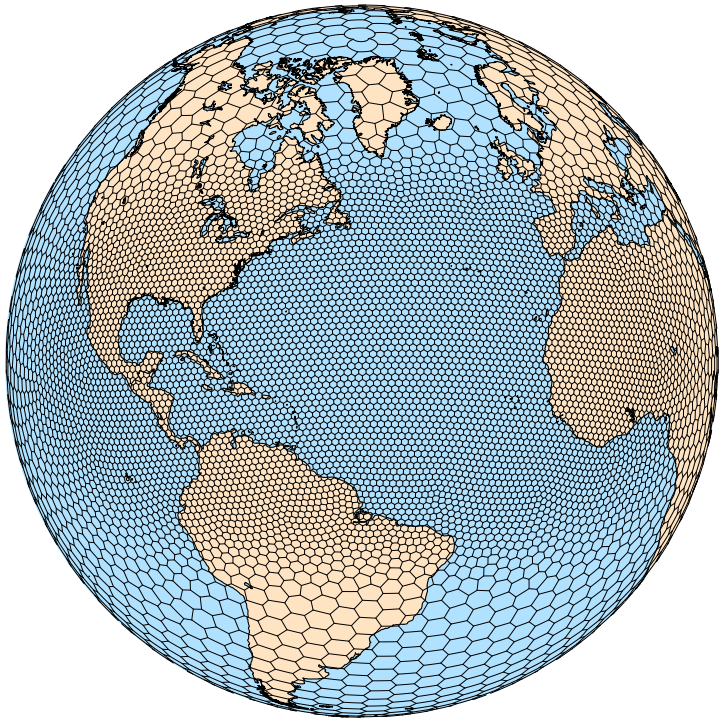
MPAS

Model for Prediction Across Scales



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

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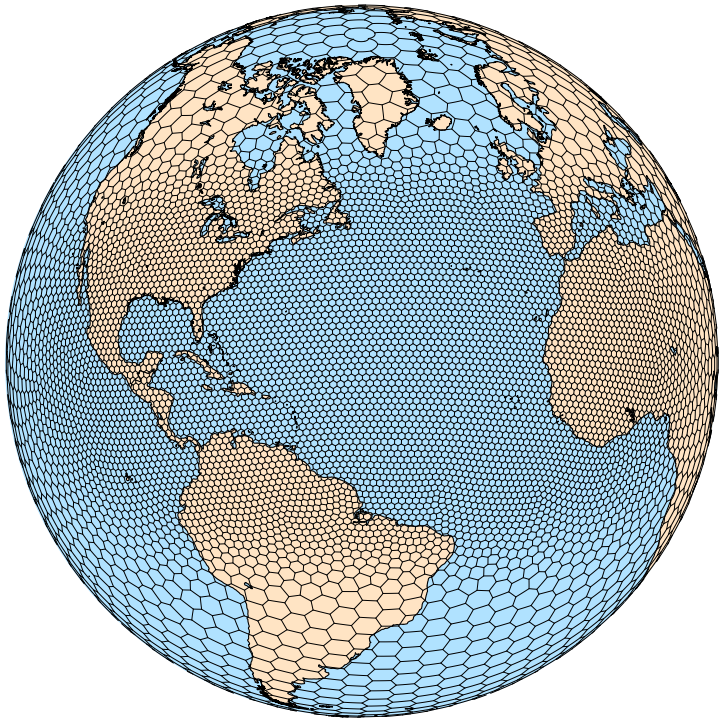
Model for Prediction Across Scales



- Overview
- Mesh description
- *Atmospheric solver, physics*

  Vertical coordinate, horizontal discretization: gradients, flux divergence, Coriolis term.

  Configuration of dynamics and physics

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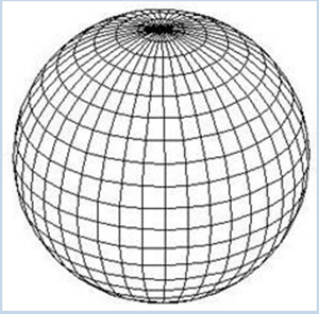
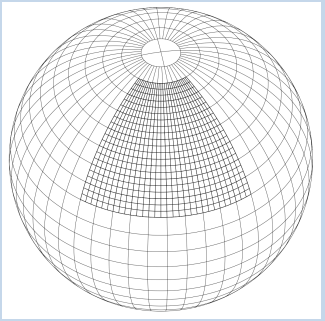
MPAS-Atmosphere solver

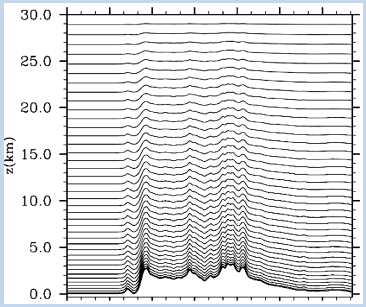
WRF Characteristics



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

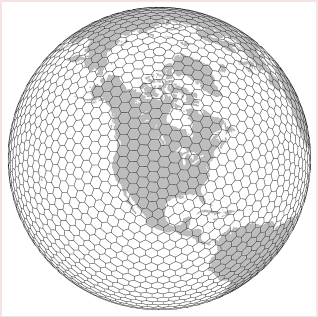


- Grid refinement through domain nesting
  - Flow distortions at nest boundaries

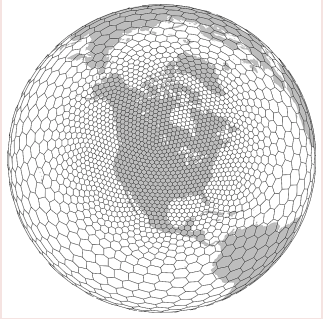


- Pressure-based terrain-following sigma vertical coordinate

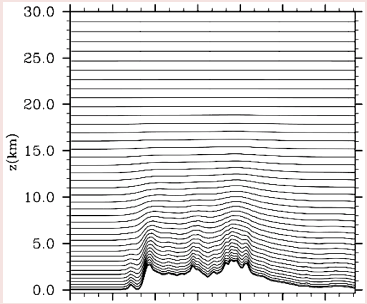
MPAS Characteristics



- 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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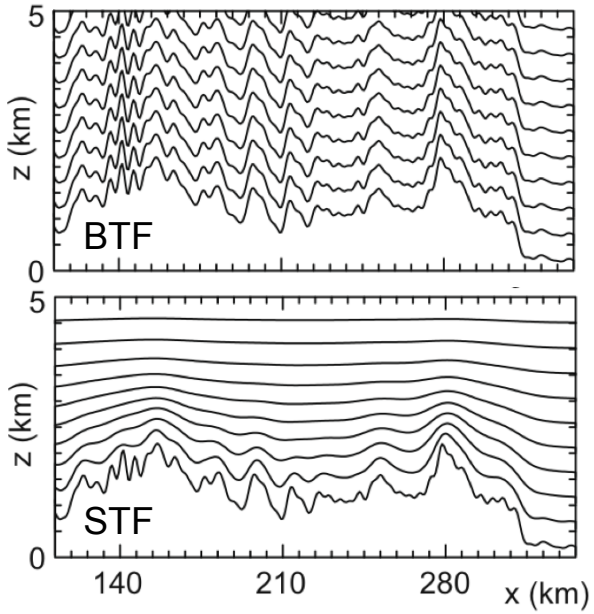
Model for Prediction Across Scales

MPAS Vertical Mesh

Specification of terrain:

- High resolution terrain data (30 arcsec) averaged over grid-cell area
- Terrain smoothing with one pass of a 4th order Laplacian

Smoothed Terrain-Following (STF) hybrid Coordinate



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

$A(\zeta)$ Controls rate at which terrain influences are attenuated with height

$h_s(x, y, \zeta)$ Terrain influence that represents increased smoothing of the actual terrain with height

