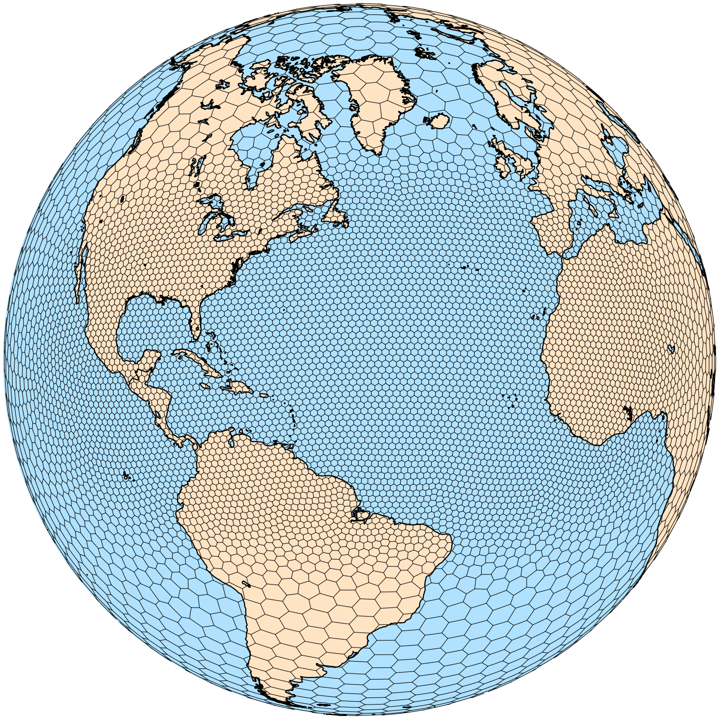
MPAS

Model for Prediction Across Scales



- *Atmospheric solver:*
  - *Equations and some aspects of the discretization*
  - *Configurations*
  - *Physics*

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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), with additional splitting options.

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:

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

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

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

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

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

Diagnostics and definitions:

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

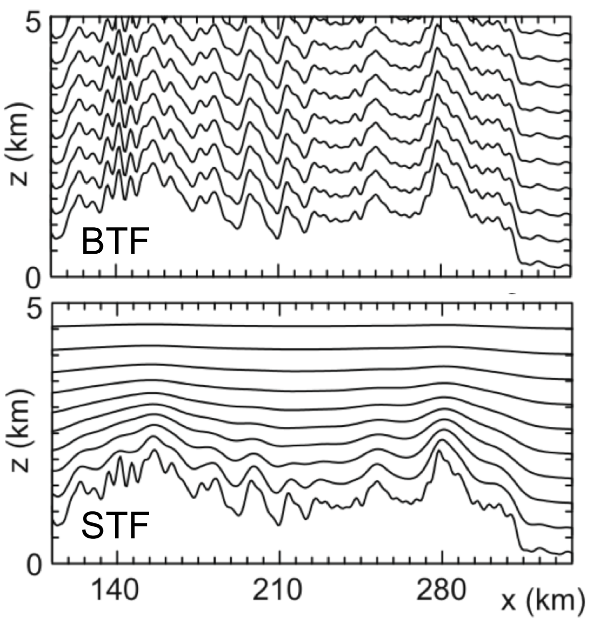
$$\frac{\rho_m}{\rho_d} = 1 + q_v + q_c + q_r + \ldots$$

MPAS Vertical Mesh

Specification of terrain:

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

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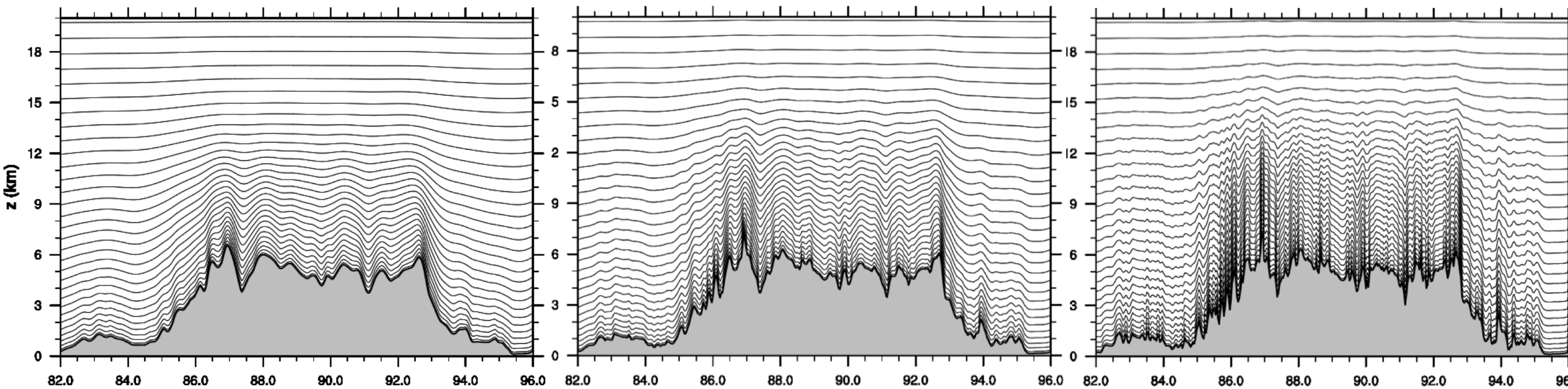
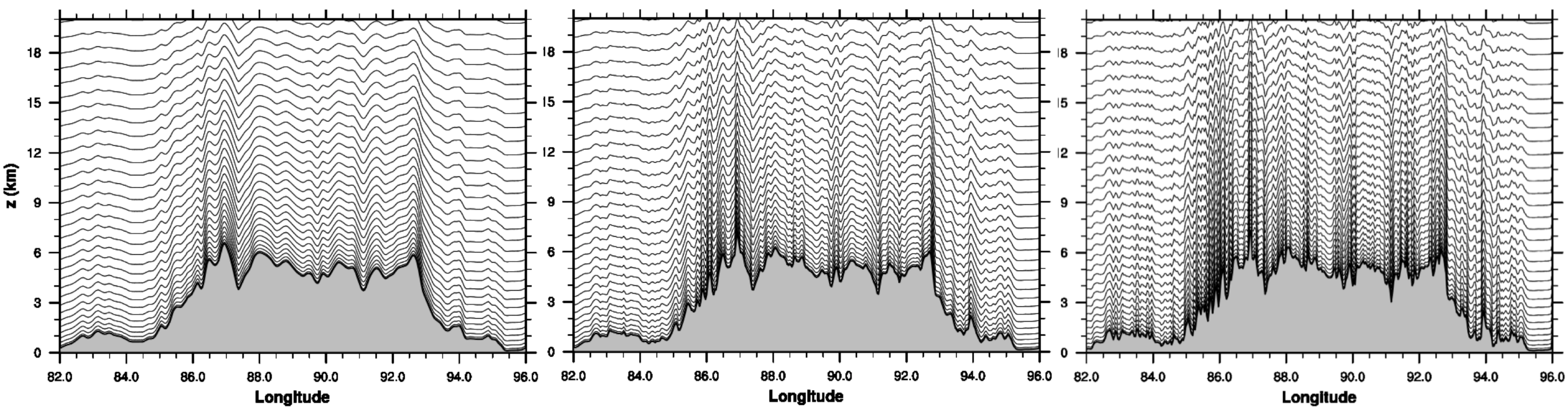
MPAS -Tibetan Plateau, 28^{o} N

