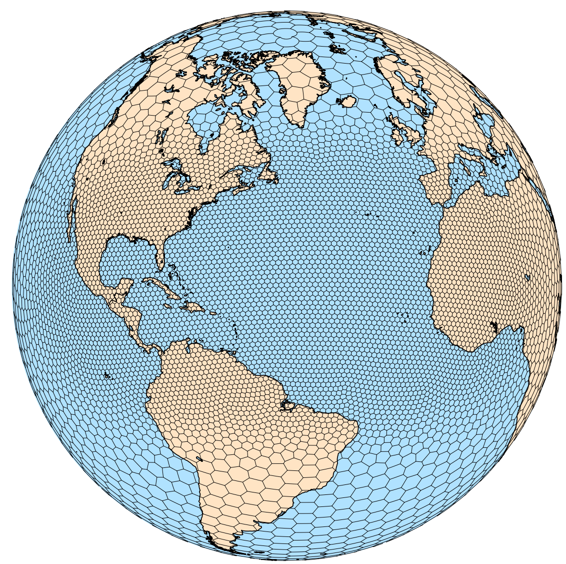
NGGPS/DTG briefing on MPAS configuration options.

Material is taken from the MPAS tutorial slides available at
http://www2.mmm.ucar.edu/projects/mpas/tutorial/UK2015/slides/MPAS-solver_physics.pdf
This presentation is available at
http://www2.mmm.ucar.edu/people/skamarock/Presentations/MPAS_config_overview_20160122.pdf
References in this presentation can be downloaded from the MPAS *Publications* page found at http://mpas-dev.github.io/

Bill Skamarock, NCAR/MMM, 22 January 2016.

MPAS
Model for Prediction Across Scales

- Overview
- Meshes
- *Atmospheric solver,* physics
- Compiling and running MPAS
- Summary
- Practical session



MPAS Nonhydrostatic Atmospheric Solver

MPAS
Model for Prediction Across Scales

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:

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

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

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

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

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

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

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 = false
   config_number_of_sub_steps = 6
   config_dynamics_split_steps = 3
   config_epssm = 0.1
   config_smdiv = 0.1
   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 = 1.0
   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_apvm_upwinding = 0.5
```

Time integration (config_dt through config_smdiv)

Explicit spatial filters:

- Spatial filters for idealized test cases (config_h_mom_eddy_visc2 through config_v_theta_eddy_visc2)
- Spatial filters for full-physics real-data cases (config_horiz_mixing through config_del4u_div_factor)

Transport (config_w_adv_order through config_apvm_upwinding)