Multiple passes of simple Laplacian smoother at each ζ level:

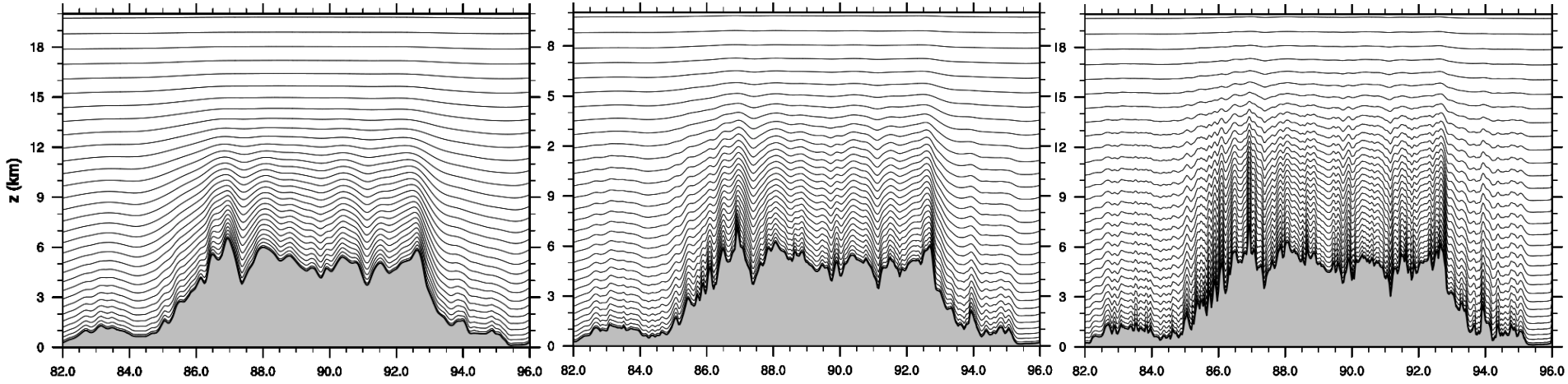
$$h_s^{(n)} = h_s^{(n-1)} + \beta(\zeta) d^2 \nabla_\zeta^2 h_s^{(n-1)}$$

STF progressively smooths coordinate surfaces while transitioning to a height coordinate

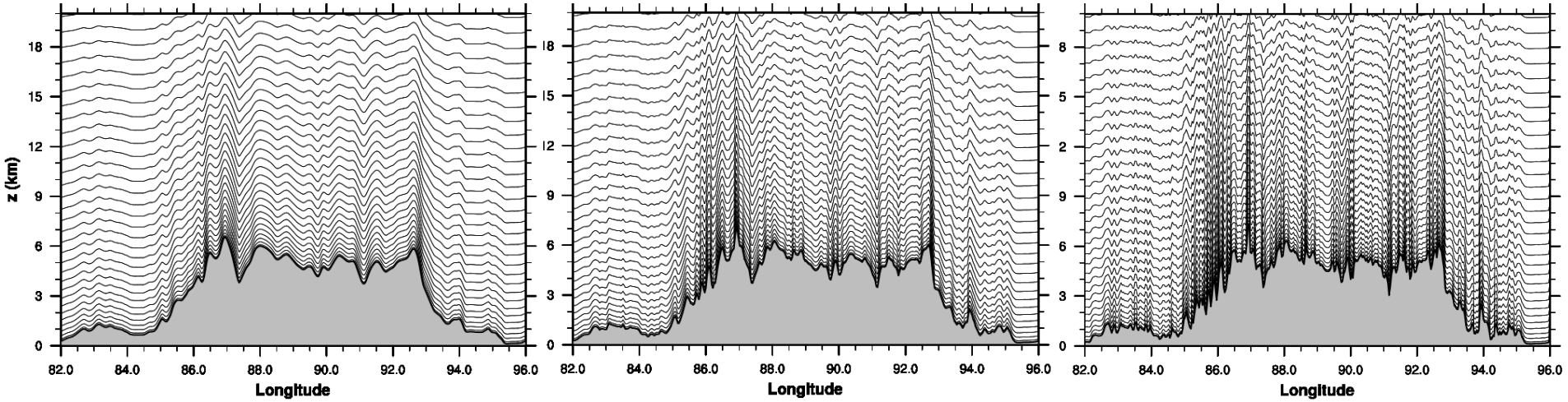
15, 7.5, & 3 km MPAS - Tibetan Plateau, 28° N

15 km grid | 7.5 km grid | 3 km grid

Smoothed hybrid terrain-following (STF) coordinate



Basic terrain-following (BTF) coordinate



(Model top is at 30 km)

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Model for Prediction Across Scales

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:

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

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

MPAS
Model for Prediction Across Scales

MPAS Nonhydrostatic Atmospheric Solver

Prognostic equations:

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

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

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

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

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

(1) Gradient operators

(2) Flux divergence operators

(3) Nonlinear Coriolis term

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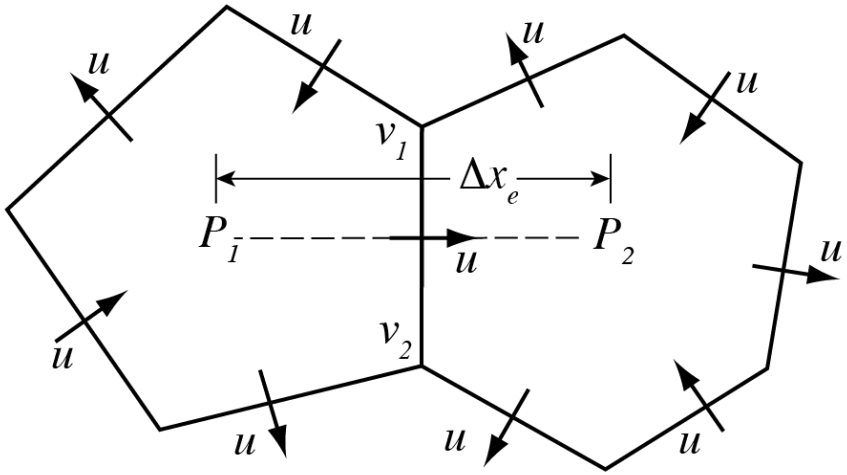
Operators on the Voronoi Mesh
Pressure and KE gradients

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



On the Voronoi mesh, P_1P_2 is perpendicular to v_1v_2 and is bisected by v_1v_2, hence $P_x \sim (P_2\text{-}P_1)\Delta x_e^{-1}$ is 2nd order accurate.

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Model for Prediction Across Scales

Operators on the Voronoi Mesh
Flux divergence and transport

Transport equation, conservative form:

$$\frac{\partial(\rho\psi)}{\partial t} = -\nabla \cdot \mathbf{V}(\rho\psi)$$

Finite-Volume formulation, Integrate over cell:

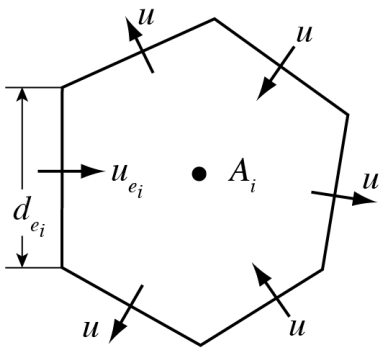
$$\int_D \left[\frac{\partial}{\partial t}(\rho\psi) = -\nabla \cdot \mathbf{V}(\rho\psi) \right] dV$$

Apply divergence theorem:

$$\frac{\partial(\overline{\rho\psi})}{\partial t} = -\frac{1}{V} \int_\Sigma (\rho\psi)\, \mathbf{V} \cdot \mathbf{n}\, d\sigma$$

Discretize in time and space:

$$(\rho\psi)_i^{t+\Delta t} = (\rho\psi)_i^t - \Delta t \frac{1}{A_i} \sum_{n_{e_i}} d_{e_i} \overline{(\rho \mathbf{V} \cdot \mathbf{n}_{e_i})\psi}$$



Velocity divergence operator is 2nd-order accurate for edge-centered velocities.

