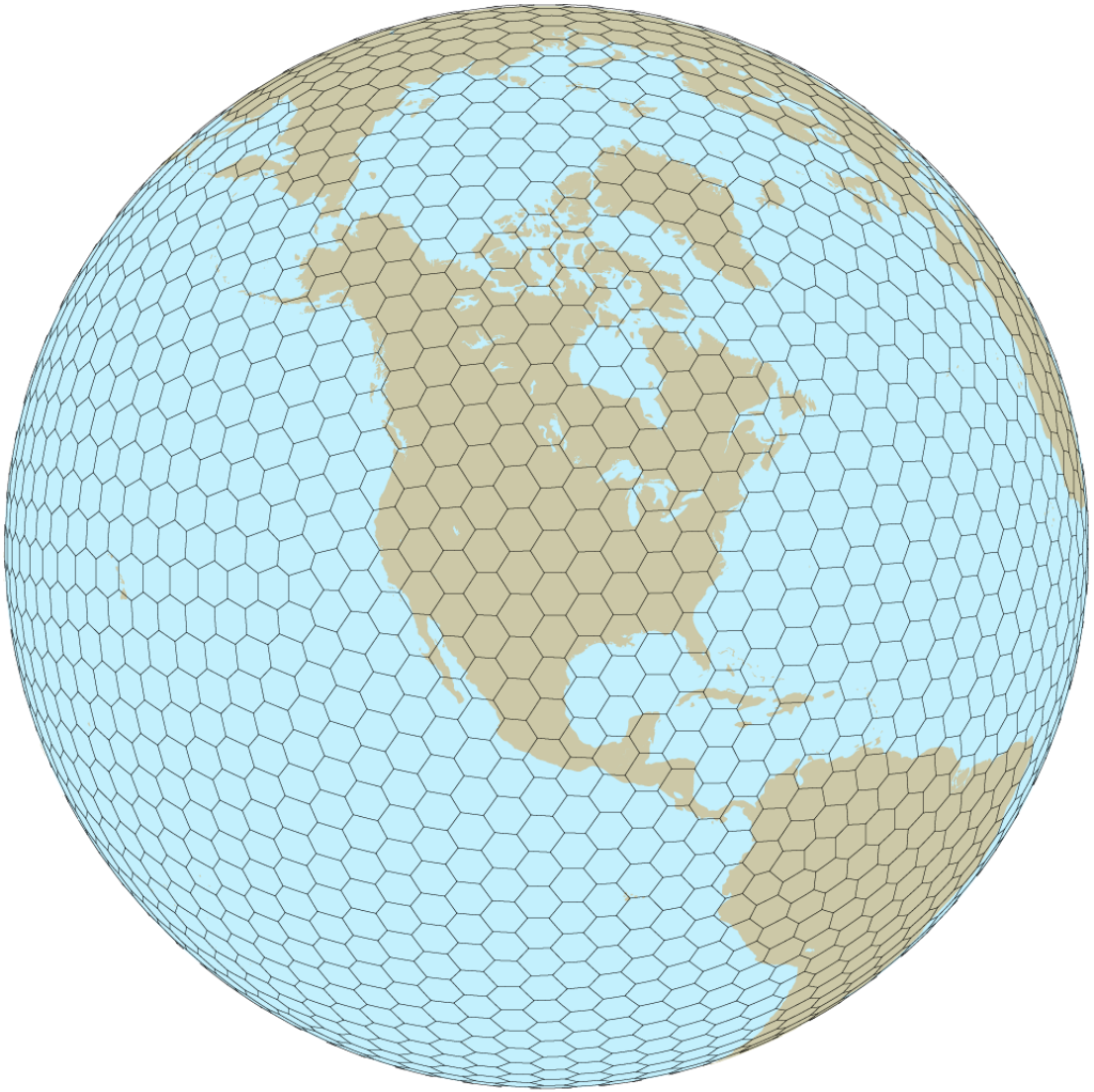
Global Meshes and Local Refinement



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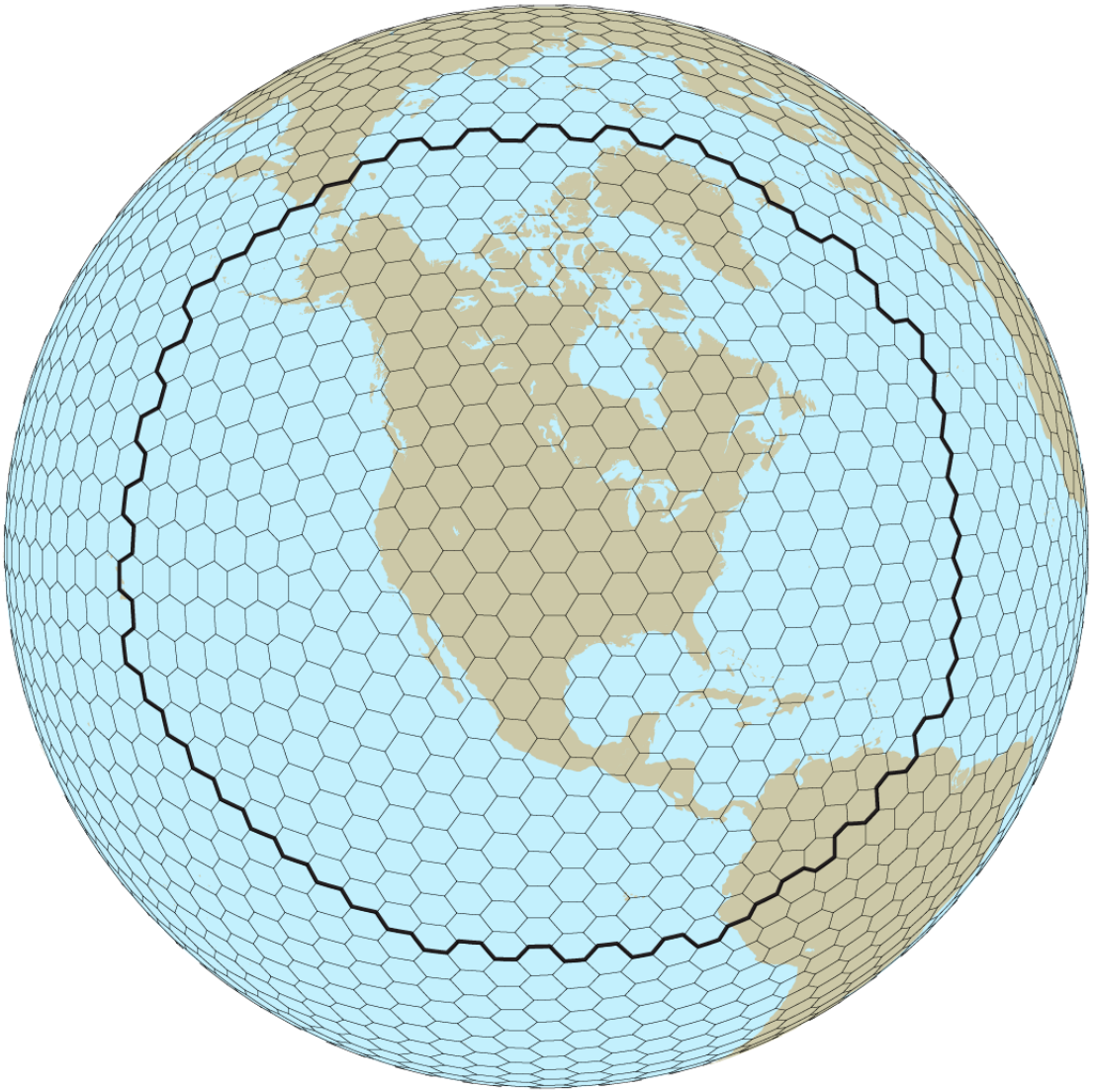