```
&damping
   config_xnutr = 0.2
   config_zdamp = 22000.
```

Gravity-wave absorbing layer

MPAS
Model for Prediction Across Scales

Dynamics: Time integration scheme

3rd Order Runge-Kutta time integration

advance $\phi^t \rightarrow \phi^{t+\Delta t}$

$$\phi^* = \phi^t + \frac{\Delta t}{3} R\left(\phi^t\right)$$

$$\phi^{**} = \phi^t + \frac{\Delta t}{2} R\left(\phi^*\right)$$

$$\phi^{t+\Delta t} = \phi^t + \Delta t \, R\left(\phi^{**}\right)$$

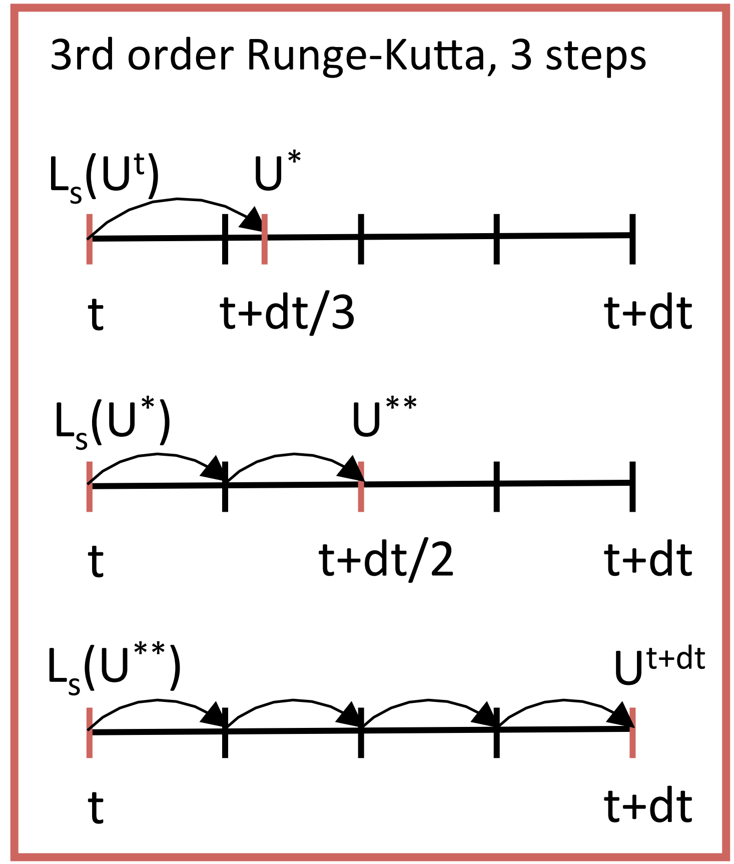
Amplification factor

$$\phi_t = i k \phi; \quad \phi^{n+1} = A \phi^n;$$

$$|A| = 1 - \frac{(k\Delta t)^4}{24}$$

Time-split acoustic integration

$$U_t = L_{fast}(U) + L_{slow}(U)$$



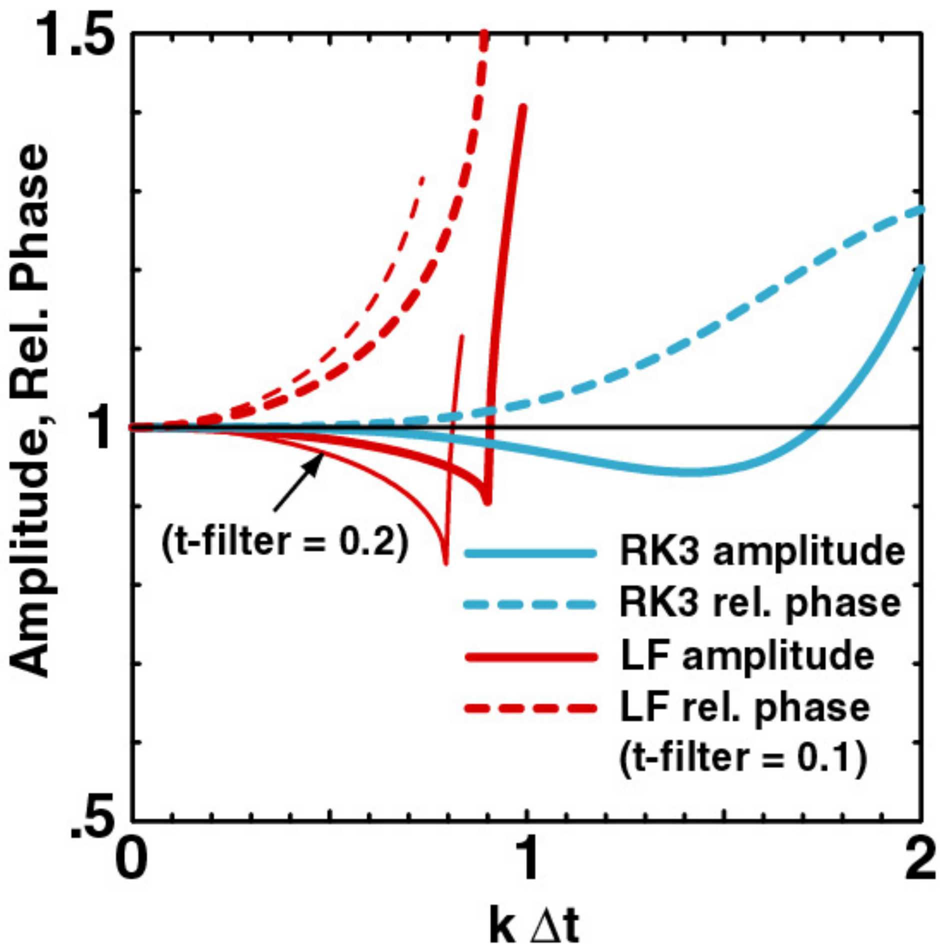
MPAS
Model for Prediction Across Scales

Dynamics: Time integration scheme

Phase and amplitude errors for LF, RK3

Oscillation equation analysis

$$\psi_t = ik\psi$$



MPAS
Model for Prediction Across Scales

Dynamics: Time integration scheme

Scalar Transport Options

Split-transport integration

```
Call physics

Do dynamics_split_steps
    Do step_rk3 = 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 step_rk3 = 1, 3
    scalar RK3 transport
End scalar rk3 step

Call microphysics
```

Unsplit integration

```
Call physics

Do step_rk3 = 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

Dynamics: Time integration scheme

Scalar Transport Options

Split-transport integration

```
Call physics

Do dynamics_split_steps
        Do step_rk3 = 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 step_rk3 = 1, 3
        scalar RK3 transport
End scalar rk3 step

Call microphysics
```

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

Dynamics: Time integration scheme

Temporal off-centering for the vertically-propagating acoustic modes on the acoustic timestep

$$\delta_\tau \mathbf{V}''_H + \frac{\rho_d^t}{\rho_m^t}\gamma R_d \pi^t [\nabla_\zeta \overline{\Theta''_m}^\tau + \partial_\zeta(\zeta_H \overline{\Theta''_m}^\tau)] = \mathbf{R}^t_{V_H}, \qquad (13)$$

$$\delta_\tau W'' + \frac{\rho_d^t}{\rho_m^t}\left[\gamma R_d \pi^t \partial_\zeta(\zeta_z \overline{\Theta''_m}^\tau) - g\tilde{\rho}_d \frac{R_d}{c_v}\frac{\pi^t}{\overline{\pi}}\frac{\overline{\Theta''_m}^\tau}{\Theta^t_m}\right] + g\overline{\tilde{\rho}''_d}^\tau = R^t_W, \qquad (14)$$

$$\delta_\tau \Theta''_m + \nabla_\zeta \cdot (\mathbf{V}''^{\tau+\Delta\tau}_H \theta^t_m) + \partial_\zeta(\overline{\Omega''}^\tau \theta^t_m) = R^t_{\Theta_m}, \quad \text{and} \qquad (15)$$

$$\delta_\tau \tilde{\rho}''_d + \nabla_\zeta \cdot \mathbf{V}''^{\tau+\Delta\tau}_H + \partial_\zeta \overline{\Omega''}^\tau = R^t_{\rho_d}, \qquad (16)$$

$$\overline{\phi}^\tau = \frac{1+\beta_s}{2}\phi^{\tau+\Delta\tau} + \frac{1-\beta_s}{2}\phi^\tau. \qquad (17)$$

$b_s = 0.1$ recommended (default)
(&nhyd_model config_epssm)

(in MPAS namelist.atmosphere)

The off-centering is relative to the acoustic time-step, not the RK3 time-step.