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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MPAS Nonhydrostatic Atmospheric Solver

Prognostic equations:

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

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

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

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

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

(1) Gradient operators

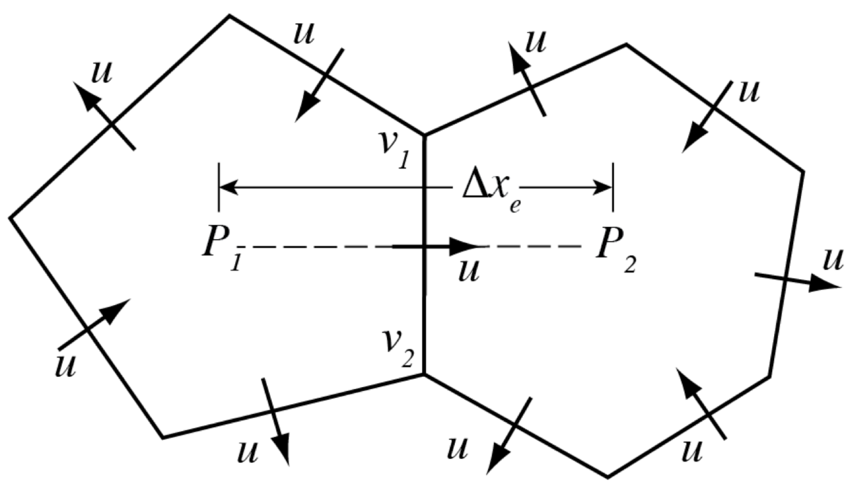
(2) Flux divergence operators

(3) Nonlinear Coriolis term

Operators on the Voronoi Mesh

Pressure and KE gradients

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



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

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Model for Prediction Across Scales

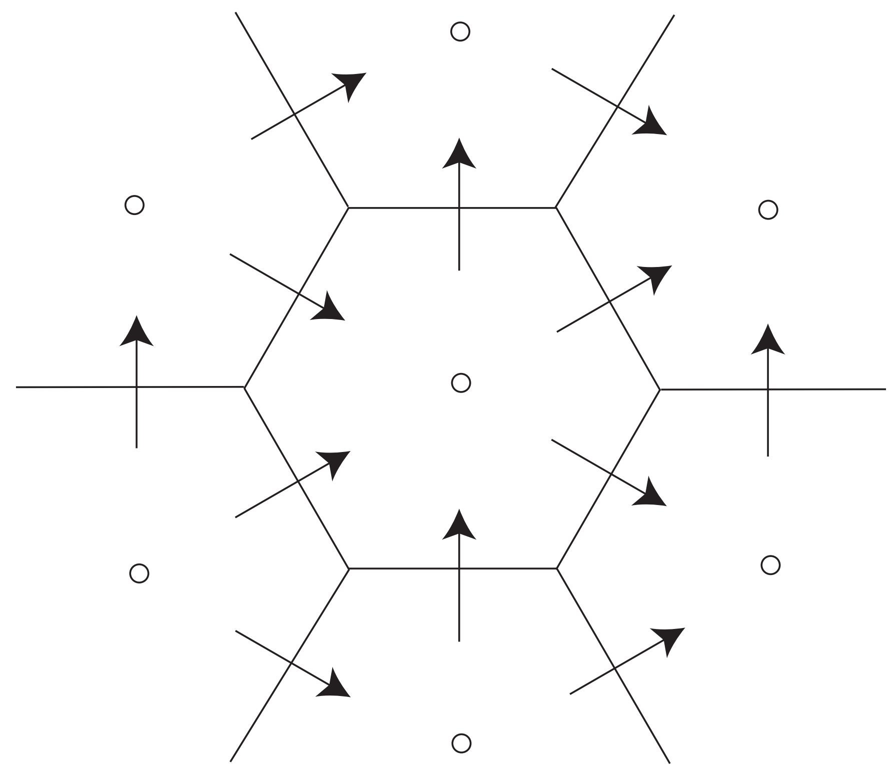
Operators on the Voronoi Mesh
cell-center KE evaluation

Cell center kinetic energy: KE_i

$$KE_i = (1-\beta)\sum_{e_i} w_{e_i} u_{e_i}^2 + \beta \sum_{v_j} w_{v_j} KE_{v_j}$$

Vertex kinetic energy: KE_v

$$KE_v = \sum_{e_v=1}^{3} w_{e_v} u_{e_v}^2$$



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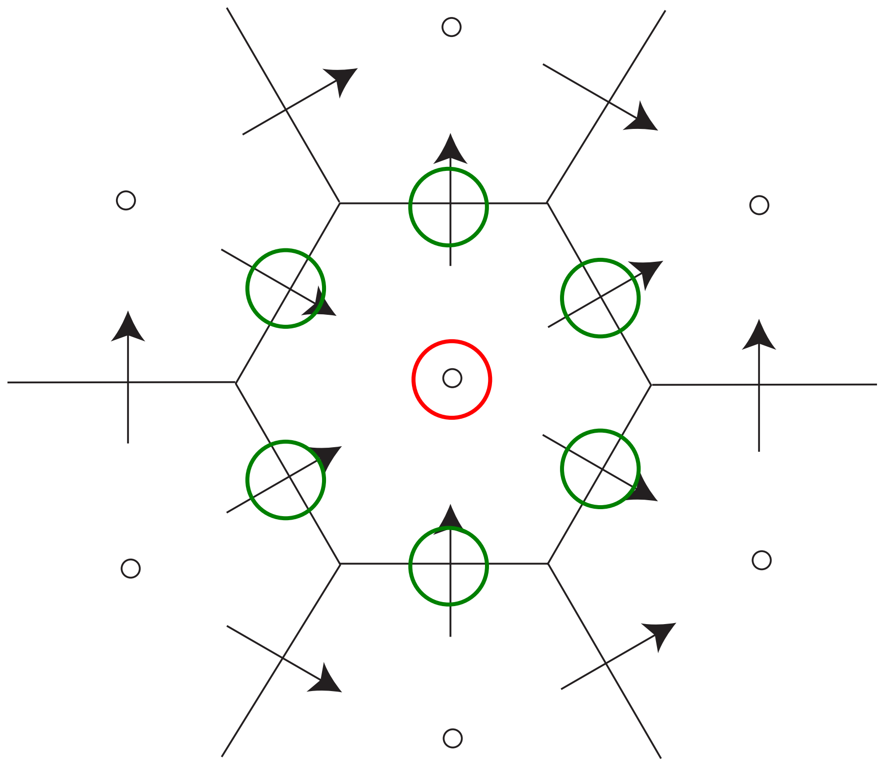