Global Meshes and Local Refinement



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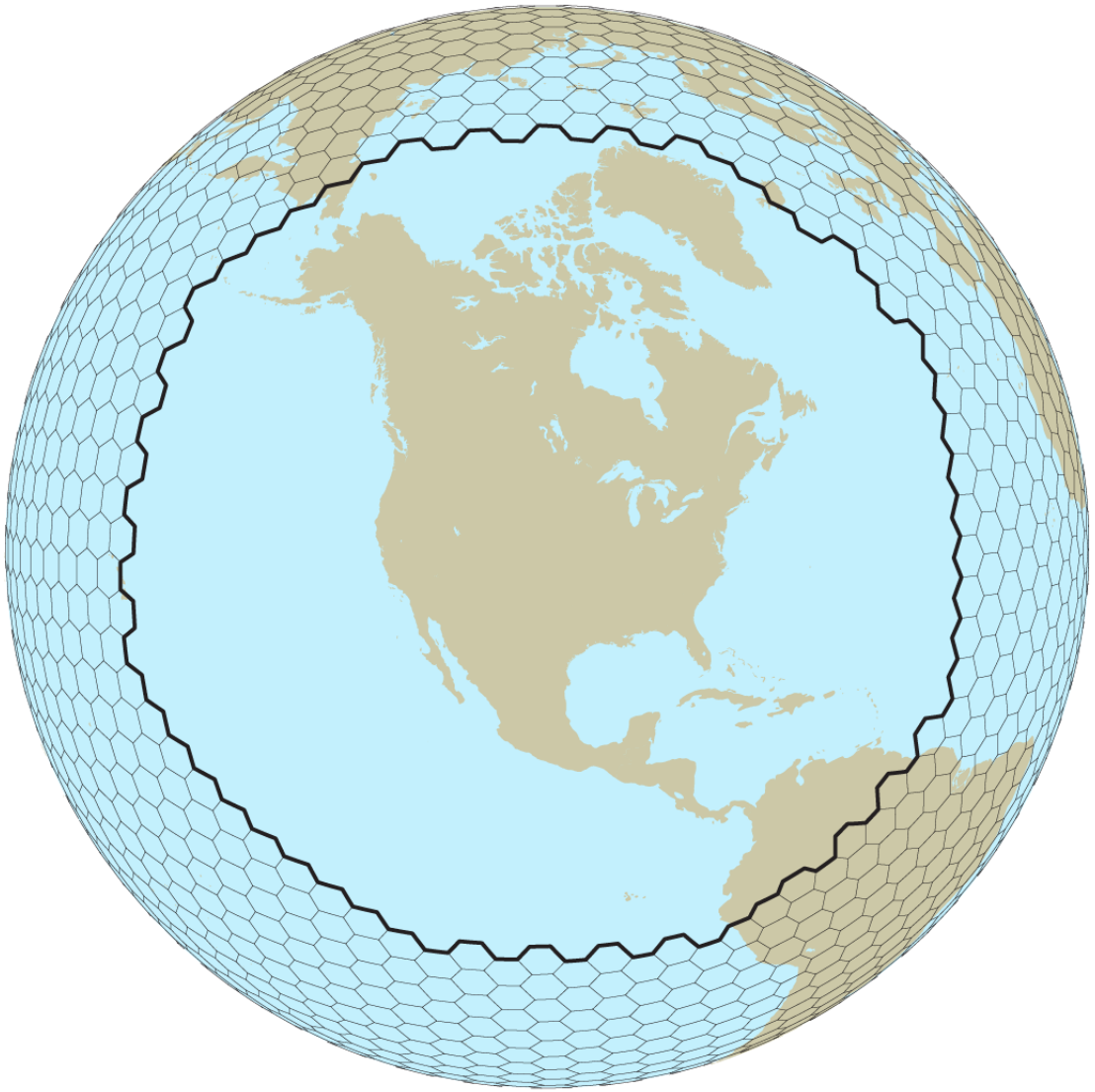