Klemp et al, MWR (2007), 2897-2913.

Dynamics: Time integration scheme

3D Divergence Damping

Purpose: filter acoustic modes (3-D divergence, $D = \nabla \cdot \rho\mathbf{V}$ *)*

$$\left\{ \frac{\partial \rho \mathbf{V}}{\partial t} + \nabla p + \ldots = \gamma_d' \nabla D \right\}$$

$$\nabla \cdot \left\{ \quad \right\} \quad \rightarrow \quad \frac{\partial D}{\partial t} + \nabla^2 p + \ldots = \gamma_d' \nabla^2 D$$

From the pressure equation: $p_t \simeq c^2 D$

$$\frac{\partial \rho \mathbf{V}}{\partial t} + \nabla [p_\tau + \gamma_d (p^\tau - p^{\tau - \Delta\tau})] + \ldots = 0$$

γ_d = 0.1 recommended (default) (&nhyd_model config_smdiv)

The time-forward weighting is relative to the acoustic time-step, not the RK3 time-step.

MPAS
Model for Prediction Across Scales

Dynamics: Time integration scheme

Anticipated Potential Vorticity Method (APVM)

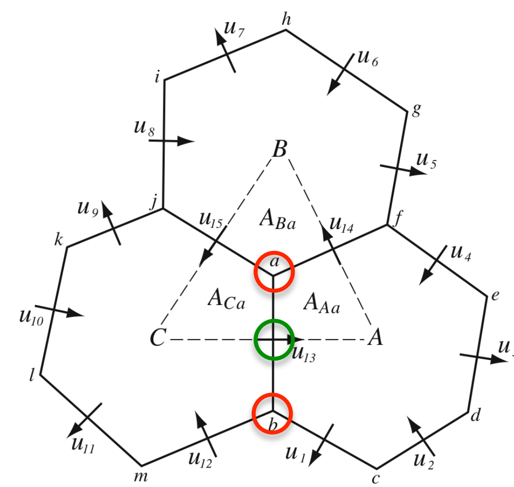
Sadourny and Basdevant,
Journal of the Atmospheric Sciences 42 (13) (1985) 1353–1363

MPAS: upwind reconstruction of the vorticity (PV) at the cell edge where is it used in the solution to the vector-invariant horizontal momentum equation.

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

$$\tilde{\eta} = \frac{1}{2} \sum_{\nu \in VE(e)} \eta_\nu - \gamma_a \left(V_e \cdot [\nabla \eta]_e\right) dt$$

Default value $\gamma_a = \frac{1}{2}$



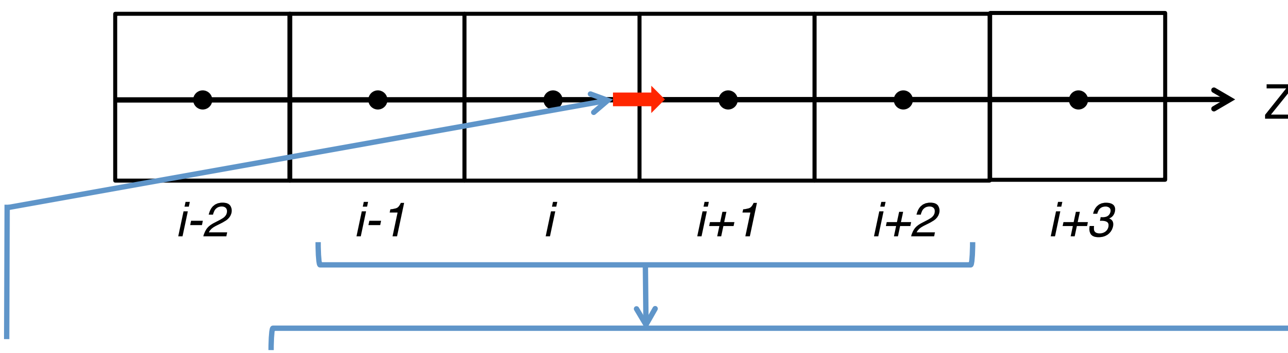
Ringler et al, Journal of Computational Physics, 229 (2010) 3065–3090. see eqn (81)

Dynamics: Transport

Vertical Discretization

Transport equation, conservative form: $$\frac{\partial(\rho\psi)}{\partial t} = -\nabla_\zeta \cdot \mathbf{V}(\rho\psi) - \frac{\partial \omega\rho\psi}{\partial z}$$

Vertical flux divergence requires fluxes at the top and bottom faces of the control volume



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

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

[See references in Skamarock and Gassmann MWR 2012]

MPAS uses this formulation for vertical advection of all prognostic variables.

Dynamics: Transport

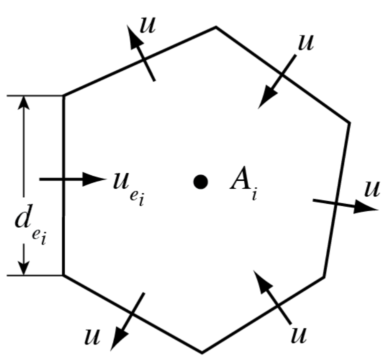
Horizontal Discretization

Transport equation, conservative form: $$\frac{\partial(\rho\psi)}{\partial t} = -\nabla_\zeta \cdot \mathbf{V}(\rho\psi) - \frac{\partial \omega\rho\psi}{\partial z}$$

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.