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Operators on the Voronoi Mesh
Flux divergence and transport

MPAS uses a Runge-Kutta time-integration scheme.

$$\frac{\partial(\rho\psi)}{\partial t} = L(\mathbf{V}, \rho, \psi)$$

$$(\rho\psi)^* = (\rho\psi)^t + \frac{\Delta t}{3} L(\mathbf{V}, \rho, \psi^t)$$

$$(\rho\psi)^{**} = (\rho\psi)^t + \frac{\Delta t}{2} L(\mathbf{V}, \rho, \psi^*)$$

$$(\rho\psi)^{t+\Delta t} = (\rho\psi)^t + \Delta t\, L(\mathbf{V}, \rho, \psi^{**})$$

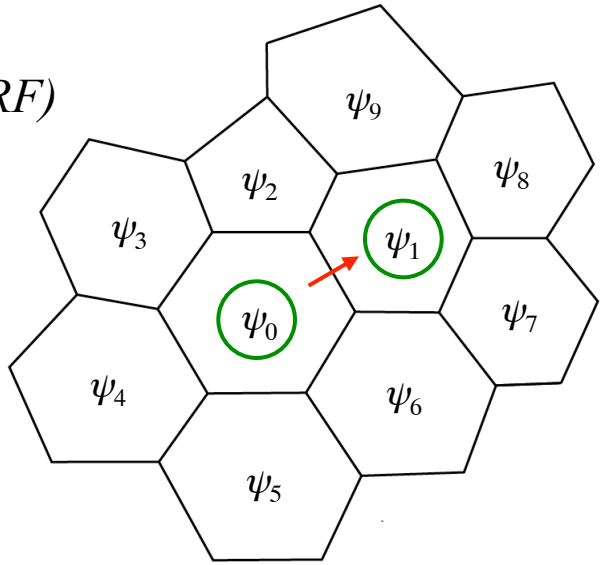
$$(\rho\psi)_i^{t+\Delta t} = (\rho\psi)_i^t - \Delta t \frac{1}{A_i} \sum_{n_{e_i}} d_{e_i} (\rho \mathbf{V} \cdot \mathbf{n}_{e_i}) \psi$$

Instantaneous flux divergence in RK-based scheme

Computing the flux - consider 1D transport (e.g. from WRF)

$$\frac{\partial(u\psi_i)}{\partial x} = \frac{1}{\Delta x}\left[F_{i+1/2}(u\psi) - F_{i-1/2}(u\psi)\right] + O(\Delta x^p).$$

2nd-order flux: $F(u,\psi)_{i+1/2} = u_{i+1/2}\left[\frac{1}{2}(\psi_{i+1} + \psi_i)\right]$



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Operators on the Voronoi Mesh
Flux divergence and transport

3rd and 4th-order fluxes:

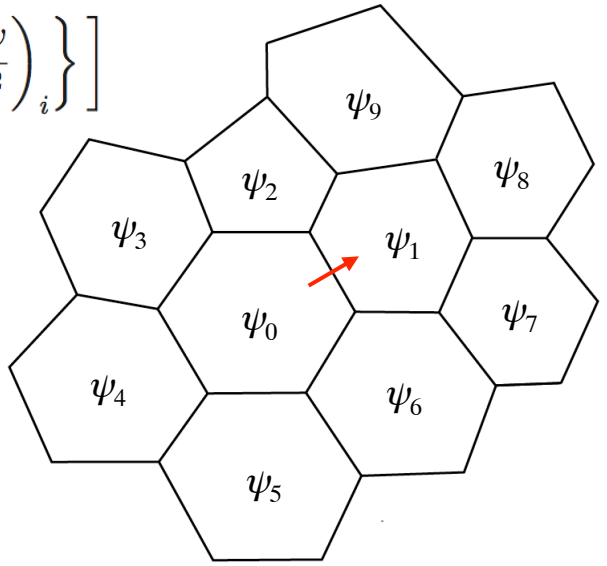
$$F(u,\psi)_{i+1/2} = u_{i+1/2}\left[\frac{1}{2}\left(\psi_{i+1}+\psi_i\right) - \frac{1}{12}\left(\delta_x^2\psi_{i+1}+\delta_x^2\psi_i\right) + sign(u)\,\frac{\beta}{12}\left(\delta_x^2\psi_{i+1}-\delta_x^2\psi_i\right)\right]$$

where $\delta_x^2\psi_i = \psi_{i-1} - 2\psi_i + \psi_{i+1}$ *(Hundsdorfer et al, 1995; Van Leer, 1985)*

Recognizing $\delta_x^2\psi = \Delta x^2 \frac{\partial^2\psi}{\partial x^2} + O(\Delta x^4)$ we recast the 3rd and 4th order flux as

$$F(u,\psi)_{i+1/2} = u_{i+1/2}\left[\frac{1}{2}\left(\psi_{i+1}+\psi_i\right) - \Delta x_e^2 \frac{1}{12}\left\{\left(\frac{\partial^2\psi}{\partial x^2}\right)_{i+1} + \left(\frac{\partial^2\psi}{\partial x^2}\right)_{i}\right\}\right.$$
$$\left. + sign(u)\,\Delta x_e^2 \frac{\beta}{12}\left\{\left(\frac{\partial^2\psi}{\partial x^2}\right)_{i+1} - \left(\frac{\partial^2\psi}{\partial x^2}\right)_{i}\right\}\right]$$

where *x* is the direction normal to the cell edge and *i* and *i+1* are cell centers. We use the least-squares-fit polynomial to compute the second derivatives.



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Model for Prediction Across Scales

Operators on the Voronoi Mesh
Flux divergence and transport

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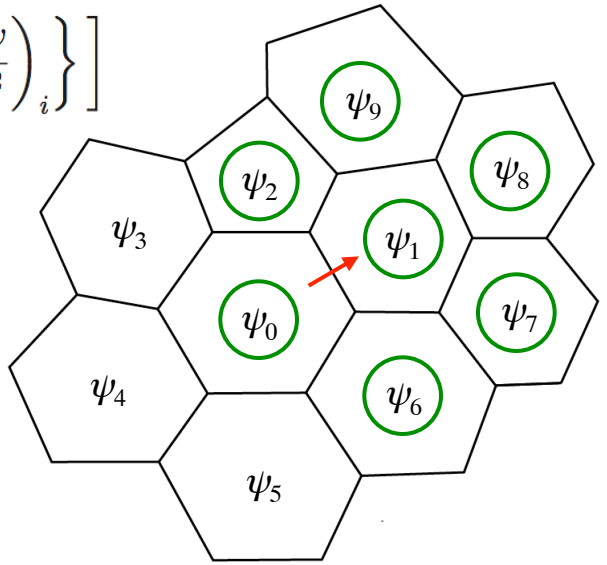

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Operators on the Voronoi Mesh
Flux divergence and transport

3rd and 4th-order fluxes:

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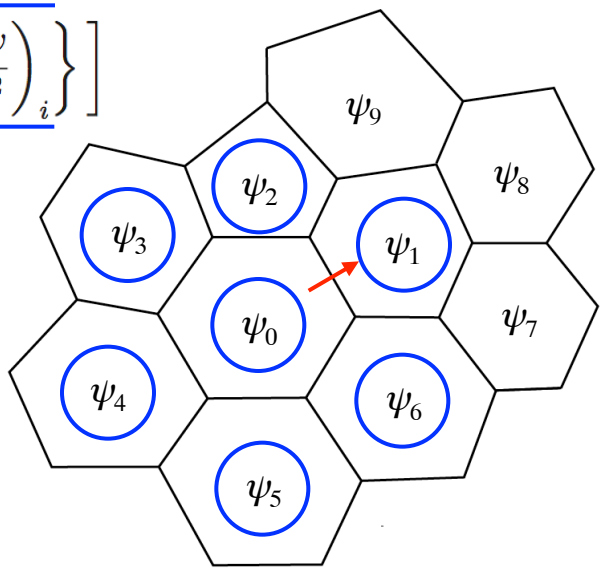


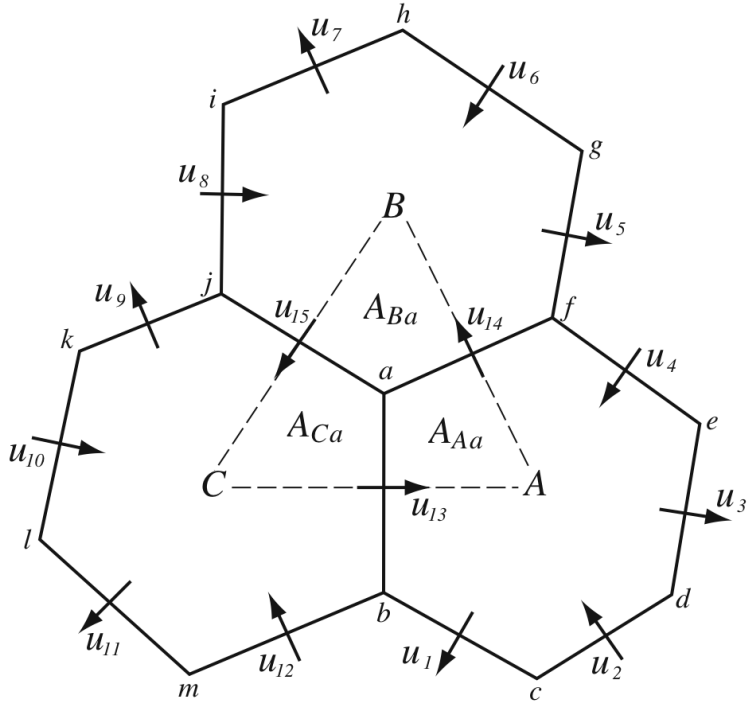
MPAS
Model for Prediction Across Scales

Operators on the Voronoi Mesh
'Nonlinear' Coriolis force

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

Vorticity is computed by evaluating the circulation around the triangles.
Vorticity *lives* on the vertices.

First, the linear piece: $f\ \boldsymbol{k}\ x\ \boldsymbol{V_H}$



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Operators on the Voronoi Mesh
'Nonlinear' Coriolis force

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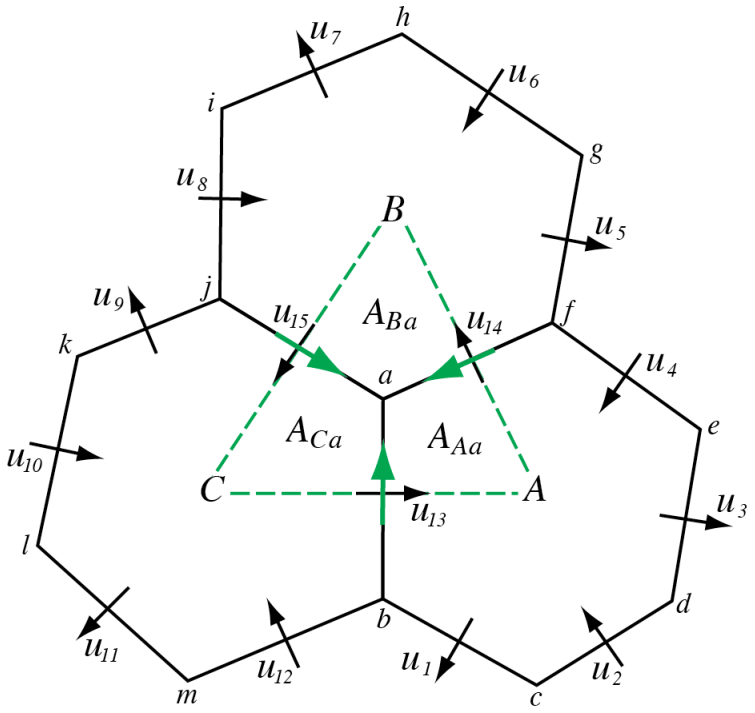
How do we compute the tangential velocity on the cell faces needed in the Coriolis term?



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Operators on the Voronoi Mesh
'Nonlinear' Coriolis force

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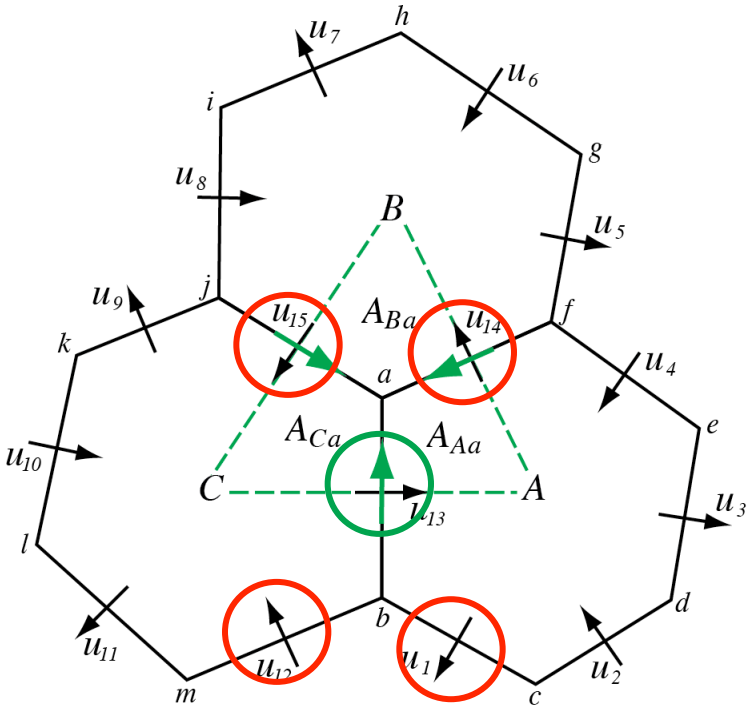
$$-\boldsymbol{v}_H\nabla_\zeta\cdot\boldsymbol{V} - \frac{\partial \Omega \boldsymbol{v}_H}{\partial \zeta} - \rho_d\nabla_\zeta K - eW\cos\alpha_r - \frac{uW}{r_e} + \boldsymbol{F}_{V_H},$$

Linear piece: $f\ \boldsymbol{k}\ x\ \boldsymbol{V_H}$

Simplest approach: Construct tangential velocities from weighted sum of the four nearest neighbors.

Result: physically stationary geostrophic modes (geostrophically-balanced flow) will not be stationary in the discrete system; the solver is unusable.