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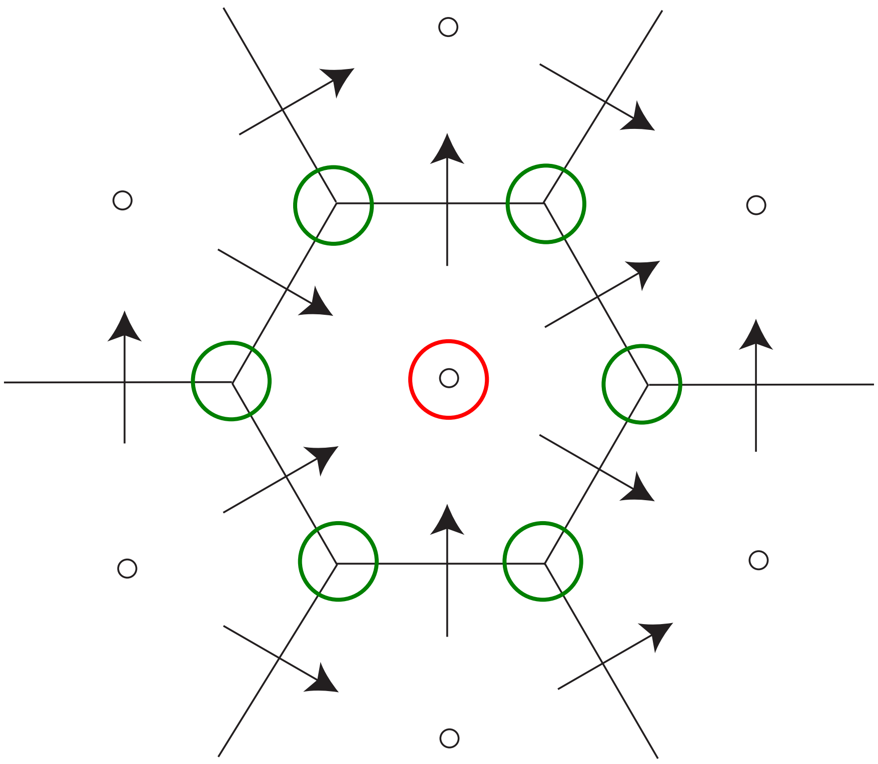

Operators on the Voronoi Mesh
cell-center KE evaluation

MPAS
Model for Prediction Across Scales

Cell center kinetic energy: KE_i

$$KE_i = (1-\beta)\sum_{e_i} w_{e_i} u_{e_i}^2 + \beta \sum_{v_j} w_{v_j} KE_{v_j}$$

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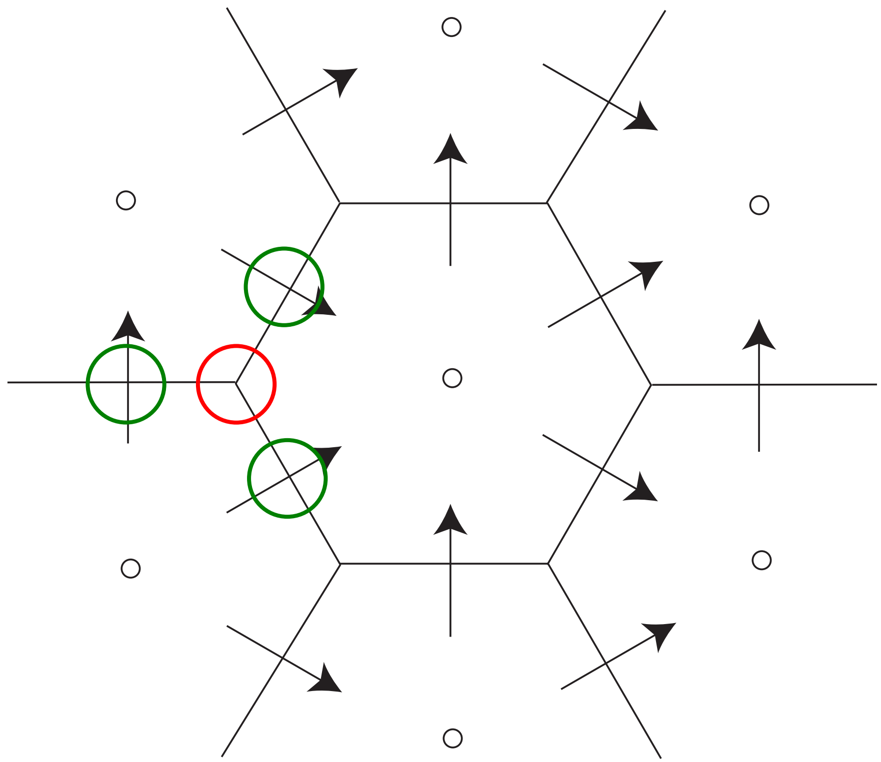
$$KE_v = \sum_{e_v=1}^{3} w_{e_v} u_{e_v}^2$$



MPAS uses β = 3/8 (see Skamarock et al 2012, coefficient is α in the paper)

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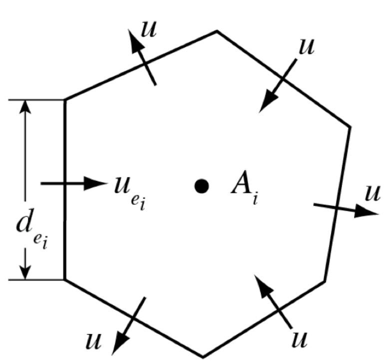
Operators on the Voronoi Mesh
Flux divergence and transport

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 2^{nd}-order accurate for edge-centered velocities.