Dynamics: Transport

Horizontal Discretization

3rd and 4th-order fluxes:

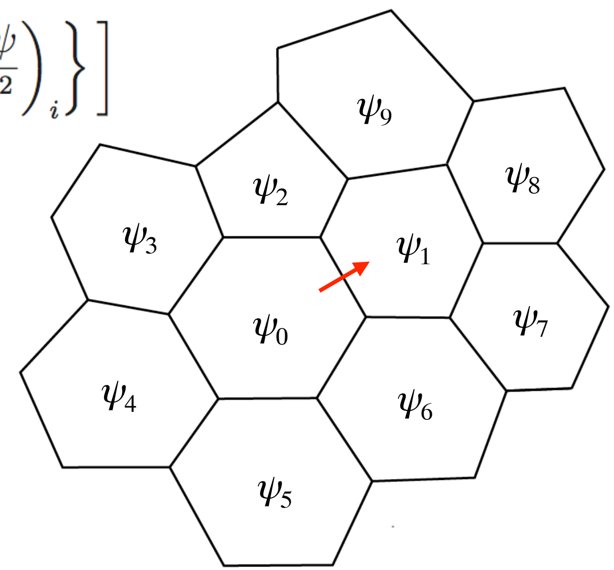
$$F(u,\psi)_{i+1/2} = u_{i+1/2}\left[\frac{1}{2}\left(\psi_{i+1}+\psi_i\right) - \frac{1}{12}\left(\delta_x^2\psi_{i+1}+\delta_x^2\psi_i\right) + sign(u)\,\frac{\beta}{12}\left(\delta_x^2\psi_{i+1}-\delta_x^2\psi_i\right)\right]$$

The coordinates are not continuous in MPAS.

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

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

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.



β = 0, 4th-order scheme, neutral.
β > 0, 3rd-order scheme, damping.

MPAS
Model for Prediction Across Scales

Dynamics: Transport

Horizontal Discretization

3rd and 4th-order fluxes:

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

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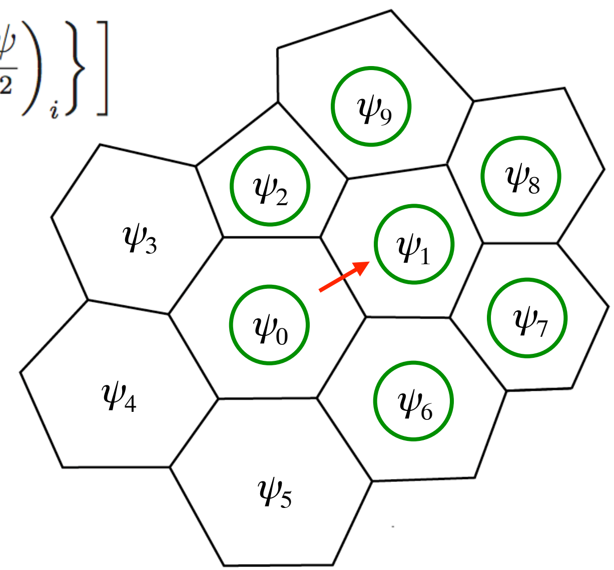
$$F(u,\psi)_{i+1/2} = u_{i+1/2}\left[\frac{1}{2}\left(\psi_{i+1}+\psi_i\right) - \Delta x_e^2\frac{1}{12}\left\{\left(\frac{\partial^2\psi}{\partial x^2}\right)_{i+1} + \left(\frac{\partial^2\psi}{\partial x^2}\right)_i\right\}\right.$$
$$\left. + sign(u)\,\Delta x_e^2\frac{\beta}{12}\left\{\left(\frac{\partial^2\psi}{\partial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

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.



β = 0, 4th-order scheme, neutral.
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MPAS
Model for Prediction Across Scales

Dynamics: Transport
Horizontal Discretization

3rd and 4th-order fluxes:

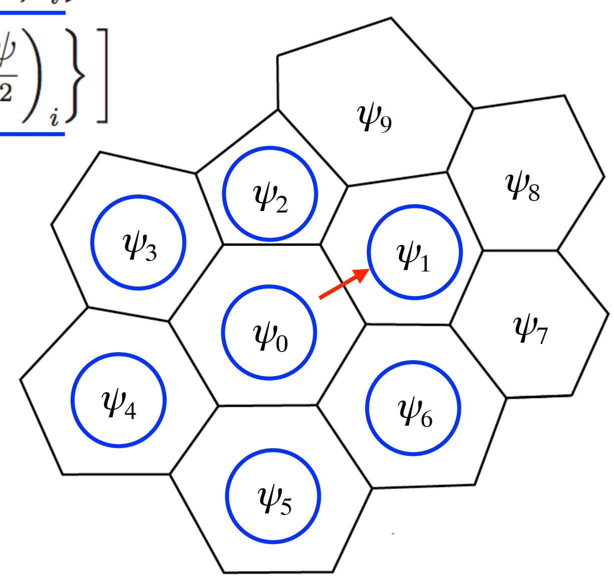
$$F(u,\psi)_{i+1/2} = u_{i+1/2}\left[\frac{1}{2}(\psi_{i+1}+\psi_i) - \frac{1}{12}(\delta_x^2\psi_{i+1}+\delta_x^2\psi_i) + sign(u)\,\frac{\beta}{12}(\delta_x^2\psi_{i+1}-\delta_x^2\psi_i)\right]$$

The coordinates are not continuous in MPAS. (Skamarock and Gassmann MWR 2012)

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

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

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.



β = 0, 4th-order scheme, neutral.
β > 0, 3rd-order scheme, damping.