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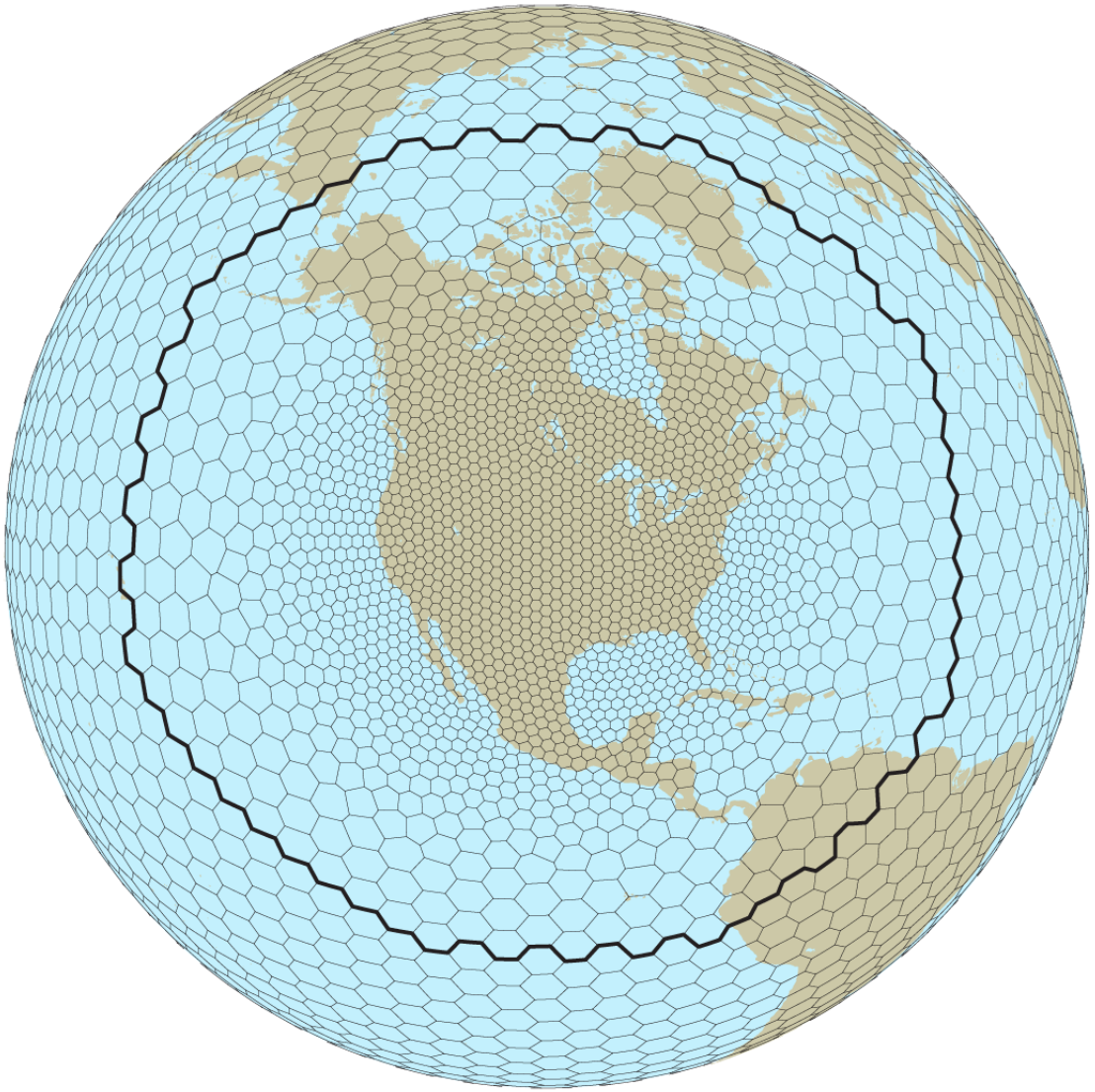