(Nickovic et al, MWR 2002)



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Model for Prediction Across Scales

Operators on the Voronoi Mesh
'Nonlinear' Coriolis force

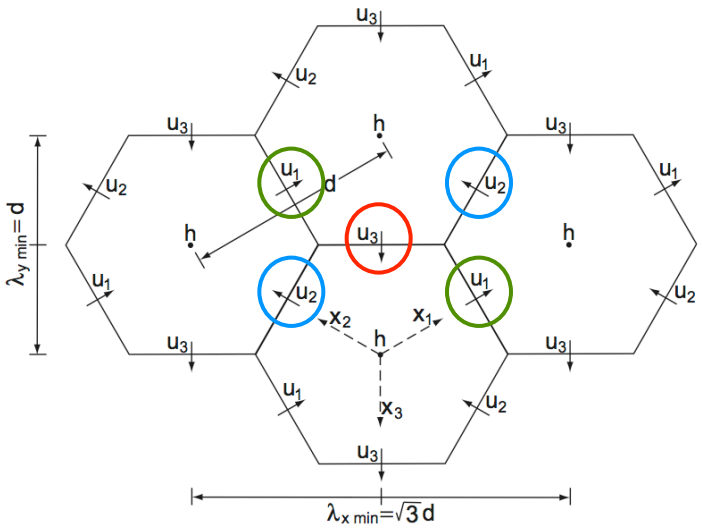
Linear piece: $f\ \boldsymbol{k} \times \boldsymbol{V_H}$

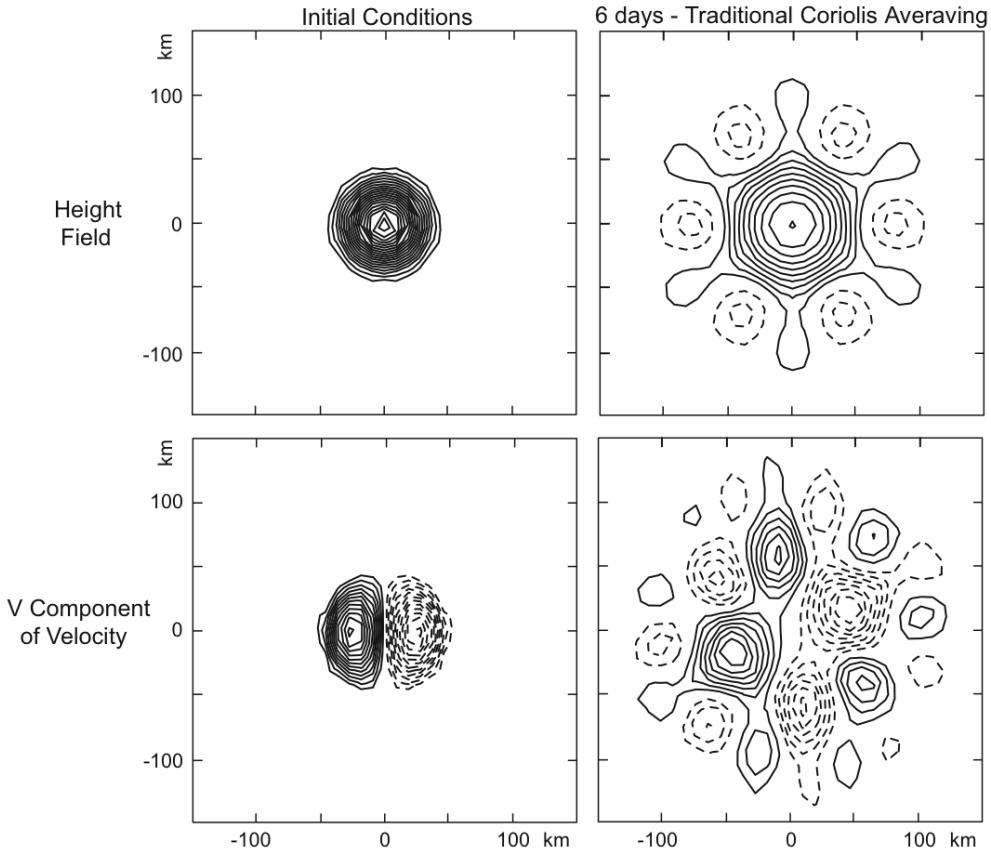
$$\partial_t u_1 + g\delta_{x_1} h + \frac{f}{\sqrt{3}}(u_{31} - u_{21}) = 0$$

$$\partial_t u_2 + g\delta_{x_2} h + \frac{f}{\sqrt{3}}(u_{12} - u_{32}) = 0$$

$$\partial_t u_3 + g\delta_{x_3} h + \frac{f}{\sqrt{3}}(u_{23} - u_{13}) = 0$$

$$\partial_t h + \frac{2}{3} H(\delta_{x_1} u_1 + \delta_{x_2} u_2 + \delta_{x_3} u_3) = 0$$





MPAS
Model for Prediction Across Scales

Operators on the Voronoi Mesh
'Nonlinear' Coriolis force

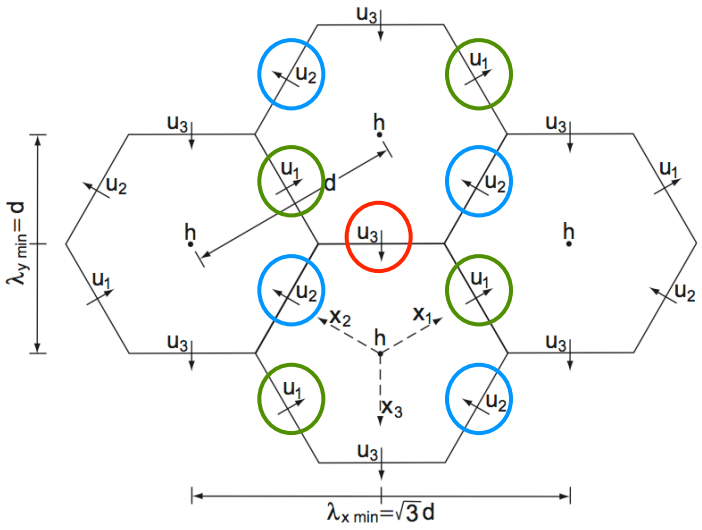
Linear piece: f $\boldsymbol{k}$ x $\boldsymbol{V_H}$

$$\partial_t u_1 + g\delta_{x_1} h + \frac{f}{\sqrt{3}}(u_{31} - u_{21}) = 0$$

$$\partial_t u_2 + g\delta_{x_2} h + \frac{f}{\sqrt{3}}(u_{12} - u_{32}) = 0$$

$$\partial_t u_3 + g\delta_{x_3} h + \frac{f}{\sqrt{3}}(u_{23} - u_{13}) = 0$$

$$\partial_t h + \tfrac{2}{3} H(\delta_{x_1} u_1 + \delta_{x_2} u_2 + \delta_{x_3} u_3) = 0$$