Dynamics: Transport

Monotonic (shape preserving) flux renormalization for scalars

Scalar update, last RK3 step

$$(\rho\phi)_C^{t+\Delta t} = (\rho\phi)_C{}^t - \frac{\Delta t}{V_c} \sum_{faces} A_f \overline{\rho v \phi} = (\rho\phi)_C{}^t - \frac{\Delta t}{V_c} \sum_{faces} f_i \qquad (1)$$

(1) Decompose flux: $f_i = f_i^{upwind} + f_i^c$

(2) Renormalize high-order correction fluxes f_i^c such that solution is positive definite or monotonic: $f_i^c = R(f_i^c)$

(3) Update scalar eqn. (1) using $f_i = f_i^{upwind} + R(f_i^c)$

Essentially the FCT limiter of Van Leer (JCP 1977)
Skamarock, MWR 2006, 2241-2250

MPAS
Model for Prediction Across Scales

Dynamics: Explicit Spatial Filters

2D (horizontal) Smagorinsky scheme for w and θ

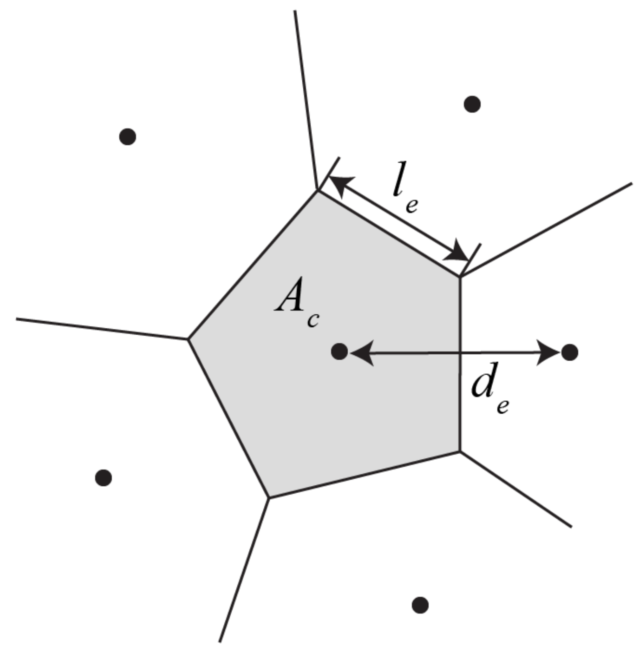
$$\frac{\partial \rho\phi}{\partial t} = \cdots + \frac{\partial}{\partial x}\left(K\frac{\partial \phi}{\partial x}\right) + \frac{\partial}{\partial y}\left(K\frac{\partial \phi}{\partial y}\right) \text{ or } \frac{\partial \rho\phi}{\partial t} = \cdots + \nabla\rho K\nabla\phi$$

where

$$K = c_s^2 l^2 \left[(u_x - v_y)^2 + (u_x + v_y)^2\right]^{1/2}$$

Spatial discretization

$$\frac{\partial(\rho\phi)_c}{\partial t} = \cdots + \frac{1}{A_c}\sum_{e_i} \overline{\rho K}^e \frac{l_e}{d_e}\delta_e\phi$$



A_c is the area of the cell bounded by edges e_i

l_e is the length of cell edge e_i

d_e is the length between cell centers across edge e_i

$\overline{\rho K}^e$ average of $(\rho K)_c$ for cells sharing edge e_i

$\delta_e\phi$ is the difference of ϕ_c across edge e_i, i.e. $\phi_{c_i} - \phi_c$

Dynamics: Explicit Spatial Filters

<u>4th-order horizontal filter (constant hyperviscosity) for w and θ</u>

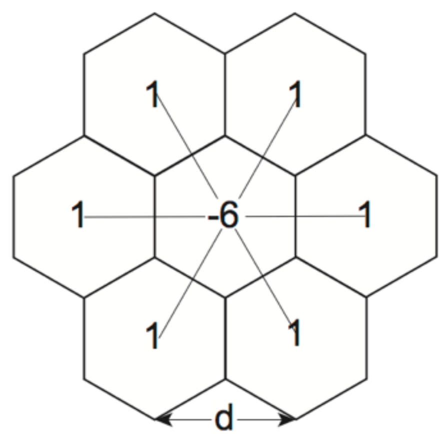
2nd-order constant eddy viscosity can be written as

$$\frac{\partial(\rho\phi)_c}{\partial t} = \cdots + K_2 \frac{1}{A_c} \sum_{e_i} \overline{\rho}^e \frac{l_e}{d_e} \delta_e \phi = \cdots + K_2 L(\rho, \phi)$$

The 4th-order filter operator consists of 2 passes of the 2nd-order operator.