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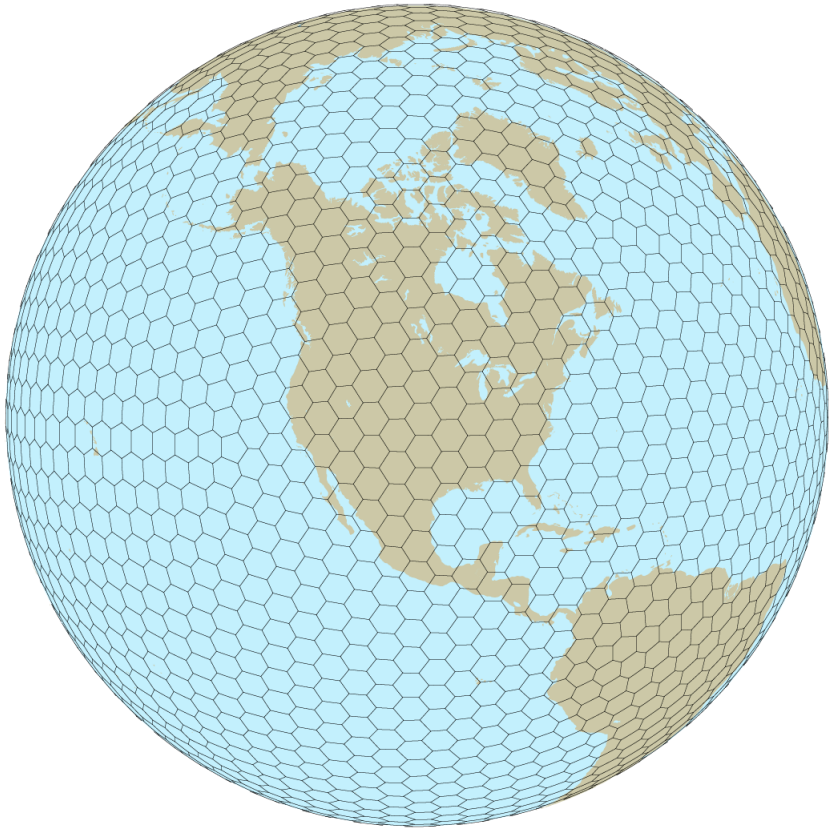
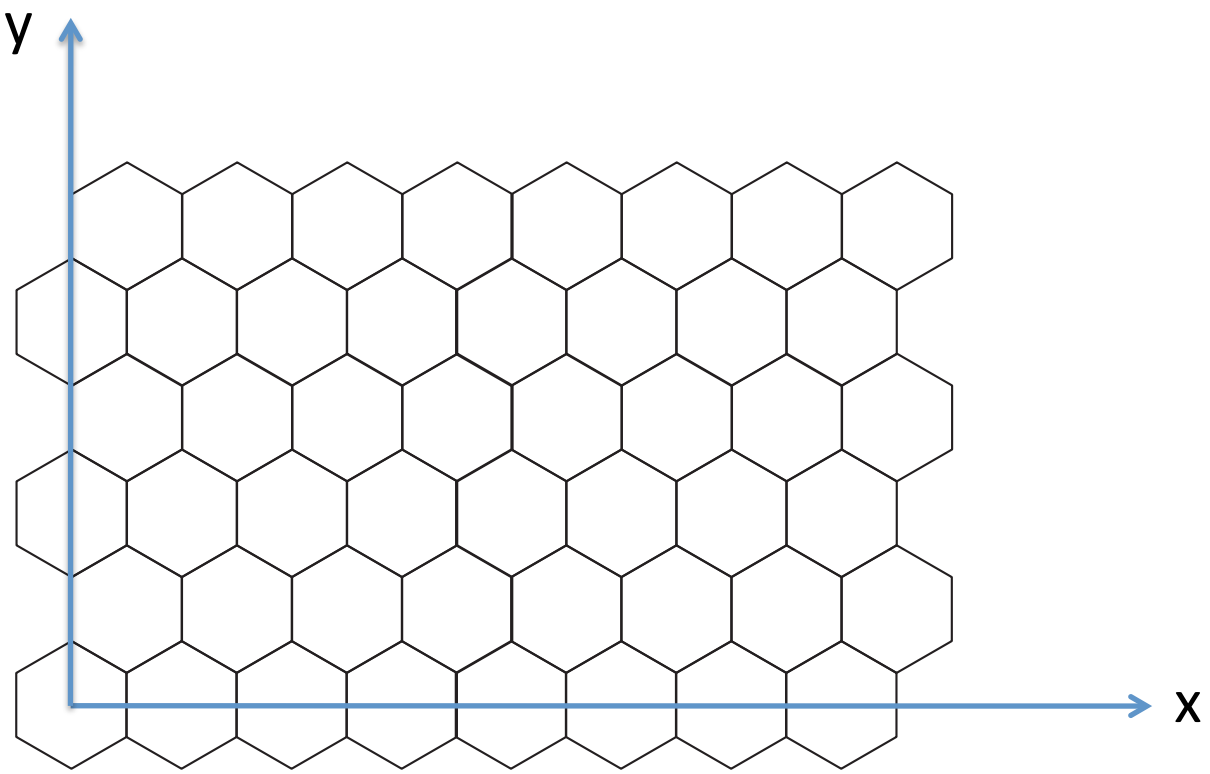
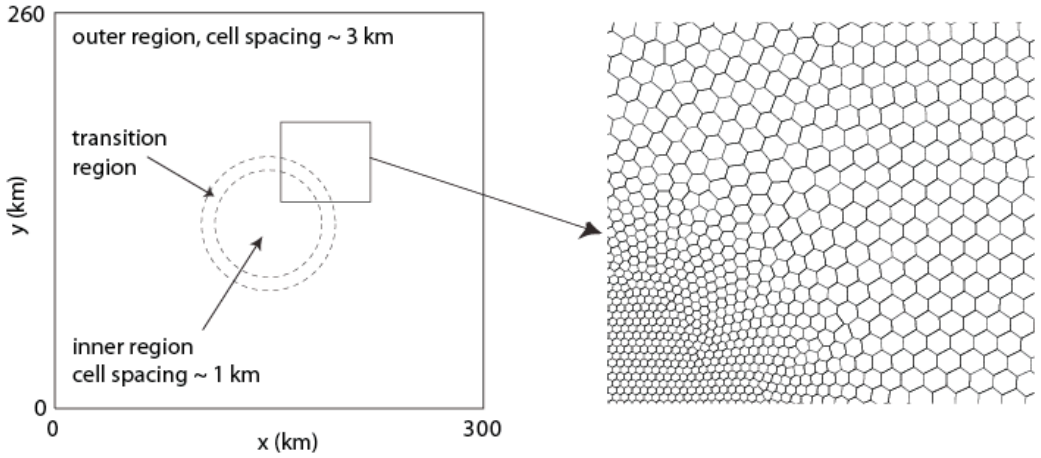