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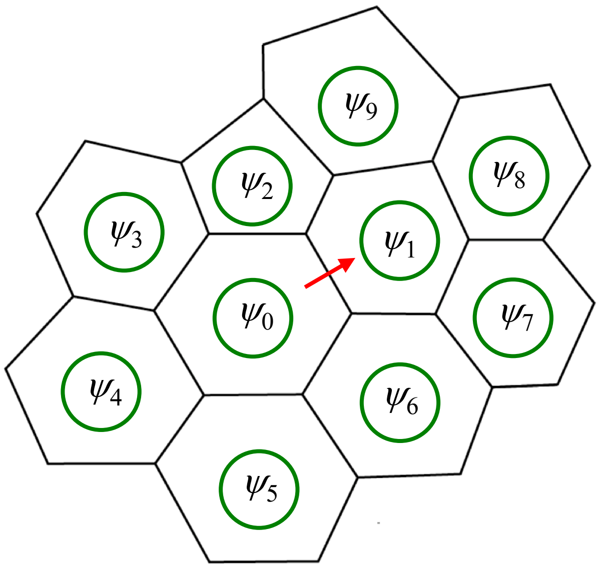
Model for Prediction Across Scales

Flux divergence, transport, and Runge-Kutta time integration

Scalar transport equation for cell *i*: $$\frac{\partial(\rho\psi)_i}{\partial t} = L(\mathrm{V},\rho,\psi) = -\frac{1}{A_i}\sum_{n_{e_i}} d_{e_i}\left(\rho \mathrm{V}\cdot\vec{n}_{e_i}\right)\overline{\psi}$$

1. Scalar edge-flux value ψ is the weighted sum of cell values from cells that share edge and all their neighbors.
2. An individual edge-flux is used to update the two cells that share the edge.
3. Three edge-flux evaluations and cell updates are needed to complete the Runge-Kutta timestep.
4. Monotonic constraint requires checking the cell-value update and renormalizing edge-fluxes if the cell updates are outside specific bounds (on the final RK3 update).



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

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

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

Transport - Weighted Sums?

3rd and 4th-order fluxes (e.g. WRF):

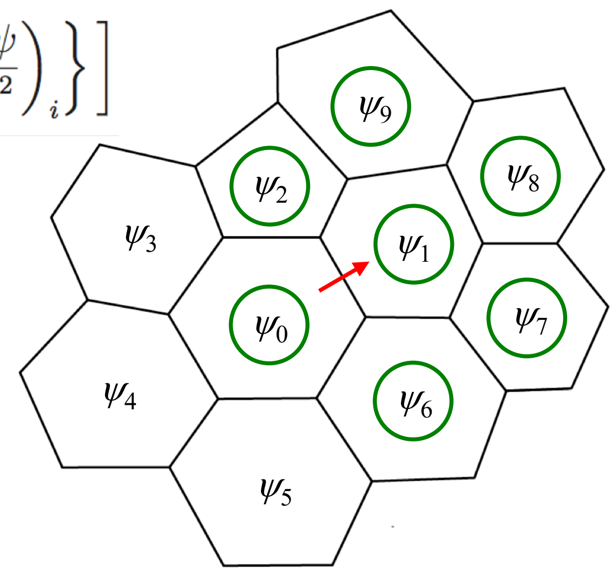
$$F(u,\psi)_{i+1/2} = u_{i+1/2}\left[\frac{1}{2}\left(\psi_{i+1}+\psi_i\right) - \frac{1}{12}\left(\delta_x^2\psi_{i+1}+\delta_x^2\psi_i\right) + sign(u)\,\frac{\beta}{12}\left(\delta_x^2\psi_{i+1}-\delta_x^2\psi_i\right)\right]$$

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

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

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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$$\left. + sign(u)\,\Delta x_e^2\frac{\beta}{12}\left\{\left(\frac{\partial^2\psi}{\partial x^2}\right)_{i+1} - \underline{\left(\frac{\partial^2\psi}{\partial x^2}\right)_i}\right\}\right]$$

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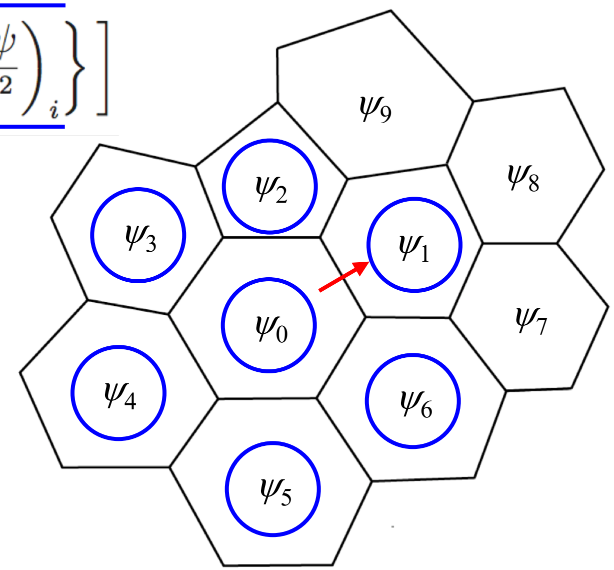