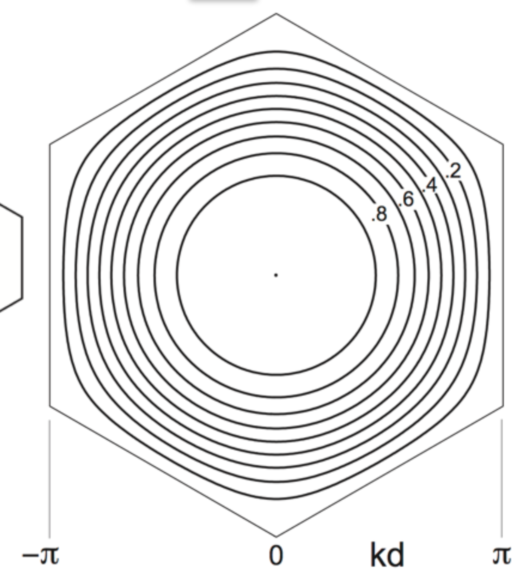
4th-order constant hyperviscosity

$$\frac{\partial(\rho\phi)_c}{\partial t} = \cdots - K_4 L^2(\rho, \phi)$$



∇^2 stencil

$$\hat{\phi} = \underline{A}^{n\Delta t} e^{i(kx+ly)}$$



Dynamics: Explicit Spatial Filters

2nd order horizontal filtering for the horizontal momentum

$$\frac{\partial(\rho u_i)}{\partial t} = \cdots + \rho K_2 \nabla^2 u_i$$

The Laplacian of horizontal momentum $$\nabla^2 u_i = \frac{\partial}{\partial x_i} \nabla \cdot \mathbf{v}_\zeta - \frac{\partial \eta}{\partial x_j}$$

$\nabla \cdot \mathbf{v}_\zeta$ is the horizontal divergence

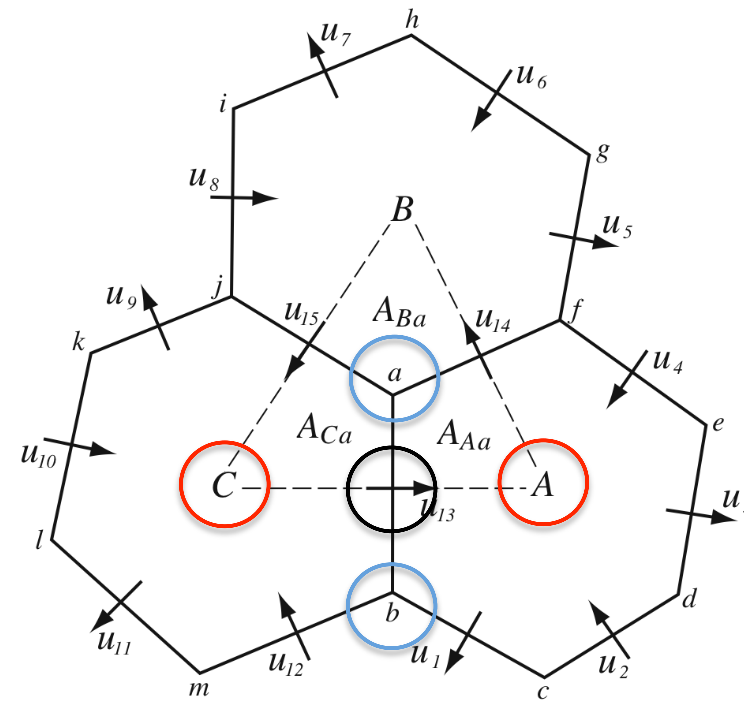
η is the vertical vorticity

$\frac{\partial}{\partial x_i}$ is the horizontal derivative normal to the edge

$\frac{\partial}{\partial x_j}$ is the horizontal derivative tangent to the edge

Divergence D lives at the cell centers, e.g. (A, B, C),
vorticity η lives at the vertices, e.g. (a, b),
thus the Laplacian $\nabla^2 u_{13}$:

$$\nabla^2 u_{13} = \frac{D_A - D_C}{d_{13}} - \frac{\eta_a - \eta_b}{l_{13}}$$



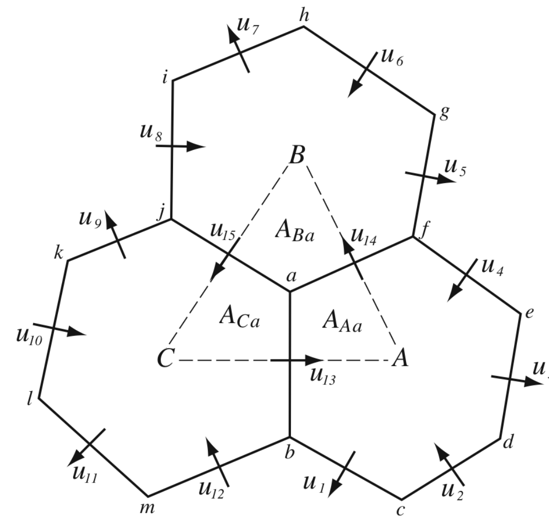
Dynamics: Explicit Spatial Filters

<u>2^{nd} order horizontal filtering for the horizontal momentum</u>

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

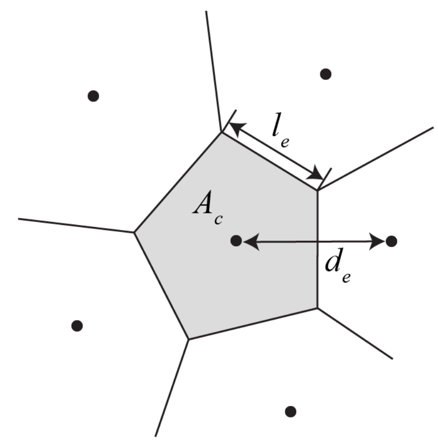
For example, the vertical vorticity at vertex a is computed as

$$\eta_a = \frac{u_{13}|\vec{CA}| + u_{14}|\vec{AB}| + u_{15}|\vec{BC}|}{A_{Ca} + A_{Aa} + A_{Ba}}$$



The horizontal divergence is computed as

$$\nabla \cdot \mathbf{v}_\zeta = \frac{1}{A_c} \sum_{e_i} l_e u_e$$



MPAS
Model for Prediction Across Scales

Dynamics: Explicit Spatial Filters

<u>4th order horizontal filtering for the horizontal momentum</u>

The 4th-order filter operator consists of 2 passes of the 2nd-order operator.

$$\frac{\partial(\rho u_i)}{\partial t} = \cdots - \rho K_4 \nabla^2(\nabla^2 u_i)$$

On the second pass of the Laplacian, there is an option to weight the horizontal divergence component relative to the vorticity component.