Uniform Cartesian Mesh

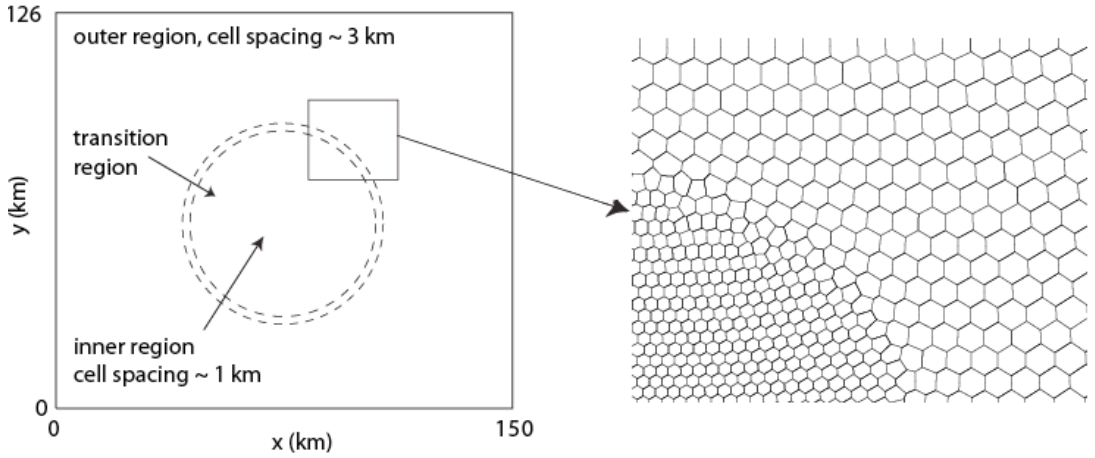


Non-Uniform Cartesian Mesh

Mesh with smooth transition

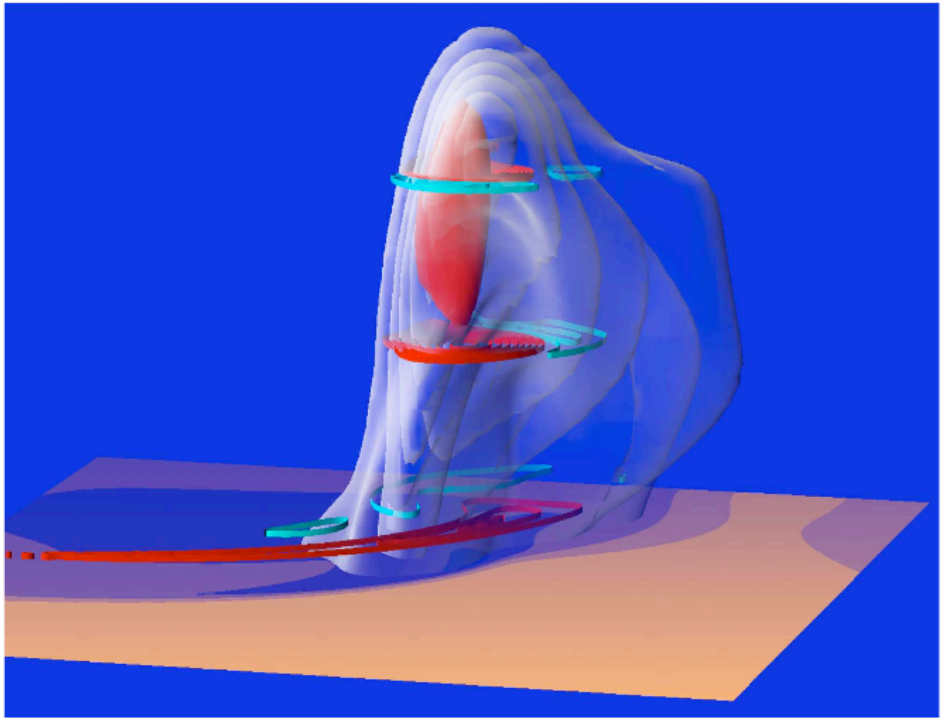


Mesh with abrupt transition

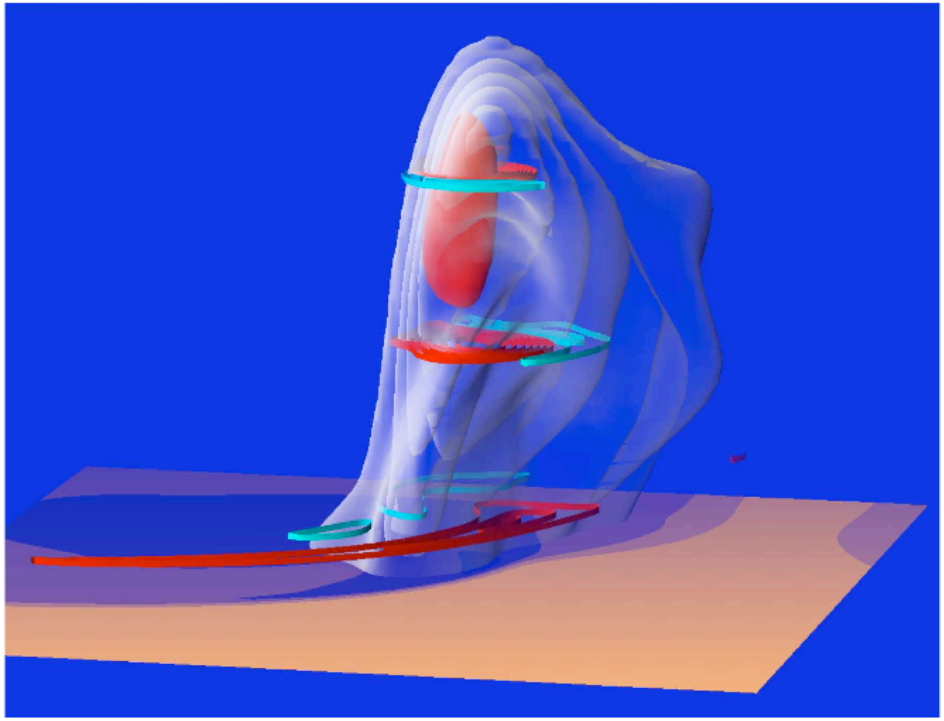


Supercell Tests

Low-level shear (0-5 km, 30 m/s), Weisman-Klemp sounding,
Warm-bubble perturbation, Periodic in x and y (Lx, Ly ~ 84 km),
3D (x,y,z) simulations, Δh = 500 m



(a) Hexagonal mesh simulation



(b) Rectangular mesh simulation

Vertical velocity contours at 1, 5, and 10 km (c.i. = 3 m/s)

30 m/s vertical velocity surface shaded in red

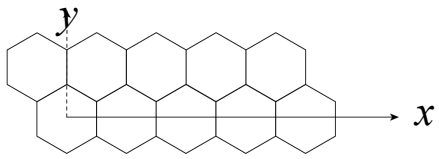
Rainwater surfaces shaded as transparent shells

Perturbation surface temperature shaded on baseplane

MPAS Nonhydrostatic Core

2D Mountain Waves - Schar Test Case

2D (y,z) simulations
Based on 3D doubly
periodic (*x,y*) config.