Conservative Transport with RK3 Time Integration

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

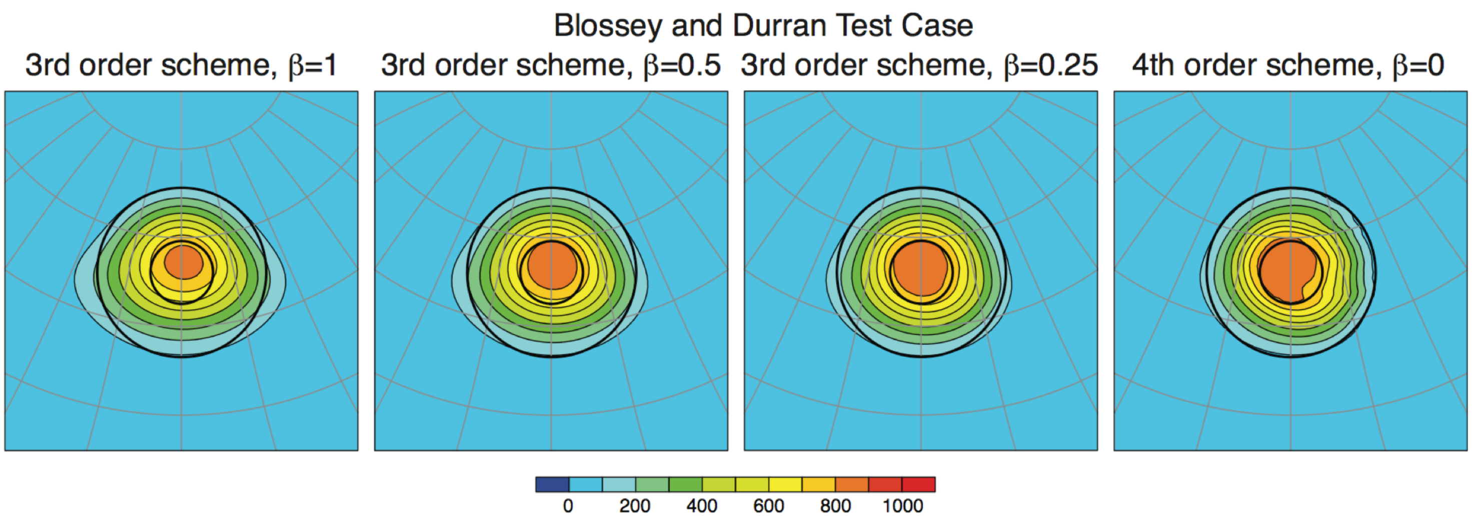
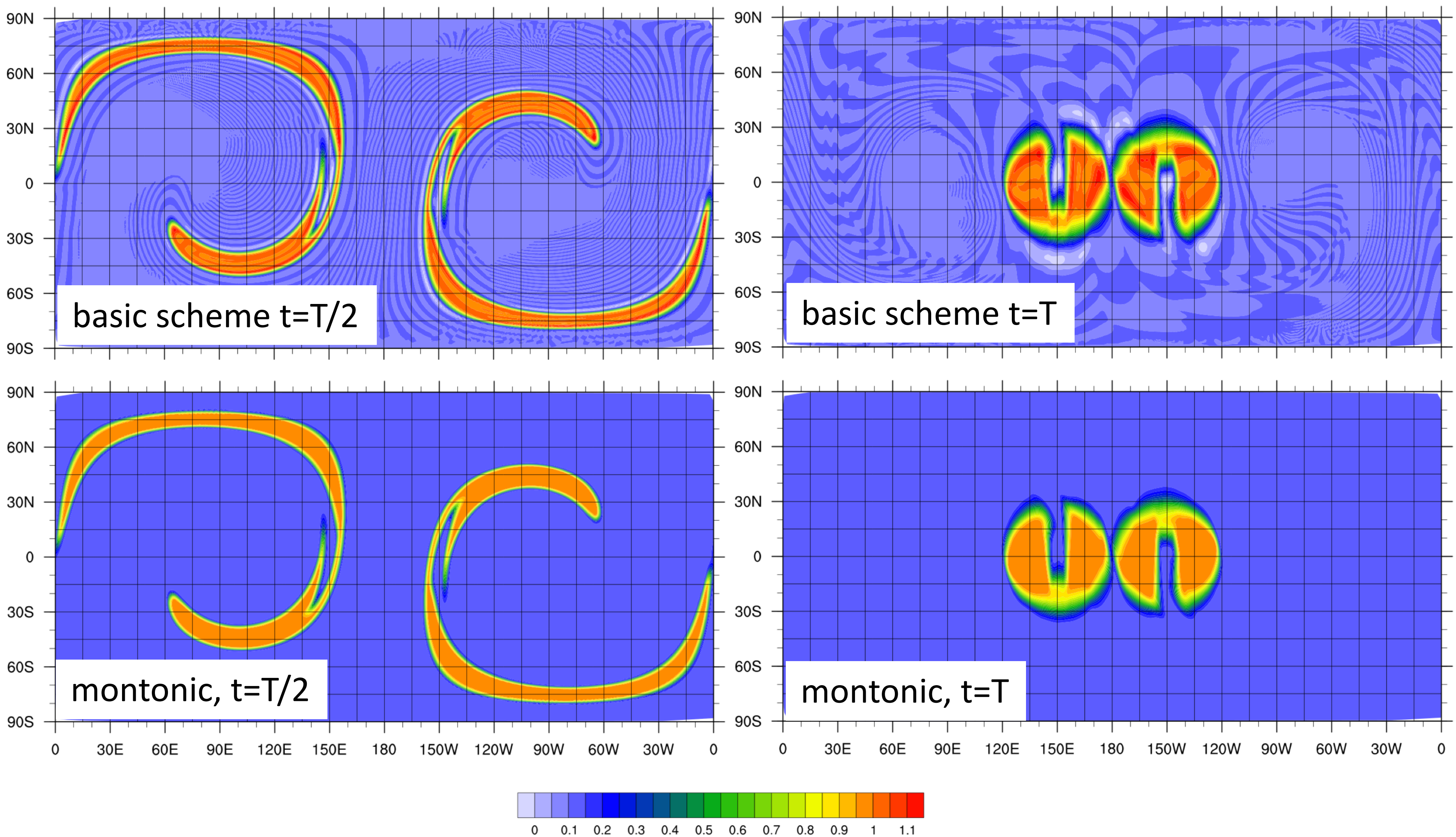


FIG. 7. Deformational flow test case results at time T using (11) with different values of the filter parameter β. The simulations were performed on the 40962-cell grid.

Conservative Transport with RK3 Time Integration

163842 cells, ~ 60 km cell spacing (~ 1/2 deg), Cr max ~ 0.8



MPAS
Model for Prediction Across Scales

Operators on the Voronoi Mesh
'Nonlinear' Coriolis force

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

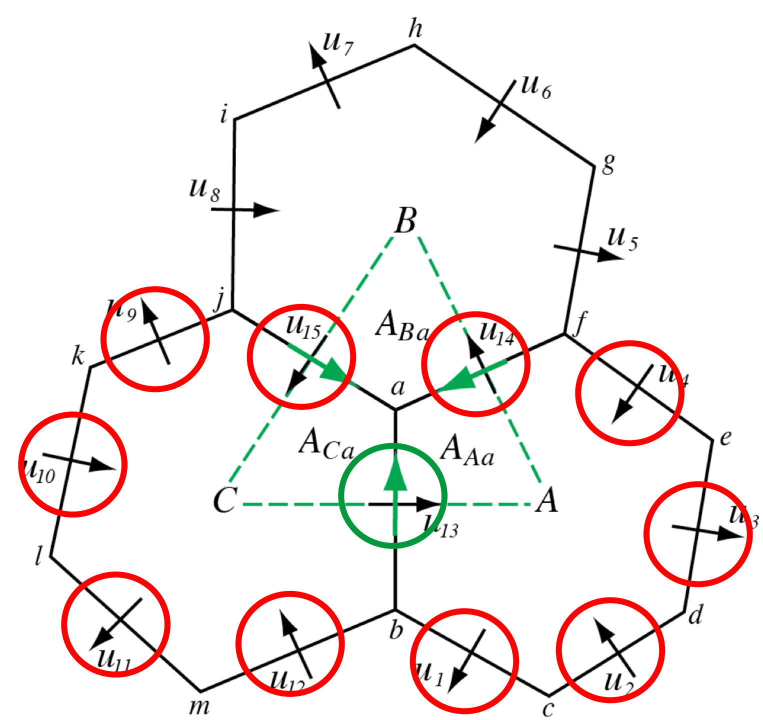
Tangential velocity reconstruction:

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

Nonlinear term:

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

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.