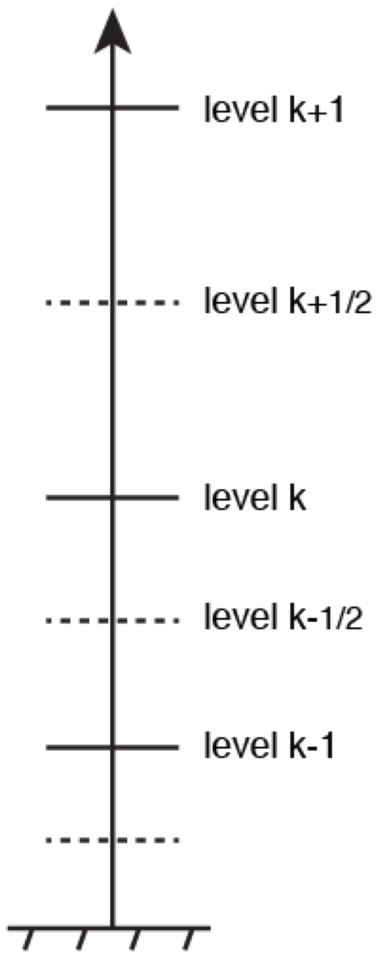
$$\tilde{\nabla}^2 u_i = \gamma_{D_h} \frac{\partial}{\partial x_i} \nabla \cdot \mathbf{v}_\zeta - \frac{\partial \eta}{\partial x_j}$$

$$\frac{\partial(\rho u_i)}{\partial t} = \cdots - \rho K_4 \tilde{\nabla}^2(\nabla^2 u_i)$$

MPAS namelist.atmosphere
&nhyd_model; config_del4u_div_factor = γ_{D_h}

Dynamics: Explicit Spatial Filters

2nd order vertical filtering (idealized applications)



$$z_{k+1/2} = 0.5\,(z_{k+1} + z_k)$$

define $$\delta_z w_{k+1/2} = \frac{w_{k+1} - w_k}{z_{k+1} - z_k}$$

$$\delta_z \phi_k = \frac{\phi_{k+1/2} - \phi_{k-1/2}}{z_{k+1/2} - z_{k-1/2}}$$

$$\frac{\partial}{\partial z}\left(\rho K_z \frac{\partial w}{\partial z}\right) \rightarrow \delta_z\left(\rho K_z \delta_z w\right)$$

for w, θ and u

Dynamics: Explicit Spatial Filters

Implicit Rayleigh w Damping Layer for Split-Explicit Nonhydrostatic NWP Models (gravity-wave absorbing layer)

Modification to small time step:

- Step horizontal momentum to new time level: $U^{\tau+\Delta\tau}$
- Step vertical momentum, potential temperature and density equations (implicit in the vertical): $W^{*\tau+\Delta\tau}, \;\; \Theta^{\tau+\Delta\tau}, \;\; \rho^{\tau+\Delta\tau}$
- Apply implicit Rayleigh damping on *W* as an adjustment step: $W^{\tau+\Delta\tau} = W^{*\tau+\Delta\tau} - \Delta\tau R_W(z)\, W^{\tau+\Delta\tau}$
- Update final values of potential temperature and density at the new time level: $W^{\tau+\Delta\tau}, \;\; \Theta^{\tau+\Delta\tau}, \;\; \rho^{\tau+\Delta\tau}$

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

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Dynamics: Explicit Spatial Filters

Implicit Rayleigh w Damping Layer for Split-Explicit Nonhydrostatic NWP Models (gravity-wave absorbing layer)

$$W^{\tau+\Delta\tau} = W^{*\tau+\Delta\tau} - \Delta\tau R_W(z)\, W^{\tau+\Delta\tau}$$

$$R_W(z) = \begin{cases} \gamma_r \sin^2\left[\frac{\pi}{2}\left(1 - \frac{z_{top}-z}{z_d}\right)\right] & \text{for } z \geq (z_{top} - z_d); \\ 0 & \text{otherwise,} \end{cases}$$