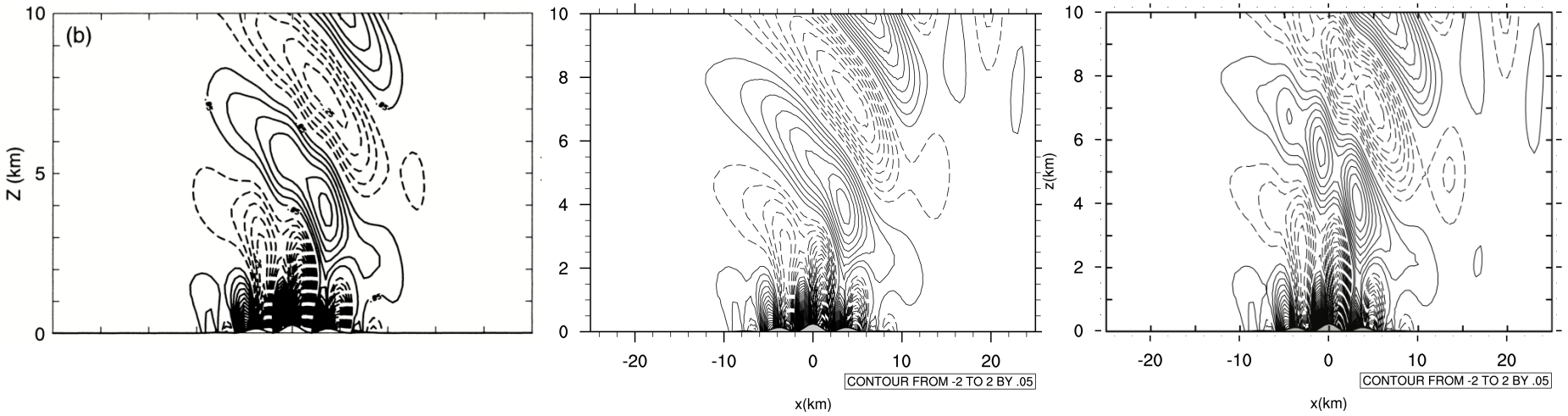
U = 10 ms^{-1} Δx = 500 m

N = .01 s^{-1} Δz = 300 m

Analytic reference solution

MPAS, 4th-order advection
4th order Ω reconstruction

MPAS, 4th-order advection
2nd order Ω reconstruction



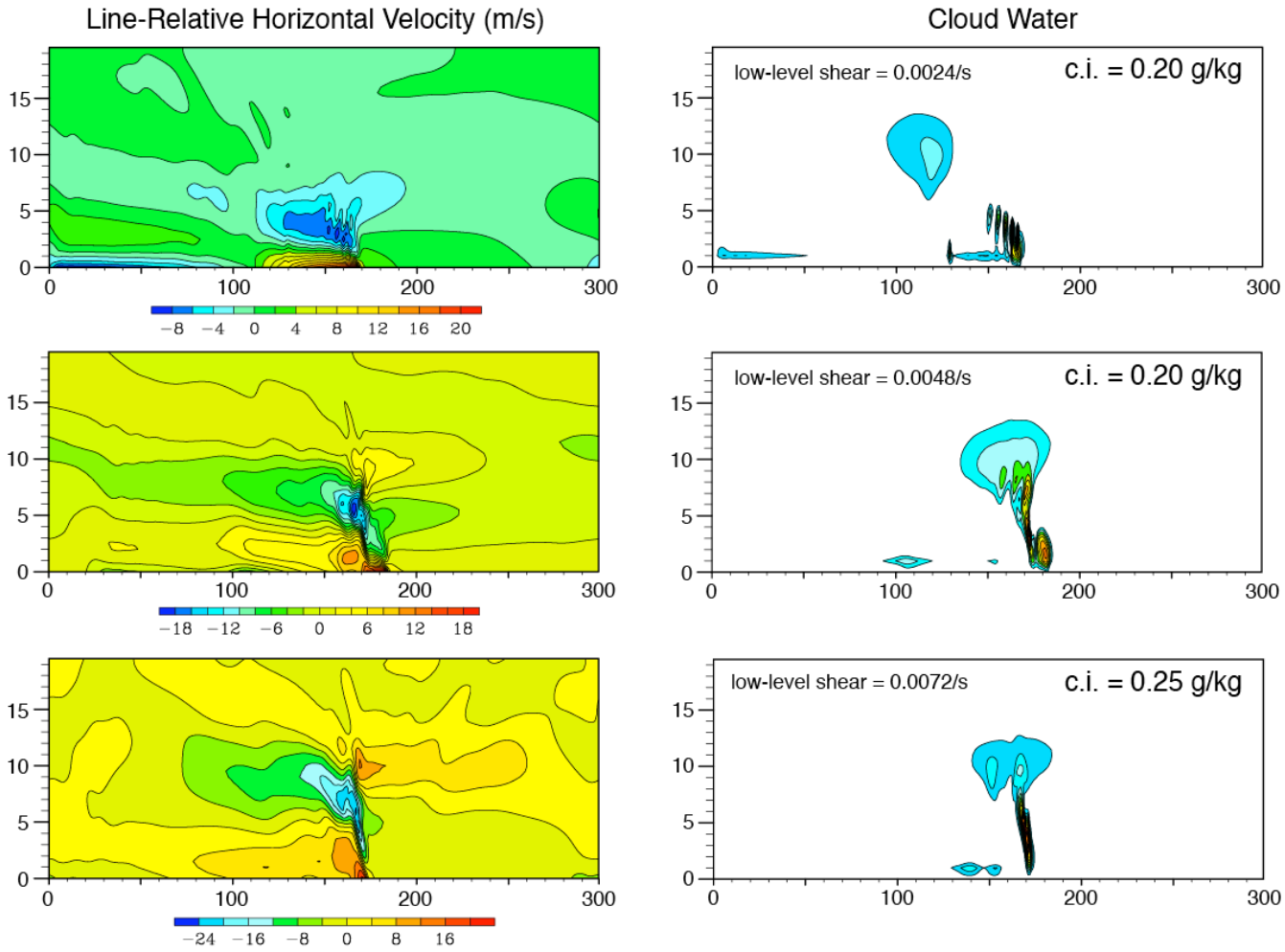
Confirms that numerical accuracy of terrain metric terms
is consistent with accuracy of advection

(Schar et al. MWR 2000)

Squall-Line Tests

Low-level shear (0-2.5 km), Weisman-Klemp sounding

Warm-bubble perturbation, results at 3 hours



(from Max Menchaca)

MPAS physics

MPAS Version 2.1 release

Surface Layer: (Monin Obukhov): module_sf_sfclay.F as in WRF 3.5.

PBL: YSU as in WRF 3.4.1.

Land Surface Model (NOAH 4-layers): as in WRF 3.3.1.

Gravity Wave Drag: as in WRF 3.5.

Convection: Kain-Fritsch: WRF 3.5; Tiedtke: as in WRFV3.3.1.