Operators on the Voronoi Mesh
'Nonlinear' Coriolis force

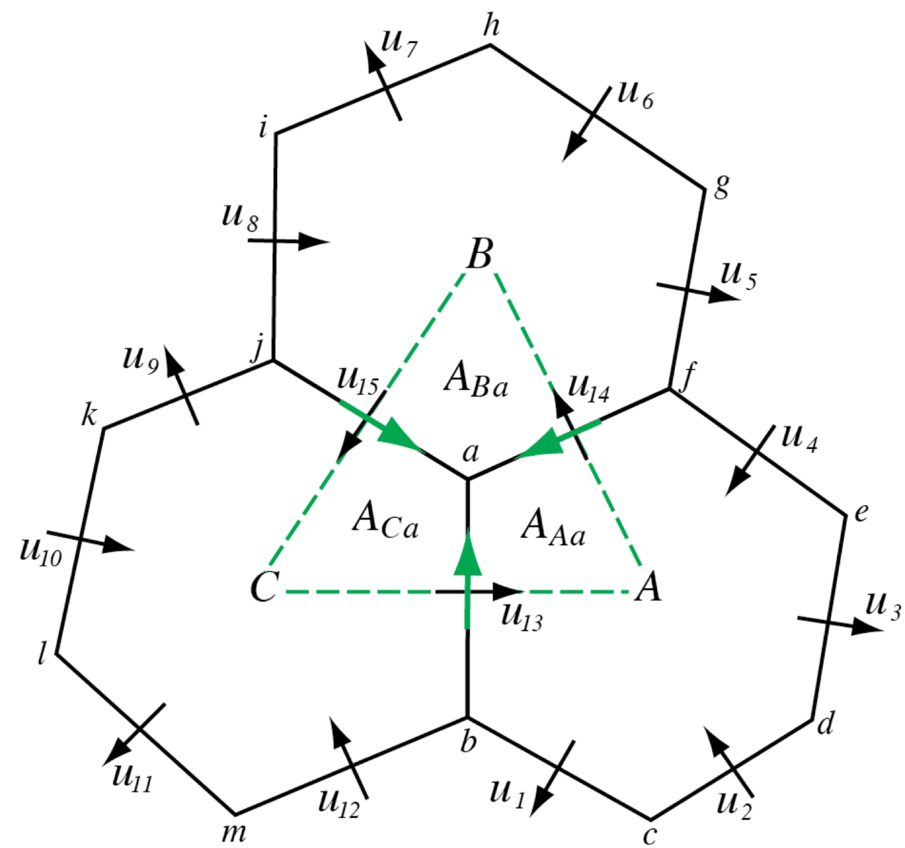
$$[\eta \boldsymbol{k} \times \mathbf{V}_H]_{e_i} = \sum_{j=1}^{n_{e_i}} \frac{1}{2}(\eta_{e_i} + \eta_{e_{i,j}}) w_{e_{i,j}} \rho_{e_{i,j}} u_{e_{i,j}}$$

Example: absolute vorticity at e_{13}

$$\eta_{13} = \frac{1}{2}(\eta_a + \eta_b)$$

Example: absolute vorticity at vertex a

$$\eta_a = f_a + \frac{\left(u_{13}\left|\overrightarrow{CA}\right| + u_{14}\left|\overrightarrow{AB}\right| + u_{15}\left|\overrightarrow{BC}\right|\right)}{Area(ABC)}$$



Time Integration
Dynamics and Scalar Transport Options

Default time integration

```
Call physics

Do dynamics_split_steps
    Do rk3_step = 1, 3
        compute large-time-step tendency
        Do acoustic_steps
            update u
            update rho, theta and w
        End acoustic_steps
    End rk3_step
End dynamics_split_steps

Do scalar_rk3_step = 1, 3
    scalar RK3 transport
End scalar_rk3_step

Call microphysics
```

ARW integration, option in MPAS

```
Call physics

Do rk3_step = 1, 3
    compute large-time-step tendency
    Do acoustic_steps
        update u
        update rho, theta and w
    End acoustic_steps
    scalar RK3 transport
End rk3_step

Call microphysics
```

config_split_dynamics_transport = true/false
config_dynamics_split_steps = 3
config_number_of_sub_steps = 2
(acoustic_steps)

MPAS
Model for Prediction Across Scales

Time Integration
Dynamics and Scalar Transport Options

Default time integration

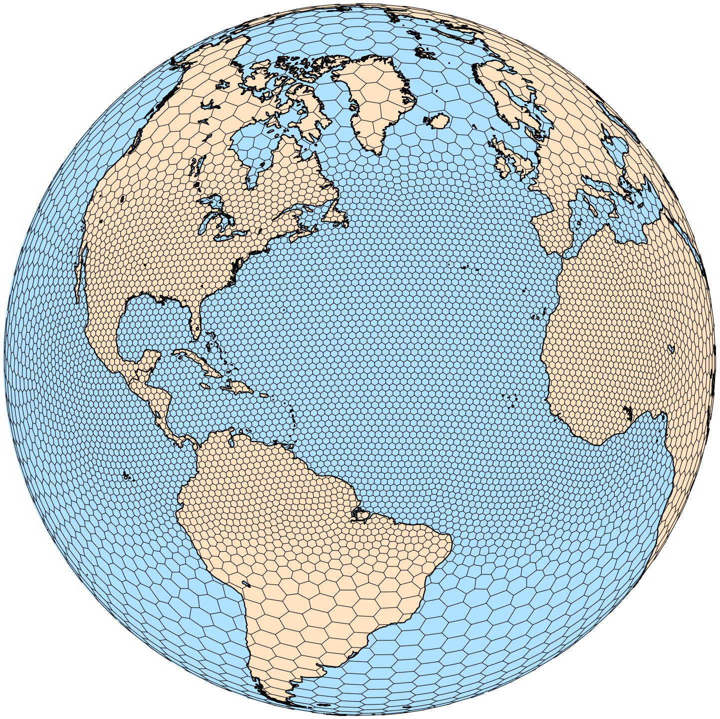
```
Call physics

Do dynamics_split_steps
    Do rk3_step = 1, 3
        compute large-time-step tendency
        Do acoustic_steps
            update u
            update rho, theta and w
        End acoustic_steps
    End rk3_step
End dynamics_split_steps

Do scalar_rk3_step = 1, 3
    scalar RK3 transport
End scalar_rk3_step

Call microphysics
```

Allows for smaller dynamics timesteps relative to scalar transport timestep and the main physics timestep.

We can use any FV scheme here (we are not tied to RK3)
Scalar transport and physics are the expensive pieces in most applications.

MPAS

Model for Prediction Across Scales



- *Configuring the dynamics and physics*

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Model for Prediction Across Scales

Configuring the dynamics and the physics

(namelist.atmosphere)

```
&nhyd_model
   config_dt = 90.0
   config_start_time = '2010-10-23_00:00:00'
   config_run_duration = '5_00:00:00'
   config_split_dynamics_transport = true
   config_number_of_sub_steps = 2
   config_dynamics_split_steps = 3
   config_h_mom_eddy_visc2 = 0.0
   config_h_mom_eddy_visc4 = 0.0
   config_v_mom_eddy_visc2 = 0.0
   config_h_theta_eddy_visc2 = 0.0
   config_h_theta_eddy_visc4 = 0.0
   config_v_theta_eddy_visc2 = 0.0
   config_horiz_mixing = '2d_smagorinsky'
   config_h_ScaleWithMesh = true
   config_len_disp = 15000.0
   config_visc4_2dsmag = 0.05
   config_del4u_div_factor = 10.
   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_scalar_advection = true
   config_positive_definite = false
   config_monotonic = true
   config_coef_3rd_order = 0.25
   config_epssm = 0.1
   config_smdiv = 0.1
   config_apvm_upwinding = 0.5
```