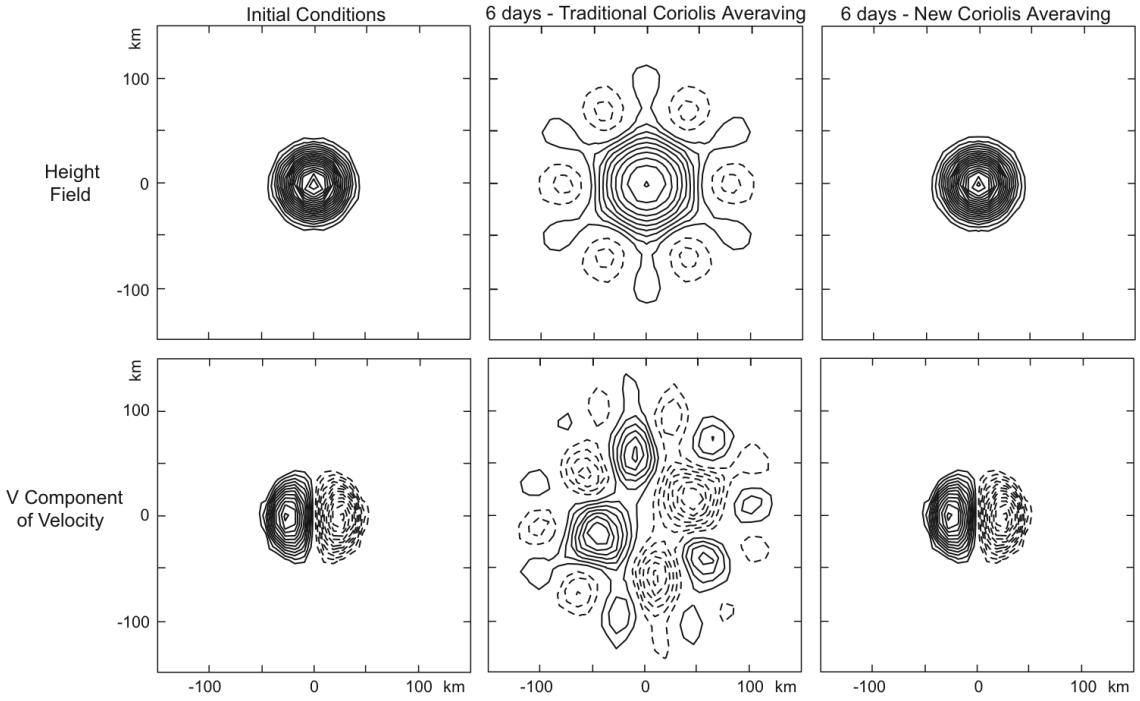


(Thuburn et al, 2009 JCP)

$$u_{21} = \tfrac{1}{3}\overline{u_2}^{x_3} + \tfrac{2}{3}\overline{\overline{u_2}^{x_1}}^{x_2}, \quad u_{31} = \tfrac{1}{3}\overline{u_3}^{x_2} + \tfrac{2}{3}\overline{\overline{u_3}^{x_1}}^{x_3},$$

$$u_{12} = \tfrac{1}{3}\overline{u_1}^{x_3} + \tfrac{2}{3}\overline{\overline{u_1}^{x_1}}^{x_2}, \quad u_{32} = \tfrac{1}{3}\overline{u_3}^{x_1} + \tfrac{2}{3}\overline{\overline{u_3}^{x_2}}^{x_3},$$

$$u_{13} = \tfrac{1}{3}\overline{u_1}^{x_2} + \tfrac{2}{3}\overline{\overline{u_1}^{x_1}}^{x_3}, \quad u_{23} = \tfrac{1}{3}\overline{u_2}^{x_1} + \tfrac{2}{3}\overline{\overline{u_2}^{x_2}}^{x_3}$$



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Model for Prediction Across Scales

Operators on the Voronoi Mesh
'Nonlinear' Coriolis force

Why does this work?

In the discrete analogue of vorticity equation (ξ_τ=-fδ_a), the divergence δ_a on the Delaunay triangulation is identical to the divergence δ_A on the Voronoi hexagons used in the height equation (h_t=-Hδ_A) integrated over the triangle.

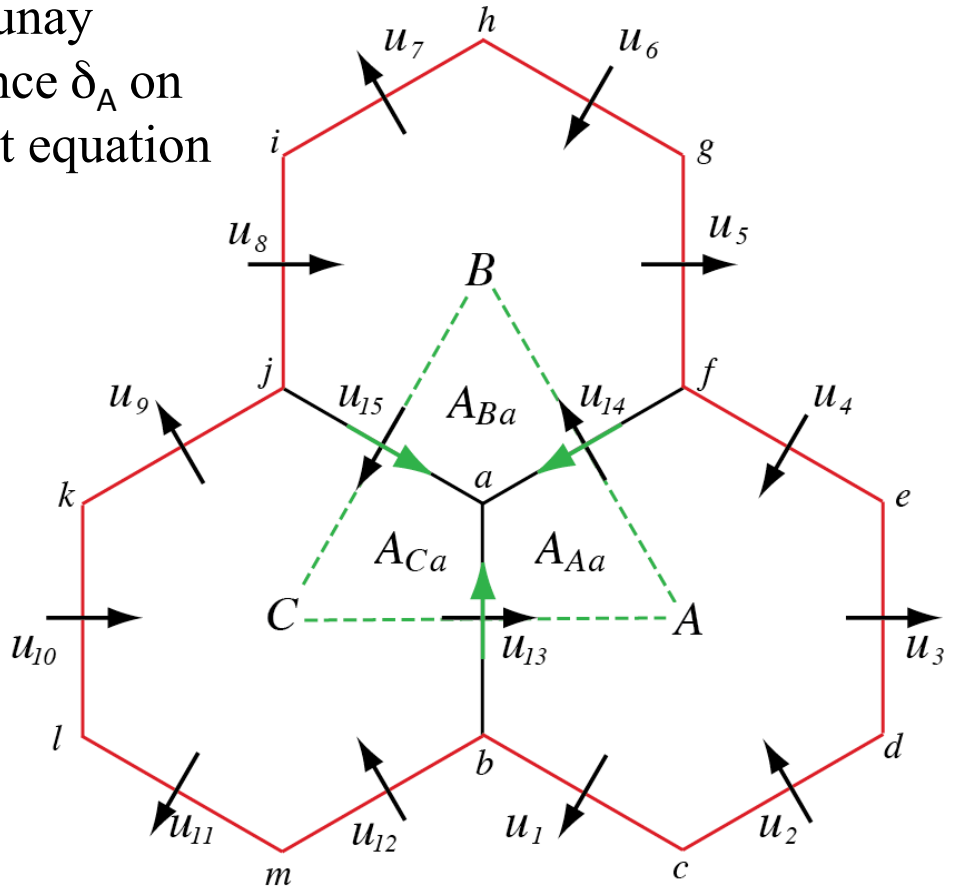
$$A_a\delta_a = \frac{A_A\delta_A + A_B\delta_B + A_C\delta_C}{6}$$

Divergence δ_A in hexagon A:

$$A_A\delta_A = \sum_{i=1}^{6} l_i u_i \cdot \mathbf{n}_i$$

Divergence δ_a in triangle ABC:

$$A_a\xi_t = -f A_a\delta_a = f\sum_{j=1}^{3} d_j u_j^{\perp} \cdot \mathbf{n}_j$$



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Model for Prediction Across Scales

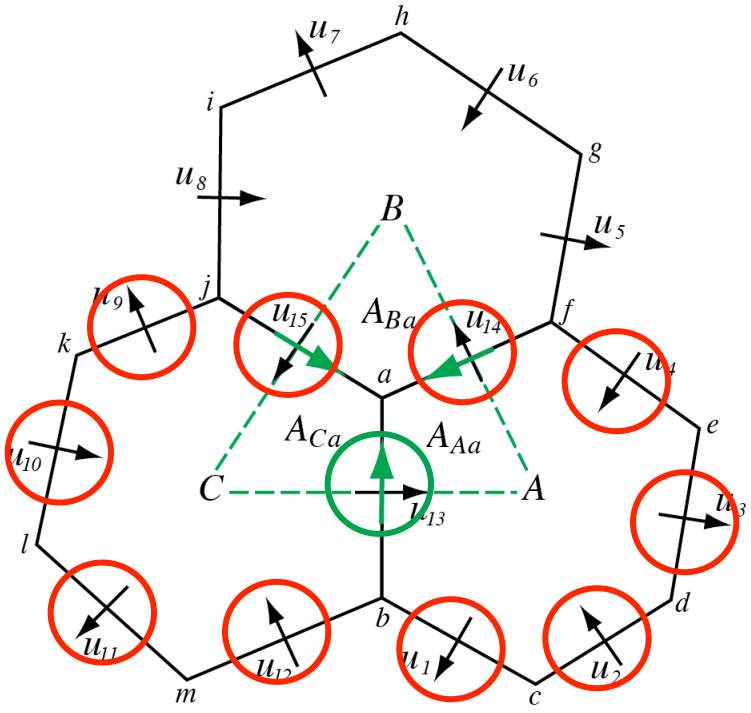
Operators on the Voronoi Mesh
'Nonlinear' Coriolis force

Linear piece: $f\ \boldsymbol{k}\ x\ \boldsymbol{V_H}$

Generalization for the Voronoi mesh:

Construct tangential velocities from weighted sum of normal velocities on edges of adjacent hexagons.

$$d_e\, u_e^{\perp} = \sum_j w_e^j\, l_j\, u_j$$



Result: geostrophic modes are stationary; local and global mass and PV conservation is satisfied on the dual (triangular) mesh (for the SW equations).