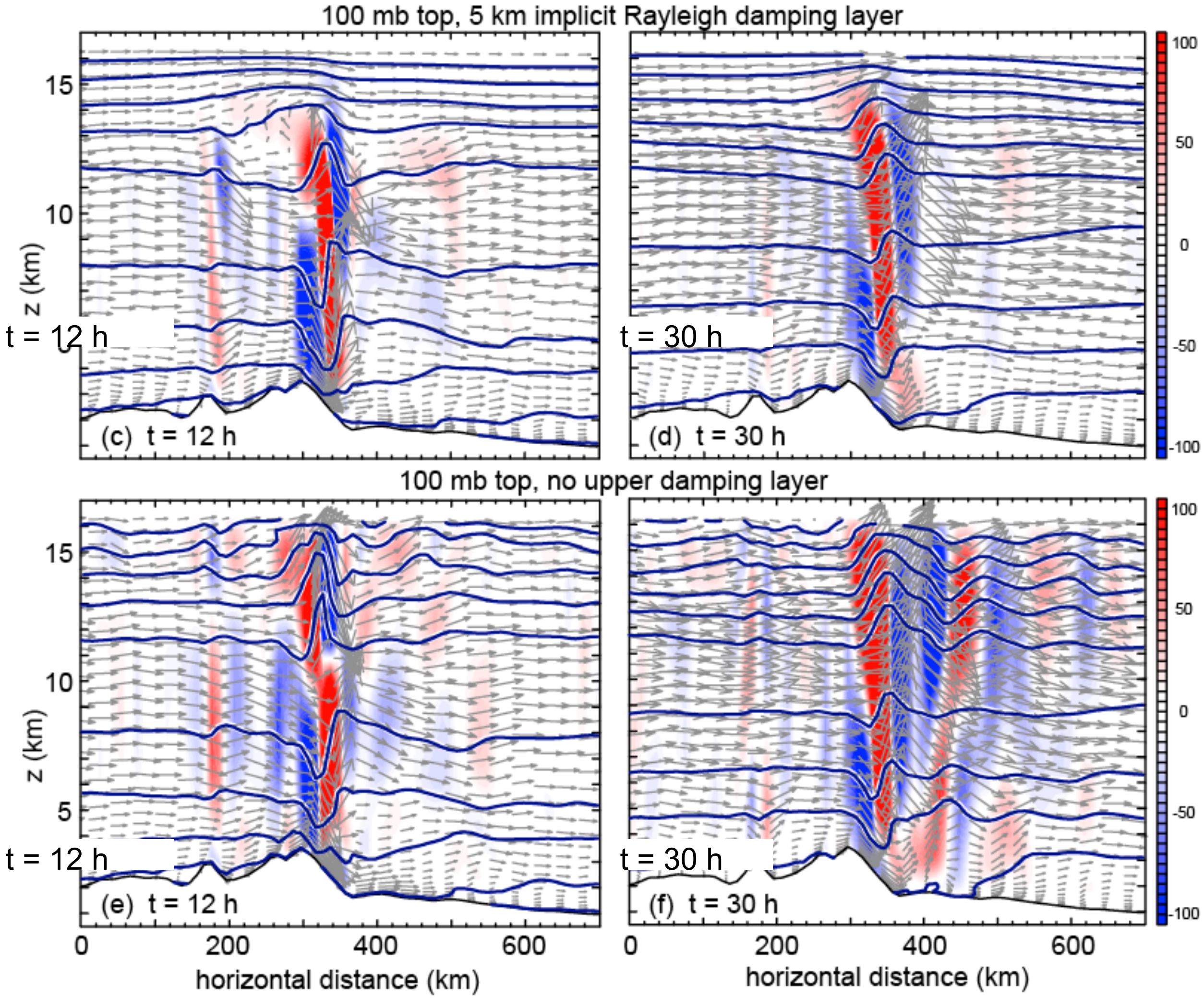
$R_w(z)$- damping rate (t^{-1})
z_d - depth of the damping layer
γ_r - damping coefficient

&damping *config_xnutr = 0.2* (recommended, = 0. default)
&damping config_*zdamp*; height where damping begins ($z_{top} - z_d$)
(in MPAS *namelist.atmosphere*)

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

Dynamics: Explicit Spatial Filters

ARW, Initialized 04 Dec 2007 00 UTC



w (cm/s)

w (cm/s)

MPAS
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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 = false
   config_number_of_sub_steps = 6
   config_dynamics_split_steps = 3
   config_epssm = 0.1
   config_smdiv = 0.1
   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 = 1.0
   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_apvm_upwinding = 0.5
```

Time integration (config_dt through config_smdiv)

Spatial filters for idealized test cases (config_h_mom_eddy_visc2 through config_v_theta_eddy_visc2)

Spatial filters for full-physics real-data cases (config_horiz_mixing through config_del4u_div_factor)

Explicit spatial filters (both groups above)

Transport (config_w_adv_order through config_apvm_upwinding)

```
&damping
   config_xnutr = 0.2
   config_zdamp = 22000.
```

Gravity-wave absorbing layer (&damping)

MPAS

Model for Prediction Across Scales

Configuring the dynamics

namelist.atmosphere for a typical forecast configuration of the horizontal 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 = false
   config_number_of_sub_steps = 6
   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_len_disp = 15000.0
   config_visc4_2dsmag = 0.05
   config_h_ScaleWithMesh = true
   config_del4u_div_factor = 1.0
   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
```

Horizontal filtering
2nd order 2D Smagorinsky formulation with a background fixed 4th-order filter

$\upsilon_4\ (m^4/s) = config\_len\_disp^3 \times config\_visc4\_2dsmag$

Δx_fine

Scale viscosities, hyperviscosities with local mesh spacing based on the density function used to generate the mesh.

$$\upsilon_4\,(x,y) = \upsilon_4\,(\Delta x_f) \times (\Delta x/\Delta x_f)^3$$

$$\upsilon_2\,(x,y) = \upsilon_2\,(\Delta x_f) \times (\Delta x/\Delta x_f)$$

NGGPS/DTG briefing on MPAS configuration options.

Material is taken from the MPAS tutorial slides available at
http://www2.mmm.ucar.edu/projects/mpas/tutorial/UK2015/slides/MPAS-solver_physics.pdf
This presentation is available at
http://www2.mmm.ucar.edu/people/skamarock/Presentations/MPAS_config_overview_20160122.pdf
References in this presentation can be downloaded from the MPAS *Publications* page found at http://mpas-dev.github.io/

Bill Skamarock, NCAR/MMM, 22 January 2016.

MPAS
Model for Prediction Across Scales

- Overview
- Meshes
- *Atmospheric solver,* physics
- Compiling and running MPAS
- Summary
- Practical session