Time and time-steps

```
&nhyd_model
   config_dt = 90
   config_start_time = "2010-10-23_00:00:00"
   config_run_duration = "5_00:00:00"
   config_split_dynamics_transport = true
   config_number_of_sub_steps = 2
   config_dynamics_split_steps = 3
```

Timestep in seconds (config_dt)

Dynamics substeps per split step (config_dynamics_split_steps)

Number of acoustic steps per timestep (config_number_of_sub_steps)

Configuring the dynamics and the physics

(namelist.atmosphere)

```
&nhyd_model
   config_dt = 90.0
   config_start_time = '2010-10-23_00:00:00'
   config_run_duration = '5_00:00:00'
   config_split_dynamics_transport = true
   config_number_of_sub_steps = 2
   config_dynamics_split_steps = 3
   config_h_mom_eddy_visc2 = 0.0
   config_h_mom_eddy_visc4 = 0.0
   config_v_mom_eddy_visc2 = 0.0
   config_h_theta_eddy_visc2 = 0.0
   config_h_theta_eddy_visc4 = 0.0
   config_v_theta_eddy_visc2 = 0.0
   config_horiz_mixing = '2d_smagorinsky'
   config_h_ScaleWithMesh = true
   config_len_disp = 15000.0
   config_visc4_2dsmag = 0.05
   config_del4u_div_factor = 10.
   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_scalar_advection = true
   config_positive_definite = false
   config_monotonic = true
   config_coef_3rd_order = 0.25
   config_epssm = 0.1
   config_smdiv = 0.1
   config_apvm_upwinding = 0.5
```

Time and time-steps

```
&nhyd_model
   config_dt = 90
```

← *Timestep in seconds*

Similar to WRF, the model timestep (in seconds) should be initially set to be 6 times the finest nominal mesh spacing in km. For example – 15 km fine-mesh spacing would use a 90 second timestep.

MPAS
Model for Prediction Across Scales

Configuring the dynamics

(namelist.atmosphere)

```
&nhyd_model
  config_dt = 90.0
  config_start_time = '2010-10-23_00:00:00'
  config_run_duration = '5_00:00:00'
  config_split_dynamics_transport = true
  config_number_of_sub_steps = 2
  config_dynamics_split_steps = 3
  config_h_mom_eddy_visc2 = 0.0
  config_h_mom_eddy_visc4 = 0.0
  config_v_mom_eddy_visc2 = 0.0
  config_h_theta_eddy_visc2 = 0.0
  config_h_theta_eddy_visc4 = 0.0
  config_v_theta_eddy_visc2 = 0.0
  config_horiz_mixing = '2d_smagorinsky'
  config_h_ScaleWithMesh = true
  config_len_disp = 15000.0
  config_visc4_2dsmag = 0.05
  config_del4u_div_factor = 10.
  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_scalar_advection = true
  config_positive_definite = false
  config_monotonic = true
  config_coef_3rd_order = 0.25
  config_epssm = 0.1
  config_smdiv = 0.1
  config_apvm_upwinding = 0.5
```

<u>*Time and time-steps*</u>

&nhyd_model

config_epssm = 0.1

time-offcentering of the vertically implicit acoustic and gravity-wave integration.

config_smdiv = 0.1

3D divergence damping

config_apvm_upwinding = 0.5

Anticipated Potential Vorticity Method (APVM): upwind-biased estimate of edge PV; provides an enstrophy sink.

MPAS
Model for Prediction Across Scales

Configuring the dynamics and the physics

Advection

(namelist.atmosphere)

```
&nhyd_model
  config_dt = 90.0
  config_start_time = '2010-10-23_00:00:00'
  config_run_duration = '5_00:00:00'
  config_split_dynamics_transport = true
  config_number_of_sub_steps = 2
  config_dynamics_split_steps = 3
  config_h_mom_eddy_visc2 = 0.0
  config_h_mom_eddy_visc4 = 0.0
  config_v_mom_eddy_visc2 = 0.0
  config_h_theta_eddy_visc2 = 0.0
  config_h_theta_eddy_visc4 = 0.0
  config_v_theta_eddy_visc2 = 0.0
  config_horiz_mixing = '2d_smagorinsky'
  config_h_ScaleWithMesh = true
  config_len_disp = 15000.0
  config_visc4_2dsmag = 0.05
  config_del4u_div_factor = 10.
  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_scalar_advection = true
  config_positive_definite = false
  config_monotonic = true
  config_coef_3rd_order = 0.25
  config_epssm = 0.1
  config_smdiv = 0.1
  config_apvm_upwinding = 0.5
```

```
&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

MPAS
Model for Prediction Across Scales

Configuring the dynamics and the physics

Dissipation

(namelist.atmosphere)

```
&nhyd_model
   config_dt = 90.0
   config_start_time = '2010-10-23_00:00:00'
   config_run_duration = '5_00:00:00'
   config_split_dynamics_transport = true
   config_number_of_sub_steps = 2
   config_dynamics_split_steps = 3
   config_h_mom_eddy_visc2 = 0.0
   config_h_mom_eddy_visc4 = 0.0
   config_v_mom_eddy_visc2 = 0.0
   config_h_theta_eddy_visc2 = 0.0
   config_h_theta_eddy_visc4 = 0.0
   config_v_theta_eddy_visc2 = 0.0
   config_horiz_mixing = '2d_smagorinsky'
   config_h_ScaleWithMesh = true
   config_len_disp = 15000.0
   config_visc4_2dsmag = 0.05
   config_del4u_div_factor = 10.
   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_scalar_advection = true
   config_positive_definite = false
   config_monotonic = true
   config_coef_3rd_order = 0.25
   config_epssm = 0.1
   config_smdiv = 0.1
   config_apvm_upwinding = 0.5
```

```
&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.
   config_del4u_div_factor = 10.
```

fixed viscosity $m^2 s^{-1}$ (config_h_mom_eddy_visc2)

Fixed hyper-viscosity $m^4 s^{-1}$ (config_h_mom_eddy_visc4)

Alternately "2d_fixed" (config_horiz_mixing)

Δx_fine (config_len_disp)

Scale viscosities, hyperviscosities with local mesh spacing (config_h_ScaleWithMesh)

4th order background filter coef, used with 2d_smagorinsky (config_visc4_2dsmag)

υ_4 (m^4/s) = config_len_disp^3 x config_visc4_2dsmag

MPAS
Model for Prediction Across Scales

Configuring the dynamics

(namelist.atmosphere)