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Model for Prediction Across Scales

Operators on the Voronoi Mesh
'Nonlinear' Coriolis force

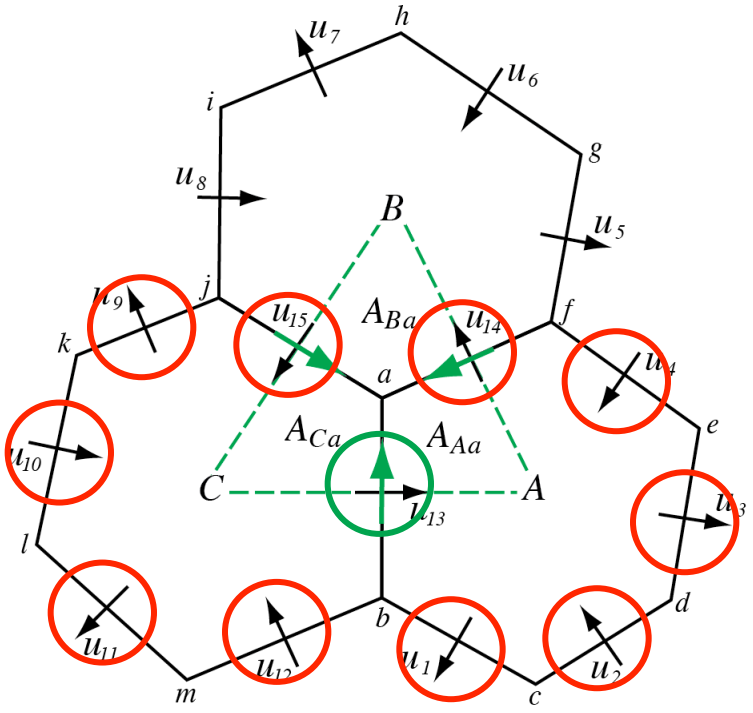
$$\frac{\partial \boldsymbol{V}_H}{\partial t} = -\frac{\rho_d}{\rho_m}\left[\nabla_\zeta\left(\frac{p}{\zeta_z}\right) - \frac{\partial z_H p}{\partial \zeta}\right] - \eta\,\boldsymbol{k}\times\boldsymbol{V}_H$$
$$- v_H \nabla_\zeta \cdot \boldsymbol{V} - \frac{\partial \Omega \boldsymbol{v}_H}{\partial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

Nonlinear term:

$$v_{e_i} = \sum_{j=1}^{n_{e_i}} w_{e_{i,j}} u_{e_{i,j}}$$

$$[\eta\,\boldsymbol{k}\times\boldsymbol{V}_H]_{e_i} = \sum_{j=1}^{n_{e_i}} \frac{1}{2}(\eta_{e_i} + \eta_{e_{i,j}})\, w_{e_{i,j}} \rho_{e_{i,j}} u_{e_{i,j}}$$

The general tangential velocity reconstruction produces a consistent divergence on the primal and dual grids, and allows for PV, enstrophy and energy* conservation in the nonlinear SW solver.



MPAS
Model for Prediction Across Scales

Configuring the dynamics and the physics

(namelist.atmosphere)

```
&nhyd_model
        config_dt = 75
        config_start_time = "0000-01-01_00:00:00"
        config_run_duration = "20_00:00:00"
        config_number_of_sub_steps = 6
        config_h_mom_eddy_visc2 = 0
        config_h_mom_eddy_visc4 = 0
        config_v_mom_eddy_visc2 = 0
        config_h_theta_eddy_visc2 = 0
        config_h_theta_eddy_visc4 = 0
        config_v_theta_eddy_visc2 = 0
        config_horiz_mixing = "2d_smagorinsky"
        config_len_disp = 15000.
        config_visc4_2dsmag = 0.05
        config_h_ScaleWithMesh = .true.
        config_w_adv_order = 3
        config_theta_adv_order = 3
        config_scalar_adv_order = 3
        config_u_vadv_order = 3
        config_w_vadv_order = 3
        config_theta_vadv_order = 3
        config_scalar_vadv_order = 3
        config_positive_definite = .false.
        config_monotonic = .true.
        config_coef_3rd_order = 0.25
        config_epssm = 0.1
        config_smdiv = 0.1
```

MPAS
Model for Prediction Across Scales

Configuring the dynamics and the physics

(namelist.atmosphere)

```
&nhyd_model
        config_dt = 75
        config_start_time = "0000-01-01_00:00:00"
        config_run_duration = "20_00:00:00"
        config_number_of_sub_steps = 6
        config_h_mom_eddy_visc2 = 0
        config_h_mom_eddy_visc4 = 0
        config_v_mom_eddy_visc2 = 0
        config_h_theta_eddy_visc2 = 0
        config_h_theta_eddy_visc4 = 0
        config_v_theta_eddy_visc2 = 0
        config_horiz_mixing = "2d_smagorinsky"
        config_len_disp = 15000.
        config_visc4_2dsmag = 0.05
        config_h_ScaleWithMesh = .true.
        config_w_adv_order = 3
        config_theta_adv_order = 3
        config_scalar_adv_order = 3
        config_u_vadv_order = 3
        config_w_vadv_order = 3
        config_theta_vadv_order = 3
        config_scalar_vadv_order = 3
        config_positive_definite = .false.
        config_monotonic = .true.
        config_coef_3rd_order = 0.25
        config_epssm = 0.1
        config_smdiv = 0.1
```

Time and time-steps

```
&nhyd_model
    config_dt = 75                          <- Timestep in seconds
    config_start_time = "0000-01-01_00:00:00"
    config_run_duration = "20_00:00:00"
    config_number_of_sub_steps = 6          <- Number of acoustic steps per timestep
```

MPAS
Model for Prediction Across Scales

Configuring the dynamics and the physics

Dissipation

(namelist.atmosphere)

```
&nhyd_model
        config_dt = 75
        config_start_time = "0000-01-01_00:00:00"
        config_run_duration = "20_00:00:00"
        config_number_of_sub_steps = 6
        config_h_mom_eddy_visc2 = 0
        config_h_mom_eddy_visc4 = 0
        config_v_mom_eddy_visc2 = 0
        config_h_theta_eddy_visc2 = 0
        config_h_theta_eddy_visc4 = 0
        config_v_theta_eddy_visc2 = 0
        config_horiz_mixing = "2d_smagorinsky"
        config_len_disp = 15000.
        config_visc4_2dsmag = 0.05
        config_h_ScaleWithMesh = .true.
        config_w_adv_order = 3
        config_theta_adv_order = 3
        config_scalar_adv_order = 3
        config_u_vadv_order = 3
        config_w_vadv_order = 3
        config_theta_vadv_order = 3
        config_scalar_vadv_order = 3
        config_positive_definite = .false.
        config_monotonic = .true.
        config_coef_3rd_order = 0.25
        config_epssm = 0.1
        config_smdiv = 0.1
```

```
&nhyd_model
    config_h_mom_eddy_visc2 = 0
    config_h_mom_eddy_visc4 = 0
    config_v_mom_eddy_visc2 = 0
    config_h_theta_eddy_visc2 = 0
    config_h_theta_eddy_visc4 = 0
    config_v_theta_eddy_visc2 = 0
    config_horiz_mixing = "2d_smagorinsky"
    config_len_disp = 15000.
    config_visc4_2dsmag = 0.05
    config_h_ScaleWithMesh = .true.
```

fixed viscosity $m^2 s^{-1}$

Fixed hyper-viscosity $m^4 s^{-1}$

Alternately "2d_fixed"