Microphysics: WSM6: as in WRF 3.5; Kessler (warm rain): as in WRFV3.5

Radiation: RRTMG sw as in WRF 3.4.1; RRTMG lw as in WRF 3.4.1; CAM radiation as in WRF 3.3.1, with some additions from WRF 3.5.

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Our plan is to support physics *suites,* with this suite being the *MPAS-WRF physics suite.*

Testing Status

Idealized tests

- Cartesian plane 2D and 3D tests: mountain waves, convection
- J&W (2006) baroclinic wave test, various DCMIP and HIWPP tests on the reduced radius sphere.

Test forecasts

- Forecast tests for various periods on 120, 60, 30, 15, 7,5 and 3 km MPAS global quasi-uniform meshes.
- Real-time TC experiment, 1 Aug – 30 Sept 2013, using (1) 15 km global mesh and (2) 60-15 km variable-resolution mesh. We will be performing a similar experiment for 1 Aug – 31 Oct 2014.
- Year-long integrations using a 90-25 km mesh for regional-climate TC evaluation.

MPAS 2.1 Release

MPAS release is available at

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

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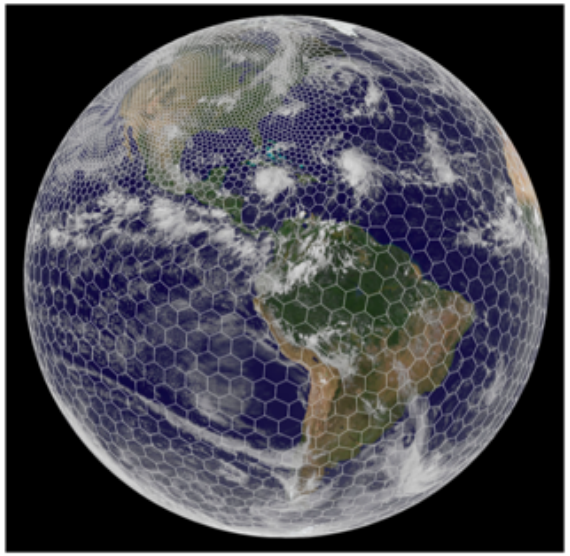

The Model for Prediction Across Scales (MPAS) is a collaborative project for developing atmosphere, ocean and other earth-system simulation components for use in climate, regional climate and weather studies. The primary development partners are the climate modeling group at Los Alamos National Laboratory (COSIM) and the National Center for Atmospheric Research. Both primary partners are responsible for the MPAS framework, operators and tools common to the applications; LANL has primary responsibility for the ocean and land ice models, and NCAR has primary responsibility for the atmospheric model.

The defining features of MPAS are the unstructured Voronoi meshes and C-grid discretization used as the basis for many of the model components. The unstructured Voronoi meshes, formally Spherical Centriodal Voronoi Tesselations (SCVTs), allow for both quasi-uniform discretization of the sphere and local refinement. The C-grid discretization, where the normal component of velocity on cell edges is prognosed, is especially well-suited for higher-resolution, mesoscale atmosphere and ocean simulations. The land ice model takes advantage of the SCVT-dual mesh, which is a triangular Delaunay tessellation appropriate for use with Finite-Element-based discretizations.

The current MPAS release is version 2.1. Please refer to each core for changes, and the github repository for source.

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MPAS Atmosphere Public Releases

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MPAS Atmosphere 2.1 was released on 6 June 2014.

Any questions related to building and running MPAS-Atmosphere should be directed to the MPAS-Atmosphere Help forum. Posting to the forum requires a free google account. Alternatively, questions may be sent from any e-mail address to "mpas-atmosphere-help **AT** googlegroups.com". *Please note that in either case, questions and their answers will appear on the online forum.*

MPAS Atmosphere 2.1 release notes

MPAS source code download

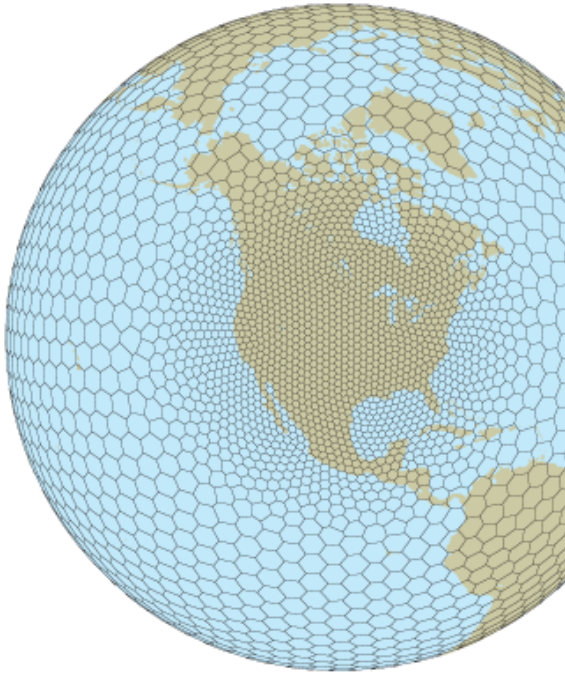
MPAS Atmosphere Users Guide

MPAS Atmosphere meshes

Configurations for idealized test cases

Sample input files for real-data simulations

Visualization and analysis tools



A variable resolution MPAS Voronoi mesh