```
&damping
   config_zd = 22000.0
   config_xnutr = 0.2
/
&physics
   config_sst_update = false
   config_sstdiurn_update = false
   config_deepsoiltemp_update = false
   config_radtlw_interval = '00:30:00'
   config_radtsw_interval = '00:30:00'
   config_bucket_update = 'none'
   config_physics_suite = 'mesoscale_reference'
```

Gravity-wave absorbing layer

&damping

config_zd = 22000.

Bottom of the gravity-wave absorbing layer (meters)
Note: WRF defines this parameter as the depth of the layer.

config_xnutr = 0.2

Gravity-wave absorbing layer damping coefficient

This is the same formulation as in WRF

Configuring the physics

MPAS
Model for Prediction Across Scales

(namelist.atmosphere)

```
&physics
   config_sst_update = false
   config_sstdiurn_update = false
   config_deepsoiltemp_update = false
   config_radtlw_interval = '00:30:00'
   config_radtsw_interval = '00:30:00'
   config_bucket_update = 'none'
   config_physics_suite = 'mesoscale_reference'
```

```
&physics
config_physics_suite = 'mesoscale_reference'
```

Mesoscale reference physics suite – MPAS V6.1

Surface Layer: (Monin Obukhov): module_sf_sfclay.F as in WRF 3.8.1
PBL: YSU as in WRF 3.8.1
Land Surface Model (NOAH 4-layers): as in WRF 3.3.1.
Gravity Wave Drag: YSU gravity wave drag scheme, as in WRF 3.6.1
Convection: new Tiedtke (nTiedtke), as in WRFV3.8.1
Microphysics: WSM6: as in WRF 3.8.1
Radiation: RRTMG sw as in WRF 3.8.1; RRTMG lw as in WRF 3.8.1
Ocean Mixed Layer: modified from WRFV3.6

MPAS
Model for Prediction Across Scales

Configuring the physics

(namelist.atmosphere)

```
&physics
  config_sst_update = false
  config_sstdiurn_update = false
  config_deepsoiltemp_update = false
  config_radtlw_interval = '00:30:00'
  config_radtsw_interval = '00:30:00'
  config_bucket_update = 'none'
  config_physics_suite = ’convection_permitting'
```

```
&physics
config_physics_suite = ’convection_permitting'
```

Convection-permitting physics suite – MPAS V6.1

Surface Layer: module_sf_mynn.F as in WRF 3.6.1
PBL: Mellor-Yamada-Nakanishi-Niino (MYNN) as in WRF 3.6.1
Land Surface Model (NOAH 4-layers): as in WRF 3.3.1.
Gravity Wave Drag: YSU gravity wave drag scheme, as in WRF 3.6.1
Convection: Grell-Freitas scale aware scheme (modified from WRF 3.6.1)
Microphysics: Thompson scheme (non-aerosol aware): as in WRF 3.8
Radiation: RRTMG sw as in WRF 3.8.1; RRTMG lw as in WRF 3.8.1

MPAS
Model for Prediction Across Scales

Configuring the physics

Physics components can be individually selected, and a suite component can be overridden, by adding the appropriate configuration setting to the &physics section of the namelist.atmosphere.

Table 6.3: Possible options for individual physics parameterizations. Namelist variables should be added to the &physics namelist record.

Parameterization	Namelist variable	Possible options	Details
Convection	config_convection_scheme	cu_tiedtke	Tiedtke
		cu_ntiedtke	New Tiedtke (WRF 3.8.1)
		cu_grell_freitas	Modified version of scale-aware Grell-Freitas (WRF 3.6.1)
		cu_kain_fritsch	Kain-Fritsch (WRF 3.2.1)
Microphysics	config_microp_scheme	mp_wsm6	WSM 6-class (WRF 3.8.1)
		mp_thompson	Thompson non-aerosol aware (WRF 3.8.1)
		mp_kessler	Kessler
Land surface	config_lsm_scheme	noah	Noah (WRF 3.3.1)
Boundary layer	config_pbl_scheme	bl_ysu	YSU (WRF 3.8.1)
		bl_mynn	MYNN (WRF 3.6.1)
Surface layer	config_sfclayer_scheme	sf_monin_obukhov	Monin-Obukhov (WRF 3.8.1)
		sf_mynn	MYNN (WRF 3.6.1)
Radiation, LW	config_radt_lw_scheme	rrtmg_lw	RRTMG (WRF 3.8.1)
		cam_lw	CAM (WRF 3.3.1)
Radiation, SW	config_radt_sw_scheme	rrtmg_sw	RRTMG (WRF 3.8.1)
		cam_sw	
Cloud fraction for radiation	config_radt_cld_scheme	cld_fraction	Xu and Randall (1996)
		cld_incidence	0/1 cloud fraction depending on $q_c + q_i$
Gravity wave drag by orography	config_gwdo_scheme	bl_ysu_gwdo	YSU (WRF 3.6.1)

'off' specifies no physics component for that parameterization.

MPAS Solver and Physics Information

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

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MPAS Atmosphere 3.0 was released on 18 November 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 3.0 release notes

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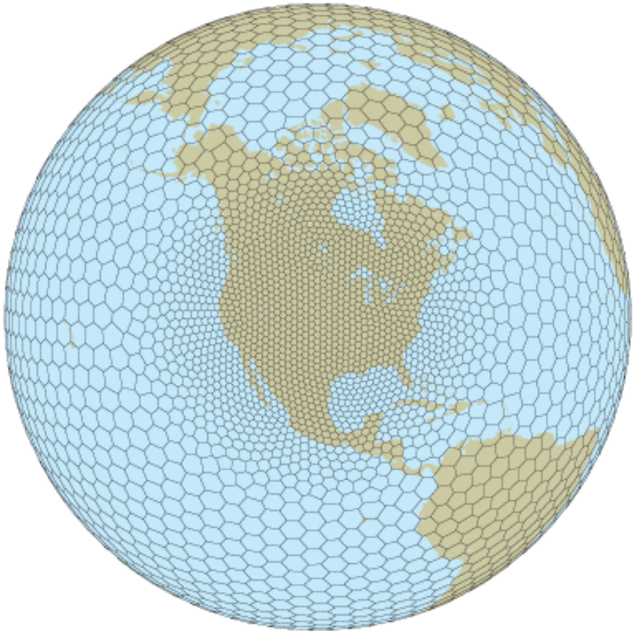
Configurations for idealized test cases

Sample input files for real-data simulations

Visualization and analysis tools



A variable resolution MPAS Voronoi mesh

MPAS Solver and Physics Information

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

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Error Characteristics of Two Grid Refinement Approaches in Aquaplanet Simulations: MPAS-A and WRF. Hagos, S., Leung, R., Rauscher, S. A., & Ringler, T., 2013, 141(9), 3022–3036. doi:10.1175/MWR-D-12-00338.1 (pdf)

2012

Exploring a Global Multi-Resolution Modeling Approach Using Aquaplanet Simulations. S. Rauscher, T. Ringler, W. Skamarock, and A. Mirin, 2012, J. Climate., 26, 2432-2452, doi:10.1175/JCLI-D-12- 00154.1 pdf

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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

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