Δx_fine

Scale viscosities, hyperviscosities with local mesh spacing

4th order background filter coef, used with 2d_smagorinsky

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Model for Prediction Across Scales

Configuring the dynamics and the physics

Advection

(namelist.atmosphere)

```
&nhyd_model
        config_dt = 75
        config_start_time = "0000-01-01_00:00:00"
        config_run_duration = "20_00:00:00"
        config_number_of_sub_steps = 6
        config_h_mom_eddy_visc2 = 0
        config_h_mom_eddy_visc4 = 0
        config_v_mom_eddy_visc2 = 0
        config_h_theta_eddy_visc2 = 0
        config_h_theta_eddy_visc4 = 0
        config_v_theta_eddy_visc2 = 0
        config_horiz_mixing = "2d_smagorinsky"
        config_len_disp = 15000.
        config_visc4_2dsmag = 0.05
        config_h_ScaleWithMesh = .true.
        config_w_adv_order = 3
        config_theta_adv_order = 3
        config_scalar_adv_order = 3
        config_u_vadv_order = 3
        config_w_vadv_order = 3
        config_theta_vadv_order = 3
        config_scalar_vadv_order = 3
        config_positive_definite = .false.
        config_monotonic = .true.
        config_coef_3rd_order = 0.25
        config_epssm = 0.1
        config_smdiv = 0.1
```

```
&nhyd_model
        config_w_adv_order = 3
        config_theta_adv_order = 3
        config_scalar_adv_order = 3
        config_u_vadv_order = 3
        config_w_vadv_order = 3
        config_theta_vadv_order = 3
        config_scalar_vadv_order = 3
        config_positive_definite = .false.
        config_monotonic = .true.
        config_coef_3rd_order = 0.25
```

Advection scheme order (2,3, or 4)

PD/Mono options for scalar transport

Upwind coefficient (0 <-> 1), >0 increases damping

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Model for Prediction Across Scales

Configuring the dynamics and the physics

Other dynamics…

(namelist.atmosphere)

```
&nhyd_model
    …
    config_epssm = 0.1
    config_smdiv = 0.1
/
&damping
    config_zd = 37000.
    config_xnutr = 0.2
```

off-centering of vertically implicit integration

3D divergence damping

height to begin gravity wave absorbing layer (m)

gravity-wave absorbing layer coefficient

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Configuring the dynamics and the physics

(namelist.atmosphere)

```
&physics
   config_frac_seaice        = .false.
   config_sfc_albedo         = .true.
   config_sfc_snowalbedo     = .true.
   config_sst_update         = .false.
   config_sstdiurn_update    = .false.
   config_deepsoiltemp_update = .false.
   config_o3climatology      = .true.
   config_bucket_update      = 'none'
   config_bucket_rainc       = 100.0
   config_bucket_rainnc      = 100.0
   config_bucket_radt        = 1.0e9
   config_radtlw_interval    = '00:30:00'
   config_radtsw_interval    = '00:30:00'
   config_conv_interval      = 'none'
   config_pbl_interval       = 'none'
   config_n_microp           = 1
   config_microp_scheme      = 'wsm6'
   config_conv_deep_scheme   = 'tiedtke'
   config_lsm_scheme         = 'noah'
   config_pbl_scheme         = 'ysu'
   config_gwdo_scheme        = 'off'
   config_radt_cld_scheme    = 'cld_fraction'
   config_radt_lw_scheme     = 'rrtmg_lw'
   config_radt_sw_scheme     = 'rrtmg_sw'
   config_sfclayer_scheme    = 'monin_obukhov'
```

Physics schemes

config_microp_scheme = 'wsm6' *(kessler, off)*

config_conv_deep_scheme = 'tiedtke' *(kain_fritsch, off)*

config_lsm_scheme = 'noah' *(off)*

config_pbl_scheme = 'ysu' *(off)*

config_gwdo_scheme = 'off' *(ysu_gwdo)*

config_radt_cld_scheme = 'cld_fraction' *(off, cld_incidence)*

config_radt_lw_scheme = 'rrtmg_lw' *(off, cam_lw)*

config_radt_sw_scheme = 'rrtmg_sw' *(off, cam_sw)*

config_sfclayer_scheme = 'monin_obukhov' *(off)*

MPAS
Model for Prediction Across Scales

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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

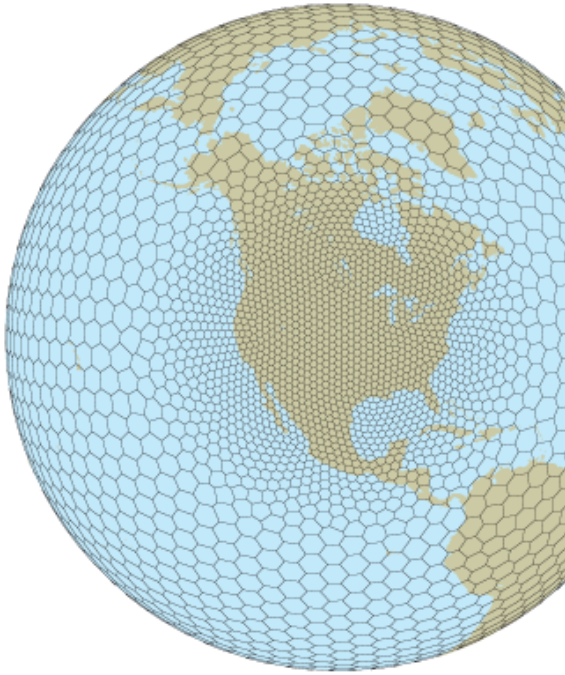
MPAS Atmosphere Users Guide

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

MPAS Solver Information

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

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Model for Prediction Across Scales

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Peer-reviewed publications relevant to MPAS

2013

Evaluation of global atmospheric solvers using extensions of the Jablonowski and Williamson baroclinic wave test case. S.-H. Park, W. Skamarock, J. Klemp, L. Fowler, and M. Duda, 2013, accepted for publication in Monthly Weather Review, pdf

A Multiresolution Approach to Global Ocean Modeling. T. Ringler, M. Petersen, R.L. Higdon, D.W. Jacobsen, P.W. Jones and M. Maltrud, 2012: , Ocean Modeling, revised (pdf).

2012

Exploring a Global Multi-Resolution Modeling Approach Using Aquaplanet Simulations. S. Rauscher, T. Ringler, W. Skamarock, and A. Mirin, 2012, in press, Journal of Climate, pdf

A Multi-scale Nonhydrostatic Atmospheric Model Using Centroidal Voronoi Tesselations and C-Grid Staggering. William C. Skamarock, Joseph B. Klemp, Michael G. Duda, Laura Fowler, Sang-Hun Park, and Todd D. Ringler. 2012 Monthly Weather Review, 240, 3090-3105, doi:10.1175/MWR-D-11-00215.1 pdf

2011

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

Conservative Transport Schemes for Spherical Geodesic Grids: High-Order Flux Operators for ODE-Based Time Integration. W. Skamarock and A. Gassmann, 2011, Monthly Weather Review, Vol. 139, pp. 2962-2975, doi:10.1175/MWR-D-10-05056.1 pdf